Using Social Network Analysis to Measure Shared Mental Models of Communication and Interdependence in a Simulated Flight Operations Command Center

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ABSTRACT

This study examined the relationship between shared mental models (SMM) of interdependence and communication in a simulated aviation flight operations center. Social network analysis indicated that following participation in multiple simulations SMM of interdependence increased while, SMM of communication importance decreased. In addition, the correlation between the two types of mental models increased. These findings warrant further study and evaluation. Exploratory density analysis decreased for both networks of communication importance and interdependence suggesting that mental models became more refined after participation in the simulation.

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Chapter I

Introduction & Literature Review

With the ever-increasing complexities involved in the world of work, many companies have turned to teams to function as dynamic systems that meet the new challenges. Innovation, globalization, and technological advances are among the many other factors influencing companies' decisions to move towards team-based work (Kozlowksi & Bell, 2003, Smith-Jentsch, Campbell, Milanovich, & Reynolds, 2001). Organizations need teams to provide quick, flexible, responses to the constant changes that occur (Kozlowski & Bell, 2003). In the world of aviation administration, flight operation centers incorporate numerous team members to integrate complex information and make decisions. Various positions are needed in these work groups, and people in each position have unique information that needs to be communicated to others on the team for effective decision-making and problem solving.

Individual team members develop mental models regarding their work systems. Mental models are mental structures that enable individuals to use experiences and contextual clues to interact more efficiently with the environment and those around them. More specifically, these models enable them to interact with their environment through cues that enable them to predict and explain events occurring around them. Mental models also help team members process the experiences for future events (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000). 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. More importantly, members must develop shared mental models.

Shared mental models are common models that enable team members to predict the behavior and actions of the system the team works in, as well as the behaviors and actions of the other individuals in the team. Shared mental models provide a common knowledge as the basis on which individuals make decisions that are in congruence with the team and the goals of the team (Mathieu, et al., 2000). Shared mental models are believed to enable teams to be more efficient by understanding the factors that influence team performance (DeChurch & Mesmer-Mangus, 2010). This allows teams to perform effectively.

Social Network Analysis (SNA), traditionally used in ethnography and sociology, is now being used to assess mental models. This procedure deals with relational data and can visually and statistically represent the social network in which individuals operate. Traditional techniques in social sciences tend to focus on variables and attributes of individuals. Alternatively, social network analysis is not focused on the variables and attributes of the individuals, but rather how they connect to each other and the attributes of these connections (Scott, 1991). Using social network analysis, mental models can be mapped and analyzed for similarity and congruence with other members' models within the team and across teams.

This research will investigate the mental models of individuals within teams. More specifically, this project will focus on mental models involving the interdependence of team members and the importance of communication among team members. The research will explore similarities between individuals within the team and how these change over time. In addition, exploratory analysis will examine subsystems within the network to determine whether key roles may exist within the groups.

Team in Flight Operations

Flight operations centers are known by different names in different airlines. Some are known as operational command centers and others are called control centers. In any case, these rooms are the hub of communication, information, and coordination among various critical aviation specialties. In these rooms converging disciplines must work together to ensure the safe and efficient operations of each individual aircraft and the overall airline. Information that is processed in this context includes data on fuel, aircraft weight and balance, maintenance issues, duty times for crew members, weather, in-flight changes, and other potentially influential matters affecting the operation of the aircraft/airline. The increased presence of technology utilized in aviation has also added layers of complexity into the workforce and, as a result, organizations in aviation, as with other industries, have begun to implement teams (Kozlowski & Bell, 2003). Some researchers (Cannon-Bowers, Salas, & Blickensterfer, 1998) have given a special name to teams such as those found in control centers and call them a "crew." The distinction of a crew from a team lies in the ability of a crew to quickly come together in a prepared manner to perform. Kozlowski and Bell (2003) stated that "Crews are used for team tasks that necessitate high expertise, extensive training, and well developed, standardized performance guidelines (p. 8). Because control center employees may consist of different members daily, these characteristics are essential as they substitute for the development of team member interaction over longer time periods (Kozlowski & Bell, 2003).

However, for purposes of this paper the terms crew and team will be used interchangeably.

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. Defined by Kozlowski and Ilgen (2006), teams are

> (a) two or more individuals who (b) socially interact (face-to-face or, increasingly virtually); (c) possess one or more common goals; (d) are brought together to perform organizationally relevant tasks; (e) exhibit interdependencies with respect to workflow, goals, and outcomes; (f) have different roles and responsibilities; and (g) are together embedded in an encompassing organizational system, with boundaries and linkages to the broader system context and task environment. (p. 79)

Moving even deeper into the construction of teams is the concept of multi-team systems in which operation control centers, the focus of the current study, fit nicely.

Multiteam systems can be thought of as teams within teams that work together, across functions, to reach a common goal. As cited by Marks, Mathieu, DeChurch, Panzer and Alonso (2005), a distinct feature of such a team, as explained by Mathieu, Marks, and Zaccaro (2001), is that "all teams within the system, while pursuing different proximal goals, share at least one common distal goal; and in doing so exhibit input, process, and outcome interdependencies with at least one other team in the system."

Each member of the multiteam system belongs to a distinct subgroup within the larger framework of the organization; however, there is still a high level of interdependence. Some systems are even composed of teams originating in different organizations. Multiteam systems are collections of individuals from different units, and though each teams' immediate goal may be different they all contribute to a commonly held goal that drives the functioning of the team. These proximal goals may or may not be in conflict with the goals of other individuals. Multiteam systems typically emerge organically, as many organizations operating in demanding environments, such as aviation, must rapidly respond to highly dynamic situations across functions, operating processes, and specialties (Zacarro, Marks, & DeChurch, 2012).

The complexities found in the aviation industry require multiteam systems to make high quality decisions by integrating different specialties and teams together to reach optimal performance. 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, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000; Mesmer-Mangus & DeChurch, 2009). No one individual could quickly and accurately gather all the information necessary to make decisions for every aircraft dispatched and landing during an 8-10 hour shift. In addition to the declarative knowledge needed in each specialty, expecting one person or even a dyad to have enough expertise to understand the separate systems and technology being used would be unreasonable. 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.

Beyond the understanding that teams are needed to meet the challenging and growing demands of this industry, it is vital that the processes these teams use are aligned with the team goal and task (Kozlowski & Illgen, 2006). These processes differentiate average teams from high-performing groups. The processes teams use and the knowledge each member holds contribute to team expertise, which is an emergent construct that develops within the team, over time, through interaction (Cooke, Gorman, Duran, & Taylor, 2007). Multiteam systems provide value in that the processes used by individual members or teams involve diverse functional expertise, allowing for increased cognitive understanding available for use by the system (Zacarro, Marks, & DeChurch, 2012).

Cognitive Structures

Recent research has confirmed that a cognitive base to teamwork exists and it has been shown to impact behavior, motivation, and performance (Cooke, Gorman, Duran, & Taylor, 2007; DeChurch & Mesmer-Mangus, 2010). Kozlowski and Illgen (2006) illustrated that team cognition, an overarching concept that includes cognitive foundations, such as mental models and transactive memory systems, emerges as teams' processes become routine. These cognitive structures enable the team to function in future situations, which only further solidifies the structure previously formed. The emergent nature of team cognition was illustrated by Cooke et al. (2007), while investigating command-and-control teams. More importantly, this research supported the observations made by Cannon-Bowers, Salas, and Converse (1993) that a team cognitive structure distinguished high and average performance at the team level. In addition, Cannon-Bowers and associates (1993) originally suggested four types of mental models;

however, Mathieu and colleagues (2000) have suggested that these four types (team interaction, equipment, task, and team member) and be covered by two over-arching types of mental models; teamwork and task work.

Team mental models (shared mental models) differ from team transactive memory systems in that the concept focuses on overall team and task structured knowledge, while team transactive memory systems focus on unique information that is not explicitly known to all members of the group; however, the members know where to retrieve the information. Both concepts are cognitive structures that enable individuals to function within a team setting.

Mental Models

Many definitions have been provided for the concept of mental models. These 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. Mental models also help process experiences. 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.

Shared Mental Models

Mental models were first applied to the team-level by Cannon-Bowers et al. in 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 open communication. Shared mental models are commonly held mental models that enable team members to predict the behavior and actions of the environment and context the team works in as well as the behaviors and actions of the other individuals in the team.

The main advantage thought to be provided with shared mental models is an increase in efficiency (Rentsch, Delise, & Hutchison, 2009). Shared mental models provide a shared knowledge as the basis on which individuals make decisions that are congruent with the team and the goals of the team. Shared mental models are key in distinguishing mediocre or average performing teams from high-performance teams. As Cooke et al. (2007) remarked, “a hallmark of team expertise... may be a shared mental model in which there is an ideal distribution of knowledge or mental models across team members” (p. 147).

In flight operation centers, communication and coordination are severely impacted by time pressure, workload, and the consequences of error. These are all factors that make shared mental models even more crucial, because normal communication channels are hampered by environmental constraints (Mathieu, et al., 2000; Stout, Cannon-Bowers, & Salas, 1996). In this situation, individual members draw on shared knowledge of the task to guide their own actions and behaviors. Researchers have argued that it may not be necessary for members to have perfectly matching mental models, and it is more likely that numerous types of mental models function simultaneously within the team (Klimoski & Mohammed, 1994).

With the understanding that shared mental models are vital to team performance in high-performance teams, an additional understanding of how shared mental models form and what needs to be present for their formation is needed. Simply gathering experts in the needed disciplines will not equate to an expert team and will not automatically increase the overall efficiency and quality of the decisions made.

Numerous things must be in place for shared mental models to develop. Members must have an adequate understanding of the tools and systems they use. In addition, they must know how the jobs or tasks performed by others are integrated into the team, and they must also know how the team interacts. This includes understanding the individual members' specializations, skills, strengths and weaknesses. This knowledge increases the likelihood that decisions and actions of individual members will be automatic and congruent with the team (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000).

Communication provides support for teamwork and taskwork coordination (Kozlowski & Ilgen, 2006). Because teams must coordinate and collaborate to address and solve complex challenges, knowledge and interaction must come from a common understanding. This shared understanding helps member of the team to identify and coordinate their activities to address dynamic and novel problems. In addition, routine and standard situations are handled efficiently and quickly as members are able to predict the actions and behaviors of others.

Shared mental models are cognitive states of teams that emerge over time. As these shared mental models are used to explain and execute team behavior, they become reinforced and subsequently used in future situations (Kozlowski & Illgen, 2006). Shared mental models become more crucial to team functioning as the work becomes more interdependent. It is possible that more interdependent tasks will benefit from shared mental models. This makes the control center teams particularly well suited to study mental models as their work is interdependent; requiring coordinated interaction (Kozlowski & Bell, 2001).

Team Communication

This research focuses on communication networks, as identified as one of the key behavioral processes in teams (Kozlowski & Bell, 2003; Salas, Sims, & Burke, 2005). Communication and coordination allow teams to be able to fully tap into their collective expertise. Before a team can coordinate, they must communicate. Without communication, coordination is unable to occur (Keyton, Ford, & Smith, 2012). Communication can lead to the development of shared mental models that facilitate coordination. The pre-cursor to coordinated communication is a shared understanding; i.e. a shared mental model. Once a shared mental model has been developed, coordinated action can take place without extensive communication.

Communication was also identified as a contributing factor to team effectiveness (Tannenbaum, Beard, & Salas, 1992). In addition, Kozlowski and Ilgen (2006) regard communication, coordination, and cooperation as interrelated and overarching. Kozlowski and Bell (2001) stated that “communication is the primary means to enable…coordination and cooperation. (p. 40). Essentially, coordination and cooperation are made feasible through communication, which supports both interdependence and coordination through a shared mental model. For teams to be effective they must develop shared mental models, which allow for more coordinated communication and understanding of whom to communicate with in each new situation. Over time communication becomes more coordinated and focused, which further solidifies the mental models of interdependence and further enable the members to work interdependently (Littlepage, Craig, Hein, Moffett, Georgiou, & Carlson, 2012).

Communication in multiteam systems serves multiple purposes. Williams and Mahan (2006) identified four major functions of communication in mutliteam systems. It provides norms to direct and control behavior, motivation and guidance through performance feedback, a forum for emotional expression, and supplies information. Other researchers have taken a different view of communication and described communication as a process that serves only two main functions; 1) development and sending of information, and 2) creation of shared meaning (Keyton, Ford, & Smith, 2012). This more general view acknowledges both the task and team related dimensions of communication. Communication serves to foster both work-related problem-solving as well as relationships among team members.

Zacarro, Marks, and DeChurch (2012) defined communication networks as “structured patterns of interaction flow” (p. 19). Because these networks are structured patterns they can differ between different systems. Some networks will be highly centralized in which information flows through one key individual or sub-team. It can also be decentralized, allowing the communication to become more dispersed throughout the team, which in turn allows for all members to communicate directly with each other. Decentralization and centralization are at the extremes of communication networks, with numerous combinations of networks existing on this continuum (Zaccaro et al., 2012;

Shaw, 1964). Some tasks are better suited for centralized communication, while others may necessitate more open decentralization of communication. Shaw (1964) reported that complex and dynamic situations, such as the ones found in aviation war rooms, call for more open dialogue and communication (decentralized network).

Social Network Analysis

Because organizations are relying on teams it is essential that researchers address variables and issues that impact the efficiency and success of teams. Though organizations want teams to function in a cohesive manner it must be recognized that teams are complex entities, with dynamic patterns. To this end it is important to understand the nature of these patterns. These patterns "represent the ways individuals and groups connect to one another; how information, affect, and resources flow between them; and how group processes emerge and evolve over the lifespan of a team" (Slaughter, Yu, & Koehly, 2009 p. 433). Social network analysis is a tool for researchers to look into the patterns that emerge as teams work together.

Most research in psychology is focused on the attributes and characteristics of specified subjects (Slaughter et al., 2009). 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. As an example, social network analysis may review the friendship ties among individuals within a given community. The people become the actors (nodes) in the study, and the relationships among them become the variable of interest. These relationships are typically depicted visually as lines connecting the nodes. In numerical form the data are typically displayed in matrix form. The matrix is not composed of one individual, but rather the entire group. This research will use individual responses to create a team matrix. This is important because the unit of analysis in social network analysis (SNA) is the group, not the individual.

Although some researchers (Cooke et al., 2007) argue that team interaction cannot be measured at the individual level, SNA seeks to fill this gap. SNA maps relational ties between individual nodes, in this case team members, to produce an illustration of the entire network. In this study, two relational ties will be examined, one representing the cognitive understanding of communication channels, and the other representing the cognitive understanding of interdependence. The network produced shows the cognitive model of communication and interdependence among the team members and can be viewed at both the individual level and team level. However, it is important to note, that the primary unit of analysis is not the individual. SNA is especially suited to study social interactions, which is only understood in its fullest by review of the entire network. The entire team network is the primary unit of analysis, which is composed of the individual units (Slaughter, Yu, & Koehly, 2009).

Social network analysis can be used to determine similarity of mental models among team members. Measures such as a QAP determine how correlated two separate square matrices are to each other. This analysis provides a correlation and p-value. A positive correlation, if significantly high indicates that the two matrices (mental models) are similar. Another measure, reciprocity, deals with whether the nodes, in this study the participants, reciprocate the relationship under evaluation. Reciprocity is useful with directed data in which the direction(s) of the relationship is important. For example, an individual A may say that individual B is their best friend; however, individual B may say individual C is their best friend. In this situation the relationship is not reciprocal.

In addition to similarity, centrality and density of the group can be determined. Centrality can be understood as a measure of "connectedness". It illustrates how many relational ties are present between a person and the remaining members of the team (Humphrey, Moregeson, & Mannor, 2009). Centrality can be used to determine if there is a strategic core role in the group. This role is one that encounters a majority of the problems, is involved in most tasks, and is a central figure in the flow of information (Humphrey, Morgeson, & Mannor, 2009). Density can be thought of in terms of how many dyadic relationships exist in the group/network versus how many could exist. Density can illustrate whether everyone in a group has a connection to everyone else, or perhaps if there are certain channels of communication, information flow, etc.

Hypotheses

1. Some degree of shared mental model of interdependence will exist prior to interaction and simulations due to similar coursework and knowledge of aerospace and aviation.
2. Initial mental models of interdependence will correlate with the initial perception of whom it will be important to communicate with during the simulations.
3. Prior to simulations and interactions some degree of shared mental model will exists regarding who it will be important to communicate with.
4. Following the simulations and interactions, perceptions of who it is important to communicate with will be more similar as shared mental models develop throughout the simulations.

5. There will be a close correspondence between final perceptions of who it is important to communicate with and the final shared mental model of interdependence.
6. The degree of shared mental model of interdependence will increase following interaction as a team during the simulations.

Chapter II

Methods

Sample

To test the hypotheses   I evaluated 10 to 14 teams of upper-level undergraduate students placed in a simulated flight operations command center. Participation in the research was part of course credit; however, students were not mandated to allow responses to be used for data analysis. They were given the option to remove their data from use at any time without penalty to course completion. Each participant had completed coursework in aerospace and aviation; however, multiple specialties were represented in each group. These concentrations consisted of professional pilot, administration, flight dispatch, technology, and maintenance. Teams varied in size, but there were about 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.

Measures

Teamwork Shared Mental Models of Interdependence.

A teamwork mental model of interdependence is a commonly held understanding of members' dependency on each other. Many researchers capture mental models by presenting the participants with a set of phrases or words and ask them to provide a similarity rating. However, the interdependence measure used in this study consisted of five questions of how much the participants' performance, goals, and position are similar or dependent on other members of the team. Responses to each question were made using a 10-point Likert scale, (1 = strongly disagree, 10 = strongly agree). Items 1 and 2 were used for purposes of this study. These items provided the mental model of interdependence. Responses were obtained at two points; prior to simulations and following simulations. For item 1, respondents answered a question that asked them how much their job is dependent on each of the other positions. Item 2 asked respondents to answer how much each other position depends on them to complete their jobs. These questions provided the basis for creating ego-net based matrices (team matrices built by combining individual perceptions) that were then analyzed using the QAP correlation to measure the correlation with other matrices (Hanneman & Riddle, 2005). These matrices represented the mental models of interdependence. To create these matrices responses were aggregated into 6x6 or 5x5 matrices. For aggregation purposes flight operations data and flight operations coordinator positions were combined into one position known as flight operations. (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).

Teamwork Shared Mental Models of Communication.

Teamwork mental models of importance of communication are commonly held understandings of which members' it is important to communicate with. This is different than pure frequency as shared mental models would decrease the amount of overt communication, they allow for communication to become more focused and concentrated to those individuals and positions that are vital for team functioning. The communication patterns measure asked the participants to indicate how frequent/important the communication or expected communication is between their position and the various other positions. For purposes of this study, only importance scales were used. This measure was scaled on a 5-point Likert scale, (0 = Not important at all, 4 = Absolutely essential). This measure was taken at two separate times; prior to simulations, which indicates expected perception of who participants thought it would be important to communicate with; and again after all the simulations which is a measure of who they actual found it was important to communicate with during interaction. This question was again used to build an ego net based matrix in which a measure of reciprocity was obtained. The matrices created from this measure provided the mental model of communication importance. Again, 6x6 or 5x5 matrices were created as they were in the interdependence measure, with one difference. For reciprocity, the answers were dichotomized; all answers under 3 were coded with 0, while all responses 3 and above were coded with 1. A 0 indicates a response that it was not important to communicate with a specific position, while 1 indicates an importance in communication exists. Reciprocity requires that the data be dichotomized and allows researchers to see if patterns are shared among dyads, and essentially the entire team. High reciprocity scores indicate that dyads share the same belief in whether they thought it would be/was important to communicate with each other. QAP correlations will also be used with communication measures; however, these matrices will not be dichotomized.

Procedure

On introduction, day one, students were told they would be taking part in a simulation exercise throughout the semester. They were given information regarding the virtual airline they would be "employed" by and asked to sign consent forms. It was clarified that participation in the simulation was part of class, but that not allowing the information to be used for research purposes will in no way influence the participants' grades. Universal E-Lines, was the airline they worked for; history of the company, explanations of all positions, and information regarding the layout and set-up of the various workstations were provided. (For a detailed layout of the placing of positions within the lab, please see Appendix A.)

Following the orientation session, students were split into work teams. Each student was assigned a position and given information specific to that position. Students then completed pre-simulations measures, including a measure of interdependence (Appendix B).

The first time participants entered the lab they did so on training day. The students reported to "work", and were given individual training regarding their position. In addition, the team got an overview of where everything was located in the lab and the functions of each position. Following this, students took another set of measures, of which one measure evaluated expected communication patterns in relation to frequency and importance (Appendix C). This will be used for pre-simulation communication importance.

After training, students were ready to participate in the high-fidelity simulation. Over the course of the semester, students participated in 2-3 simulations each lasting roughly two and a half hours. Following the first and last simulation, students were again given the measure of communication patterns. This time; however, the measure was reflective of actual perceptions of communication and not expected patterns. Post-simulation communication importance was used from the data collected immediately following the last simulation. In addition, teams participated in after action reviews following each simulation. During these reviews teams discussed the positive and negative outcomes of the simulation, the behaviors that contributed to those outcomes, and possible changes that could help change these outcomes during the upcoming simulation(s). Following the final after action review, students took their post-simulations measures, that are identical to the first set of measures, of which includes a measure of interdependence.

Analysis

Mental models were assessed using UCInet. 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 (Hanneman & Riddle, 2005). In this study, the networks were created from the interdependence items 1 and 2, as well as the item on communication importance. One matrix was created for each team, for each item, at each time. Numerous QAP correlations were obtained using the matrices created from the interdependence measure and communication measure. Significant QAP correlations indicated the presence of correlation between the mental models.

To investigate the hypotheses numerous QAP correlations and reciprocity indices were obtained for the matrices created. QAP measures the association of ties between two networks with the same individuals (Hanneman & Riddle, 2005). This measure of convergence also provides information regarding whether the correlation is significant.

This p-value is interpreted the same as other p-values used in statistical procedures. Reciprocity measures sharedness of relationships; whether both individuals acknowledge the presence or lack of relationship under investigation. In this study it will be used with the communication measure.

To test whether SMM of interdependence prior to simulations will show some similarity as a result of educational curriculum and general knowledge of aerospace and aviation (H1), a QAP correlation was taken using pre-simulation item 1 and transposing pre-simulation item 2 from the interdependence measure. The same analysis was done post-simulation with items1 and 2 (H6). This provides measures of sharedness prior to interaction and following all interaction.

To examine whether the initial mental models of interdependence correlate with the ratings of expected importance of communication (H2), a QAP correlation was obtained using pre-simulation interdependence item 1 and the pre-simulation item regarding communication importance. Similarly, to assess if post-communication importance correlates with post-simulation interdependence (H5), post-simulation interdependence item 1 was converged with post-simulation communication ratings and a QAP correlation was obtained.

To review whether pre-simulation importance of communication had a lower reciprocity score than the ratings of importance of communication following all the simulations, reciprocity scores were taken pre-simulation (H3) and post-simulation (H4) for ratings of communication importance.

Chapter III

Results

Analysis of hypothesis one found a lack of shared mental models of interdependence prior to simulations. The QAP correlation between interdependence item 1 and item 2 (transposed) ranged from -.50 to .33 (Table 1), and on average was very small ($r_{average}$ = -.041). The average correlation was calculated using Fisher's z transformation as cited in McNemar (1969). This involves transforming each correlation to a z-score, weighting each z score, averaging the weighted z values, and then converting this back to a correlation. This transformation allows for averaging of correlations from independent samples. These results indicate that even though students have similar knowledge of aviation and have experienced similar coursework they do not exhibit shared mental models of interdependence prior to participation in the simulation

Hypothesis two was evaluated by examining the correlation between pre-simulation interdependence and communication importance. The correlations varied across groups, ranging from .21 to .54 (Table2), but provided an average correlation of r = .177. Again Fisher's z transformation was used. This suggests that a weak relationship may exist between participants' understanding of communication importance and interdependence prior to simulation and interactions, but it is doubtful that pre-simulation mental models of interdependence appreciably influence pre-simulation mental models of communication importance.

Hypothesis three predicted that, prior to simulations, participants would have a shared mental model of communication importance. Results revealed an average reciprocity of .427 among team members indicating a moderate degree of shared mental models of communication prior to the simulation. All reciprocities were positive and ranged from .17 to .63 (Table 3). This indicates that, prior to the simulations, members may have had a slight to moderate level of agreement about who it would be important to communicate with.

Hypothesis 4 predicted, that following the simulations and interactions, perceptions of who it is important to communicate with will be more similar as shared mental models develop throughout the simulations. Surprisingly, hypothesis 4 results of reciprocity analysis produced a lower average reciprocity following participation in the simulations (average reciprocity = .179) and were extremely variable, ranging from 0 to .8 (Table 4). Reciprocity did not increase from pre-test to post-test; therefore, hypothesis 4 was not supported.

The analysis for hypothesis 5, regarding the correlation between post-simulation interdependence and communication, held mixed results for individual teams; however, all were positive and half were significant (Table 5). These correlations ranged from .01 to .85 with an average correlation of .537. Though results were not as strong as anticipated, 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 from r = .177 prior to simulations to r =.537 following simulations. 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, but suggests that the mental model of interdependence may have influenced who the participant felt it was important to communicate with.

Finally, hypothesis 6 predicted that the degree of shared mental model of interdependence would increase following interaction as a team during the simulations. The QAP analysis of interdependence following the simulations found no significant increase in sharedness of mental models of interdependence ($r_{average}$ = .021). As shown in table 6, individual correlations ranged from -.34 to .44, and none of these correlations were significant. Although the average correlation did increase slightly from -.04 prior to simulations to .02 following simulations, the change was very small and there was little evidence that shared mental models of interdependence developed.

Exploratory Density Analysis

The results obtained while testing the previous hypotheses provided mixed results. Sharedness of interdependence mental models barely increased ($r_{increase}$ = .061), while communication importance mental models decreased by .248. However, the relationship between mental models of interdependence and communication importance became more correlated throughout the simulation ($r_{increase}$ = .36). This was an interesting finding; therefore, an investigation of the density of the networks of both communication and interdependence were performed to gain a more robust picture of the changes occurring during the simulations. Density was computed as it allows a better understanding of how much traffic exists in the network. It can provide clarity and context in which to explain and understand other measures used in SNA.

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 ($t(11) = 2.42$, p <.05, $d = .295$ and $t(13) = 4.99$, $p < .05$, $d = .979$ respectively.) These findings may indicate that the mental models are becoming more refined, and the networks less tangled. To investigate whether the density decreased for both interdependence and communication importance happened in parallel a correlation of the differences was performed. No significant correlation was found between the differences of pre and post simulation interdependence and communication importance ($r = 0.42$, $p > .10$).

Chapter IV

Discussion

Results from hypothesis 2 and 4 indicated that post-simulation, participants' mental models of interdependence and communication were more closely related than prior to simulations. This finding suggests that participant's understanding of how interdependent their jobs were became more similar to their understanding that communication with these positions was important. This allowed 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. The exploratory density analysis further supported this view. As individuals within the team began to understand how they fit into the group and whom it was important to communicate with, the networks became simpler and less tangled. Interestingly, teams perform better as simulations continue (Littlepage et al., 2012), but frequency of communication decreases. This finding is similar to the observations that Cannon-Bowers et al., made (1993) that expert team performed better, without increasing overt communication. 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, which echoes Tannenbaum et al., (1992). In addition, these findings might support Kozlowski and Bell's statement (2001) that "communication is the primary means to enable…coordination and cooperation. (p. 40). These findings, in context with previous research support the idea that experience within a team increases performance. Cooke and associates (2007) found that teams with previous experience had higher performance in later tasks. In addition to this research, Mathieu and colleagues' (2000) found that team mental models impacted team processes which impacted team performance. During the Mathieu, et al. study mental models were captured by providing the team members with empty matrices (grids) with the attributes of study across the top and side. Each attribute was then rated in relation to all other attributes. This provided an entire picture of the mental model of each participant. These matrices were assessed using QAP analysis and analyzed with performance measures.

Interestingly, the remaining hypotheses did not provide support that sharedness of mental models increased across simulations. Shared mental models of communication importance and interdependence showed little change and development throughout the simulations. Sharedness of mental models of interdependence barely increased from pre-simulation to post-simulation and communication importance actually decreased. However, these two mental models (interdependence and communication importance) became more similar over time and participants began to show a greater awareness and understanding that positions vary in the needs of communication importance and interdependence. These finding warrants further research, as they may suggest that different positions view positions and relationships of interdependence and communication importance between those positions differently. In addition, communication may be thought of in directional terms. While reciprocity was used for communication matrices, which removes directionality of the matrix, participants could have indicated that it was not important to communicate with other positions because the communication has an inward direction. For example, crew scheduling may have indicated that it was not important to communicate with flight operations, because information and communication typically comes from flight operations to crew scheduling. This could drastically impact the matrix produced if participants did not view communication as a two-way channel.

Limitations & Future Research

This study, like all, has its limitations. Sample size (9 – 14 teams) was a limitation. This limitation could not easily be overcome as only a limited amount of students are enrolled in the class used for this research and it is part of a capstone class. Students need specialized aviation knowledge prior to entering the lab. As part of the course, students within aerospace, but not enrolled in this course do not have access to the simulation lab. Over the years, as more students take the course, sample size will increase.

In addition, 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 develop and can become more congruent as a result of team experience.

While the simulation was relevant and held high fidelity subjects participated in 2 to 3 simulations, totaling 6 to 9 hours, over the course of one semester. More simulation participation or more frequent participation might provide better results as there is no clarity around how long it takes for shared mental models to develop.

Another limitation regarded the way data was collected. The surveys were not originally constructed with social network analysis in mind and revisions of content, wording, and data collection methods may provide more robust data collection. Measures in this study were based on a self-report Likert scale and were ego-centric questions. Participants were asked questions regarding how their position was interdependent with various other positions, or how important it was for their position to communication with other positions. Participants were never explicitly asked about their understanding of the relationship between various other pairs of positions. Using measures, such as those used by Mathieu and colleagues (2000), that provide a matrix for students to fill in could be a possible solution. Each position would be across the top and in the same order down the side, creating a square matrix. A number of questions could be asked on a number of different scales and each position could be evaluated in relation to all other positions. This would enable a full picture of the mental model and students would be able to answer interdependence and communication questions for all dyadic pair in the simulation, not just from an ego-net perspective.

Conclusion

In conclusion, the experiment provided support for the notion that over time team dynamics and mental models change. However, it was difficult to capture the change in communication importance and interdependence apart from each other. Taking the two mental models in correlation with each other, the change was much more apparent. As teams work together the communication importance and interdependence become more intertwined and overt communication and the channels of who it is important to communicate with become more refined. Future research could investigate how the density actually changes, while we know it decreases, little is known about what dyadic relationships change and how this change may or may not create sub-teams within the system. In addition, future research can focus on providing robust measures to capture non-egocentric mental models.

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Table 1

QAP Analysis Interdependence Hypothesis 1 (Pre-Simulation Shared Mental Model)

TEAM	*r*	*P*
1,6	0.196	0.200
2,6	0.247	0.195
3,6	-0.273	0.106
4,6	-0.411	0.025
1,7	-0.144	0.218
3,7	-0.499	0.059
4,7	0.333	0.086
5,7	-0.349	0.072
6,7	0.146	0.278
1,8	0.166	0.263
3,8	-0.294	0.120
4,8	-0.146	0.344
6,8	0.187	0.216

Table 2

QAP Analysis Hypothesis 2 (Pre-Simulation Correlation)

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

Table 3

Reciprocity: Communication Hypothesis 3(Pre-Simulation Shared Mental Model)

TEAM	Reciprocity
6,8	0.250
6,7	0.625
5,8	0.250
5,7	0.166
4,8	0.416
4,6	0.363
3,8	0.375
3,7	0.500
3,6	0.181
2,8	0.500
2,7	0.500
2,6	0.230
1,8	0.222
1,7	0.500
1,6	0.250

Table 4

Reciprocity: Communication Hypothesis 4 (Post-Simulation Shared Mental Model)

TEAM	Reciprocity
6,8	0.800
6,7	0
5,8	0
5,7	0
4,8	0.200
4,6	0
3,8	0.444
3,7	0
2,8	0
2,7	0.500
2,6	0.142
1,8	0
1,7	0
1,6	0.428

Table 5

QAP Analysis Hypothesis 5(Post-Simulation Correlation)

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

Table 6

QAP Analysis Interdependence Hypothesis 6 (Post-Simulation Shared Mental Model)

TEAM	*R*	*P*
1,6	0.383	0.058
2,6	-0.190	0.201
3,6	0.437	0.093
4,6	-0.282	0.126
1,7	-0.109	0.384
3,7	-0.104	0.314
5,7	-0.127	0.334
6,7	-0.341	0.052
1,8	-0.007	0.458
2,8	0.383	0.053
3,8	0.316	0.121
4,8	-0.019	0.480
5,8	0.317	0.233
6,8	-0.274	0.191

APPENDICES

Appendix A

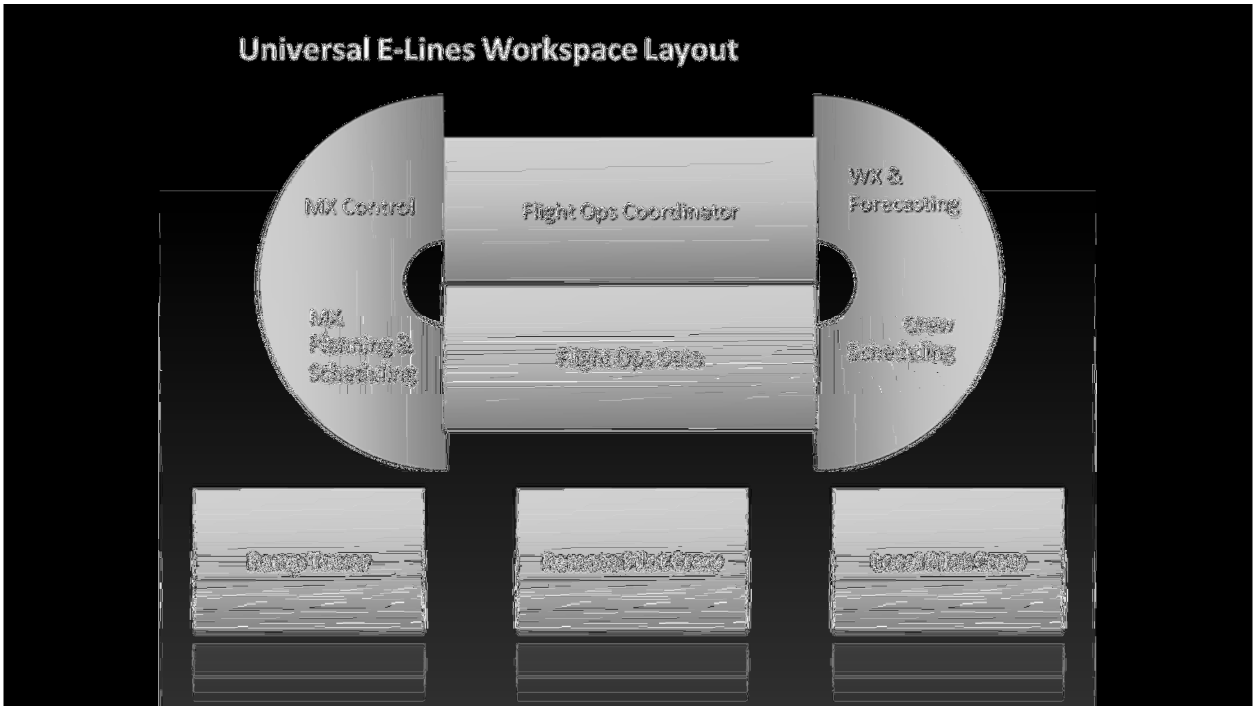

Figure 1. Simulation lab layout. This figure represents the location of each position, with the exception of those positions listed across the bottom, which are located in separate areas to provide more fidelity.

Appendix B

Interdependence

"Perceptions of Airline Industry Roles"

The following questions ask about your perceptions of various airline industry roles. Please respond to each question using the scale below (for each question, CIRCLE the number that best reflects your response). Please answer open and honestly, there are no right or wrong answers.

ITEMS		**Strongly Disagree**		**Disagree**		**Neutral**		**Agree**		**Strongly Agree**	
My job performance is heavily dependent on:											
1.	Pilots	1	2	3	4	5	6	7	8	9	10
2.	Maintenance	1	2	3	4	5	6	7	8	9	10
3.	Crew Schedulers	1	2	3	4	5	6	7	8	9	10
4.	Ramp Tower	1	2	3	4	5	6	7	8	9	10
5.	Flight Ops (Dispatchers)	1	2	3	4	5	6	7	8	9	10
6.	Weather Briefer (Forecasting)	1	2	3	4	5	6	7	8	9	10
7.	Air Traffic Control	1	2	3	4	5	6	7	8	9	10
Their job performance is heavily dependent upon me:											
8.	Pilots	1	2	3	4	5	6	7	8	9	10
9.	Maintenance	1	2	3	4	5	6	7	8	9	10
10.	Crew Schedulers	1	2	3	4	5	6	7	8	9	10
11.	Ramp Tower	1	2	3	4	5	6	7	8	9	10
12.	Flight Ops (Dispatchers)	1	2	3	4	5	6	7	8	9	10
13.	Weather Briefer (Forecasting)	1	2	3	4	5	6	7	8	9	10
14.	Air Traffic Control	1	2	3	4	5	6	7	8	9	10

Appendix C

Communication Patterns

Please use the following scale to indicate how frequently you got or received information from each job assignment. Treat each conversation as a separate instance; that is, if you discussed something count this as one instance. If you later talked with this person about the same issue or another issue count this as a separate instance. When describing the position you occupied, respond to how often you communicated with the other person in this position. If you were the only person in this position, leave the item blank.

0	1	2	3	4
Never	Once or Twice	Three to Five Times	Six to Ten Times	More than Ten Times

	Communication Frequency
Pilot	
Crew Scheduling	
Weather & Forecasting	
Flight Operations Coordinator	

Flight Operations Data	
Maintenance Control	
Maintenance Planning and Scheduling	
Ramp Tower	

Please use the following scale to indicate how important it was to communicate with people in each of the following positions. When describing the position you occupied, respond to how often you communicated with the other person in this position. If you were the only person in this position, leave the item blank.

0	1	2	3	4
Not At All Important	Somewhat Important	Moderately Important	Very Important	Absolutely Essential

	Communication Importance
Pilot	
Crew Scheduling	
Weather & Forecasting	
Flight Operations Coordinator	

Flight Operations Data	
Maintenance Control	
Maintenance Planning and Scheduling	
Ramp Tower	

Appendix D

IRB Approval

MIDDLE TENNESSEE STATE UNIVERSITY

February 13, 2013

Emily Sanders, Dr. Glenn Littlepage
Department of Psychology
emily.sanders10@gmail.com, Glenn.Littlepage@mtsu.edu

Protocol Title: "USING SOCIAL NETWORK ANALYSIS TO MEASURE MENTAL MODELS OF COMMUNICATION AND INTERDEPENDENCE IN A SIMULATED FLIGHT OPERATIONS CONTROL CENTER"

Protocol Number: 13-204

Dear Investigator(s),

The exemption is pursuant to 45 CFR 46.101(b) (2). This is because the research being conducted involves the use of educational tests, survey procedures, interview procedures or observation of public behavior.

You will need to submit an end-of-project report to the Compliance Office upon completion of your research. Complete research means that you have finished collecting data and you are ready to submit your thesis and/or publish your findings. Should you not finish your research within the three (3) year period, you must submit a Progress Report and request a continuation prior to the expiration date. Please allow time for review and requested revisions. Your study expires on **February 13, 2016.**

Any change to the protocol must be submitted to the IRB before implementing this change. According to MTSU Policy, a researcher is defined as anyone who works with data or has contact with participants. Anyone meeting this definition needs to be listed on the protocol and needs to provide a certificate of training to the Office of Compliance. **If you add researchers to an approved project, please forward an updated list of researchers and their certificates of training to the Office of Compliance before they begin to work on the project.** Once your research is completed, please send us a copy of the final report questionnaire to the Office of Compliance. This form can be located at www.mtsu.edu/irb on the forms page.

Also, all research materials must be retained by the PI or **faculty advisor (if the PI is a student)** for at least three (3) years after study completion. Should you have any questions or need additional information, please do not hesitate to contact me.

Sincerely,

Andrew W. Jones

Compliance Office
615-494-8918
Compliance@mtsu.edu