2011

Multiteam Coordination in Simulated Airline Operations: Assessment of Interpositional Knowledge and Task Mental Models

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Effective airline operations require coordination among various specializations such as pilot, flight dispatch, and maintenance. Interpositional knowledge (IPK) and task mental models are emergent cognitive states that can facilitate effective coordination. This study examined the extent of IPK and similarity and accuracy of task mental models among aerospace students. Results indicated relatively low levels of IPK and mental model similarity and moderate levels of mental model accuracy. Training activities that enhance IPK and task mental models have the potential to improve coordination and performance of airline personnel.

Flight cancellations and delays inconvenience passengers, disrupt business activities, and cause operational problems for airlines. The overall economic impact of delays and cancelations in the U.S. exceeds $31 Billion annually (NEXTOR, 2010). While disruptions cannot be eliminated entirely, more effective coordination among differing specializations of aviation professionals offers to reduce their frequency and duration. When unexpected problems arise (e.g. weather conditions, mechanical difficulties, passenger illness or incidents) effective communication, similar mental models, effective coordination, and proactive action can help avoid or limit possible disruption. Currently, we are conducting a multi-year project to study coordination between various aviation specializations. In order to examine group processes and emergent states that impact multiteam performance, we utilized a high-fidelity simulation that incorporates both routine and non-routine work situations. Recent theory and research on multiteam systems provides a perspective from which to view the coordination required to maintain efficient airline performance.

A multiteam system is composed of two or more teams that must work interdependently to reach one or more collective goals (DeChurch & Marks, 2006; Mathieu, Marks, & Zaccaro, 2002). Just as members of cross-functional teams may have mixed motives, component teams may have proximal goals that are not fully synchronized, nevertheless they must coordinate to achieve critical distal goals. The effective and efficient operation of an airline depends on the coordinated actions of persons in various aviation specializations such as pilot, flight dispatch, maintenance, and others. Although these specializations may have differing proximal goals (e.g., thorough maintenance inspection vs. on-time departure), they share common superordinate goals of safety and operational efficiency.

Research suggests that coordination among persons or teams with different types of expertise is critical to effectiveness (Marks, Mathieu, & Zacarro, 2001; Salas, Sims, & Burke, 2005). This may be especially true for teams that operate in dynamic environments, such as emergency response, military operations, and commercial aviation. Shared cognitive states are important factors that facilitate effective, coordinated team performance (DeChurch & Mesmer-Magnus, 2010; Mathieu, Hefner, Goodwin, Salas, & Cannon-Bowers, 2000; van Ginkel, Tindale, & van Knippenberg, 2009). One cognitive state that relates to effective team performance is interpositional knowledge (IPK). IPK represents a team member's knowledge of the tasks, roles, and behaviors required of other team members. A related cognitive state that enhances team performance is a shared mental model. A shared mental model exists when team members share a common view of the task or teamwork requirements. Team coordination, viability, and performance are enhanced when members share accurate mental models (Resick, Dickson, Mitchelson, Allison, & Clark, 2010; Smith-Jentsch & Mathieu, 2005).

Traditionally, aviation students are trained primarily in their specific specialization and have limited knowledge of other specializations. Upon entering professional employment, aviation personnel must develop the ability to effectively coordinate with other specializations. We are currently engaged in a multi-year project directed at two goals: to understand emergent states and processes that affect effective performance, and to develop and evaluate a training program to enhance coordination among aviation professionals. This report describes only results of the first of three phases of this project. Before presenting the results of this initial phase, an overview of the entire project is presented.

For this project, a high-fidelity simulation of an airline was constructed. The simulation involves coordination among several workstations at three separate locations: local airport operations (Ramp Tower), cockpit operations, and airline flight operations. Together these locations control the operation of a simulated airline with a fleet of 30 aircraft. The simulation requires coordinated action of 10-12 persons working in different aviation specializations. The local airport operations center controls airport functions such as gate departure and arrivals, taxiway clearances, and takeoff and landing clearances. This location houses up to three participants and provides a panoramic view of the airline's gates. Persons working at these stations control all aspects of airplane movement from the gate to takeoff. The airport area and all plane movements are displayed on three large video screens. A pilot/captain and first officer work in a second location where they control a flight simulator. Currently, they operate a low-fidelity simulator from a computer screen, but in the near future, they will work from a fully functional flight simulator designed to mirror the aircraft used by the virtual airline.

The third location, the flight operations center is the most complex. It contains six workstations: flight operations coordinator, flight dispatch data, maintenance control, maintenance scheduling, crew scheduling, and weather monitoring. Each station contains a computer with station-relevant information. Seven large video screens display information such as flight schedules, radar views of flights in progress, and a weather map. The two flight dispatch positions monitor flights and make scheduling adjustments. Maintenance control engages in real-time conversations with pilots in flight to evaluate maintenance issues that arise. Maintenance scheduling oversees routine and non-routine maintenance activities and is aware of planes that may be available for service. Crew scheduling has data about crew service limitations and availability of other personnel for backup duty. Weather monitoring is aware of weather conditions that may affect airline operations.

In Phase One, we examine the IPK and task mental models of traditionally trained aerospace students—students trained almost exclusively in their area of specialization. These students are not exposed to the simulation lab. In Phase Two, we examine the effects of an extremely low-fidelity, talk-through simulation. In this phase, participants learn the functions of the various workstations and participate in guided discussions of the coordinated actions required to collectively deal with various scenarios such as a bird strike or a temporary disruption of the fuel distribution system. In Phase Three, participants complete the high-fidelity simulation. Participants in this phase manage their workstations and respond to normal and non-routine situations.

Phase One, the focus of this paper, provides baseline data for traditionally trained aerospace students. Because these students have had only few opportunities for coordinated work with students in complementary aerospace specializations, we expect them to have low levels of IPK. Thus, we expect pilot, flight dispatch, and maintenance management students to have higher levels of knowledge specific to their respective specializations than to complementary specializations. Likewise, we expect that mental models of members of different specializations will not be highly similar. We anticipate that interactive coordination training among specializations will enhance IPK and lead to the development of more accurate shared mental models, although tests of this hypothesis await collection of data in Phases Two and Three.

Method

Participants in Phase One consisted of 63 students enrolled in a capstone course in the Aerospace Department of a large university in the Southeastern United States. The specializations represented were Professional Pilot ($N = 29$), Airport Administration ($N = 22$), Flight Dispatch ($N = 8$), and Maintenance Management ($N = 8$).

With the assistance of Subject Matter Experts (SMEs), we developed a number of measures. A quiz covering several aviation specializations was used to assess IPK. Specific questions were designed to reflect job-related knowledge related to each specialization. SMEs from three specializations (pilots, flight dispatchers, maintenance technicians) answered the questions related to their area of expertise and verified the previously identified correct answers. Also, with the assistance of SMEs, following Smith-Jentsch and colleagues (2005), another measure containing seven scenarios was developed. The scenarios included the following problems: alternator failure at night, runway incursion, nighttime runway incursion, communication failure, bird strike, unruly passenger, and an equipment problem complicated by weather. Each scenario included four to six alternative possible responses to the problem. To successfully deal with the problem presented in a scenario, action is required by one or more aerospace specialization(s). All scenarios required responses from pilots, while the last three also required responses from flight dispatchers, and scenarios 5 and 7 also required responses from maintenance personnel. SMEs, from the three specializations mentioned above, also rated the effectiveness of various responses to scenarios that were relevant to their specialization. Their ratings were used to develop indices of task mental model accuracy. Participants in this study completed the quiz and scenario instruments during the final meeting of the course.

Results

Interpositional Knowledge

We evaluated the hypothesis that positional knowledge would be greater than IPK by examining the accuracy scores of responses to quiz items that did and did not reflect the participant's aviation specialization. To control for difficulty differences across quiz items, scores for each item were standardized prior to analysis. Overall, positional knowledge was somewhat higher than IPK. Flight dispatch students were more accurate on dispatch items ($z = .97$) than non-dispatch items ($z = -.81$), $t\,(7) = 4.49$, $p < .01$. Likewise, maintenance students were more accurate on maintenance items ($z = .88$) than non-maintenance items ($z = -.50$), $t\,(3) = 2.45$, $p < .05$, one-tailed. Pilots in training did not differ in accuracy between pilot and non-pilot items.

We also examined this hypothesis by examining quiz items related to a specific specialization and comparing the responses of students trained in that specialization with students trained in other specializations. For items related to flight dispatch, dispatch students displayed greater accuracy than students in other specializations, $F\,(1, 61) = 9.87$, $p = .003$. For maintenance items, maintenance students displayed a significant tendency for greater accuracy than students from other specializations, $F\,(1, 61) = 3.46$, $p = .034$, one-tailed. For items related to pilots, pilots in training were slightly more accurate than other specializations, but the difference was not statistically reliable, $F\,(1, 61) = 1.18$, $p = .28$. Both sets of analyses provide partial support for this hypothesis; positional knowledge was higher than IPK for both dispatch and maintenance students, but not for pilots in training.

Mental Models

We conducted a mixed factorial ANOVA for each specialization (pilot, flight dispatch, maintenance, aerospace administration) by response alternative for all 7 scenarios. For each scenario, a highly significant ($p < .001$) and strong ($\eta^2 > .45$) main effect for response alternative was observed. This indicates that each scenario contained response options that varied in perceived effectiveness. Only one of the scenarios (bird strike) yielded a significant specialization effect ($p < .05$, $\eta^2 = .15$). For this scenario (that required action by all three specializations), the overall level of effectiveness of the response options varied across specializations. For the other scenarios, effectiveness ratings did not differ across specializations. Based on these analyses, Intraclass Correlations (ICCs) were computed to determine if members of the same aerospace specialization held views about the effectiveness of various response options that were more similar than those of all aerospace specializations. Most of the ICCs were very small (< .044), but for one scenario (bird strike), there was a moderate tendency for members of the same specialization to show greater similarity (ICC = .14). This pattern of results suggests that, among traditionally trained aerospace students, there is not a large degree of differentiation between the mental models of students representing various specializations.

Next, we examined the similarity of evaluations of the effectiveness of response options. This provides evidence about the degree of mental model similarity of aerospace students in general and additional evidence about mental model similarity within specific specializations. For each scenario, we examined the consistency across participants of effectiveness ratings of the various response options. This involved computing the mean of the correlations between all possible pairs of participants. This provided an index of agreement about the relative effectiveness of the various response options to a scenario across all aerospace specializations. For each scenario, we also computed the mean correlation between participants within each specialization that would need to respond to the scenario. In four scenarios only pilots were critical, but for three scenarios multiple specializations were critical. For these scenarios, correlations were computed separately for each critical specialization and then a sample size-weighted average was computed. For all participants, across scenarios correlations ranged from .27 to .56 with a mean of .38. When only participants in critical specializations were examined, correlations ranged from .29 to .55 with a mean of .40. This pattern of results indicates that participants showed moderate agreement about the relative utility of various responses to the problems presented in the scenarios. That is, there is some degree of similarity among the task mental models of participants. Since the level of agreement between members of the same specialization did not differ appreciably from those of all participants, it appears that the mental models of members of the same specialization are not markedly more similar than the models of aerospace students in general.

Mental model accuracy was examined for each scenario. For each response option in a given scenario, each participant's effectiveness rating was compared to the previously established SME mean. For each scenario, these discrepancies were averaged across the response options to yield an error score for the scenario. These individual error scores were averaged across all participants. This procedure was repeated for each scenario. Lower error scores represent higher levels of mental model accuracy. The mean error scores ranged from 2.02 to 2.85 points on the 11-point effectiveness scale. Based on the effectiveness rating of the SMEs, the maximum average discrepancy for a typical scenario was 6.08. The mean error score for each scenario expressed as a percentage of possible error ranged from 25.7% to 42.4% and the mean error across all scenarios was 35.4%. This suggests that participants did not have extremely accurate mental models. Accuracy scores were examined using a specialization (4) by scenario (7) mixed factorial ANOVA. This analysis yielded only a main effect for specialization, $F(3, 59) = 6.31$, $p = .001$, $\eta^2 = .243$. Follow-up LSD tests indicated that maintenance students had higher levels of error ($M = 3.45$) than all other specializations (pilot = 2.28, flight dispatch = 2.65, administration = 2.41). Pilots in training had the lowest error scores on each of the seven scenarios, although these differences were only occasionally significant. Across scenarios, error scores for pilots in training were marginally lower than for flight dispatch students ($p = .082$). These results indicate that mental model accuracy varies across specializations. Maintenance students have less accurate task mental models than all other specializations and pilots in training seem to have the most accurate task mental models.

Discussion

Findings from analyses of IPK suggest that both flight dispatch and maintenance students have a greater knowledge of their respective specializations than of other specializations. However, pilots in training did not display greater knowledge of their specialization relative to knowledge of other specializations. While the findings for pilots in training are puzzling, findings for flight dispatch and maintenance students are consistent with our hypothesis concerning IPK.

Examination of the scenarios revealed that across disciplines, students showed some degree of mental model similarity. Contrary to expectations, mental models were not markedly more similar within disciplines than across disciplines. Comparison of student and SME responses to scenarios indicates that students showed only modest levels of mental model accuracy. Analyses suggest that mental model accuracy is highest for pilots in training. One potential explanation is that all scenarios involved situations requiring action from pilots. Maintenance students have the least accurate task mental models. This may partially reflect the fact that only two scenarios require action by maintenance personnel. However, the pattern of less accurate mental models for maintenance students was also found in the two scenarios that involve actions by maintenance. Thus, it seems that the maintenance function may be more isolated and maintenance students (and perhaps airline maintenance personnel) are less aware of the big picture of airline operations. Because some situations require close coordination between maintenance and other functions, this may be problematic.

This study has a number of limitations that should be addressed in subsequent studies. The sample involved all students in the capstone course across two semesters, but it contained only a small number of flight dispatch and maintenance students. Data collection over a longer period of time or across aerospace and aviation programs would provide for a larger sample and more stable baseline measures. Utilization of data from various programs would provide evidence concerning the extent of generalization of our current findings. The quiz could be expanded to include more items from each specialization and the set of scenarios could be expanded. Of particular importance, problem scenarios that do not require responses from pilots should be developed.

Despite these limitations, current findings provide evidence concerning the state of IPK, mental model similarity, and mental model accuracy among aerospace students. They suggest that traditionally trained students do not have extensive awareness of knowledge relevant to job demands of other aviation specializations. Results also suggest that task mental models of aerospace students are moderately similar, but the level of similarity is not much greater within specializations than across specializations. Finally, results indicate that aerospace students did not have highly accurate task mental models and that accuracy was lower for maintenance students than for students in other specializations. Because mental models facilitate coordination and effective performance, steps to increase IPK, mental model similarity and accuracy may enhance effective airline performance and safety. The results of this study can provide a baseline that can be used to evaluate the effectiveness of training programs designed to enhance coordination among aviation students.

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Acknowledgements

This research was supported by NASA Contract NNX09AAU52G, Paul Craig principal investigator. Correspondence concerning this article should be addressed to Glenn Littlepage, glittlepage@mtsu.edu.