Shared Mental Models in Military Command and Control Organizations: Effect of Social Network Distance

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This paper presents an investigation on the relationship between social network distances and shared mental models in military command and control organizations. Previous research has shown that physical distance is the gold standard for high performance (Olson & Olson, 2000). However, social network distance may be equally or more important, as social network graphs inherently take into account the group's context and environment (Krackhart, 1994). We conducted this research on a new 56-member command and control organization using computer-based collaborative tools as they engaged in a five day simulation exercise. As military command and control organizations are difficult to evaluate based on outcome and performance, we chose shared mental models as a proxy. We hypothesized that in a command and control organization, social network distance and physical distance are independent of one another. Further we hypothesized that social network distance would be a predictor of mental model congruence. We found that there is a very weak positive correlation between social network distance and physical distance. Further, we found that, controlling for physical distance, social network distance is a predictor of mental model congruence. This research validates that high frequency of communication, mediated by computer based collaborative tools, can effectively generate shared mental models.

INTRODUCTION

Olson & Olson (2000) found that physical distance matters to performance in group work. Despite the gains achieved in distance communication during the last ten years by the internet and collaboration tools, performance in groups is still strongly predicted by physical distance. This paper is based on our belief that social network distance is not the same as physical distance but is equally or more important to predicting performance. Social network distance is potentially more important because context and task requirements of a group are implicitly embedded within the social network graph (Krackhart, 1994).

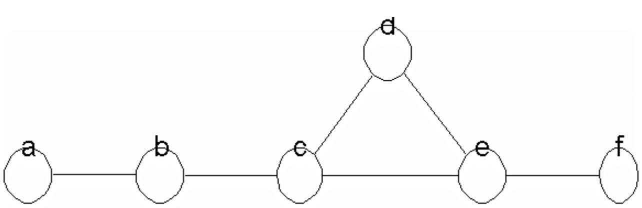

Figure 1. A simple network graph. (Borgatti, 1994)

A social network is a graph consisting of individuals and connections between them. In a social network graph, individuals are represented as nodes and communication between individuals is represented by links between the nodes (Figure 1) (Borgatti, 1994; Scott 1992). Communication data can be gathered by looking at various measures such as shared email headers or phone calls, or by surveying the individuals (Wasserman & Faust, 1994). Social network distance (often referred to as a geodesic) (Borgatti, 1994) is the number of links or actors between two members of a social network graph.

Previous research has shown that shared mental models are a feature of high-performing command and control teams. (Cannon-Bowers, Salas & Converse, 1993). According to Kraut et al. (1999), the creation of shared mental models happens through three factors: opportunities to observe, communication, and division of labor within a team. Bolstad & Endsley (1999) found that placing team members physically adjacent allowed more rapid development of shared mental models by creating more opportunities for observation and monitoring.

Much of the previous research in shared mental models uses questions about the team, task, and situation to generate a congruence measure for a group's mental model (Espinosa et al, 2001; Cannon-Bowers & Salas, 1993; Entin & Serfaty, 1999). Entin (1999) found that a measurement of workload estimation is a useful proxy for direct measures of shared mental models. This work validated the assumption that, to accurately estimate another's workload, a member must understand the other person's tasks, team relationships, and situation.

While physical distance has been explicitly linked to the development of shared mental models, social network distance has not. Since social networks are based on the level of communication between members, we hypothesize that shorter social distances between team members will create more congruent mental models. The remainder of this paper documents our efforts to test this theory.

METHOD

Context and Participants

The US Army is in the infancy of a ten-year organizational design process for a knowledge-centric command and control element. In support of this initial effort, the Fort Leavenworth Battle Command Battle Laboratory (BCBL) gathered fifty-six army officers to serve as role-players for a experimental command and control staff (Figure 2).

Figure 2: Command post exercise

All participants were experienced (7-25 years) in the general requirements of their assigned roles, such as intelligence, psychological operations, artillery, and aviation. Each role-player was assigned to a functional cell with three to eight other role-players. They spent one week in team training. During this time, they were required to learn a) the concepts behind the experimental organization, b) a new method to make decisions in the experimental organization, c) their role in the structure of the experimental organization, and d) how to use the simulation software during the evaluation.

During the simulation, the role-players gathered information, coordinated with appropriate staff members, and entered battlefield actions into the simulation. Partitions or walls separated the seven cells, so that a participant could talk directly to members of his own cell, but could only communicate with members of other cells using the communication tools.

Data Collection

The research reported in this paper was conducted over five days immediately following the one-week training period. A plan-execute-plan-execute cycle was used. Data was collected every 60-90 minutes using networked questionnaire that asked the participants for feedback regarding the prior session. Questionnaire data was collected for a total of 16 sessions.

Social network data was gathered by asking the participants to report the people they had communicated with in the time since the previous questionnaire (Scott, 1992). They could give up to 10 responses by selecting participants from pull-down menus. The responses were ordered by the frequency of communication during the previous session.

Shared mental model estimates were gathered using the NASA TLX (Task Load Index) (Hart & Staveland, 1988) assessment consisting of seven workload parameters on a Likert scale. The version of the NASA TLX used in this research consisted of six workload parameters on a Likert scale. The parameters were mental demand, temporal demand, effort, own performance, frustration level, and physical demand.As in Entin (1999), participants were asked to rate themselves as well as five other people randomly selected from the other participants. When rating other people, participants had the option of selecting "Don't Know" for each of the seven questions.

Measures

The data were analyzed on a per session basis. The first independent variable was social network distance, which is the shortest path distance separating two people within the social network. The second independent variable was physical distance, for which we used shared cell membership as a proxy.

The dependent measures were willingness-to-rate and mental model congruence (workload). Willingness-to-rate was determined by number of the six NASA TLX items for which the participant chose to rate the other person divided by the total number of questions.

Mental model congruence was determined by comparing each person's self-reported workload with the estimation of that person's workload by other participants. This measure was computed by summing the absolute differences between the self-reported ratings and the rater's estimations. Congruence scores could range from 0 (indicating perfect congruence) to 36.

RESULTS

We first compared Social Network Distance (SND) to physical distance. We found that the two distance measures were weakly correlated at r = .247. This supports the concept that SND and physical distance are not the same.

Next, we tested the hypothesis that physical distance is a predictor of willingness-to-rate. Recall that we are using same cell membership as a proxy for physical distance. The effect of physical distance on the willingness-to-rate is significant ($F[1, 24] = 211$, $p < .0001$), controlling for the effect of SND, rater, and survey period (Figure 3).

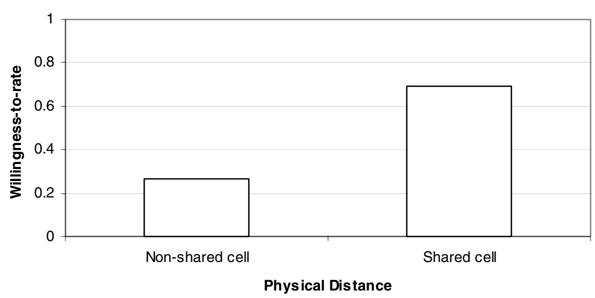

Figure 3: Mean willingness-to-rate by physical distance (shared cell vs non-shared cell) (n = 3028)

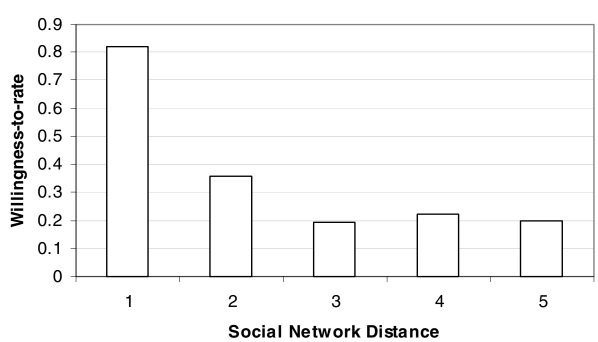

Figure 4: Mean willingness-to-rate by SND (n = 3028)

Then we tested the hypothesis that SND is a predictor of willingness-to-rate. The effect of SND on the willingness-to-rate is significant ($F[1, 34] = 302$, $p < .0001$), controlling for the effect of physical distance, rater, and survey period (Figure 4).

Our next step was to run a regression model to test the hypotheses that both physical distance and SND are predictors of mental model congruence. We used the variables of rater and survey period to control for the person and the effect of time. The results are as in Table 1.

Parameter	Estimate	Std Error	DF	Sum of Squares	t-ratio
Intercept	10.65	0.83	1	n/a	12.81***
Rater	n/a	n/a	32	2037	n/a
Session	-0.03	0.05	1	9.7	-0.54
Physical Distance	-0.96	0.49	1	128.5	1.96*
Social Network Distance	0.49	0.24	1	138	2.04*

Table 1: Predictors of Mental Model Congruence

Regression results indicate that both physical distance and SND are predictors of mental model congruence, supporting our hypotheses. SND is a significant predictor of mental model congruence (Figure 5) ($p < .05$), as is physical distance ($p < .05$). The mean congruence of individuals in the same cell is 10.65, which is significantly more congruent than those in different cells (mean = 11.61).

DISCUSSION

Both social network distance and physical distance were predictors of mental model congruence. However these distance measures are qualitatively different from each other. Physical distance provides information about who is likely to use face-to-face coordination and who is proximate. SND is capable of providing information about who is linked by the task structure, context, and organizational structure. The weak correlation between the two distance measures further supports the difference between SND and physical distance.

Our results did show a significant decrease in mental model congruence as both SND and physical distance increased. Thus, the qualititative aspects of physical distance and SND should be considered. Physical distance is often immutable and static. It is unlikely that key agents can simply be placed in the same room every time their mental model congruence falls below threshold. However SND, as a function of task, context, and organizational structure, is dynamic and is under greater personal control. SND can be reduced by simply increasing communication between distant agents. The tradeoff is that with increased communication, the workload of the agents increases as well.

Limitations

This research was based on measurements of one organization over a short period of time. Therefore the results may not apply to other types of organizations and other contexts. Furthermore, there are other methods besides self-reported communication frequency that could be used to develop social network graphs. Other criteria such as background information, collaboration tool use, or actual measured communications frequency (email logs etc) may yield stronger relationships between SND and shared mental models. Also, physical distance was represented as a binary variable (shared vs non-shared cell). Measuring the actual distance could have yielded a more nuanced analysis. Finally, the structure of the organization was unstable due to the newness of the organization. It could be that these relationships do not hold true in an organization that has had time to stabilize.

CONCLUSION

This research suggests that SND may be as important as physical distance for understanding group performance and organizational structure. We found that physical distance and SND are independent from each other, yet they are both good predictors of shared mental models. However SND has inherent qualities that capture context and task more effectively than physical distance.

As we move to network organizations (Nohira & Eccles, 1992, Miles & Snow, 1995), SND will become more critical as a design tool for organizational structure and collaborative tool selection. Finding ways to shorten the social network distance without increasing workload, and finding ways to increase mental model congruence without high training costs, are worthwhile areas for future research.

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REFERENCES

Bolstad, C. A., & Endsley, M. R. (1999) Shared mental models and shared displays: An empirical evaluation of team performance. In *Proceedings of the 43rd Annual Meeting of the Human Factors and Ergonomics Society.* Santa Monica, CA.

Borgatti, S.P. (1994) A quorum of graph theoretic concepts. *Connections* 17(1): 47-49.

Cannon-Bowers, J. A., Salas, E., & Converse, S. A. (1993) Shared mental models in expert decision making teams. In N. J. Castellan, Jr. (Ed.), *Current Issues in Individual and Group Decision Making* (pp. 221-246). Hillsdale, NJ: Erlbaum.

Entin, E.E. (1999). Optimized command and control architectures for improved process and performance. In *Proceedings of the 1999 Command and Control Research and Technology Symposium*. United States Naval War College, Newport, RI.

Entin, E.E and Serfaty, D. (1999) Adaptive team coordination. *Human Factors*, 41, 312-325.

Espinosa, J. A., Kraut, R. E., Slaughter, S. A., Lerch, J. F., Herbsleb, J. D., & Mockus, A. (2001) Shared Mental Models and Coordination in Large-Scale, Distributed Software Development. *ICIS 2001*: 513-518.

Hart, S.G. & Staveland, L.E. (1988) Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P.A. Hancock & N. Meshkati (eds.) *Human Mental Workload*, 139-183. Elsevier Science: NorthHolland.

Krackhardt, D. (1994) Graph Theoretical Dimensions of Informal Organizations. In *Computational Organization Theory*. K.M. Carley and M.J. Pretula, eds., 89-111. Hillsdale, NJ: Lawrence Erlbaum Assoc.

Kraut, R. E., Fussell, S. R., & Lerch, F. J. (1999) Shared mental models in work groups: A controlled field study. *The Symposium on Shared Cognition in Teams: Predictors, Processes, and Consequences at the Annual Meeting of the Society for Industrial and Organizational Psychology (SIOP),* Atlanta, GA

Miles, R. E. & Snow, C. C.. (1992) Causes of failure in network organizations, *California Management Review*, vol. 34, pp. 53-71.

Nohria N, Eccles RG. (1992) *Networks and Organizations: Structure, Form and Action*. Boston, Mass.: Harvard Business School Press.

Olson, G. M., & Olson, J. S. (2000) Distance Matters. *Human-Computer Interaction. Special Issue: New agendas for human-computer interaction*, 15(2-3), 139-178.

Scott, J., (1992) *Social Network Analysis*. Newbury Park CA: Sage.

Wasserman, S. and Faust, K. (1994) *Social Network Analysis: Methods and Applications.* Cambridge: Cambridge University Press.