SIMULATING THE ROLE OF TRANSACTIVE MEMORY IN GROUP TRAINING AND PERFORMANCE[1]

Yuqing Ren

Dept. of Social & Decision Sciences
Carnegie Mellon University
Pittsburgh, PA 15213

Kathleen M. Carley

Dept. of Social & Decision Sciences
Carnegie Mellon University
Pittsburgh, PA 15213

Linda Argote

Graduate School of Industrial Administration
Carnegie Mellon University
Pittsburgh, PA 15213

July, 2001

Draft, please do not cite without explicit agreement from the authors.

---

[1] Please direct all correspondence to:
Yuqing Ren, Dept. of Social and Decision Sciences, Carnegie Mellon University, Pittsburgh, PA 15213
Email: yren@andrew.cmu.edu
Tel: 1-412-268-3009
Fax: 1-412-268-6938

Simulating the Role of Transactive Memory in Group Training and Performance[2]

ABSTRACT

Transactive memory systems refer to the idea that people in continuing close relationship develop a shared system for encoding, storing and retrieving information from different substantive domains. Previous studies provide both direct and indirect evidence of the positive impact of transactive memory systems on group performance, such as the efficient storage and recall of knowledge, the development of trust in groups, and the accuracy of group performance. This paper is an attempt to unify the experimental research on transactive memory and to extend it to a more dynamic setting for larger groups. In this paper, we develop an empirically grounded simulation model – ORGMEM, a multi-agent information processing system, which can be used to explore the formation of transactive memory and how transactive memory affects group performance. The virtual experiment results are compared against relevant lab experiment results and demonstrate the validity of ORGMEM as a mechanism to study transactive memory related phenomenon. Through a series of virtual experiments, we find that transactive memory improves group performance, decreases group response time, and increases decision quality. Our results also suggest that the impact of transactive memory tends to depend on group characteristics, such as group size.

I. INTRODUCTION

The rapid development of computer and information technologies has led experts to claim that a knowledge-based information economy has begun (e.g. Eliasson, 1990; Winslow & Bramer, 1994). In a knowledge-based economy, knowledge, as a key resource, has become more and more crucial in determining the competitiveness of both firms and individuals. Therefore, scientists from a variety of fields, such as sociology, psychology, economics, organizational theory and information technology, have found their interests converging on the study of knowledge management (Alvesson, 1998; Cohen, 1998; Burton-Jones, 1999; Cook & Brown, 1999). A key issue in knowledge management is "what knowledge needs to be managed?" Some researchers suggest that it is not only technical knowledge that plays a key part in impacting group performance, but also social knowledge or metaknowledge (Kang, Waisel & Wallace, 1998; Argote, 1999). In other words, knowledge about social networks and expertise distribution also affects different aspects of group performance (Carley & Dayanand, working paper). This is the idea behind transactive memory systems.

---

[2] This work was supported by the National Science Foundation KDI IIS 9980109 and by the Center of Computational Analysis of Social and Organizational Systems (CASOS). We are grateful to Mark Fichman for his helpful comments and Nicole Lazar for statistical suggestions.

Transactive memory systems[3], as a concept of social cognition, refer to the idea that people in continuing close relationship tend to develop a shared system for encoding, storing and retrieving information from different substantive domains (Wegner, 1987). By knowing what other people know, individuals in groups can have access to external memory as well as their own individual memory. As a result, a group information-processing system is formed. Three relevant key processes of transactive memory systems are identified using the metaphor of a directory-shared computer network: directory updating, information allocation, and retrieval coordination (Wegner, 1995).

Previous studies provide both direct and indirect evidence of the positive impact of transactive memory on group performance. First of all, transactive memory helps to efficiently store and recall knowledge through interpersonal relationships (Wegner, Erber & Raymond, 1991; Moreland, Argote, & Krishnan, 1998). When people work together continuously in a group, they tend to develop specializations. As a result, new knowledge is directed to those people who are experts in a particular field so that knowledge can be acquired and stored quickly. In the recalling process, due to the recognition of expertise, groups with well-developed transactive memory systems can retrieve more knowledge than other groups. Secondly, knowing other people's expertise helps people to develop a sense of trust and to work together better (Metcalf, 1986; Carley, 1990). In general, individuals are more likely to trust and act on information from the "right" source. Therefore, groups make better decisions when group members accurately recognize the relative distribution of expertise within the group. (Henry, 1995; Littlepage, Robison, & Reddington, 1997; Hollenbeck, Ilgen, Sego, Hedlund, Mafor, & Philips, 1995). Thirdly, groups whose members are trained together recall more and perform better than those whose members are trained separately (Hollingshead, 1998c; Liang, Moreland, & Argote, 1995; Moreland, Argote, & Krishnan, 1996).

Most of the research about transactive memory systems has been conducted using laboratory experiments. Giuliano and Wegner (1985) study the operation of transactive memory in intimate couples and show that in transactive memory systems, individuals are linked to knowledge on the basis of both their personal expertise and circumstantial knowledge responsibility (Wegner, 1987). Hollingshead (1998a) conducts a laboratory experiment on collective recall using dating couples and dyads of strangers to examine the impact of communication during the learning and recalling processes. Another experiment study conducted by Liang, Moreland, & Argote (1995) using college students demonstrates the benefits of training people together and the mediating role of transactive memory on group performance.

In this paper, we try to complement and extend the lab experiment studies using computational modeling and simulation techniques. First of all, most of the lab experiments conducted so far study small groups containing two to three persons (Hollingshead, 1998a; Moreland, Argote, & Krishnan, 1998). Through virtual experiments, we are able to examine groups as large as twenty or thirty people. Secondly, most of the relationships studied so far are either intimate couples or strangers (Wegner, 1987, Hollingshead, 1998a). Using virtual experiments, a wide range of relationships, such as boss/subordinate, friends, workmates, etc. can be examined. Thirdly, by

---

[3] In this article, the idea transactive memory systems refer to the system including individuals, resources, tasks, and personal memory as a whole while transcative memory only refers to personal memory about who knows whom, who has what, and who does what.

modeling transactive memory mathematically as three matrixes, we are able to calculate a variety of measurements of transactive memory precisely both on an individual level and a group level.

The rest of this paper is organized as follows. The first two sections describe the design and implementation of the computational model, ORGMEM. Then two measurements of transactive memory are presented and a list of variables of interest is identified. Finally, virtual experiment results and their analysis results are presented to demonstrate the validity of ORGMEM and the impact of transactive memory in organizations.

II. MODELING DESCRIPTIONS

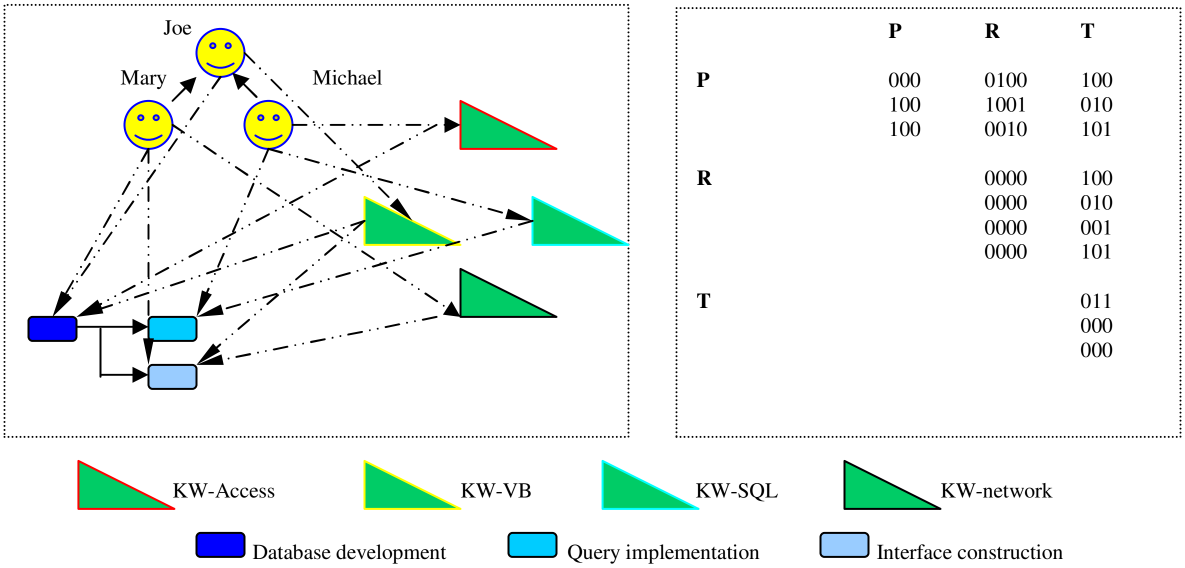
ORGMEM is a multi-agent simulation system that imitates the interpersonal communication, information-processing, and decision-making processes in organizations. In ORGMEM, agents are intelligent, adaptive, and heterogeneous (Ren, 2001). In other words, each agent has access to some knowledge (intelligence), is able to conduct a specific number of tasks, and can learn from each other (adaptation). As socially connected agents, each of them also has a transactive memory about who talks to whom, who knows what, and who does what in the group. During the operation process, each agent is able to conduct a variety of activities, such as communicating knowledge, searching for resources, and making decisions. Over time, organizations receive a series of tasks. Agents work on subtasks assigned by the program, make decisions by combining personal knowledge and information from their subordinates, communicate both technical knowledge and social knowledge, and learn from each other. As a result, group communication structure regarding who talks to whom, skill structure regarding who knows what, and transactive memory change over time.

Groups. In ORGMEM, groups are modeled as multi-agent information-processing and decision-making units by applying the PCANNS representation scheme (Krackhardt & Carley, 1998). The PCANNS model assumes that network-based organizations consist of three domain elements: individuals (P), tasks (T), and resources[4] (R). The relationships among these three elements can be summarized into six relational primitives from which the acronym PCANNS is derived: precedence of tasks (P), capabilities linking individuals to resources (C), assignment of individuals to tasks (A), networks of relations among personnel (N), resource needs of tasks (N), and substitutes of resources (S) (Carley, Ren, & Krackhardt, 2000).

According to the PCANNS model, a group can be represented as six relational matrixes in which the values are either 1 or 0, as shown in Figure 1. The value 1 indicates that there exists a connection between two elements; while the value 0 indicates there is no connection between two elements. Take the assignment matrix as an example. The assignment matrix (PxT) tells people who are assigned to what tasks. $A_{ij} = 1$ means that person i is assigned to task j and $A_{ij} = 0$ means that person i is not assigned to task j.

---

[4] In this paper, we use the words "resource" and "knowledge" interchangeably.



	P	R	T
P	000 100 100	0100 1001 0010	100 010 101
R		0000 0000 0000 0000	100 010 001 101
T			011 000 000

Figure 1: Illustrative group representation scheme & a group example

The group representation can be explained better using a canonical example. Suppose that the group in Figure 1 is working together to develop a website that handles on-line transactions. Joe is the team leader who manages two subordinates, Mary and Michael (PxP matrix). Four pieces of knowledge are required in this group – knowledge of MS Access, Visual Basic, SQL, and network. Three subtasks – database development, interface construction, and query implementation need to be finished to achieve the final goal. According to the Skill matrix (PxR), Joe is knowledgeable in VB; Mary is knowledgeable in network; Michael is an expert in both Access and SQL. According to the Assignment matrix (PxT), Joe and Mary are both assigned to work on database development, which has to be finished before the other two subtasks as indicated in the Precedence matrix (TxT). Mary and Michael are assigned to work respectively on interface construction and query implementation. The Substitute matrix (RxR) shows no links between resources, which mean they cannot substitute for each other. Finally, the Needs matrix (RxT) indicates that knowledge of Access and VB is required to develop database, knowledge of SQL is required to implement queries, and knowledge of VB and network is required to construct interface. Therefore, this group setting and the interrelationships among personnel, resources, and tasks can be all represented in the PCANSS model.

Agents. In the ORGMEM program, each agent has a title (analyst, manager, CEO, or president) and a name. Depending on his/her position in the organization, an agent may or may not have a boss or subordinates. Each agent also has certain skills, is assigned to certain tasks, and accumulates experience in their decision-making process. At the same time, each agent has a transactive memory, which contains social knowledge about who talks to whom (IxI), who has access to what resources (IxR), and who is assigned to what tasks (IxT) (as shown in Figure 2). We apply a trinary representation here to better reflect three possible states of transactive memory. A value of 1 in transactive memory indicates that the agent “sees” that there exists a connection between two elements. A value of –1 indicates that the agent “sees” that there doesn’t exist a connection between two elements. A value of 0 indicates that the agent doesn't have any knowledge about the connection.

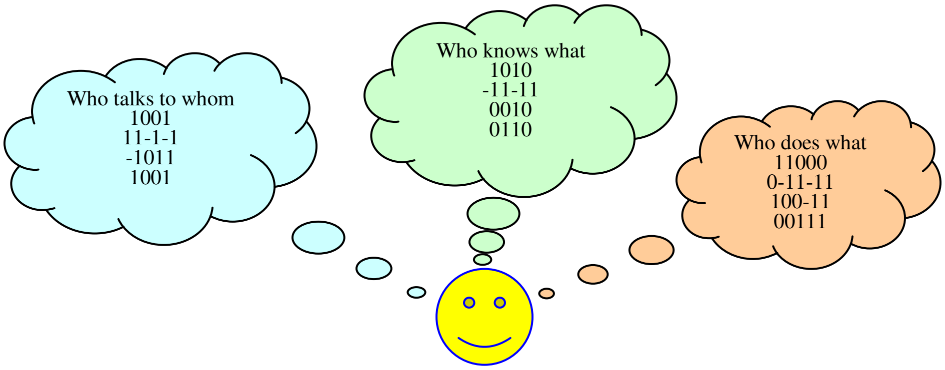


Figure 2: Representation of Transactive Memory

In ORGMEM, transactive memory is constructed and modified through interpersonal communication and interaction. At the beginning of the simulation, each individual has only knowledge about his/her own connections to other people, resources, and tasks. When group members communicate with each other, they can exchange their knowledge. For example, person A knows that he himself knows knowledge X, and he can tell person B about this. As a result, person B gains this piece of knowledge and is able to communicate it to other people. As the process continues, individual transactive memory grows. Another way of changing transactive memory is through observation. For instance, two people who have never talked to each other before can both learn that there is a connection between them once they start talking. Person A who lends a resource to person B gets to know that person B has access to that piece of resource. Therefore, both individual transactive memory and group transactive memory grow through communication and observation.

Based on their attributes, agents are able to take a series of actions to finish their tasks, such as searching for relevant resources, exchanging information, and making decisions. The following session briefly describes these actions.

Resource searching. In order to perform certain tasks, agents need to have access to relevant resources, such as specific equipment, materials or more frequently technical knowledge[5]. But it is not always true that they already have these resources. As a result, they need to search for the required resources in the group. To be more realistic, in this model, we assume that even if agents have some resources they can still choose to improve their skills by asking for that resource from other agents so that they can perform tasks better. If transactive memory doesn't exist in this group, agents will search for resources by randomly asking other group members until they find the resources they have been looking for or have asked everybody in the group. On the other hand, if transactive memory does exist, rather than random searching, agents will first look through their transactive memory and query the person that they think might have the

---

[5] Even though resource includes both physical materials and knowledge. In this paper, we focus on only knowledge. Therefore, resource and knowledge are interchangeable and both refers to knowledge in human being's mind.

required resource. Since we assume that the cost from one person to another person is equal across the group, agents don't account for distance when picking somebody to inquire.

According to organizational learning literature, knowledge diffusion is influenced by a variety of factors, such as the recipient's absorptive capacity (Cohen, 1990), the source's motivation, and the relationship between the source and the recipient (Darr, Argote & Epple, 1995; Szulanski, 1996). In this model, we assume that interpersonal knowledge transfer is influenced by the difficulty of the knowledge, the recipient's knowledge base, and the source's knowledge base (see Equation 1 in the appendix).

Communication. Previous work has suggested that communication plays an important role in the manner in which knowledge is learned and retrieved in transactive memory systems (Hollingshead, 1998a). In ORGMEM, communication is modeled as the process through which people share and exchange knowledge, and can be based on three mechanisms: random, relative similarity, and information seeking. Relative similarity refers to the phenomenon that people tend to talk to those who are similar to them or have knowledge in common with them (Carley, 1990). Information seeking refers to the phenomenon that people tend to seek for new knowledge by interacting with people from different knowledge domains or from different backgrounds (Carley, 1990). The interpersonal communication probabilities based on both mechanisms are calculated based on both transactive memory and personal skills. Driven by relative similarity (information seeking), agent i is more likely to interact with those agents who are linked to people, resources, and tasks that are similar to (different from) what agent i is linked to. Formula (2) and (3) in the Appendix demonstrate respectively how to calculate interaction probability based on relative similarity and information seeking.

Forgetting. Human beings forget. Modeling forgetting enables us to simulate the real world better. According to human cognition (Newell & Simon, 1972), a human being's memory consists of two parts: long-term memory and short-term memory. In the process of learning, knowledge is first stored in short-term memory. If this knowledge is repeated or rehearsed enough times, it will be further stored into long-term memory using an index structure. Every time a piece of knowledge is accessed and recalled, the linkage between the index and the knowledge is reinforced. However, if a piece of knowledge is not accessed for a long time, the linkage might become weak and even disappear (Newell & Simon, 1972). That is when forgetting happens. Therefore, in our model, we assume that a piece of knowledge is forgotten if it has not been recalled or accessed for a specific time periods. Similar to the process of knowledge transfer, knowledge forgetting happens continuously. If a piece of knowledge has not been recalled for such a long time period that nobody in the group has access to it anymore, we say this knowledge is out-of-date and organizational forgetting happens. The forgotten knowledge is thrown into a "knowledge trash-can". If that happens, under most conditions, the knowledge doesn't disappear completely. Although the knowledge does not exist in human beings' brains anymore, it still exists in organizations in the form of physical products, documents, and information systems (Argote, 1999). It is retrievable but to a lesser extent compared to knowledge in human beings' brains.

Decision making. Each agent works on subtasks assigned to him/her by the organizational structure and makes decisions independently by applying resources and referring to information from other people. If an agent doesn't have the required resources, s/he needs to find the resources first. In a hierarchical structure, decisions are made from the bottom up along the imposed authority structure. Subordinates make decisions first and then pass their decisions up to the boss. Facing the information from their subordinates, agents refer to their transactive memory and evaluate the value of the information before making their own decisions. Finally, a group decision is made and group performance is determined.

Information evaluation. Agents evaluate information from other agents based on their trust of that agent. The IxR matrix in an agent's transactive memory indicates the skill level of every agent in the group, represented by an integer falling in [0, 9]. Based on that information, every agent is able to count a trust coefficient array that represents his/her trust toward other agents in the group. When an agent receives a piece of information from his subordinate, he weighs this information by referring to his trust coefficient of the source. Equation (5) in the Appendix shows the formula used to calculate trust coefficients.

III. MODEL IMPLEMENTATION & MEASUREMENTS

As shown in Figure 3, several processes are simulated simultaneously in ORGMEM. Although decisions are made sequentially along the hierarchy, interpersonal communication and individual forgetting can happen anytime during organizational operations. Figure 3 also demonstrates the interactive and dynamic relationships between organizational processes and agents' skills,

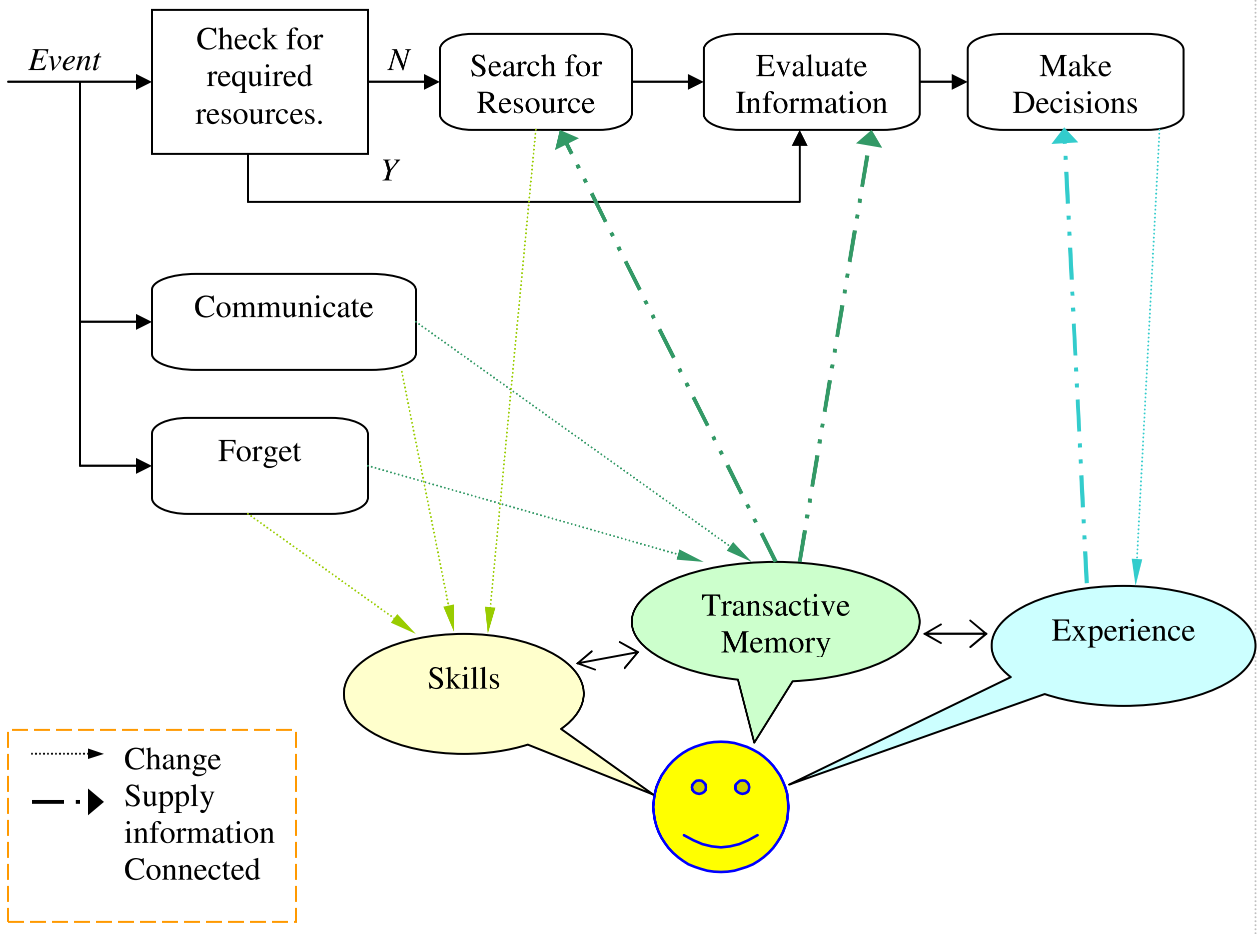


Figure 3: The Dynamic Processes of ORGMEM

↔

transactive memory and experience. For example, agents make decisions based on their past experience, while the feedback regarding the decisions they made supplies information that can be used to update their experience. Similarly, transactive memory indicates the expertise distribution in groups and facilitates the processes of resource searching and information evaluation. At the same time, new knowledge can be introduced into transactive memory through communication and knowledge decays through forgetting.

Dependent variables. Group performance is measured by two variables: the time taken to finish group tasks and the quality of group operation or decision. Both theoretical and practical reasons can be identified to support these measurements (Moreland, Argote, & Krishnan, 1998). In practice, timing is a crucial factor in organizational operation and decision-making. Usually, the faster groups act or react, the more competitive advantages they could obtain and maintain. On the other hand, organizations need to do the "right" thing and do things "right". Quality becomes another key organizational goal. In ORGMEM, quality is design to be a abstract measure that can capture a variety of aspects of group performance. In the operation task settings, quality can reflect how good the products are or how well the operation processes are planned. In the decision task settings, quality can reflect how good the group decisions are as well as how good the consequences resulted from the decision. Overall, it describes how well the group performs the tasks. In ORGMEM, time is measured by counting the time periods elapsed between the initiation of decision and when it is finished; quality is jointly decided by the resources available and the organizational settings (Kunz, Levitt, & Jin, 1998).

Independent variables. ORGMEM adopts an innovative memory representation of transactive memory. No matter organizational memory or individual memory, it is usually represented as a binary matrix (Carley, 1991). To better reflect the feature of transactive memory, a trinary format is taken to represent transactive memory instead of a binary one in ORGMEM. Hence there are three values in the memory: 1 means yes; -1 means no; 0 means not sure. Let's take agent i's IxI matrix as an example. An 1 between j and k means that agent i knows agent j communicates with agent k; a –1 means that agent i knows that agent j does not communicate with agent k; a 0 means that agent i doesn't know anything about or not sure about the connection between agent j and agent k. This representation helps us to discriminate "knows not connected" from "don't know if connected", which otherwise will both be denoted as 0. The tradeoff is that it makes the measurement of transactive memory more complicated. Transactive memory is measured from two aspects in ORGMEM: density and accuracy. They can be collected on both individual level and group level. To assure measurement efficiency, self-knowledge is excluded from the calculation of all measures because it is helps neither resource searching nor information evaluation.

Density measures how much useful knowledge exists in transactive memory. It is calculated by dividing the actual number of non-zero information in transactive memory by the maximal possible number of non-zero information. In this context, useful knowledge is equal to non-zero knowledge. Thus, density at the individual level can calculated using the equation 6 in the Appendix. The nominator of the formula consists of three parts corresponding to the three matrixes in transactive memory – people by people (Network/Social matrix), people by resources

(Skill/Knowledge matrix), and people by tasks (Assignment matrix). For each matrix, the density is calculated by dividing the number of zeros by the maximal number of zeros that is also the size of the matrix. Afterwards, the densities of three matrixes are averaged to get the overall zero-density of this agent's transactive memory and the density of non-zero knowledge can be obtained by subtracting zero-density from 1. Finally, individual transactive memory densities are average across to get group transactive memory density. Group density is 1 if everybody in the group has a complete knowledge about other groups members' resources or tasks, say the transactive memory systems reach the potential maximum value.

Accuracy measures the percentage of knowledge in the transactive memory that is accurate. In other words, it tells us how much knowledge in the transactive memory reflects the reality. The inaccuracy of knowledge comes from several sources. The main source is out-of-date knowledge. In other words, a piece of information may be true at one moment, but not true any more as time goes on. For instance, Mr. Brown used to work on a C project, learned a lot of C programming, and became an expert of that project. People went to him with questions about that project. Then Mr. Brown switched to work on another project that requires different skills. Six months later, Mr. Brown's mind is filled with the new project and many of the details of the old project are forgotten. But other people don't know this change and keep regarding him as the expert of the old project. Now their knowledge of Mr. Brown as an expert in the old project becomes out of date and thus inaccurate. The inaccurate knowledge won't go away. It stays in people's mind and keep getting diffused through interpersonal communication. That makes another source of inaccurate knowledge. Accuracy can be calculated by dividing the number of accurate non-zero knowledge by the total number of non-zero knowledge. Similarly, individual transactive memory accuracy is obtained by calculating and averaging accuracy across three matrixes in transactive memory and group transactive memory accuracy is obtained by averaging across group members.

IV. VIRTUAL EXPERIMENTS & RESULTS

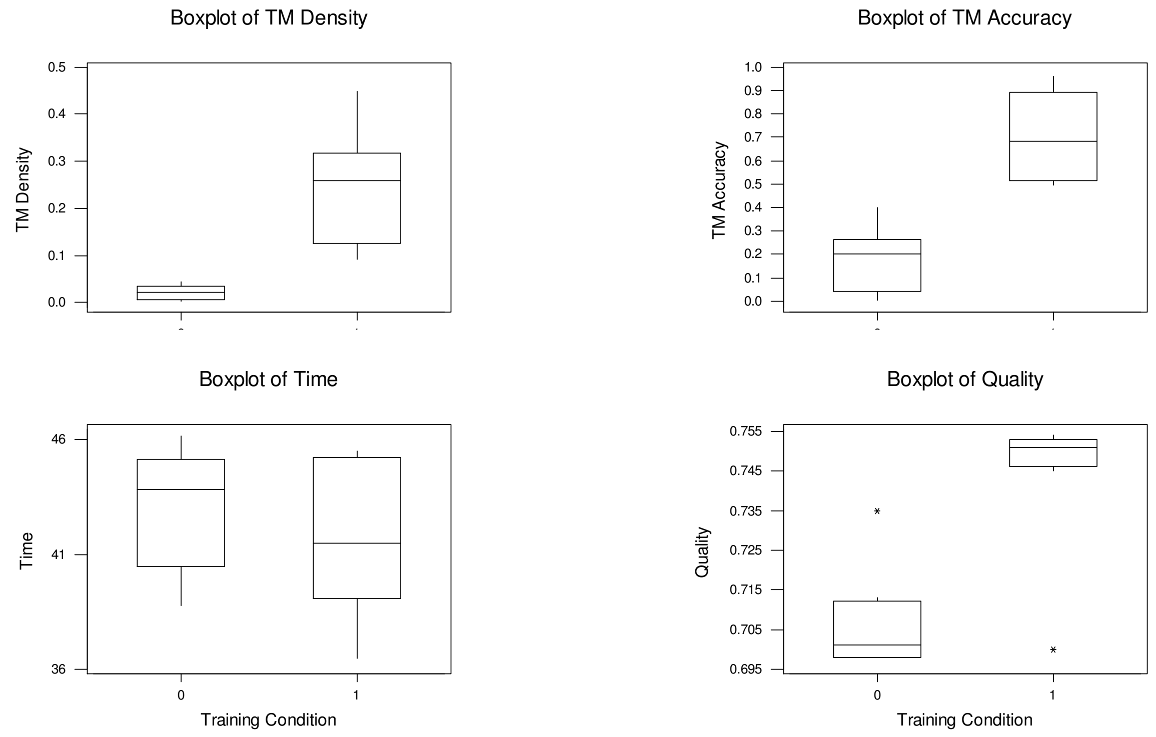
Modeling Validation. Moreland, Argote and Krishnan (1998) systematically study the role of transactive memory in group training using lab experiments and find out that group performance can be improved by training its members together rather than apart and stronger transactive memory is developed in groups whose members are trained together. Put in another way, greater complexity, greater accuracy, and greater agreement of transactive memory is found in groups whose members are trained together.

The virtual experiment setting in this paper can be paralleled with the lab experiment setting discussed above by considering the following connections.

- The training process in ORGMEM can be equalized to the training session in the lab experiment. Compared to individual training, the distinctiveness about group training is that it facilitates the communication and observation processes through which group members can learn who is good at what. In that sense, the training process in ORGMEM that involves learning, communicating and observing, captures the training process in Moreland et al.'s study reasonably well.

- The operation and decision-making process in ORGMEM can be equalized to the testing session in the lab experiment. Although group members apply their knowledge to make decisions in one process while assemble a radio in the other, both processes have one feature in common that is the group performance largely depends on the knowledge and experience group members have. In that sense, two processes are comparable.
- There is an almost one-to-one match between the measures of transactive memory in ORGMEM and the lab experiment. In ORGMEM, we measure transactive memory in terms of density, accuracy, consensus, and union, in which density, accuracy, and consensus respectively correspond to the complexity, accuracy, and agreement indexes applied in the lab experiment.
- There is also a good match between the group performance measurements between the virtual experiments and lab experiments. In ORGMEM, group performance is measured by the time taken to finish tasks and the quality of task performance. In the lab experiments, group performance is measured by speed to assemble a radio and the number of assemble errors groups made.

Therefore, we can say that the lab experiments setting is appropriate to validate our virtual experiment results as well as the computational model – ORGMEM. In Moreland et al.'s study, the unit is three people group consisting of the same sex. To better match the lab experiment setting, we construct groups with three people and assume that group members don't have much background knowledge and only have social knowledge of their own, such as their own knowledge and social connections at the beginning.



0 – individual training 1 – group training

Figure 4. Differences between Group Training and Individual Training

Figure 4 shows the differences between group training and individual training in terms of transactive memory density, accuracy, time taken for groups to finish their tasks, and group performance quality. Group training condition is denoted by 1 and individual training is denoted by 0. Consistent with the findings in lab experiment, the virtual experiment results suggest that group training helps to construct more complex and accurate transactive memory and groups trained together tend to outperform groups trained individually by making more accurate decisions and producing better products. However, training people together doesn't seem to speed up group operation or decision, at least in the 3-person setting. All of the results above are highly consistent with the lab experiment results, indicating that the external validity of ORGMEM is reasonably high[6].

Another important finding in Moreland et al.'s study is that transactive memory tends to mediate the relationship between group training and group performance. This phenomenon is also investigated in our study and the virtual experiment results are shown in Table 1.

Table (a)

	Time	Time	Time	Time	TM dns	TM acc
Train type	-0.8083 ($p=0.4661$)	3.7729 ($p=0.0779$)	4.1855 ($p=0.0064$)	5.7514 ($p=0.0048$)	0.2592 ($p<0.001$)	0.4835 ($p<0.001$)
TM density		-17.6771**		-8.2698		
TM accuracy			-10.3295***	-9.1351**		
R-square	0.0116	0.1343	0.3103	0.3331	0.7524	0.5973
Adj R-sq	-0.0099	0.0958	0.2796	0.2877	0.7470	0.5885

Table (b)

	Quality	Quality	Quality	Quality	TM dns	TM acc
Train type	**0.0420** **($p<0.0001$)**	**0.0169** **($p=0.1431$)**	**0.0146** **($p=0.0730$)**	**0.0061** **($p=0.5648$)**	0.2592 ($p<0.001$)	0.4835 ($p<0.001$)
TM density		0.0966**		0.0449		
TM accuracy			0.0567***	0.0502***		
R-square	0.5166	0.5769	0.6649	0.6760	0.7524	0.5973
Adj R-sq	0.5061	0.5581	0.6500	0.6539	0.7470	0.5885

* $p<0.1$; ** $p<0.05$; *** $p<0.01$

Table 1: Regression Analysis Results of Transactive Memory's Mediation Role

According to Baron & Kenny (1986), to detect mediation we need to be able to prove (1) the independent variable affects the dependent variable; (2) the independent variable affects the mediator variable; (3) when we include mediator variable into the regression of independent variable on dependent variable, the independent variable's influence becomes weaker or insignificant. For the analysis of group performance quality, all of these three conditions are confirmed by the regression analysis results. After introducing transactive measures into the regression on quality, as shown in table 1, the coefficient of train type becomes both smaller and

---

[6] The *t*-test results show that the difference between group training and individual training is significant for TM density, TM accuracy and quality, but not for time taken to finish tasks.

insignificant[7]. Therefore we can roughly conclude that transactive memory does mediate the relationship between group training and group performance.
Now let's compare the results from virtual experiments with lab experiment results. The comparison is presented in Table 2.

	Lab experiment	**Virtual experiment**
How does group training affect transactive memory?	Positive, significant	Positive, significant
How does group training affect time taken to finish tasks?	Decreased, insignificant	Decreased, insignificant
How does group training affect group performance quality?	Improved, significant	Improved, significant
What is the role of transactive memory between group training and group performance?	Mediate	Mediate

Table 2: Comparison of Lab vs. Virtual Experiments

How group training affects transactive memory? The lab experiment results conclude that groups member trained together have transactive memory with greater complexity, greater accuracy, and greater agreement with each other and hence are more likely to specialize in remembering different aspects of the assembly processes, coordinate their activities better, and display greater trust in one another's radio expertise. The virtual experiment results indicate that group training is associated with transactive memory with higher density and accuracy, which corresponds to the lab experiment results.

How group training affects group performance? The lab experiment results suggest that group members trained together work better than those trained apart and make fewer errors in assembling a radio, but not necessarily work faster. The virtual experiment results in Table 1 correspond to this finding and show that being trained as a group both improves group performance quality and decreases the time taken by the group to finish tasks, but the impact on time is not significant. Therefore, virtual experiment findings are consistent with the lab experiment results.

What is the role of transactive memory between group training and group performance? In the lab experiments, three alternative explanations – task motivation, group cohesion, and social identity are explored and excluded from the analysis. This result together with the fact that including transactive memory into analysis changes the effects of training from significant to insignificant proves that transactive memory systems do mediate the effect of training on group performance. Our conclusion from virtual experiment about the mediator role of transactive memory closely corresponds to the lab experiment results.

---

[7] We tried two ways of including TM variables – one is to introduce TM density and TM accuracy separately and the other is to introduce both of them simultaneously. The reason is that the correlation between TM density and TM accuracy is high (0.7922) and we doubt that there may exist multicollinearity problem. It turns out that under both conditions, the introduction of TM variables into the analysis causes the train type coefficient become insignificant as well as smaller.

Based on the comparison above, ORGMEM, as a computational model to study transactive memory and group performance, has been briefly validated. In the future study, more detailed and elaborated validation will be continued to better demonstrate the power of this computational model.

Contingency Effect. In a previous study, we have demonstrated that transactive memory helps groups to perform better, by either taking less time to finish their tasks or producing higher quality decisions or products (Ren, 2001). The previous results also suggest that groups can achieve these purposes by having either more complex transactive memory or more accurate transactive memory. Since these results are based on a dataset that is collected from groups with a variety of sizes, from 9 to 45, it enables us to investigate the impact of transactive memory on groups with different characteristics. To extend the existing literature, especially previous lab experiment findings that are primarily obtained in small groups, a series of virtual experiments are run by manipulating the following parameters as shown in Table 3.

Virtual Experiments		
Group size	9, 15, 21, 27, 35, 45	6
Network density	10%, 40%, 70%	3
Capability load	10%, 40%, 70%	3
Communication mode	Random, relative similarity, information seeking, synthesis	4
Communication complexity	1, 5, 10, 20, 30	5
Transactive memory state	Start with everybody knows only about their own TM	1
Total		1080

Table 3: Virtual Experiment Design[8]

By applying ordinary regression analysis techniques, we investigate the relationship between training and group performance as well as the relationship between transactive memory and group performance in different-sized groups. The results are shown in Table 4 and several interesting phenomena can be observed. First, as group size goes from smaller to larger, the impact of group training on group performance time changes from insignificant to significant, which suggests that the benefits of group training in terms of time saving can only make a significant difference in groups large enough. Second, the coefficients of transactive memory density and accuracy jointly suggest that transactive memory structured differently may have distinctive impact on group performance. For example, for groups with size 3, having more complex and more accurate transactive memory are predicted to help shorten group performance time to the same degree; while in groups with size 9 or 15, having more accurate transactive memory has much larger effect on the time than having more complex transactive memory. As group size is increase to over 30, transactive memory has almost no effect while transactive memory accuracy is still significantly negative. Third, although overall the coefficients of transactive memory density and accuracy and their significant level vary across different conditions, the effect of transactive memory accuracy on performance time is highly significant

---

[8] Network density refers to the density of interpersonal ties in the people by people network. Capability load refers to the density of the people by resources network – the denser the network is, the more resources group members will have access to.

in all groups, which implies that having accurate knowledge of other people's knowledge plays a very crucial role in helping people to locate knowledge within groups and thus shorten the time taken to finish their tasks. A plot between group size and the coefficient of transactive memory accuracy is drawn in Figure 5. The graph demonstrates an obvious U-shape, which implies that having more accurate meta-knowledge tends to be more important in middle-size groups.

Group size Coefficients	3	9	15	21	27	35	45
Train-time	-0.808	-1.301	-4.246	-3.687	-5.714*	-3.961***	-3.489***
Train-quality	0.042***	0.067***	0.063***	0.055***	0.042***	0.036**	0.025
TMdns-time	-15.47*	-8.947***	-8.11*	-15.26**	3.515	-12.80*	-6.535
TMacc-time	-14.14***	-106.1***	-222.1***	-321.1***	-230.3***	-57.62***	-43.23***
TMdns-quality	0.079**	0.060***	0.045**	0.067*	0.071	0.162	0.395
TMacc-quality	0.058***	0.207***	0.049	0.228	0.099	0.037	0.004

* p<0.1; ** p<0.05; *** p<0.01

Table 4: Impact of Training and Transactive Memory under Different Group Sizes

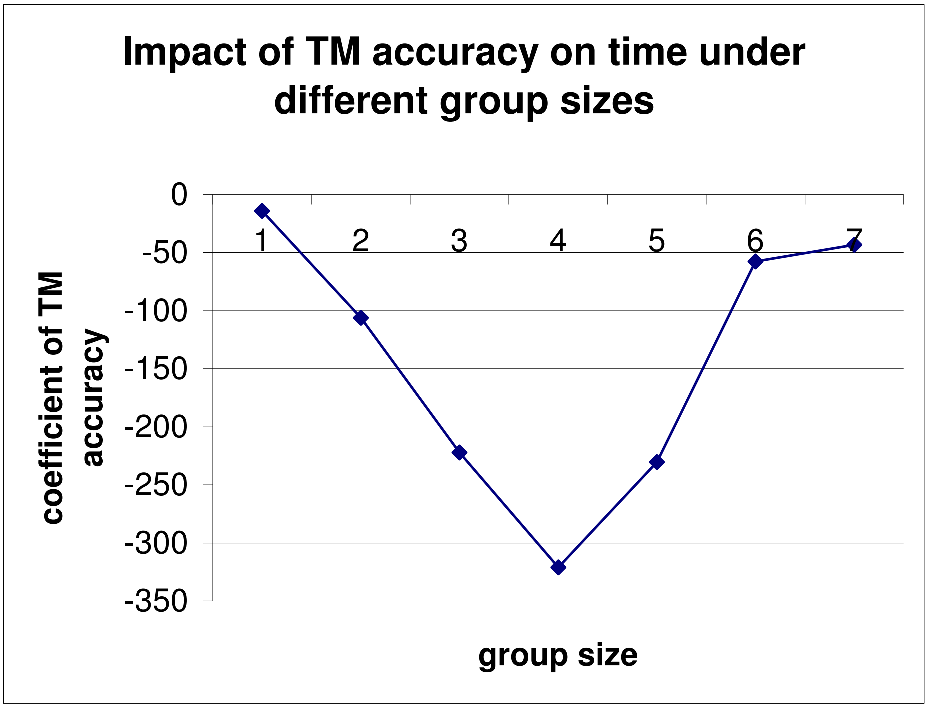


Figure 5: Impact of Transactive Memory Accuracy under Different Group Sizes

VI. CONCLUSION

A computer simulation program – ORGMEM is designed and implemented in this project and applied to explore the relationships between transactive memory and group performance. Transactive memory's positive impacts on group decision timing and quality are demonstrated and the results partially correspond to the previous studies. Moreland, Argote and Krishnan (1998) study radio assembly in their lab experiments and conclude that groups whose members are trained together appear to have more complex and accurate transactive memory and thus generate fewer errors in their operations. Our findings from virtual experiments regarding group performance are consistent with the lab experiment results and both suggest that three-person groups with members trained together tend to develop a more complex and accurate transactive memory system and outperform other groups in terms of quality but not time. Based on that, our virtual experiment results examining a variety of group settings indicate that group training may significantly decrease performance time in larger groups and implies that there may exist a size effect. More specifically, in the three-person group, the time taken to search for a specific knowledge is so trivial that it can be completely ignored. But in large groups with twenty or forty people, the search cost may increment dramatically with the group size. By examining the impact of transactive memory on group performance in more details, the size contingency effect is supported. This realistic implication drawn from this study is that groups with different sizes can all benefit "optimally" by adopting the kind of transactive memory that best fits their characteristics.

APPENDIX

Knowledge Diffusion. Let agent i's knowledge in domain r at time (t) be denoted by $S_{ir}(t)$ and the maximum knowledge in domain r be M_r. An agent's learning potential in domain r, i.e. how much this agent can learn is denoted by $(\mathrm{M}_\mathrm{r} - S_{ir}(t))$. Since the amount of knowledge an agent can learn in each domain is limited, the more knowledge an agent has, the more difficulty the agent experiences to improve his/her knowledge. There is a decreasing return to scale. So what agent i knows at time (t+1) is denoted by:

$$S_{ir}(t+1) = S_{ir}(t) + \alpha_r * S_{jr}(t) * (M_r - S_{ir}(t)) \qquad (1)$$

s.t. $0 \le S_{ir}(t) \le M_r$ and $0 \le \alpha_r \le 1$

Communication Probability. Let $S_{ir}(t)$ be agent i's knowledge in domain r and $S_{jr}(t)$ be agent j's knowledge in domain r, $RS_{ij}(t)$, the probability that agent i will interact with agent j based on relative similarity, can be calculated as:

$$RS_{ij}(t) = \frac{\sum_{r=1}^{R} \min(S_{ir}(t), S_{jr}(t))}{\sum_{k=1}^{I} \sum_{r=1}^{R} \min(S_{ir}(t), S_{kr}(t))} \qquad \text{s.t.} \qquad 0 \le RS_{ij}(t) \le 1 \qquad (2)$$

The probability that agent i will interact with agent j based on information seeking, IS_{ij}, can be calculated by dividing the relative expertise of agent j compared to agent i with the sum of relative expertise of everyone else in the group compared to agent i.

$$IS_{ij}(t) = \frac{\sum_{r=1}^{R}(S_{ir}(t)=0 \,\&\, S_{jr}(t)\neq 0)}{\sum_{k=1}^{I}\sum_{r=1}^{R}(S_{ir}(t)=0 \,\&\, S_{jr}(t)\neq 0)} \qquad \text{s.t. } 0 \leq IS_{ij}(t) \leq 1 \tag{3}$$

Forgetting. Let β_r be the forgetting coefficient in domain r. By combining knowledge transfer and forgetting, an individual agent's knowledge at time (t+1) can be represented using the following formula.

$$S_{ir}(t+1) = S_{ir}(t) + \alpha_r * S_{jr}(t) * (M_r - S_{ir}(t)) - \beta_r * S_{ir}(t) \tag{4}$$

s.t. $0 \leq S_{ir}(t) \leq M_r$ and $0 \leq \alpha_r \leq 1$ and $0 \leq \beta_r \leq 1$

Trust. Let $trust_{ij}$ be agent i's trust toward agent j at time (t) and IR_{ij} be agent j's knowledge level in agent i's transactive memory. Agent i's trust toward agent j can be calculated as:

$$trust_{ij}(t) = \frac{\sum_{j=1}^{R} IR_{ij}(t)}{M_r * \mathrm{Re}\,sourceComplexity} \tag{5}$$

Transactive Memory Measures. Both transactive memory measures depend on an agent's perception of the underlying social structures, rather than the actual structures. For example, agent i's perception of the underlying social network, i.e. who does agent i thinks interact with whom can be denoted by $PSN_{ijl}(t)$ and it can have one of three types of states: i thinks j interacts with l ($PSN_{ijl}(t)=1$), i thinks j doesn't interact with l ($PSN_{ijl}(t)=-1$), or i doesn't know ($PSN_{ijl}(t)=0$). Similarly, agent i's perception of the underlying knowledge network, i.e. who does agent i thinks has access to what knowledge can be denoted by $PKN_{ijk}(t)$ and it can have one of three types of states: i thinks j has k ($PKN_{ijk}(t)=1$), i thinks j doesn't have k ($PKN_{ijk}(t)=-1$), or i doesn't know ($PKN_{ijk}(t)=0$). Finally, agent i's perception of the underlying assignment network, i.e. who does agent i thinks is assigned to what tasks can be denoted by $PAN_{ijw}(t)$ and it can have one of three types of states: i thinks j does w ($PAN_{ijw}(t)=1$), i thinks j doesn't do w ($PAN_{ijw}(t)=-1$), or i doesn't know ($PAN_{ijw}(t)=0$). On the other hand, the actual social, knowledge and assignment networks can be denoted as $ASN_{jl}(t)$, $AKN_{jk}(t)$, and $AAN_{jw}(t)$.

$$density_i(t) = 1 - \frac{\sum_{j=1}^{I}\sum_{l=1}^{I}(PSN_{ijl}(t)=0)/(I*I) + \sum_{j=1}^{I}\sum_{k=1}^{K}(PKN_{ijk}(t))/(I*K) + \sum_{j=1}^{I}\sum_{w=1}^{W}(PAN_{ijw}(t))/(I*W)}{3} \quad (6)$$

Let $CT(PSN_{ijl})$ be the number of non-zeros in the network matrix of agent i's transactive memory. Accuracy at the individual level can be calculated by the following formula[9].

$$accuracy_i = \frac{accuracy_{SN} + accuracy_{KN} + accuracy_{AN}}{3} \quad (7)$$

in which $accuracy_{SN} = \sum_{j=1}^{I}\sum_{l=1}^{I}(PSN_{ijl} \wedge ASN_{jl})/CT(PSN_{ijl})$

$$accuracy_{KN} = \sum_{j=1}^{I}\sum_{k=1}^{K}(PKN_{ijk} \wedge AKN_{jk})/CT(PKN_{ijk})$$

$$accuracy_{AN} = \sum_{j=1}^{I}\sum_{w=1}^{W}(PAN_{ijw} \wedge AAN_{jw})/CT(PAN_{ijw})$$

$$CT(PSN_{ijl}) = I*I - \sum_{j=1}^{I}\sum_{l=1}^{I}(PSN_{ijl}=0)$$

REFERENCES

Argote, Linda (1999), *Organizational learning: Creating, retaining and transferring knowledge*, Norwell, MA: Kluwer

Burton-Jones, Alan (1999), Knowledge capitalism: business, work, and learning in the new economy, New York: Oxford University Press.

Carley, K., (1990), Groups stability: A socio-cognitive approach, *Advances in Group Processes*, Vol. 7, 1-44

Carley, K. (1991), A Theory of Group Stability, *American Sociological Review*, 56(3): 331-354

Carley, Kathleen M. & Dayanand, Nalini (working paper), Beliefs and Group Stability, Carnegie Mellon University

Carley, K., Ren, Y., & Krackhardt, D. (2000), Measuring and modeling change in C^3I architecures, in proceedings of the 2000 International Symposium on Command and Control Research and Technology. June, Monterray, CA.

Cohen, Don (1998), Managing knowledge in the new economy, New York: Conference Board.

---

[9] $\wedge$ here means the value in matrix PSN_{ij} is consistent with the value in matrix ASN_{ij}. We consider only useful information here, say 1s and –1s in matrix PSN_{ij}. $PSN_{ij} \wedge ASN_{ij} = 1$ if $PSN_{ij} = 1$ and $ASN_{ij} = 1$ or $PSN_{ij} = -1$ and $ASN_{ij} = -1$. This formula can be applied at different time points. The item (t) is ignored to save space.

Cohen, W. M. & Levinthal, D. A. (1990) Absorptive capacity: A new perspective on learning and innovation, *Administrative Science Quarterly,* 35, 128-152

Cook, Scott D. N., Brown, John Seely (1999), Bridging epistemologies: The generative dance between organizational knowledge and organizational knowing, *Organization Science*, Vol. 10, No. 4: 381-400

Eliasson, Gunnar (1990), The knowledge based information economy, Stockholm, Sweden: Industrial Institute for Economic and Social Research: Telecom: Almqvist & Wiksell.

Henry, R., (1995), Improving group judgment accuracy: Information sharing and determining the best member, *Organizational behavior and Human Decision Processes*, 62, 190-197

Hollenbeck, J. R., Ilgen, D. R., Sego, D. J., Hedlund, J., Mafor, D. A., & Philips, J., (1995), Multilevel theory of team decision making: Decision performance in teams incorporating distributed expertise, *Journal of Applied Psychology*, 80, 292-316

Hollingshead, A. B., (1998a), Communication, learning, and retrieval in transactive memory systems, *Journal of experimental social psychology*, 34, 423-442

Hollingshead, A. B., (1998b), Retrieval process in transactive memory systems, *Journal of personality and social psychology*, Vol. 74, No. 3, pp.659-671

Hollingshead, A. B., (1998c), Group and individual training: The impact of practice on performance, *Small Group Research*, 29(2), 254-280

Kang, M., Waisel, L. B., & Wallace, W. A. (1998), Team-Soar: A model for team decision making, In M. J. Prietula, K. M. Carley, L. Gasser (Eds.), *Simulating Organizations: Computational Models of Institutions and Groups*, AAAI Press/ The MIT Press, Menlo Park, California, Cambridge, Massachusetts, London, England

Krackhardt, D. & Carley K. M. (1998), PCANS model of structure in organizations, IN proceedings of the 1998 International Symposium on Command and Control Research & Technology, June, Monterray, CA

Kunz, John C., Levitt, Raymond E. & Jin, Yan (1998), The virtual design team: A computational simulation model of project organizations, *Communications of the Association for Computing Machinery*, Vol. 41, No. 11:84-92

Liang, D. W., Moreland, R., & Argote, L., (1995), Group versus individual training and group performance: the mediating role of transactive memory, *Personality and social psychology bulletin*, Vol. 21, No. 4, pp. 384-393

Littlepage, G. E., Robison, W., & Reddington, K., (1997), Effects of task experience and group experience on group performance, member ability, and recognition of expertise, *Organizational Behavior and Human Decision Processes*, 69, 133-147

Metcalf, J. (1986), Decision making and the Grenada rescue operation, In March, J. G. & Weissinger-Beylon, R. (Eds.), *Ambiguity and Command: Organizational Perspectives on Military Decision Making,* Marshfield, MA: Pitman Publishing Inc.

Moreland, R. L. (in press), Transactive memory: Learning who knows what in work groups and organizations, In L. Thompson, D. M. Messick & J. M. Levine (Eds.), *Shared knowledge in organizations*, Lawrence Erlbaum

Moreland, R. L., Argote, L., & Krishnan, R. (1996), Socially shared cognition at work: Transactive memory and group performance, In J. L. Nye & A. M. Brower (Eds.), *What's social about social cognition? Research on socially shared cognition in small groups* (pp. 57-84), Thousand Oaks, CA: Sage

Moreland, R. L., Argote, L., & Krishnan, R. (1998), Training people to work in groups, In R. S. Tindale, L. Heath, J. Edwards, E. J. Posvac, F. B. Bryant, Y. Suarez-Balcazar, E. Henderson-King & J. Mayers (Eds.), *Applications of theory and research on groups to social issues* (pp. 37-60), New York: Plenum Press

Newell, Allen & Simon, Herbert A. (1972), Human problem solving, Englewood Cliffs, N.J., Prentice-Hall

Ren, Yuqing (2001), Simulating the Role of Transactive Memory in Group Performance. In Proceedings of the 4th International Organizational Learning and Knowledge Management Conference, London, Ontario, Canada

Szulanski, G. (1996) Exploring internal stickiness: Impediments to the transfer of best practice within the firm, *Strategic Management Journal*, 17 (winter special), 27-43

Wegner, D. M. (1987), Transactive memory: A contemporary analysis of the group mind, In B. Mullen & G. R. Goethals (Eds), *Theories of group behavior* (pp. 185-205), New York: Springer-Verlag

Wegner, D. M. (1995), A computer network model of human transactive memory, *Social Cognition*, 13, 319-339

Wegner, D. M., Erber, R., & Raymond, P. (1991), Transactive memory in close relationships, *Journal of Personality and Social Psychology,* 61, 923-929

Wegner, D. M., Giuliano, T., & Hertel, P. T. (1985), Cognitive interdependence in close relationships, In W. J. Ickes (Ed.), *Compatible and incompatible relationships* (pp. 253-276), New York: Springer-Verlag

Winslow, Charles D. & Bramer, William L. (1994), Future work: putting knowledge to work in the knowledge economy, New York: Free Press; Toronto: Maxwell Macmillan Canada; New York: Maxwell, Macmillan International.