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TEAMWORK AND PERFORMANCE OUTCOMES OF HIGH-FIDELITY AIRLINE OPERATIONS CENTER SIMULATIONS

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This study describes effects of a series of simulations of an airline flight operations center and related functions such as pilots and airport ramp control. It is continuation of a multi-year project designed to develop an effective training program for entry level aviation professionals and to develop insights into teamwork processes. Results indicate that the interdependent multi-specialization simulations enhanced teamwork and performance.

A variety of highly-trained professionals are needed to operate an airline. These include various specializations such as: pilot, flight dispatch, weather, crew scheduling, ramp control, and maintenance. Not only must these persons be proficient in their respective specializations, they must work together in a coordinated manner. Effective teamwork is essential for optimal airline operations and this is especially true when non-routine events occur (DeChurch & Marks, 2006; Marks, Mathieu, & Zacarro, 2001; Salas, Sims, & Burke, 2005). Previous research suggests that airline professionals in training do not have high levels of interpositional knowledge that may be needed for high levels of coordinated action (Littlepage & Henslee, 2011). Poor coordination can lead to costly flight delays and can compromise safety. Flight and delays and cancellations result in inconvenienced passengers, disruptions in business activities, and operational problems for airlines. The annual negative economic impact of delays and cancelations in the U.S. is estimated to exceed $31 billion (NEXTOR, 2010). Safety is greatly affected by a lack of coordination among aviation specializations. Merket, Bergondy, & Salas (2000) examined military accident records and determined that 68% of serious (class A) mishaps involved aircrew coordination problems. While accidents and disruptions cannot be eliminated entirely, more effective coordination among differing specializations of aviation professionals can decrease their frequency, duration, and impact.

In order to achieve these objectives, we utilize a series of high-fidelity simulations that incorporates both routine and non-routine work situations. We also incorporate after-action reviews to enhance the beneficial impacts of the simulations. Theory and research on group processes, group/team performance, and multiteam systems provides perspectives from which to view the coordination required to maintain efficient airline performance.

Effective teamwork is important for optimal levels of group performance. Multi-person simulation that captures the essential task and teamwork functions is considered to be an effective approach to team training (Howard, 2011; Salas, et al., 1998, 2010). Despite the fact that training on complex tasks facilitates transfer, most of the training literature tends to focus on relatively simple, routine tasks rather than complex, dynamic tasks requiring adaptation (Kozlowski, et al., 2001). In the current research program, we utilize individual task instruction followed by high fidelity simulations and after-action reviews in an attempt to increase awareness of interdependencies and to enhance teamwork. We do this using complex, high-fidelity simulations of the operations of a regional airline. Like actual airlines, coordination is required among various specializations. To further enhance the effectiveness of training, we utilize a series of facilitated after-action reviews. Recent research indicates that after-action reviews can lead to enhanced team performance (Villado & Arthur, 2013). The goal of this research program is to demonstrate that a training program based on these accepted practices can be used to increase awareness of interdependencies and to enhance teamwork among entry-level aviation professionals.

Method

Participants

Participants were assigned to one of 10 teams of approximately 10 persons per team. All were Aviation Science students enrolled in a senior level capstone course. The following specializations were represented: professional pilot, flight dispatch, maintenance management, aerospace administration, and aviation technology. Each of the students had completed extensive coursework in his or her respective specialization, but had relatively little knowledge of the other specializations and had limited experience working with other specializations.

Setting

The research was conducted in a four room lab facility. This facility includes a flight operations center, a ramp control tower, a pseudo-pilot room, and a CRJ flight simulator. This setting mirrors the task environments of a regional airline.

The **flight operations center** houses multiple workstations. The *flight operations coordinator* has the most central role and has final decision making authority for most matters related to the operation of flights. In order to make effective decisions, this person must utilize information from all other participants in the simulation including those in other rooms. The other positions in this room insure that flights are properly loaded and have sufficient fuel, consider weather conditions, insure that flight crews do not exceed legal duty time limitations and insure that aircraft are properly maintained and safe for flight. Personnel in the flight operations center are seated around the rim of a double row of long tables. This allows for face-to-face communication between these positions, but headset and text communication are also available. Six large screen monitors are wall-mounted, three behind each long side of the tables so that each side displays the flight schedule, a radar view of the flights in the air, and a weather map. These displays provide real-time information during the simulation. In addition, each work station is equipped with a computer and two monitors to allow access to multiple sources of data relevant to that position.

The **ramp control tower** is in an adjacent room and simulates the operation of one of the airline's hub airports (Nashville). The *ramp control specialist* directs arriving and departing flights to appropriate taxiways and gates and provides notification when a plane is ready for pushback. This room contains three wall-mounted large screen monitors providing panoramic real-time views of the gates, runways, and taxiways. Another display shows a radar view of flights preparing for landing and takeoff, and a computer allows the operator to direct the planes to gates and taxiways. The ramp control specialist can communicate with the flight operations coordinator via headphone and text.

The **pseudo-pilot room** consists of a single workstation where flights from locations other than Nashville are started. (As described above, flights from the Nashville airport are requested from the ramp tower)The *pseudopilot* can also divert aircraft if so directed and can report any issues that arise with these flights. This location consists of a single computer station. Voice and text communication are available with positions in the flight operations center and with the ramp control tower.

The **CRJ-simulator** is a fully functional simulation of a CRJ-200 cockpit area located off site. Voice and text communication is available with the flight operations center and the ramp control tower.

Procedure

The procedure consisted of a series of steps: orientation, task-specific training, initial simulation, initial after-action review, second simulation, a second after-action review, a third simulation, and a third after action review. Data were collected during four semesters. Procedures differed somewhat between the 2011 and 2012 academic years. During 2011 each team participated in two simulations and the CRJ simulator was not utilized. During 2012, the CRJ simulator was utilized and a third simulation and after-action review were added. Each of the training components is briefly described below. Following most training components, participants completed research instruments at individual computer stations. All sessions involved the operation of the same airline routes with the same resources, but weather conditions varied and events such as maintenance problems or other issues were manipulated. The simulations were designed to create the feel of a work shift much like participants will experience upon entering the workforce in commercial aviation.

Orientation. A 45-minute presentation and discussion provided a description of the lab and the various work roles. At the conclusion of the orientation, participants were informed of their team assignments and schedule of training activities.

Task Specific Training. During this 45 minute to one-hour session, each team was taken into the lab and each member was provided with instruction, demonstration, and opportunity to practice at his or her work station. The purpose of this session was to ensure that each participant developed an understanding of his or her role, responsibilities and the technical knowledge to do the job.

Simulation One. During this 2.5 hour simulation, the participants collectively worked to operate the simulated airline. The airline is a regional carrier with a fleet of 30 aircraft, two regional hubs, and 14 additional airports. During the simulation, approximately 60 flight events (takeoffs and landings) occurred. Much of the activity involved routine handling of flights and required communication and teamwork. In addition, unexpected events (such as severe weather, maintenance issues, or other problems requiring attention) occurred and further increased the need for information transfer, coordinated action, and adaptation.

After-Action Review One. Following the first simulation, participants individually completed a form about successful and unsuccessful events and reasons for these. In a follow-up session, the group participated in a facilitated discussion of positive and negative events and opportunities for improvement. This session typically lasted approximately one hour.

Simulation Two. This simulation was similar to the first simulation. It involved the same flight schedule, but a different set of problems arose.

After- Action Review Two. The second after-action review followed the same format as the first one.

Simulation Three. This simulation was similar to the first two simulations. It involved the same flight schedule, but a different set of problems arose.

After- Action Review Three. The third after-action review followed the same format as the first two.

Measures

Teamwork. Teamwork was assessed using a 30-item self-report teamwork scale developed by Mathieu and Marks and based on Marks, Mathieu, & Zaccaro, 2001. Each item was phrased as the extent to which the team actively worked to do various teamwork behaviors; the response scale ranged from 1 (not at all) to 10 (to a very great extent). The scale yields an overall teamwork score and scores for teamwork during action and transition (planning and reflection) phases and interpersonal behavior. Observer ratings of teamwork were also collected using a 10 item scale reflecting problem solving, coordination, and information utilization as well as an overall teamwork score. These measures were collected following each simulation.

Interdependence Questionnaire. This four item scale was developed to reflect facets of task interdependence (Wageman, 2001). For six positions within the simulation, participants rated the extent agreement that: their job depended on that position, that position depended on them, they had common goals, and they were part of the same team ($\alpha = .86$). Response categories ranged from 1 (strongly disagree) to 10 (strongly agree). Data were collected following the initial orientation and following the second simulation.

Communication Frequency and Communication Importance. These constructs were assessed by participant ratings of the frequency and importance of communication with seven positions within the simulation. Scales were completed following training (expected communication) and following each simulation. Frequency was measured on a 5 point scale anchored by 0 (never) to 4 (more than 10 times). Importance ratings were anchored by 0 (not at all) to 4 (absolutely essential).

Team Performance. Performance was measured by delay time during each simulation. This reflects the total hours of delays pooled across all flights scheduled during the simulation.

Results

Data were examined using repeated measures ANOVAs contrasting pre-training and post-training measures and follow-up tests as needed. See Table 1 for means and standard deviations.

Teamwork. Analysis of the self-report teamwork scale indicated that training improved overall teamwork ($p < .01$, $\eta^2 =.16$). Teamwork improved for action, $p < .001$, $\eta^2 = .10$, transition, $p < .001$, $\eta^2 = .16$, and interpersonal processes, $p < .001$, $\eta^2 = .13$. Examination of observer ratings of teamwork also revealed large improvements in teamwork. Observer ratings of teamwork increased for the overall rating, $p < .001$, $\eta^2 = .83$, problem solving, $p < .001$, $\eta^2 =.80$, coordination, $p < .001$, $\eta^2 = .85$, and information utilization, $p < .001$, $\eta^2 = .80$. These results indicate that experience working on highly interactive simulations involving specialized professional roles leads to improved teamwork.

Interdependence. Interdependence ratings were made following the first and last simulations and examined using a pre-post by position repeated measures ANOVA. This analysis did not yield a significant main effect for pre vs. post simulation, but did yield significant effects for position, $p < .001$, $\eta^2 = .55$, and the interaction, $p < .001$, $\eta^2 = .15$. Follow-up tests indicated only one change: ratings of interdependence with flight operations were higher following simulation 2 ($M = 8.36$, $SD = 1.78$) than following simulation 1 ($M = 7.87$, $SD = 2.03$), $p = .004$, $\eta^2 = .05$.

Extent of interdependence may vary across positions; for example, weather may be more interdependent with pilots than with maintenance. Since the previous analyses reflect the ratings of all participants, we conducted more refined analyses that examined interdependence between specific pairs of positions. For participants serving as flight operations coordinator, ratings of interdependence increased across simulations for the positions of: maintenance, crew scheduling, and weather. For flight operations data positions, interdependence ratings with flight operations increased while ratings with pilots decreased. For participants in the crew scheduling position, interdependence ratings with flight operations increased. These findings suggest that the simulations result in a more refined understanding of the extent of interdependence between various positions.

Communication. A pre-post by position repeated measures ANOVA compared training measures of expected communication frequency with measures following the final simulation. It revealed main effects for pre vs. post ($p < .001$, $\eta^2 = .23$), position ($p < .001$, $\eta^2 = .75$), and the interaction ($p < .001$, $\eta^2 = .42$). Additional analyses revealed that communication frequency decreased for five positions, but did not change for the flight operations coordinator or maintenance positions. Similar analyses were conducted for communication importance. Significant effects were observed for pre vs. post ($p < .001$, $\eta^2 = .45$), position ($p < .001$, $\eta^2 = .84$), and the interaction ($p < .001$, $\eta^2 = .65$). Additional analyses indicated that ratings of communication importance decreased for five positions, but remained stable for the flight operations coordinator position. These findings that the simulations result in an overall decrease in communication and in communication patterns that are more focused toward the key position of flight operations coordinator.

Delay Time. Delay time decreased in 15 of the 17 teams (88%). Mean delay time decreased by more than five hours, ($p = .015$, $\eta^2 = .32$). These results indicate that team performance improved as training progressed.

Table 1

Measure	Initial	Final
	Mean (*SD*)	Mean (*SD*)
Overall (Self-Rated) Teamwork	3.68 (.70)	3.97 (.64)
Action Processes	3.59 (.76)	3.85 (.72)
Transition Processes	3.50 (.85)	3.88 (.75)
Interpersonal Processes	3.97 (.73)	4.23 (.65)
Overall (Observer-Rated) Teamwork	3.03 (.45)	4.37 (.64)
Problem Solving	2.88 (.44)	4.25 (.70)
Coordination	2.97 (.47)	4.38 (.65)
Information Utilization	3.24 (.48)	4.49 (.61)
Interdependence	7.64 (1.67)	7.72 (1.55)
Communication Frequency	2.42 (.74)	1.65 (.74)
Communication Importance	2.95 (.62)	2.16 (.88)
Delay Time (hours)	11.33 (5.11)	6.31 (5.47)

Discussion

The reduction in delay times indicates that team performance improved as a result of the training. It is likely that some of the performance gain resulted from improved individual knowledge and skill, but our other findings suggest that another reason why performance improved is that participation in the simulations and after-action reviews allowed participants to learn to work more effectively as a team. These findings suggest that high-fidelity simulations of complex tasks can lead to enhanced teamwork, an increased and more intricate awareness of interdependencies, a reduction in overt communication, and a more differentiated pattern of communication to specific positions. Additional work is planned to examine the effects of training on emergent cognitive states and to examine the relations of processes and cognitive states to team performance. The current research extends work on team training by showing that high-fidelity simulations can facilitate teamwork and awareness of interdependence in cross-functional teams conducting extremely complex tasks

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