Houston, We Have a Problem Solving Model for Training

Lynne Martin
San Jose State University Foundation, NASA Ames Research Center

William O'Keefe
United Space Alliance, NASA Johnson Space Center

Lacey Schmidt
EASI/Wyle, NASA Johnson Space Center

Immanuel Barshi
NASA Ames Research Center

Robert Mauro
Decision Research

Like many organizations, NASA needs to efficiently train new employees to effectively handle a variety of complex situations. We describe how a model of problem solving for flight controllers was built through combining data, a number of decision models already in existence, and expertise. We then describe how the model was used to drive the construction of a new decision-making training program, containing both lessons (directed instruction) and different levels of simulated exercises (focused practice), that will be more efficient and as or more effective than previous training.

The Mission Operations Directorate (MOD) of the National Aeronautics and Space Administration's (NASA) Johnson Space Center (JSC) provides continuous operations support for the International Space Station (ISS). One component of that support is the Flight Controllers who monitor, command, and respond to the vehicle, crew, and ground equipment associated with the ISS. Each Flight Controller continuously monitors one or more ISS systems using computer console displays. The flight controllers require advanced problem solving skills as well as a thorough understanding of the technical complexities of the system(s) for which they are responsible. Traditionally, problem solving on-console has been learned through scores of expensive simulations and years of on-the-job training watching other flight controllers. While simulations and job shadowing can be effective ways to learn how to perform the flight control function, there are many reasons why obtaining decision making and problem solving expertise through this strategy alone is not efficient, or necessarily successful. The average certification times for flight controllers prior to 2008 spanned from 18 months to three years. Flight controllers sometimes participated in more than 50 eight-hour full-mission (i.e., multi-system, integrated) simulations before becoming certified. Running these simulations proved very costly in terms of both facility costs and labor hours (Baldwin, 2008). The Missions Operations Directorate, which is responsible for technical training, was eager to develop creative solutions that would increase training efficiency and reduce training time to 12 months.

In late 2006, NASA MOD began looking at ways to increase efficiency in the training flows for ISS Flight Controllers. They approached this in two ways: firstly splitting the training into two phases, separated by a period of working as a flight controller under specific (low risk) conditions; and secondly, by redesigning both phases of the training so that, ultimately, new trainees would gain proficiency with far fewer lessons and far fewer training simulations than their predecessors.

The two phases of training were intended to take approximately two years in total – just over a year for the first phase and six months for the second. The first phase of the training introduces basic technical knowledge and Space Flight Resource Management (SFRM) skills, such as decision making and teamwork that are practiced in some desktop simulation sessions and discipline-specific simulations and in approximately eight full-mission simulations. The Flight Controller graduates from this phase as an "Operator" who is qualified to handle quiescent operations only. The second phase of the training takes place a year or so later and introduces more advanced technical and SFRM skills, again focused on decision making, that are practiced in discipline-specific simulations, and four to five full-mission simulations. The Flight Controller graduates from this phase as a "Specialist" who is fully qualified to handle any level and type of operation in his/her technical area(s). Given the complexities of the operation, the number of simulations and amount of training could not just be reduced. The revised certification program had to be designed so that by completing each segment, trainees would add definable new skills to their repertoire.

This is one case in which research supports management's wishes. Empirical findings suggest that task specific training in decision making together with practice in a variety of problem presentations is more important for helping trainees learn to generate quality solutions to novel problems than encountering a large number of full-mission simulations (Baldwin, 1992; Bottger & Yetton, 1987; Ganster, Williams, & Poppler, 1991; Salas & Klein, 2001). Thus, the training program could be changed, replacing much of the on-the-job learning-by-example with directed instruction and focused practice. By providing trainees with an appropriate structure that they could begin to use immediately to organize their experiences, coupled with focused simulation sessions – where decision processes were specifically briefed, practiced and debriefed – training-to-certification time has been reduced substantially.

THE PROBLEM WITH DECISION MAKING MODELS IN TRAINING

Even a brief review of the decision making literature reveals that there are many generic decision making models, with still more that have been specifically crafted for particular domains (see, e.g., Salas & Klein, 2001). General models range from optimizing approaches (Simon, 1979) to the real-world driven sequences of Recognition-Primed Decision Making (Klein, 1989) and the codified strategies put in place by organizations (see, e.g., Mauro, Barshi, Pederson & Bruininks, 2001). No one strategy works for all instances or all levels of skill. The right strategy depends on the type of decision needed, environmental conditions, experience with that problem, whether the solution is prescribed or needs to be developed, time available, etc. (Mauro, et al., 2001). Many models incorporate some of these different aspects at different times or in different ways that all seem applicable to problem solving in mission control. Moreover, much of the literature on training problem solving expertise has focused on what such expertise looks like and on how to certify that a student has reached that point, rather than on how to help trainees obtain this expertise efficiently (Neal, Godley, Kirkpatrick, Dewsnap, Joung, & Hesketh, 2006).

Research articles describing problem solving and decision making models have one suggestion in common about how to develop expertise through training: provide an attentional or metacognitive model for trainees to use as a structure for their experiences (Cooke, Gorman, Duran, & Taylor, 2007; Day, Arthur, & Gettman, 2001; Ericsson & Williams, 2007; Ford, Smith, Weissbein, Gully, & Salas, 1998; Mesmer-Magnus, & Viswesvaran, 2008; Neal, et al., 2006). It is important to chart and represent the high level mental processes that experts implicitly use to solve problems so that this knowledge can be explicitly trained. To this end, NASA's MOD decided to build a context specific model of problem solving and decision making that could drive the re-structuring of the flight controller training program to make it more directed, and hence efficient.

A working group consisting of experienced flight controllers, instructors, I-O psychologists, and human factors scientists was formed to develop a model of flight controller decision making and, from this, a new training program. This paper outlines the process of developing and verifying this context specific problem solving and decision making model and the way the model was used to drive the content and structure of a new flight controller problem solving training program.

REQUIREMENTS FOR A MISSION CONTROL DECISION MAKING MODEL

Mission Control is an unusual environment. Routine mundane housekeeping chores can become time-critical safety-related operations due to the extreme conditions in which the Space Station operates. As a result, existing decision models did not provide complete maps of flight controllers' decision making strategies. For example, in space operations time is often a critical factor. Time becomes an overarching consideration in many more decisions than it does in other environments. A solution that cannot be implemented in time is useless. Thus, a controller may decide to switch goals in midstream from finding a way to return a system to full operation to finding a way to shut it down safely – simply because the estimated time available to solve the problem and implement the solution is greater than the estimated time before a critical condition would develop.

To ensure that operations are safe and predictable, Mission Control relies heavily on processes and procedures that have been developed and tested over the fifty-five years that the space program has been in existence. Reliable solutions are preferred over potentially quicker but less predictable ideas. Thus, the organization leans heavily toward a codified (i.e., rule based; Rasmussen, 1983), approach to decision making as often as possible. In rule-based decision making, the conditions that trigger a prescribed solution and the procedures to be followed to carry out that solution are clearly specified. In Mission Control, previous decisions and solutions are codified in "Flight Rules."

However, space flight is still a relatively new domain. Problems frequently arise for which there is no previously defined solution. In these situations, even experts are forced to use other decision strategies. In such situations, a key step is recognizing that one is moving out of a situation in which rule based decision making can help solve the problem into a situation in which a different strategy is needed. Any model of decision making that is designed to guide flight controller training must incorporate steps that help trainees to recognize this key turning point and assist them to move smoothly from a decision strategy that relies on using rules to other decision making strategies.

To train flight controllers to be expert decision makers within the mission control environment, a model of decision making had to be developed that accurately reflects the complexity of the flight controller decision process. This model had to incorporate the time critical nature of many ISS decisions and it had to reflect the controllers' needs to use different decision strategies appropriate for the type of problem encountered. Based on these requirements, a description of expert controller decision making was developed that incorporated a step-by-step model containing generic problem-independent steps that could move the trainee through a problem solving process that covered all the crucial steps to a successful solution.

MODEL DEVELOPMENT

To create a model that accurately reflected flight controller decision making, the working group studied real events from the flight controller's perspective and reviewed general decision making models to identify frameworks that closely mapped flight controllers' processes. The MOD working group approached the task of constructing a decision making model in four steps: 1) describe the general mission control decision process by extracting general phases from accounts of actual events; 2) structure the decision process description through reference to established models; 3) cross check the resulting model with other established decision models; and 4) verify the model by working back through the available event data.

Describing Decision Making

The working group began by collecting data about a number of ISS-related events that had occurred in the Mission Control Center. Eight interviews were conducted with personnel who had been key players in the events that they described. The eight participants were senior ISS or Shuttle Flight Controllers who were in charge of different operational systems. Demographics were not collected, but from those who volunteered information, the approximate average time as a flight controller was five to six years at the time of the interview.

A team of three interviewers (who were members of the working group) conducted cognitive interviews (Fisher & Geiselman, 1992) with experienced Flight Controllers. Prior to the interviews, interviewees were asked to think of two or three events that occurred while they were on-console that were not easily solved and required problem solving and decision making skills. The interviews lasted for approximately two hours each. During this time, the interviewers encouraged the participants to share their stories and asked open-ended questions to probe either for more detail or for participants' opinions of how they developed expertise. Notes were taken during the interview and digital recordings of a portion of each interview were made.

Initial Model Development

Prior to examining the interviews, the working group identified six key problem solving skills:

- Recognizing and confirming the situation
- Determining indirect and direct impacts to the system, vehicle, crew and mission
- Determining time constraints
- Determining goal(s)
- Developing and evaluating options
- Planning and implementing a plan.

Through expert discussion during two workshops and by analyzing the interviewers' notes from the Flight Controller interviews, the working group expanded upon these six steps to develop an initial version of the "Solving Problems In Complex Environments" (SPICE) model. In a brainstorming process, they assessed and combined steps and ideas from well-known models, their in-house training flows, and their assessment of the eight expert-interviews. The resulting SPICE model was represented both through a verbal description and through a flow diagram (see Barshi & Mauro, 2009, for more details).

Cross Checking

Given the relatively small number of interviews and the unusual operation, the working group took steps to ensure that important steps in the flight controller decision process had not been missed. The working group compared the model to other models including the FOR-DEC model (Hörmann, 1995) used by the ISS Expedition Behavioral Health and Performance Working Group; the ISS SFRM Operator learning objectives and skills compiled during an internal training needs analysis); the DECIDE model (Benner, 1975) used by the US Army; and, the STAR (Stop-Think-Act-Review) model taught in the ISS SFRM training flow (derived from the training program of the Callaway Nuclear Power Plant, see Baldwin, 2008).

Like the SPICE model, these four decision making models are step or flow models that describe a method for decision making, but can be used as a series of steps to assist a decision maker through the process. However, the SPICE model encompasses a number of different strategies, and the flow shifts between these strategies. This blend of strategies arose as a direct result of focusing on real world events and building a model that reflected the successful processes that are followed rather than attempting to define an optimal strategy or derive a model based on a single perspective.

Verification for the SPICE Model

To verify that the SPICE model accurately and completely captured the decision-making processes followed by experienced flight controllers, the model was used to categorize the decision making steps described by the interviewees (see above). Transcripts of the digital recordings made of a portion of seven of the eight interview sessions were coded. When necessary, the interviewers' notes were used as a secondary data source. The digital recordings captured twelve event descriptions, which were used for the analysis.

Two comparisons were undertaken, firstly how many steps of each event could be described or labeled by a step in the model and, secondly, how many of the 22 steps in the model were required to account for each event. When all the model's descriptors were considered, the model could account for all of the steps described in the twelve events recounted by participants. Secondly, the average number of SPICE model steps used to describe each event was 12.67 – over half of the steps available. The number of steps utilized ranged from 9 to 17 (40.9% to 77.2% of the model). However, event steps could only be identified if a participant talked about them. So, these values probably underestimate the number of steps taken. The Flight Controllers may have engaged in more of the model steps but failed to mention them explicitly during the interviews.

It was not possible to ascertain whether the steps of the model were in the right order. The participants recounted their experiences in a free-form manner making it difficult to determine the exact chronology of events. However, the cyclical pattern depicted in the SPICE model was apparent in the described events. Participants often related that they and their team worked through a problem to a point at which it became evident that a chosen course of action was not going to work. Then the team cycled back to a much earlier point in their decision making process and began to work through the problem again with a fresh approach (sometimes bringing in other teams or experts). In other cases, the controllers would reach an interim goal and then cycle back to begin work on a subsequent goal.

On the basis of this retrospective analysis, three changes were made to the SPICE model:

- Labeling was updated in the flow diagram.
- Some of the steps at the beginning of the second stage of the model were reorganized.
- A return loop was included that links the second stage of the model back to the middle or beginning of the first stage.

These recommendations and suggestions are included in Figure 1, which is a revised version of the original SPICE model flow diagram. The SPICE model has explanatory and descriptive value. If a problem is relatively straightforward, the flight controller could solve it by working through the model once from beginning to end. With more complex problems, multiple cycles may be required.

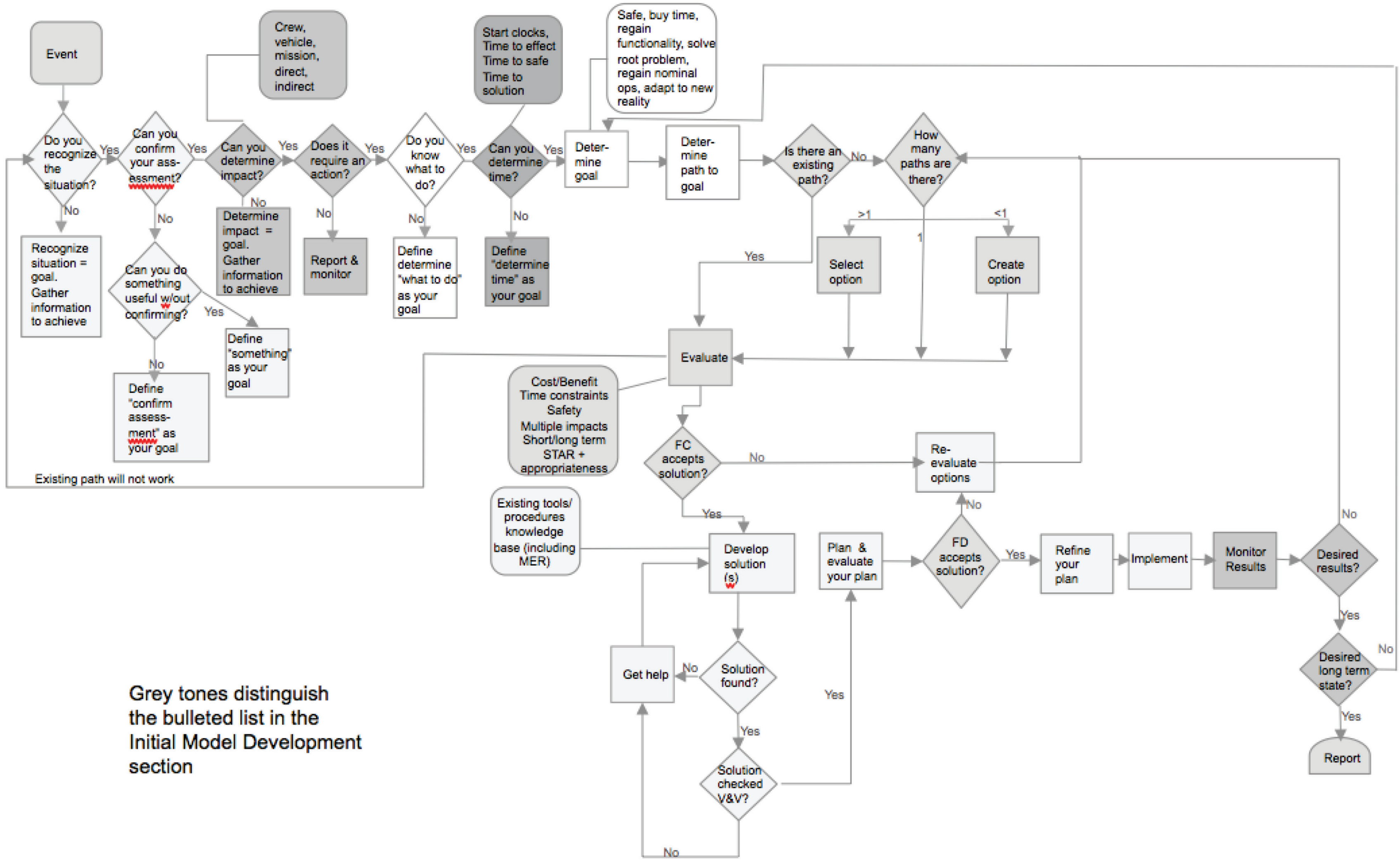

FIGURE 1
ISS MISSION CONTROL SOLVING PROBLEMS IN COMPLEX ENVIRONMENTS (SPICE) MODEL

EXTRACTING MODEL ELEMENTS FOR THE TRAINING PROGRAM

At this point, the challenge for the MOD working group was to convert the model into effective material for a problem solving training program. Decision making models can be difficult to apply because: 1) they are necessarily abstract and 2) they are often perceived to be rigid, requiring each step to be followed in order.

Using Abstract Models

People find it hard to think about how they think. An abstract model is often difficult to utilize because trainees cannot apply the general model to the situation in front of them. Helping a student to label the processes and steps in their decision making allows them to make connections between their situation and the model. One way to achieve these connections is to convert the passive labels in the model to actions that can be taken by the trainee, almost creating a "do-list" of steps to take during an event. To achieve this conversion, Mission Control training developers and other subject matter experts advocated framing the key steps of the SPICE model as general questions that an Operator flight controller could use on-console to prepare for, or evaluate, problem-solving actions.

Emphasizing Flexibility

Users of decision models often believe that the decision process will only work if all the model steps are followed and followed in the order that they are diagrammed. However, real world constraints may interfere so that a step cannot be completed until more information is available or some other condition is met. In a time critical environment, like Mission Control, it is often better to begin working on another step than to wait until all prior steps are completed. Furthermore, not all steps are always required. As the primary goal was to teach a generalized and shared problem solving strategy broadly applicable to the technical context of spaceflight operations, a presentation technique that emphasized the elements of the model rather than its flow was desired. For these reasons, a card sorting exercise was developed.

GENERATING THE MATERIALS TO INTRODUCE A PROBLEM SOLVING FRAMEWORK

To construct lesson materials and lesson plans, the lead training developer used the model, the notes from the interviews (discussed above), his own expertise, and knowledge of the information Flight Directors require from Flight Controllers during an event. Flight Directors orchestrate all activities at the Mission Control Center, and constructing the training around the information they need allowed the lead training developer to 'operationalize' the steps of the SPICE model. He re-phrased the list of problem steps as a list of operational questions that, when answered, can drive a problem solving process. He then combined and removed questions to reduce this list to only the most important questions from a decision making perspective, leaving 17 key questions that focused on the information gathering and manipulation required to understand and solve a problem at the flight controller level (See Figure 2).

The 17 questions are couched at a different level of abstraction from the SPICE model. They guide the students to consciously consider whether they know what the problem is, encouraging the "thought before action" that is emphasized in the STAR model (Question 1, Figure 2). While initial questions in the list focus on safety and factors that need to be immediately weighed and acted upon to prevent a rapid worsening of the situation (e.g., Q2, Q3), later questions encourage the student to view the problem from a wider perspective and to actively consider additional costs, benefits, and potential risks and to check over the work that has been done (e.g., Q13, Q16).

The 17 questions were then used to form a summary sheet that covers all the main points of the lesson, and serves as the students' study guide. The first side of the summary sheet includes only the 17 questions (as shown in Figure 2) and is intended to fit into the personal notebook that many Flight Controllers keep to use as a quick reference when on-console in Mission Control. The back-side of the sheet is a (more detailed but not all inclusive) listing of the factors that a flight controller needs to consider to properly answer these 17 questions. For example, in order to answer the sixth question about the amount of time until an effect, the controller would need to know system, vehicle, mission, process, environmental and timeline factors.

FIGURE 2
THE "17 QUESTIONS" – DECISION MAKING PROMPTS

Failure

1. Can you recognize and (dis)confirm the failure?

Impact

2. Any immediate crew actions required for safety?
3. What functionality/ capability has been affected?
4. What are the immediate impacts?
5. What are the near-future impacts?
6. What are the Times-to-Effect?
7. What are the critical circumstances?
8. How have you checked your assessment?
9. What is your immediate goal?

Workarounds

10. Is there an existing course of action?
11. What are the options?
12. What are the risks of each option?
13. What are the Benefit/ Cost/ Risk trades?
14. What is your contingency plan?
15. What is your Plan of Action?
16. How have you checked your plan?
17. What is your next goal?

The summary sheet was reviewed by experienced Senior Flight Controllers and a Flight Director, and modified accordingly. One of the most important modifications was to group (or pre-sort) the 17 questions into the accepted structure flight controllers typically use to communicate information to the Flight Director. This structure involves arranging message content to address three main points: the observed Failure (F), the expected Impact (I) of this failure, and the Flight Controller's recommended solution or Workaround (W; a way to solve the problem or work around the failure). The first question addresses the Failure (F) aspect of the FIW communication structure, questions number two through nine address the Impact (I) aspect, and questions number ten through seventeen address the Workaround (W) aspect (Figure 2).

To introduce these 17 questions in the classroom and to promote the desired discussion about common problem solving issues, a card sorting exercise was developed from this material. Card sort exercises (see Canter, Brown & Groat, 1985) are a good way to demonstrate to a group that different constructs can be applied to elements of complex situations. Students can easily sort and re-group key problem solving steps for themselves when given different categories that are drawn from relevant events. By running the card sort in a group setting, such as a class, the students can experience how people can take different approaches but still reach acceptable solutions as long as they consider all the key elements of the problem. This kind of exercise, in which students are guided in an exploration of critical aspects, is useful in helping trainees develop common mental frameworks for problem solving (Berardi-Coletta, Buyer, Dominowski, & Relinger, 1995).

One question was placed on each of 17 cards to form a set. In the exercise, small groups of students are given a set of cards and asked to sort the cards into three piles that are labeled "Failure," "Impact" and "Workaround." Through this exercise the students begin to develop their own mental models of problem solving that map closely with those of other trainees and with the SPICE model. This exercise also helps students to see how they could apply these questions to real-world problems by linking them to the commonly used FIW structure.

DEVELOPING THE DECISION MAKING TRAINING LESSONS

The card sort is only the first exercise in a series of Space Flight Resource Management exercises developed for the Operator and Specialist training. A full lesson plan was developed around the SPICE model. In this lesson, students are encouraged to “actively explore” their own decision processes in a manner similar to the approach that was taken in developing the SPICE model. Active exploration is a method that has been advocated for aviation training for some time.

Training in aeronautical decision-making (e.g., Jensen, 1989; Kanki, Helmreich & Anca, 2010; O’Hare, 1992) has received considerably more attention than mission control decision training. Aviation is similar to spaceflight in many ways. Both rely upon highly technical systems; decisions are often made under time pressure; and there are many codified procedures. Hence, it is possible that principles advocated for training aeronautical decision making may be also well-suited to training flight controller decision making. Robertson (2004) stresses that pilots need to be taught higher order thinking skills so that they can develop judgment and decision making techniques. He emphasizes using training strategies that will help trainees develop such cognitive skills. Landa (1999) suggests that learners have to be actively engaged in mental activities to promote effective learning. He suggests using focused practice and directed instruction techniques to actively engage learners. Others advocate basing training on goal-derived and technical task context as well as the metacognitive and shared mental models used by experts (Ganster, Williams, & Poppler 1991; Hartel and Hartel 1997; Chrysikou 2006).

Basing methods “on real world problems, student-centered, active learning” (Robertson, 2004, p 204) as well as customizing them to the domain is likely to help trainees understand and apply the training material. Hence, training developers decided to engage students in case study exercises as part of training the problem solving model.

The lesson plan followed from these basic tenets. The training begins with the card sort exercise (described above) that introduces key decision processes as questions that are immediately situated in the mission control domain. Then the students begin to apply the 17 questions first to simple then to more complicated real world problems. Meanwhile the students are encouraged to discuss the problems to see how using the questions at different points in problem solving can lead to alternate acceptable solutions. Using a variety of different scenarios enables the students to understand the importance of flexibility in the decision process, as well as anchoring the learning in tangible and relevant event sequences.

Lessons were developed for the Operator level of flight controllers first, because the need for improved problem solving skills was noted in earlier operator classes. The second part of the operator lesson (following the card sort) consists of case study exercises. The lesson is designed to be given just prior to a simulation in which there will be a major malfunction. In the simulation, the students must ask and answer the 17 questions to properly solve the problem. An advanced case study lesson was also developed for the Specialist level of flight controllers to be taken when an Operator upgrades to Specialist. This lesson assumes that a Specialist will have to deal with unique problems that are more complex and ambiguous than those addressed by Operators.

The exercises used in the problem solving lessons were designed to mirror real problems seen in-flight and to be applicable to all the different flight control positions. The exercises were also designed to emphasize problems for which there was no approved solution. Hence, the various student teams can develop different answers based on how they perceive mission priorities and how they assess risks.

To work through an exercise, the students first read an account of an event, which contains all the relevant contextual information (e.g., what was happening, system and mission status, constraints, etc.) and a description of what the flight control team that was on-console at the time did. To help facilitate the learning of a common framework for problem solving, the students are then asked to determine when the flight control team asked each of the 17 questions and to mark these points on the case study by writing the appropriate question label in the margin of the case study description next to the relevant communication (e.g., noting 'Contingency' next to the part of the dialogue that shows information relevant to question number 14). The case studies were selected to showcase all 17 questions, but to vary the order that they are asked and answered. In the real world this "asking process" is cyclical, with some questions re-asked and re-answered several times when new information is available.

Each exercise ends with the students (in groups of three to four) making their simulated FIW calls to a Flight Director. As each call is made, the students discuss how they considered each of the 17 questions in composing their calls, and which answer to which question(s) drove them to the specific workaround recommendation they gave in their simulated call. Finally, students are guided to discuss how the questions helped them determine what information they needed and how solving real problems (like those discussed in the case study exercises) is more complex than simply following through the seventeen questions in order.

VALIDATING THE TRAINING APPROACH

As in many organizations, we have yet to collect sufficient data to validate this training program via traditional training evaluation models (c.f. Kirkpatrick, 1979). However, some operational evidence of training validity and utility has been collected. Both the material (the 17 questions) and the facilitated instructional style were vetted through a series of dry-runs and a certification run in which multiple groups of technical, operational, human factors, and I-O psychology subject matter experts reviewed the lesson. During the dry-runs, the lesson received high marks from certified Operators, Specialists, and their management. Additionally, the Specialist version of the lesson has been taught to the first class of students and student responses indicated the lesson was interesting and valuable to them. Pending the required resources (e.g., time, money, management support for data collection), we hope to examine transfer of training more quantitatively. The current lesson is designed to be given after a few initial simulations but just prior to a more complex simulation in which there will be a major malfunction. We are interested in examining whether Operator students who have received the problem solving training respond to this major malfunction simulation more successfully than a control group.

CONCLUSIONS

We described the development and use of a specific problem solving model designed to provide the framework from which to develop a training course. Using models to drive training is not a novel approach, but bridging the gap between theory and practice is hard to achieve. The SPICE model has been a useful guide to keep the lesson plan on-topic – an important property, as limits on time and available resources were key drivers for the requirement to revise the training program. The model itself offers a framework to guide students' exploration and learning of key steps in mission control decision making, but also has potential as a frame for describing real-world events and for investigating decision processes in more detail. However, translating the model from a series of charted steps to an operationally relevant training course, which emphasizes a series of factors that are key to successful decision making but are not context specific, was the crux of the problem for the training developers. The development of 17 practically phrased questions that seem relevant and reasonable to trainees allowed a training program to be created from the SPICE model. This experience suggests that by developing a context specific problem solving model and designing technical training that includes the explicit and practical sharing of that model an organization can better prepare its personnel to solve complex problems in the operational environment.

REFERENCES

Baldwin, E. (2008). Integrating space flight resource management skills into technical lessons for international space station flight controller training. *Proceedings of the Third Annual Conference of the*

International Association for the Advancement of Space Safety, "Building a Safer Space Together", Rome, Italy, October 21-23.

Baldwin, T.T. (1992). Effects of alternative modeling strategies on outcomes of interpersonal-skills training. *Journal of Applied Psychology, 77*(2), 147-154.

Barshi, I. & Mauro, R. (2009). International Space Station (ISS) Space Flight Resource Management (SFRM) Technical Interchange Meeting (TIM): March 24-27, 2009. Unpublished meeting notes. NASA Ames Research Center.

Benner, L. (1975). D.E.C.I.D.E. in the hazardous materials emergencies. *Fire Journal, 69 (4),* 13-18.

Berardi-Coletta, B., Buyer, L., Dominowski, R., & Rellinger, E. (1995). Metacognition and Problem Solving: A process oriented approach. Journal of Experimental Psychology, 21, 1, 205-223.

Bottger, P.C., & Yetton, P. W. (1987). Improving group performance by training in individual problem solving. *Journal of Applied Psychology, 72*(4), 651-657.

Canter, D.V., Brown, J. & Groat, L. (1985). A multiple sorting procedure for studying conceptual systems. In M. Brenner, J. Brown & D.V. Canter, *The Research Interview: Uses and Approaches*, pp79-113. London: Academic Press.

Chrysikou, E.G. (2006). When shoes become hammers: Goal-Derived Categorization Training enhances Problem-Solving Performance. Journal of Experimental Psychology, 32, 4, 935-942.

Cooke, N.J., Gorman, J.C., Duran, J.L., & Taylor, A.R. (2007). Team cognition in experienced command-and-control teams. *Journal of Experimental Psychology: Applied, 13*(3), 146-157.

Day, E.A., Arthur, W., Jr., & Gettman, D. (2001). Knowledge structures and the acquisition of a complex skill. *Journal of Applied Psychology, 86*(5), 1022-1033.

Ericsson, K.A., & Williams, A.M. (2007). Capturing naturally occurring superior performance in the laboratory: Translational research on expert performance. *Journal of Experimental Psychology: Applied, 13*(3), 115-123.

Fisher, R.P. & Geiselman, R.E. (1992). *Memory-enhancing techniques in investigative interviewing: The cognitive interview.* Springfield, IL: C.C. Thomas.

Ford, J.K., Smith, E.M., Weissbein, D.A., Gully, S.M., & Salas, E. (1998). Relationships of goal orientation, metacognitive activity, and practice strategies with learning outcomes and transfer. *Journal of Applied Psychology, 83*(2), 218-233.

Ganster, D.C., Williams, S., & Poppler, P. (1991). Does training in problem solving improve the quality of group decisions? *Journal of Applied Psychology, 76*(3), 479-483.

Hartel, C.E. & Hartel, G.F. (1997). SHAPE-Assisted intuitive decision making and problem solving: Information processing based training for conditions of cognitive busyness. Group Dynamics: Theory, Research, and Practice, 1(3), 187-199.

Hörmann, H-J. (1995). FOR-DEC: A prescriptive model for aeronautical decision making. In R. Fuller, N, Johnston & N. McDonald (Eds), *Aviation Psychology in Practice*, Aldershot: Avebury.

Jensen, R. (1989). *Aviation Psychology*. Aldershot, UK; Gower, Technical.

Kanki, B., Helmreich, R., & Anca, J. (2010). *Crew Resource Management, Second Edition*. San Diego, CA: Academic Press.

Kirkpatrick, D.L. (1979). Techniques for evaluating training programs. Training and Development Journal (June 1979), 178-192.

Klein, G.A. (1989). Recognition-primed decisions. . In W.B. Rouse (Ed.), *Advances in man-machine system research* (Vol. 5, pp. 47-92). Greenwich, CT: JAI Press.

Mauro, R., Barshi, I., Pederson, S. & Bruininks, P. (2001). Affect, Experience, & Aeronautical Decision-making. Proceedings of the 11th International Symposium on Aviation Psychology, March 5-8, Columbus, OH: Ohio State University.

Mesmer-Magnus, J., & Viswesvaran, C. (2008). The role of pre-training interventions in learning: A meta-analysis and integrative review. *Human Resource Management Review, 20*(4), 261-282.

Neal, A., Godley, S.T., Kirkpatrick, T., Dewsnap, G., Joung, W., & Hesketh, B. (2006). An examination of learning processes during critical incident training: Implications for the development of adaptable trainees. *Journal of Applied Psychology, 91*(6), 1276-1291.

O'Hare, D. (1992). The "artful" decision maker: A framework model for aeronautical decision making. *International Journal of Aviation Psychology*, 2 (3), 175-191.

Rasmussen, J. (1983). Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems Man and Cybernetics (SMC), 13 (3)*, 257-266.

Robertson, C. (2004). Teaching pilots judgement, decision-making, and critical thinking. *International Journal of Applied Aviation Studies, 4 (2),* 203-220.

Salas, E., & Klein, G. (2001). *Linking expertise and naturalistic decision making*: Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

Simon, H.A. (1979). Rational Decision Making in Business Organizations. *The American Economic Review, 69*(4), 493-513.