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Refinement of Mental Models of Interdependence and Communication

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This study examined the relationship between mental models of interdependence and communication in a simulated aviation flight operations center. Social network analysis indicated that mental models of both interdependence and communication importance develop with team interaction and that, following team interaction, the two types of models were closely related.

Increasing complexities involved in the world of work have forced companies to turn to teams in order to meet the new challenges (Smith-Jentsch, Campbell, Milanovich, and Reynolds, 2001). In the world of aviation, flight operation centers incorporate numerous team members to integrate complex information and make decisions in real-time. Various positions are needed in this work group, and each has unique information that needs to be communicated for effective decision-making and problem solving.

Flight operations centers are the hub of communication, information, and coordination among various critical aviation specialties. It is here that the converging disciplines must work together to ensure the safe and efficient operations of each individual aircraft and the overall airline. With the magnitude of information needed to accurately and efficiently make decisions in this industry and with the high consequences of errors, airlines need teams to meet the growing demands of information processing, technology, and high-stakes decision-making. Researchers have argued that these teams should be better equipped to function in this industry by sharing the burden of the tasks, backing each other up, contributing specialized skills, increasing the available amount of knowledge, and managing themselves (Mathieu, et al., 2000; Mesmer-Mangus & DeChurch, 2009). By utilizing groups of experts, teams can filter the necessary information through the group. The group can then integrate the information from various disciplines and make the best possible decision.

Mental models

Rouse and Morris (1986) defined mental models as "mechanisms whereby humans generate description of system purpose and form, explanations of systems functioning and observed system states, and predictions of future system states." (p. 7). This definition describes the three purposes of mental models; description, explanation, and prediction. As individuals increase their interaction with the team, they begin to understand how they fit into the overall teamwork process. This enables them to explain with whom they need to communicate and what they should be doing in any given situation. This understanding will also help them predict what their team members will do, which further helps them to determine their role in each novel situation. Over time, teams develop a deeper understanding of the systems they utilize, the information needed for optimal operation, and the team members that should be contacted for specific knowledge. They understand how they must coordinate their activities and who needs to be involved in what decisions.

Mental models were first applied to the team-level by Cannon-Bowers, et al., (1993) during observations of expert systems in which it was noted that some teams outperformed others by having highly coordinated actions and behaviors, while not necessarily increasing overt communication. Recent research illustrated that a cognitive base to teamwork exists and it was been shown to impact behavior, motivation, and performance (Cooke, Gorman, Duran, & Taylor, 2007; DeChurch & Mesmer-Mangus, 2010). Mental models are essentially mental patterns and structures that enable individuals to interact with their environment through cues that enable them to predict and explain events occurring around them (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000). In flight operation centers, communication and coordination are severely impacted by time pressure, workload, and the consequences of error are great. These factors make mental models crucial, because normal communication channels are hampered by environmental constraints (Mathieu, et al., 2000; Stout, Cannon-Bowers, & Salas, 1996).

Team communication

Communication was identified as one of the key behavioral processes in teams (Kozlowski & Bell, 2003; Salas, Sims, & Burke, 2005). Communication allows teams to be able to fully tap into their collective expertise.

Communication seems to contribute to the development of shared mental models and once these models have been developed, they serve to refine and focus communications. Before a team can coordinate, they must communicate. Without communication, coordination is unable to occur (Keyton, Ford, & Smith, 2012). As team processes, such as communication, become routinized over time, they produce shared cognition. The pre-cursor to coordinated communication is a shared understanding; i.e. a shared mental model. In the case of communication, this shared mental model allows for more coordinated communication and understanding of whom to communicate with in each new situation.

Teamwork mental models of communication importance are mental understandings of the importance of various communication channels. Previous team research has indicated that with interdependent team interaction, overt communication decreases and that the decreases are specific to certain positions within the team. (Littlepage, Craig, Hein, Moffett, Georgiou, & Carlson, 2012). This suggests that communication becomes more selective and focused as a result of the development of mental models. Other research has found that high performing teams did not necessarily increase the amount of communication occurring within the team (Cannon-Bowers et al., 1993).

Social network analysis

Most research in psychology is focused on the attributes and characteristics of specified subjects. Social network analysis has a primary focus on the relational ties between actors; the actors in a study being organizations, groups, or individuals in a previously determined context (Scott, 1991). Social network analysis (SNA) maps relational ties between individual nodes, in this case team members, to produce an illustration of the entire network. SNA is especially suited to study social interaction, which is only understood in its fullest by review of the entire network. Social network analysis can be used to determine similarity of mental models among team members.

Research questions

As individuals increase their interaction with the team, they begin to understand how they fit into the overall teamwork process. This enables them to explain with whom they need to communicate and what they should be doing in any given situation. This understanding will also help them predict what their team members will do, which further helps them to determine their role in each novel situation. Participants may come into the simulation with previously set mental models due to understanding and a general knowledge of their specialization, but because team interaction influences mental model development and because mental models help individual members determine with whom they will communicate, the following research questions will be evaluated in this study.

1. Will mental models of interdependence change over time as a result of team interaction?
2. Will mental models of communication importance change over time as a result of team interaction?
3. Are mental models of interdependence related to mental models of communication importance?
4. Does any change in communication importance occur in parallel with interdependence?

Method

Sample and procedures

To test our hypotheses we evaluated multiple teams of upper-level undergraduate students placed in a simulated flight operations command center. Participation in the research was a course requirement; however, students were not mandated to allow responses to be used for data analysis. Multiple specialties were represented in each group. These concentrations consisted of professional pilot, administration, flight dispatch, technology, and maintenance. Teams varied in size, but on average there were 10 participants in each team. Each participant was assigned a position in the lab. These positions were as follows: flight operations coordinator, flight operations data weight and balance, flight operations data planning and scheduling, weather and forecasting, crew scheduling, maintenance, pilot, and ramp tower. For purposes of analysis flight operations data and flight operations coordinator were aggregated into one flight operations position.

On day one, students were given information, in on-boarding fashion, regarding the virtual airline where they were "employed" and asked to sign consent forms. During this time explanations of all positions and information regarding the layout and function of the various workstations was provided. Following the on-boarding session, students were split into work teams. Each student was assigned a position and given information specific to that position. Students then completed pre-simulation measures, including a measure of interdependence. This measure captured the participant's perception of the extent of interdependence; each participant rated the extent of agreement that his or her job depended upon each other position. Following this the students were given individual training regarding their position, a rundown of where everything was located in the lab, and the functions of each position. Students then completed another set of pre-simulation measures, including expected communication importance. This measure asked participants to indicate how important it was for their position to communicate with each of the other positions within the simulation.

After training, students participated in the high-fidelity simulations. Over the course of the semester, students participated in two or three 2.5 hour simulations. Next, participants were given the post-simulation measure of communication importance. In addition, teams participated in after-action reviews following each simulation to discuss the outcomes of the simulation, behaviors that contributed to those outcomes, and possible changes for upcoming simulation(s). After the final after-action review, students completed the post-simulation measure of interdependence.

Variables and measures

Mental models of interdependence. Mental models of interdependence are mental understanding of members' dependency on each of the other positions. The interdependence measure consisted of a question of how much the participant's job was dependent on each of the other positions. Responses were made using a 10-point Likert scale, (1 = strongly disagree, 10 = strongly agree). This question provided the basis for creating ego-net based matrices that could then be analyzed using the QAP correlation to measure the correlation with other matrices (Hanneman & Riddle, 2005). To create these matrices responses were aggregated into 6x6 or 5x5 matrices. (Ideally, all matrices would be 6x6 to account for all the functions in the simulation, but for some teams missing data resulted in 5 x 5 matrices). The QAP correlation allows researchers to analyze how two matrices converge onto each other and provides a correlation between the two networks. A measure of density was computed to indicate the extent to which all positions were perceived as interdependent.

Mental models of communication importance. The communication patterns measure asked the participants to indicate how important the communication is between their position and the various other positions. This measure is scaled on a 5-point Likert scale, (0 = Not important at all, 4 = Absolutely essential). It is taken at two separate times; prior to simulations and again after all the simulations. This question is used to build an ego net based matrix and QAP correlations were computed. For measures of density, the communication importance matrices were dichotomously coded to represent the lack of communication (0), or the presence of communication (1). Values 3 and above were coded with a 1.

Analysis

Because of missing data, the number of matrices (teams) varied across analyses from 9 to 13 teams. Correlations among mental models were assessed using UCInet (Borgatti, Everett, & Freeman, 2002). This software allows for a network of relational ties to be created, which can then be compared for a number of measures including correlation within and across networks. In this study, the networks (matrices) were created for both interdependence and communication importance at two time periods. In order to address the research questions, QAP correlations were obtained using the matrices created from the two measures. QAP analysis provides a correlation of how similar two square matrices are to each other. Significant QAP correlations indicate similarity between the two matrices and, thus, the presence of a correlation between the mental models. In addition, density was used to investigate the connectedness of communication importance and interdependence networks. For binary data, decreases in density represent a decrease in the number of ties between dyads. These ties do not take into account the direction of the relationship. For valued data, density can be thought of as the strength of the ties present between dyads (Hanneman & Riddle, 2005).

To investigate whether mental models of interdependence changed over time as a result of team interaction pre-simulation interdependence matrices were correlated with post-simulation interdependence matrices (QAP 1). The size of the QAP correlation indicates stability. Low correlations indicate change and are consistent with the development of mental models. In the same fashion, pre-simulation communication importance matrices were correlated with post-simulation communication importance matrices, QAP 2, to evaluate the changes in mental models of communication importance. Again, a lack of correlation will suggest that changes in mental models occurred. In addition to these QAPs, density was measured for both communication importance matrices (pre-simulation and post-simulation) using a dichotomized matrix, Likewise, density was measured for matrices of interdependence both pre and post simulation. Matrices of interdependence were not dichotomized.

Analyzing the correlation between pre-simulation measures for both interdependence and communication importance illustrated how closely related the two mental models were initially (QAP 3). Analyzing post-simulation measures for interdependence and communication importance displayed the relationship between the two models after the simulations (QAP 4). QAP correlations between communication measures and interdependence measures at each time period indicate the degree of similarity between mental models of interdependence and communication importance prior to and following simulations.

Results

QAP analyses 1 and 2 examined the stability of mental models from initial to post-simulation. Some teams showed significant correlations, while others did not. The mean correlation for QAP1 was .24 while the mean correlation for QAP 2 was .43. These correlations indicate that the initial mental models account for less than 19% of the variance in post-simulation mental models. This suggests that mental models may be revised as a result of team interaction.

Average pre-simulation interdependence density (7.76) was found to be higher than post-simulation density (7.34). In the same fashion pre-simulation density of communication importance (.52) was found to be higher than post-simulation communication importance (.29). A paired comparisons t-test performed on both interdependence and communication importance found that these decreases were statistically significant ($p < .05$, in both cases). This may indicate that the mental models are becoming more refined, and the networks less tangled. Although density decreased for both interdependence and communication importance, there was no significant correlation between the differences of pre and post simulation interdependence and communication importance.

Correlation between pre-simulation interdependence and communication importance (QAP analysis 3) was variable, but provided an average correlation of $r = .17$. This suggests that a weak and/ or inconsistent relationship exists between participants' understanding of communication importance and interdependence prior to simulation and interactions. QAP 4, regarding the correlation between post-simulation interdependence and communication, held mixed results for individual teams. However, it is important to note that more teams showed a significantly positive correlation at post-simulation than at pre-simulation. In addition, the average correlation increased to $r = .46$. This suggests that, following team interactions in the simulations, mental models of communication importance were more closely related to mental models of interdependence. Participants thought communication was more important between team members who were highly interdependent. The pattern of correlations between post-simulation interdependence and post-simulation communication importance warrants further research. (QAP results for each team are presented in the Appendix.)

Conclusions

In conclusion, analysis indicated that mental models may be refined as teams interact, and that little variance in post-mental models can be explained by pre-simulation mental models. In addition, density analysis illustrated a significant decrease in both models. This indicates that individuals may begin to become more aware of the positions with which they are truly interdependent, and which positions are important to communicate with. They begin to understand how their position fits into the entire network. QAP analysis 3 & 4 indicated that post-simulation, participants' mental models of interdependence and communication were more closely related than prior to simulations. This finding suggests that as participants realized how interdependent their jobs were they also realized that communication with these positions was important. Again, this allows communication to become more focused and narrowed. Taken in the context of other research (Littlepage et al., 2012), as teams continue to interact their mental models of interdependence change which influences who they perceive it is important to communicate with. Interestingly, teams perform better as simulations continue, but frequency of communication decreases. As team members begin to understand who they need to interact with in order to perform their tasks, their communication becomes more selective and coordinated, which can lead to higher performance. Taken as a whole these results imply that mental models are refined through interaction, and that as these refinements take place smaller and more unified networks are formed within the team. Although mental models of both interdependence and communication importance develop and are related, these mental models are not refined in parallel and the time of this refinement is still unknown.

Limitations and future research

This study, like all, has its limitations. Sample size (9 – 13 teams) was a limitation. Because this is a simulation, generalization is an issue. However, the situation was realistic and professionally relevant to participants. Although additional studies using larger samples of teams are needed, these results suggest that mental models of interdependence and communication importance can become more refined and more accurate as a result of team experience.

REFERENCES

Borgatti, S.P., Everett, M.G. & Freeman, L.C. (2002) Ucinet for Windows: Software for Social Network Analysis. Harvard, MA: Analytic Technologies.

Cannon-Bowers, J. A., Salas, E., & Converse, S. (1993). Shared mental models in expert team decision making. In N. r. Castellan (Ed.), *Individual and group decision making: Current issues* (pp. 221-246). Hillsdale, NJ England: Lawrence Erlbaum Associates, Inc.

Cooke, N.J., Gorman, J.C., Duran, J.L., & Taylor, A.R. (2007). Team cognition in experienced command-and-control teams. *Journal of Experimental Psychology 13*(3), 146-157.

DeChurch, L.A. & Mesmer-Mangus, J.R. (2010). Measuring shared team mental models: A meta-analysis. *Group Dynamics: Theory, Research, and Practice 14*(1), 1-14.

DeChurch, L.A. & Mesmer-Mangus, J.R. (2010). The cognitive underpinnings of effective teamwork: A meta-analysis. *Journal of Applied Psychology 95*(1), 32-53.

Hanneman, R.A. & Riddle, M. (2005). Introduction to Social Network Methods. Riverside, CA: University of California, Riverside (published in digital form at http://faculty.ucr.edu/~hanneman/)

Keyton, J., Ford, D.J, & Smith, F.L. (2012). Communication, Collaboration, and Identification as Facilitators and Constraints of Multiteam Systems. In S. Zaccaro, M. Marks & L. DeChurch (Eds.) *Multiteam Systems* (173-190). New York, NY: Taylor & Francis Group.

Kozlowski, S.W. & Bell, B.S. (2003). Workgroups and Teams in Organizations. In W. Borman, D. Ilgen & R. Klimoski (Eds.) *Handbook of Psychology: Vol. 12 Industrial and Organizational Psychology* (333-375) London: Wiley.

Littlepage, G., Craig, P., Hein, M., Moffett, R., Georgiou, A., & Carlson, P. "Training to Enhance Mutliteam Coordination in the Airline Industry" Society of Industrial Organizational Psychology [Conference] San Diego. 26. April. 2012.

Mathieu, J.E., Heffner, T.S., Goodwin, G.F., Salas, E. & Cannon-Bowers, J.A. (2000). The influence of shared mental models on team process and performance. *Journal of Applied Psychology 85*(2), 273-283.

Mesmer-Mangus, J.R. & DeChurch, L.A. (2009). Information sharing and team performance: A meta-analysis. *Journal of Applied Psychology 94*(2), 535-546.

Rouse, W.B., & Morris, N.M. (1986). On looking into the black box: Prospects and limits in the search for mental models. *Psychological Bulletin*, *100*, 359 – 363.

Salas, E., Sims, D.E., & Burke, C.S. (2005). Is there a "big five" in teamwork? *Small Groups Research, 36*, 555 – 599.

Scott, J. (1991). *Social Network Analysis: A Handbook.* Newbury Park, CA: Sage.

Smith-Jentsch, K.A., Campbell, G.E., Milanovich, D.M., Reynolds, A.M. (2001). Measuring teamwork mental models to support training needs assessment, development, and evaluation: two empirical studies. *Journal of Organizational Behavior, 22,* 179-194.

Stout, R. J., Cannon-Bowers, J. A., & Salas, E. (1996). The role of shared mental models in developing team situational awareness: Implications for training. Training Research Journal, 2, 86-116

Appendix

QAP Analysis1-4.

QAP Analysis 1 (Interdependence)		
TEAM	*R*	*P*
Team 1,6	0.616	0.021
Team 3,6	0.170	0.250
Team 4,6	0.065	0.415
Team 1,7	0.663	0.000
Team 3,7	0.717	0.000
Team 5,7	-0.621	0.036
Team 6,7	0.621	0.000
Team 1,8	-0.266	0.143
Team 6,8	0.164	0.333

QAP Analysis 2 (Communication)		
TEAM	*r*	*p*
Team 1,6	0.336	0.128
Team 2,6	0.189	0.17
Team 4,6	0.344	0.081
Team 1,7	0.619	0.023
Team 2,7	0.559	0.041
Team 3,7	0.450	0.043
Team 6,7	0.606	0.018
Team 3,8	0.451	0.101
Team 4,8	0.342	0.087
Team 6,8	0.443	0.061

QAP Analysis 3 (Pre-Simulation)		
TEAM	*r*	*P*
Team 1,6	0.364	0.059
Team 2,6	0.366	0.045
Team 3,6	-0.149	0.267
Team 4,6	-0.201	0.174
Team 1,7	0.124	0.236
Team 3,7	0.339	0.082
Team 4,7	0.543	0.110
Team 5,7	0.118	0.342
Team 6,7	0.185	0.241
Team 1,8	-0.044	0.410
Team 3,8	0.001	0.486
Team 4,8	0.141	0.417
Team 6,8	0.464	0.016

QAP Analysis 4 (Post-Simulation)		
TEAM	*r*	*p*
Team 1,6	0.502	0.032
Team 2,6	0.659	0.022
Team 4,6	0.627	0.006
Team 1,7	0.389	0.159
Team 5,7	0.320	0.180
Team 6,7	0.505	0.064
Team 2,8	0.849	0.018
Team 3,8	0.267	0.178
Team 4,8	0.007	0.506
Team 6,8	0.446	0.022