Development of Criterion Measures to Assess Interpositional Knowledge and Task Mental Models

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Of utmost importance in the aviation industry is the ability for professionals to work well in a team and understand the intersections of positions for safe operations. In an effort to enhance the understanding of teamwork and communication, senior-level undergraduate aerospace students are currently participating in a NASA funded replica of an airline Flight Operations Center of a regional airline. Students from six aerospace specializations interactively complete a simulated work shift playing roles of aircraft dispatchers, pilots, ramp controllers, maintenance technicians, crew schedulers, and weather briefers. Surveys were collected from Subject matter Experts (SME), and the data statistically analyzed to determine areas of significant agreement. As a result, criterion measures were developed to assess the degree of accuracy and similarity of tasks mental models, as well as positional and interpositional knowledge.

Within high-risk environments such as aviation, it is vital individuals understand the importance of teamwork and the presence of interdependencies in order to ensure safe and efficient operation. Particularly with the ever-increasing technology present with the Next Gen Initiative, every person working within an airline must be competent in a wide range of complex tasks from flying sophisticated aircraft, ensuring safe separation, properly dispatching the flight, and maintaining the aircraft in an airworthy condition. All these tasks, and much more, require every worker to understand how their position affects the entire organization and to take into consideration ways in which their decisions may affect daily operations. At the individual level, this type of knowledge of the basic functioning of tasks which allows individuals to form predictions and expectations about future circumstances is referred to as task mental models (DeChurch & Mesmer-Magnus, 2010). Undoubtedly, the absence of task mental models would be detrimental to the safety of airplane operations as individuals would view their actions in a sort of “tunnel-vision” and lack the knowledge of the overall organizational structure present in aviation.

Resounding throughout the federal regulations, advisory circulars, and National Transportation of Safety Board (NTSB) safety recommendations, the Federal Aviation Administration (FAA) and NTSB emphasize concepts of teamwork, communication, and interdependence of expertise from all levels within an organization with a familiar term coined crew resource management (CRM) (FAA, 2004; FAA, 2005; FAA 2010, NTSB, 2010). According to the FAA Advisory Circular 120-51E, crew resource management training focuses on the importance of crewmembers, dispatchers, mechanics, Air Traffic Controllers, flight attendants, and others involved to operate as one unit or team and to understand their actions and attitudes affect safety (2004). In an effort to better prepare aviation collegiate students to enter the workforce with a deeper understanding of CRM, senior-level undergraduate aerospace students from six aerospace specializations participate in high-fidelity simulations of a regional airline. Funded through a NASA grant, students interactively participate in a simulated work shift playing roles of aircraft dispatchers, pilots, ramp controllers, maintenance technicians, crew schedulers, and weather briefers. Combining the efforts of aerospace and psychology professors and graduate assistants, the simulation lab, referred to as NASA FOCUS, (flight operations center-unified simulation) has a number of research efforts currently underway including concepts of teamwork, shared task mental models, interpositional knowledge, attitudes, and future curriculum revisions. The purpose of this paper is to present the types of criterion measures developed to assess positional and interpositional knowledge and the degree of similarity and accuracy of task mental models, as well as report the findings from the subject matter expert (SME) surveys. The SME data were collected and statistically analyzed to determine areas of significant agreement.
Review of Related Literature

Generally, the collegiate environment offers very few opportunities for cross-training across various disciplines for aerospace students. As it stands, students pursuing a career in aircraft dispatch take a majority of their major courses with other aircraft dispatch students, pilots take courses with other pilot classmates, and so forth. In this type of educational environment a student has very little exposure to the responsibilities and tasks required of other positions and as a result have limited interpositional knowledge. Some of the earliest research in team member effectiveness indicated that cross-training better equips individuals to handle high workload conditions and positively affects the overall team member effectiveness. (Cannon-Bowers, Salas, Blickensderfer, & Bowers, 1998; Volpe, Cannon-Bowers, Salas, & Spector, 1996). Cross-training was positively correlated with improvements in team accuracy, speed, interpositional knowledge, and volunteering information. Further illustrating the importance of cross-team processes, Marks, DeChurch, Mathieu, Panzer and Alonso (2005) discovered that for organizations that utilize two or more teams which interact directly and interdependently, the cross-team processes were more important than within-team processes for predicting effective team performance. In other words, the action processes of the cross-teams within a system are most valuable when operating in a unique environment of high interdependence.

Another important aspect of team functionality towards reaching a common goal is the accuracy and similarity of individual and shared mental models. Shared mental models “allow team members to draw on their own well-structured knowledge as a basis for selecting actions that are consistent and coordinated with those of their teammates” (Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000, p. 274). Mathieu et al.,(2000) discovered cognitive ability was important for the initial emergence of mental model accuracy and similarity in teams. In other words, since new teams lack the experience necessary to develop shared mental models necessary to predict behaviors and actions necessary for team effectiveness, each team member must have a foundational level of cognitive ability to be aware of basic tasks necessary to complete the mission. Although mental model similarity was positively related to team agreeableness, it was not significantly related to goal accomplishment. A study of Air Traffic Controller’s interactions among shared mental models proves it is less important to agree on a strategy and more important to consistently judge the likelihood of success of potential strategies under different conditions (Smith-Jentsch, Mathieu, & Kraiger, 2005). Taking into consideration the ever-changing environment unique to aviation, it is of utmost importance for individuals to be able to quickly, and effectively develop strategies while being mindful of all other factors affecting operations.

More important than similar shared mental models was the degree of accuracy as there was a small positive relationship with mental model accuracy and goal accomplishment (Mathieu et al., 2000). A team may develop a similar mental model yet this does not help towards accomplishing a goal as the entire team may have developed an inaccurate model of thinking. This type of flawed phenomena is often referred to as groupthink, in which an entire group of people conform to the same ideas and beliefs despite the fact they are not accurate. The priority becomes seeking agreement among the group rather than accurate task models or appropriate decisions (Kassin, Fein, & Markus, 2008). Proving similar mental models does not necessary translate to accomplishing a task, Resick et al., (2010) discovered mental model similarity does not always correlate with goal accomplishment, as the entire team may have developed similar yet inaccurate task mental models. DeChurch and Mesmer-Magnus (2010) point out that regardless of accuracy or similarity, shared mental models positively relate to team performance.
Method

Participants

The participants for this study were voluntary and purposefully selected based on their area of expertise. According to Leedy & Ormrod (2010), purposive sampling is appropriate when specific groups of people are needed for a particular purpose, which aligns with this study’s focus on aircraft dispatchers, mechanics, and pilots. Two groups of Subject Matter Experts (SME) were utilized for the development of the criterion-measures. The first group of SME’s consisted of MTSU Aerospace faculty members who were responsible for the design of the assessment tool survey; the second group of SME’s was working aviation professionals who provided answers to the surveys. Responses were received from 10 professional pilots (ranging from 4-25 years experience, 1,000 to 16,900 logged flight time), 10 aircraft mechanics (8-25 years experience), and 7 aircraft dispatchers (9-32 years experience). With the exception of one individual, all SMEs that completed the survey work at Part 121 Air Carrier operations.

Criterion Measures for Interpositional Knowledge and Task Mental Models

The MTSU Aerospace faculty members developed 38 questions to measure knowledge of various aerospace specializations and seven scenarios. These questions were later rated by industry SMEs to develop measures of positional knowledge (PK) which is knowledge of one’s area of specialization, and interpositional knowledge (IPK) which is knowledge of other team member’s roles and responsibilities. Each of the scenarios described some type of dilemma occurring either on the ground or in flight, followed by strategies to resolve the issue. The industry SMEs were asked to rate the likelihood that each strategy would be effective in resolving the issue. Ratings were made using a likert scale from 1-11 with 1 representing 0% likelihood of success and 11 representing 100% likelihood of success. The purpose of the scenarios was to develop criterion to measure the accuracy of task mental models.

Selected quiz items and scenarios were included in questionnaires that were emailed to the industry SMEs. Three different questionnaire packets were developed and emailed to individuals working within the specific area, each containing quiz items and scenarios relevant to one of the following specializations: aircraft dispatchers, aircraft mechanics, and professional pilots. To clarify, professional pilots were emailed the professional pilot questionnaire, dispatchers the dispatch questionnaire, and aircraft mechanics the appropriate questionnaire. Individuals participated on a voluntary, anonymous basis and completed demographic information to ensure they worked in the appropriate area and had sufficient experience to be able to contribute to the study. Each questionnaire contained the following three sections: 1) information about the extent and nature of professional experience, 2) multiple choice questions relevant to the specialization, and 3) scenarios of a non-routine nature relevant to the specialization.

Results

For the multiple choice questions, the frequency distribution was calculated to determine the percentage of SME agreement on the correct answer. For aircraft dispatch, all 7 items showed acceptable agreement ranging from 71% to 100% agreement. For aircraft maintenance 5 items showed acceptable agreement (ranging from 80% to 100% agreement) and two question items had significant disagreement. With agreement ranging from 67% to 100%, 5 of 7 items indicated agreement for professional pilot experts. Any items with significant disagreement will not be used as criterion to assess accuracy of task mental models.

For the scenarios, we calculated the mean effectiveness rating for each option for each of the seven scenarios. Because some scenarios were relevant to only some specializations, Scenarios 1-4 were rated only by pilots (N=10) while Scenarios 5 & 7 were rated by all 3 specializations (N =27) and Scenario 6 was rated by pilots and dispatch (N = 17). Within each scenario, we examined the mean SME rating of effectiveness for each option.
Across the seven scenarios, the mean difference between the most and least effective options to resolve a specific scenario was 5.43. When looking at each scenario separately, the difference between the most and least effective options ranged from a low of 2.5 to a high of 7.41. This indicates that although some scenarios provided options with only a limited range of effectiveness, in general, SMEs perceived substantial differences in effectiveness between various options. One-way repeated measures ANOVAs for each of the seven scenarios further supported the conclusion that SMEs ratings differed across various responses to the scenario. Effectiveness ratings differed for six of the seven scenarios (p < .05); this was true even though 4 of the scenarios were rated only by pilots (N = 10).

For each scenario, SME agreement was assessed by examining the similarity between the effectiveness ratings of the SMEs. The average correlations between SMEs varied considerably. For two scenarios, they were very low (-.01 and .03), for one scenario the mean correlation was .34, and for the remaining four scenarios the mean correlation was higher (ranging from .53 to .71). Despite the varied correlations, a composite measure derived from the set of SME ratings yielded a highly reliable measure for 5 of the 7 scenarios (α > 84). The set of mean ratings of SMEs to each of the options serves as the criterion needed in later studies to evaluate the accuracy of the task mental models.

Discussion

There was excellent agreement between aircraft dispatchers for the multiple choice items. All SMEs selected the same answer for all 7 items, which indicates accuracy among the dispatcher’s task mental models. Agreement among maintenance and pilot SMEs was lower, but still resulted in a pool of items with acceptable levels of agreement. Aircraft maintenance had at least 80% agreement on the answers for 5 out of 7 items, and the pilots had at least 66% agreement, which still indicates a fairly accurate mental model. The pool of items with acceptable SME agreement provides a way to measure accuracy of knowledge relevant to three professional specializations, dispatch, maintenance, and pilots. These items allow for the measurement of positional and interpositional knowledge of students in each of these disciplines. In later phases of this research program, this will facilitate the examination of the following questions related to positional knowledge (PK) and interpositional knowledge (IPK).

1. Will students have a greater level of their own specialization (PK) than of other specializations (IPK)?
2. Will a student’s knowledge of their own area (PK) improve after participating in the NASA FOCUS lab simulations?
3. Will the NASA FOCUS training increase student interpositional knowledge?

SME evaluations of the effectiveness of various options indicate that some options are more effective than others. The mean SME evaluations establish criteria that can be used to evaluate the accuracy of task mental models. For future purposes, the data collected and analyzed from the SME measures will be used as the criterion to research the following questions:

4. Do traditionally trained aerospace students have accurate task mental models?
5. Does the training in the NASA FOCUS lab cause the student’s mental models to become more similar?
6. Does the training in the NASA FOCUS lab cause the students mental models to more accurate?

A limitation to this study was in the small sample size. Future studies of similar nature with a larger sample size of subject matter experts would supplement and solidify the development of criterion measures to assess mental models, positional and interpositional knowledge as it correlates with effective teamwork. Another limitation is the small number of quiz items. Only 5-7 items are available to measure knowledge of each of the three focal aerospace specializations. Likewise, only two scenarios are related to maintenance and only three are related to dispatch, while
all seven involve pilots. This imbalance may make it more difficult to adequately access the mental model similarity and accuracy for maintenance and dispatch. A larger pool of quiz items and a larger and more varied pool of scenarios, as well as a larger sample of SMEs could provide for more effective measurement of PK, IPK, and similarity and accuracy of task mental models. Nevertheless, the current work seems to provide an initial foundation that can be used to examine PK, IPK, and task mental models among aerospace students and professionals.

While our primary focus has been on the use of SMEs to establish criteria for measuring knowledge and mental models, the program of research utilizes additional measures that will be used to supplement our understanding of the effects of coordination training in the NASA FOCUS lab. Examples of these measures include:

- Perceptions of Aerospace Professionals (Occupational Stereotypes). For each of three specializations (dispatch, maintenance, pilot) measures perceptions of own versus other specializations. Measures are computed from the favorability ratings of adjectives used to describe members of various aviation specializations.
- Interdependence Questionnaire. Measures the extent to which participants think their specialization needs to rely on other specializations.
- Beliefs about Groups. Measures reactions to working in teams vs. alone.
- Communication Requirements. Measures perceptions of information flow requirements across various specializations.
- Communication Patterns. Measures extent of communication between various positions in the simulation.
- Teamwork Questionnaire. Measures the extent of teamwork during the simulation.

Although our program of research is clearly a work in progress, it provides a foundation to evaluate efforts such as the coordination training provided in the NASA FOCUS lab. Learning how to facilitate effective coordination across aerospace specializations holds much promise for increasing airline safety and efficiency.

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