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It is critical that pilots make appropriate flight path deviation decisions when faced with threats of inclement weather. This research demonstrates a latent growth model of pilots' confidence in flight path deviation decisions when faced with potential weather threats. Twenty-four commercial airline pilots encountered 6 weather threats during a simulated flight from New York, NY to Miami, FL. Pilots made deviation decisions at 4 distance points from each potential weather threat. Results from the latent growth model (LGM) of pilots' distance confidence as a function of the distance to the potential weather threat showed a statistically significant growth in confidence as pilots flew closer to the weather threat. Pilots exhibited an escalated commitment bias such that confidence in subsequent decisions increased more if their confidence was high in the initial decision. Weather forecasting is unreliable; therefore airlines should train pilots to avoid this type of decision making bias.

Introduction

Pilots make frequent and important decisions about flight path deviations to avoid potential weather threats. There is pressure to minimize fuel consumption and flight time and to maximize passenger comfort; therefore it is important to make appropriate decisions about potential weather threats. Weather information is particularly unreliable at farther distances from the center of the potential threat. Yet pilots must quickly make appropriate decisions regarding deviations from the original flight plan. Their confidence in their initial decision may influence their confidence at later time points. Yet it is important that pilots remain unbiased and flexible when facing potential weather threats. For this study, investigators studied how confidence in deviation decisions changed as pilots flew closer to the potential weather threat. Most importantly, the researchers studied how confidence in an initial decision influenced confidence in subsequent decisions.

Naturalistic decision making models illustrate how teams make meaningful decisions in complex environments (Lipshitz, Klein, Orasanu & Salas, 2001). Pilots make complex decisions in demanding environments and these decisions have a large impact on the safety of passengers. This is applicable to how experienced aviators respond to uncertain information. Weather information often provides incomplete and unreliable information; therefore, pilots make decisions under uncertainty from a lack of information (Lipshitz & Strauss, 1997). In such situations pilots may manage uncertainty by making a best guess with limited information, evaluating the advantages and disadvantages associated with deviating from the flight path, or ignoring uncertainty (Lipshitz & Strauss, 1997). Naturalistic decision making describes how people make initial decisions under uncertainty, yet it fails to explain how people view their initial decision over time.

Escalating bias refers to a decision maker viewing past decisions more favorably if he or she was initially involved in making the decision (Russ, 2004). Most of the past research concerning escalation of commitment focused on monetary investments (Hantula & DeNicolis-Bragger, 1999; Lewicki, 1980), specifically the notion that people may inappropriately commit to failing investments because of their bias. This is relevant for decisions made across time because people's opinions of their initial decision impact subsequent decisions despite new information. Research suggests that investors may commit to their initial decision even when they discover that their initial decision had negative consequences (Lewicki, 1980).

There are several reasons why escalated commitment occurs. People's confidence in their initial decision may increase over time because of the notion of sunk costs (Staw, 1976). Research suggests that people may regard their initial decision more positively when they devoted considerable effort and time to a subsequent action (Garland, 1990). Therefore people are unwilling to suspend a project once they invested in it.

Escalation of commitment is applicable to other types of decision making, especially when decisions are made under uncertainty. In aviation, pilots receive unreliable information about potential weather threats and they must decide to maintain their current flight path or deviate from it. Escalated commitment in this instance refers to a greater sense of confidence in the initial flight path decision as pilots approach adverse weather. People may experience escalated commitment as the action nears completion. Therefore, pilots would be less likely to change their action as they draw nearer to the weather threat (Boehne & Paese, 2000).

The purpose of this study was to develop a latent growth model of pilots' confidence of their decision making when faced with potential weather threats. The researchers hypothesized that the pilots would exhibit escalated commitment bias and become more confident in their original decision as they flew closer to weather threats (Boehne & Paese, 2000; Staw, 1976). Commercial airline pilots flew from New York, NY to Miami, FL. During the round trip flight, pilots encountered six potential weather threats at four distance points from the center of the potential weather threat. The pilots rated their confidence in each decision.

Method

Experimental Design

We used a multilevel experimental design. Flight crews' team-based decision-making confidence constituted the dependent measure. Confidence at each distance level from the potential weather threat (i.e., 160nm, 80nm, 40nm, 20nm) was nested within each flight crew, which was composed of a Captain and a First Officer (FO).

Flight crews flew a roundtrip from New York, NY to Miami, FL. Throughout each flight leg, flight crews encountered three potential weather threats, for a total of six potential weather threats. However, to increase the reliability of the dependent measure, we aggregated flight crews' decision-making confidence across the two flight legs for a total of four data points, one at each distance point.

Participants

Twenty-four male commercial aviation and air carrier pilots participated in this study. We recruited pilots from six different airlines, including: American Airlines, Delta, FEDEX, Northwest, United Airlines, and U.S. Airways. Twelve of the pilots were Captains and 12 were FOs. We randomly assigned pilots to flight crews consisting of a Captain and an FO. Captains' ages ranged from 46 to 60 years (M = 55.33, SD = 4.01), whereas FOs' age ranged from 34 to 56 years (M = 46.00, SD = 6.02). Captains' flight experience ranged from 10,000 to 19,000 flight hours (M = 13,166.67, SD = 2,910.27), whereas FOs' flight experience ranged from 5,000 to 13,800 flight hours (M = 8,845.83, SD = 2,383.80).

Independent Variable

We presented flight crews with weather information regarding potential weather threats at four distance points from the center of the potential weather threat: 160nm, 80nm, 40nm, and 20nm. Flight crews received static images of potential weather threats at each of these distance points through two automated systems: a simulated real-time Onboard weather system and a simulated delayed NEXRAD weather system. The focus of this study was to examine how flight crews' decision-making confidence changed as a function of decreasing the distance away from potential weather threats. Therefore, we coded the variable distance as: -160nm, -80, -40, -20nm from the center of the potential weather threat. The major reason for doing this was to ease the interpretation of results.

Dependent Measures

Decision-making confidence. Once flight crews received information from both the Onboard and the NEXRAD weather systems, they had to make team-based decisions and answer each of four weather deviation questions at each distance point from the potential weather threat (i.e., 160nm, 80nm, 40nm, 20m). The first question required flight crews to rate their confidence that a weather threat actually existed on a 0 to 100 continuous rating scale. The second question assessed flight crews' confidence that they should avoid the potential weather threat and deviate from the predetermined flight path, also on a 0 to 100 continuous rating scale. The third question required flight crews to make an ultimate decision about whether or not to deviate. However, for the purposes of maintaining experimental control, flight crews were not allowed to actually deviate from the predetermined flight path. The results from the previous questions were analyzed elsewhere (see

Bliss, Fallon, Bustamante, Bailey, & Anderson, 2005). However, the focus of this study was the last question, which assessed flight crews' confidence in their decision to the third question. Flight crews' confidence in their decision was also measured on a 0 to 100 continuous rating scale.

Materials

Flight simulator. Flight crews completed the simulated round trip flight from New York to Miami using an EPIC AV-B/IFR™ General Aviation Flight Console linked to a Pentium 4 IBM-compatible computer running Microsoft Flight Simulator 2004. A rudder control module, sub panel assembly, external power quadrants, and avionics stacks were also attached to the console, which came equipped with a flight yoke and basic flight instruments. We simulated flight dynamics within Microsoft Flight Simulator using a Boeing 737 aircraft model.

Weather Displays. The Onboard and NEXRAD weather displays were modeled using Visual Basic software and presented on a Pentium 4 IBM-compatible computer located to the right of the flight console. Graphical Onboard (see Figure 1) and NEXRAD depictions of weather (see Figure 2) were periodically presented to flight crews to notify them of potential weather threats.

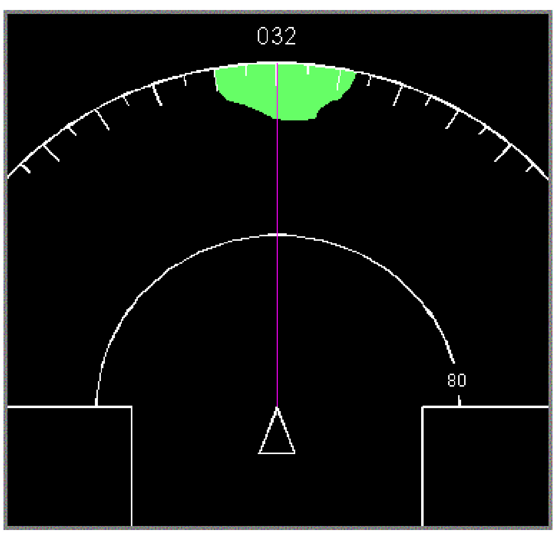

Figure 1. Sample Onboard Weather Imagery.

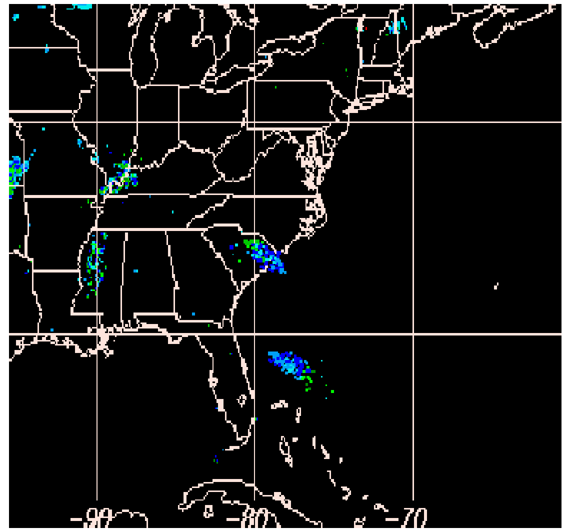

Figure 2. Sample NEXRAD Weather Imagery.

The Onboard system presented weather information from the flight crews' point of view, and it was presented as the aircraft approached the weather threat at 160nm, 80nm, 40nm, and 20nm from the weather threat. The NEXRAD system presented weather information from a "God's-eye" point of view, and it was also presented at 160nm, 80nm, 40nm, and 20nm from the weather threat. The NEXRAD system updated information as it approached the weather threat by zooming in the specific waypoint, thereby providing flight crews with more resolution of the area.

Procedure

After entering the experimental laboratory, pilots completed an informed consent form. They then completed a background information form to provide demographic information that included flight experience, age, and sex. After being familiarized with the simulator setup, pilots were randomly assigned to Pilot Flying (PF) or Pilot-Not-Flying (PNF) roles and were given the predetermined flight plan. To familiarize flight crews and reduce practice effects, we instructed them to first fly a practice flight from Sacramento, CA to Los Angeles, CA. Flight crews were not required to take off or land, but were instructed to maintain an altitude of 19,000 feet, and an airspeed of 325nm per hour through the use of the autopilot.

Prior to each flight leg, flight crews also received preflight briefing information. This information included the flight path and a minimal packet of weather information. The weather packet included information such as wind speed, direction, and convective activity along the projected flight path.

We informed flight crews that this information was 8 hrs old. The usefulness of this information was limited by its age to ensure that flight crews would focus more on the weather displays.

During the practice flight, flight crews encountered a single potential weather threat. During most of the flight, the weather displays did not present any information on the monitor. The program displayed weather information only at set distances from potential weather events. Weather events represented potential thunderstorms at specific waypoints that were considered threats to flight safety. At each distance point (i.e., 160nm, 80nm, 40nm, 20nm) from the center of the potential weather threat, the Onboard and NEXRAD weather displays appeared on the weather display monitor, as well as the four weather deviation questions. At this point, the PF was instructed to disengage the autopilot and fly the aircraft manually. The Captain and FO collaborated to complete the series of deviation questions based on the Onboard radar and NEXRAD information. Although flight crews were permitted to work together, they were reminded that the Captain would give final approval of any deviation decision that was reached. After reaching a decision, the simulation was paused to allow pilots to individually complete a series of questionnaires geared toward assessing each aviator's individual level of trust on the Onboard and NEXRAD weather systems, their perceived level of workload, and their perceived level of situation awareness. Results from these measures have been published elsewhere (see Bustamante, Fallon, Bliss, Bailey, & Anderson, 2005).

After completing the practice flight, flight crews began to fly the specified route from New York to Miami. During the flight, flight crews encountered three weather events. Graphical displays of weather (Onboard and NEXRAD) occurred at 160nm, 80nm, 40nm, and 20nm away from the center of each potential weather threat. Each distance represented a decision point that required flight crews to decide whether and how to perform weather avoidance maneuvers based on the representation of weather provided by the Onboard and NEXRAD displays. At each decision point, the PF disengaged the autopilot and manually flew the aircraft. After deciding on a course of action, the simulation was briefly paused to allow each pilot to complete the trust, workload, and situation awareness questionnaires. The simulation was resumed after the questionnaires were completed and the flight crews continued along their original flight route. However, as previously mentioned, to maintain experimental control, although flight crews made deviation decisions, they were not permitted to actually deviate from the flight path.

After completion of the first flight leg, the flight crews took a one-hour break for lunch and then reconvened for the second experimental flight leg. The Captain and FO switched roles for the return trip. Once flight crews completed both experimental flights, experimenters debriefed and dismissed them.

Results

Descriptive Statistics

Preliminary statistics showed that flight crews' decision-making confidence ranged from 55.00 to 100 (M = 90.21, SD = 9.46). Flight crews' decision-making confidence seemed to be normally distributed (*Skewness* = -1.18, SE = .25; *Kurtosis* = 1.49, SE = .49). Furthermore, a box-whiskers plot of mean flight crews' decision-making confidence scores for each flight crew indicated that there were only three potential outliers. However, this does not raise a major issue of concern given that the normality assumption is based on the distribution of residuals of the final fitted model as opposed to the observed scores of the dependent measure.

Inferential Statistics

Flight crews' reported decision-making confidences during each of the distance points (i.e., 160nm, 80nm, 40nm, and 20nm) were nested within flight crew. Because of this nested nature of the data, we conducted a latent growth model of flight crews' decision-making confidence using the hierarchical linear modeling program. All models were estimated using full maximum likelihood estimation to allow for comparisons of deviance tests. Models were built using a forward approach, starting with the random-effects ANOVA and including set of variables based on whether or not they improved the overall model fit and were statistically significant predictors of flight crews' decision-making confidence.

Random-effects ANOVA. Results showed that the grand mean of flight crews' decision-making confidence across all four distance points and all 12 teams was significantly different from zero, π_{00} = 90.21, SE = 2.06, $t(11)$ = 43.75, $p < .001$. However, from a mathematical point of view, this test of statistical significance was somewhat trivial because although the range of the decision-making confidence scale (i.e., 0 – 100) included a value of zero, it is unlikely to obtain such a score for the grand mean. Nevertheless, this test of statistical significance could have practical applications (discussed later). Another important point to note though was that results showed that the variance component due to differences between flight crews was significantly different from zero, τ_{00} = 45.65, $\chi^2(11)$ =114, $p < .01$. The level-one variance component was 42.85. An analysis of the intraclass correlation coefficient revealed that approximately 51.52% of the variance in crews' decision-making scores was due to differences between teams. Last, the deviance test was significantly different from zero, $\chi^2(3)$ = 660/43, $p < .001$, suggesting that the random-effects ANOVA was not a good-fitting model for the data.

Latent growth model as a function of distance to the potential weather threat. The next model analyzed was a linear growth model of flight crews' decision-making confidence as a function of distance to the potential weather threats in the presence or absence of display agreement. Given that we did not center the distance variable, in this model, π_{00} represented the expected mean value of flight crews' decision-making confidence at the center of the weather threat. Results showed that the expected grand mean of flight crews' decision-making confidence at the center of the weather threat across all 12 teams was significantly different from zero, π_{00} = 92.08, SE = 1.64, $t(11)$ = 56.26, $p < .001$. As expected, results showed a statistically significant growth in flight crews' confidence as they flew closer to the potential weather threat, π_{10} = .03, $t(11)$ = 2.49, $p < .05$ (see Figure 3).

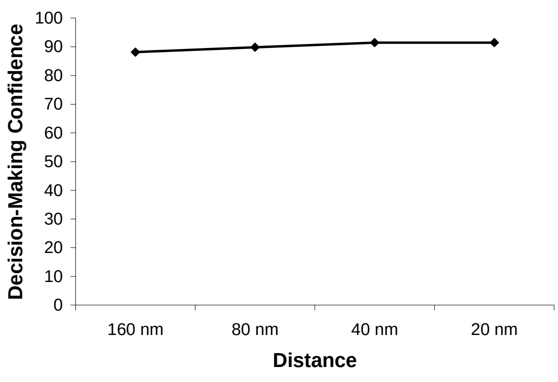

Figure 3. Flight-crews' decision-making confidence.

Results also indicated a high positive relationship between the intercepts and the slopes of the LGM, r = .97. Furthermore, a χ^2 difference test between this model and the previous random-effects ANOVA was statistically significantly different from zero, $\chi^2(3)$ = 10.72, $p < .05$, which suggested that this model significantly improved the fit to the data.

Discussion

The results of our latent growth analysis showed that pilots' confidence in their decisions increased as they flew closer to the center of the potential weather threat. In fact, their confidence in their subsequent decisions increased especially if they were initially highly confident at the first time point.

The notion of sunk costs supports the finding that pilots became more confident as they approached the weather threat. Past research suggests that people regard initial decisions more favorably even in the presence of conflicting subsequent information (Garland, 1990). When deciding to either deviate from or maintain a current flight path, pilots invest time and effort into that decision (Staw, 1976). Therefore they may be less willing to reverse their decision.

This finding has important implications for aviation safety. Research demonstrates that people may view their initial decision more positively despite information that the original decision was inappropriate (Lewicki, 1980). It is crucial for pilots to be flexible when presented with weather threat information. However, greater initial feelings of initial confidence may lead to escalated commitment so that pilots become more confident in their flight path decision regardless of the appropriateness of their decision.

Pilots should be trained to effectively make decisions by having confidence in their ability to make the decision rather than confidence in the decision. Orasanu (2005) suggests that aviation crew members can make more appropriate decisions if they continue to search for new information and reevaluate the situation (Orasanu, 2005). Pilots should seek more information and fill in missing information with their knowledge and experience. Therefore training pilots for decision making under uncertainty is crucial to reducing errors.

Escalated commitment may have detrimental effects on aviation safety. Pilots' initial decisions regarding potential weather threats may impact their confidence in subsequent decisions. This may cause pilots to be inflexible when presented with updated weather information. Therefore it is important that pilots remain adaptable to new information despite their previous decisions.

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