Applied Cognitive Task Analysis in Aviation

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9 Determining decision making skills

This chapter describes procedures for analyzing the decision and problem solving components of complex tasks, and methods for communicating the findings of these analyses. The analyst must select the most appropriate procedure based on the goal of the analyses, the desired products, the characteristics of the task and job to be analyzed, and the resources available. Two detailed examples are presented to illustrate how these analyses can be implemented and how they differ.

9.1 Introduction

Decision making and problem solving are complex cognitive tasks requiring substantial skills. These tasks lie at the heart of proficient performance and serve to guide the overt motor behaviors that are the meat of traditional task analyses. Of particular interest here are the cognitive skills needed to support proficient decision making including tactics, metacognitive skills, mental simulation, and team skills. Tactics are relatively simple procedures which decision makers apply in response to specific situations. These tactics are learned with experience, and serve to support and enhance the pilot's decision making. This chapter addresses methods for identifying such tactics. Chapter 10 addresses the remaining higher level decision skills: metacognition, mental simulation, and team skills.

This chapter describes analytic procedures for identifying and reporting these decision tasks and the supporting information. The examples illustrate these techniques, the cognitive task requirements, potential errors, and the tactics or processes that skilled performers implement to accomplish their job. This presentation continues into Chapter 10, which discusses an equally important component of cognitive performance: the high level cognitive strategies that skilled performers use to manage and organize their work. These strategies help skilled performers organize and manage their work. Though the strategies are qualitatively different from the tactics described in this chapter, they are uncovered while conducting the same analytic procedures. Thus, the analyst will identify strategies while in the process of identifying tactics.

9.1.1 Decision making in aviation

Decision making, judgment, and problem solving are important components of safely piloting airplanes. When asked which skill differentiates captains from first officers, one frequently hears that captains make the decisions. Similarly, when asked what single characteristic distinguishes good aviators from mediocre ones, pilots often answer that good pilots make good decisions and exhibit good judgment. What constitutes good decision making? What skills enable a good decision maker? What can an individual do to ensure or improve the quality of his/her decisions?

In training, flight crews learn to make decisions through several relatively simple steps: understand the situation, generate all possible courses of action, evaluate these courses of action based on some criteria, select the course of action deemed most valuable based on these criteria, implement that course of action, and evaluate the success of the outcome. This decision making strategy is useful and effective, but only under a limited set of circumstances. For example, this type of comparative strategy may be useful when the decision maker has little or no experience with the specific situation, when all the necessary information is at hand, and when ample time exists to make the decision and implement the course of action.

When flying an airplane, however, these conditions are rarely met. Most frequently, the crew has little time to implement their decision and they rarely have all the information they would like to have. Yet pilots and flight crews make decisions frequently, rapidly, correctly, and often without the outward appearance of having made a decision. For example, a flight crew may experience many situations in which more than one course of action is possible, but one may not notice the crew deliberating about what to do or weighing the pros and cons of the various alternatives. But the crew decides how to configure the aircraft, how to divide the crew responsibilities, which route to take, and selects many other alternatives. Many decisions occur rapidly and with very little information. A pilot
often interprets a situation and immediately implements an action without deliberating.

For many decisions, this is exactly what happens. The decision maker recognizes the existing situation as familiar, remembers what actions worked successfully in the past, and implements those actions. In some cases, the existing situation is not exactly like prior ones, and the decision maker must modify his understanding of the situation or the course of action that comes to mind. The decision maker does not go through an elaborate process of generating a variety of different responses and comparing their relative worth. These recognitional decisions are not bad ones. In most cases they are quite appropriate and effective. Recognitional decision processes enable decision makers to respond rapidly to ambiguous situations, thus leveraging their training and experience. Pilots are not the only ones to invoke recognitional processes. Proficient operators and experts in many domains rely on recognition as a principal means of making decisions and responding to dynamic environments. For a complete discussion of recognitional decision, see Zemke and Klein (1996). This book reviews the emerging field of Naturalistic Decision Making (NDM). In addition, Kaempf and Klein (1994) and Kaempf and Orasanu (1996) describe it as it occurs on the flight deck.

9.1.2 Characteristics of experienced decision makers in aviation

Experienced flight crews and operators of most other systems do not just let events flow over them. Effective decision makers are proactive rather than reactive. They exert control over their environment and impose a structure that serves as a framework for interpreting the environment and stimulating the appropriate courses of action. How can they do this? What skills enable a pilot, for example, to control the situation?

First, they have an adequate experience base. As decision makers experience an increasing number of situations, they learn which patterns in the environment provide relevant cues and obtain feedback about what does and does not work in each situation. Using a library of prototypical cases, experienced decision makers recognize situations as familiar, and implement courses of action that have worked in similar situations in the past. Thus, it is important for decision makers to build a library of prototypical cases.

Second, they have a set of tactics for interacting with their environment. Tactics help decision makers exert some control over the situation, and often provide a means of segmenting and understanding a complex environment. They may be a set of simple steps (a procedure), a rule of thumb, a shortcut, or a more complex structure for organizing thinking.

They may be formally recognized or informal. They may be learned during training, passed down from others, or developed as personal rules through experience.

Consider an air traffic controller. How does the controller sequence numerous aircraft converging from different directions into a single file line on an airway? Which aircraft goes first or last? Does the controller determine all possible combinations of aircraft sequence, assign a weight or value to each combination, and then select the combination with the highest value? No, this cumbersome approach would paralyze any controller and create havoc in the skies. Instead, controllers implement shortcuts for these frequently recurring tasks. For example, any aircraft separated from a cluster of aircraft either goes first or last; increase the speed of a line of aircraft beginning with the first one in line; decrease their speed beginning with the last. These rules of thumb help controllers organize relatively complex situations.

It is important to identify effective tactics and to incorporate these tactics into training programs. It also is important to identify these tactics when designing decision supports or human-computer interfaces in order to understand how the decision maker performs the task to be supported. The following paragraphs describe a framework for identifying and understanding tactics, and presents several sample cases that illustrate the analyses in action.

Tactics must be understood within the context of the operator’s goals and the decisions and judgments they make to accomplish these goals. These data can be obtained from Subject Matter Experts (SMEs): the patterns of cues that are relevant; knowledge the decision maker must have to interpret the cue patterns; sources of information, problems or difficulties commonly encountered; courses of action commonly taken; and tactics employed to accomplish each goal. These data constitute the higher level cognitive requirements of the tasks. The analyst must focus on identifying these cognitive requirements to elicit and understand the tactics employed by experienced decision makers.

Analyses of this type have several points in common. First, the primary sources of data are self-reports presented by SMEs talking about their experiences and thought processes. Second, analyses are based on retrospective accounts of incidents experienced personally by SMEs. It is critically important that the SME experience the situation and not recount the experiences of others. Third, the analysis and extraction of data from these accounts generally is subjective in nature. Analysts review transcripts, notes, and tapes to extract information to reconstruct the significant events in the incidents and to identify the cognitive components supporting performance.
But these analyses also vary in the method used to generate the incident recounted during the interviews. In some cases, the SME is interviewed about an incident experienced sometime in the past. While this approach often produces very rich incidents, the analyst cannot control the types of tasks performed during the incident. Therefore, without conducting a large number of interviews the researcher cannot ensure that the analyses will cover all tasks of interest. In other cases, the analyst constructs a scenario for the SME to complete in a simulation, and subsequently interviews the SME about his performance. This approach provides considerable control because it enables the analyst to incorporate the tasks of interest and provides standardization among SMEs, thus facilitating the interview process. The analyst knows the significant events in the scenario, may have some knowledge of an optimal solution to the scenario, and can observe the SME as he performs the scenario. The analyst can mark or note specific events in the scenario and ask the SME specific probes that focus on those events.

Constructing effective scenarios and interview protocols are not simple tasks, but they are of critical importance. Scenarios must be constructed to incorporate all tasks of interest and to elicit all relevant behaviors. Considerable effort and iteration are required to ensure all possible alternatives are considered to permit comparison among SMEs performing the scenario. In addition, considerable effort is required to prepare the interview protocol so it will elicit the information needed for the analysis. Far too often, analysts miss golden opportunities to collect data because they were not well prepared for the face-to-face session with SMEs. Development of the scenarios and interview protocols should be an iterative process of pretest and revision. The protocols can initially be tested using fellow analysts. Subsequent pretests should be conducted with individuals who more closely resemble the SMEs.

9.1.3 Examples of analyses

Several CTA examples are presented in this chapter to illustrate how to identify the cognitive task requirements and skills that differentiate experts from less experienced operators. These examples were selected to show how analyses vary depending on the specific goals of the project and the resources available. The first example concerns the cognitive processes of airport security personnel as they use x-ray imagery to check baggage. The second example is an analysis of en route air traffic control. Both examples demonstrate how CTA techniques can be applied to identify decision making tactics, and illustrate how the techniques can be modified to fit the specific goals of an analysis and task characteristics. These examples focus on identifying the decision requirements of the task, and specific tactics operators employ to meet these decision requirements. Data collection was based on specific incidents experienced and identified by the SMEs, but the two CTAs vary in how the analysts obtained that information.

The two example analyses presented here demonstrate the use and combination of several CTA methods, including the Critical Decision Method (CDM), observations, verbal protocols, and structured interviews. These methods complement one another in the search for decision requirements. The CDM has proven to be the cornerstone to this approach in that it is quite effective for identifying the high level decision and problem solving requirements. Other methods also have been used to analyze the decisions. Methods such as the Goals, Operators, Methods, Selection Rules (GOMS) model have been used in numerous studies (described in Chapter 4). Their benefits lie in the ability of analysts to identify very detailed information regarding the underlying cognitive events. Their shortcomings lie in their lack of flexibility, the extensive amount of work required to set up and perform the analyses, and the advanced skills required for the analyst to successfully apply the techniques. The approach described in the following sections enables the analyst to identify the high level decision requirements of complex tasks fairly easily and without extensive training and experience. This approach also compliments the techniques needed to identify skill representations, and can be incorporated in a way that provides an integrated analysis.

9.2 The critical decision method

The critical decision method (CDM) has been used in numerous domains to investigate the cognitive components of proficient performance. The goal of this type of analysis is to define the decision requirements of the task which can be used to drive training and system design. CDM data are derived from interviews an analyst guides using a well-sculpted set of probes. These probes focus the data collection and analysis on specific aspects of cognitive performance, decision making.

The goals of these kinds of analyses are to model the decision making process by identifying the tasks’ decision requirements. The decision requirements comprise:

- Decisions made
- Assessments made by decision makers
- Cues attended to
Factors affecting how decision makers interpret cues
Cognitive processes decision makers invoke to make assessments
Differences between experienced and less experienced decision makers.

CDM is rarely the only method or technique used in an analysis. CDM provides the centerpiece of the analysis, establishing the goals and serving as the central means of data collection. However, CDM must be supported by other methods and techniques, such as observations, structured and unstructured interviews, and concurrent verbal reports. An important task of the analyst is to select and integrate the procedures for these methods and adapt the CDM interview probes for the specific situation. More information concerning these considerations is presented below.

The remainder of this section provides some detail about the steps of a CDM analysis. These steps are offered in the abstract. The following sections present examples of how to apply CDM methods and the kinds of information that can be derived from these analyses. The examples demonstrate: (1) how CDM can define the goals and type of data of interest in an analysis; (2) how several methods or techniques can be folded together to accomplish these analytical goals; and (3) how CDM can be adapted to specific analytic problems.

9.2.1 The CDM interview

CDM is a semistructured interview technique developed to elicit information from expert decision makers about critical incidents experienced previously. The types of probes normally used in a CDM interview are listed in Table 9.1. This list represents categories of probes and not specific questions. They are the types of information to be elicited; specific questions are usually generated by the interviewer as the interview progresses. This enables the interviewer to adapt his style to the interviewee and the emerging information.

The CDM focuses on previous experiences of domain experts. The CDM interviewer generally makes four sweeps through the same incident. The first sweep captures the story. The expert relates, in his own words, a particular incident that challenged his skills. This helps the interviewer understand the dynamics of the incident, and determine whether the incident is suitable for further examination.

<table>
<thead>
<tr>
<th>TYPE OF PROBE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>DECISION OPTIONS</td>
<td>Which course of action could have been taken?</td>
</tr>
<tr>
<td>CRITICAL CUES</td>
<td>Which cues were critical for understanding the situation?</td>
</tr>
<tr>
<td>GOAL ALTERNATIVES</td>
<td>What different objectives could have been set?</td>
</tr>
<tr>
<td>GOAL SHIFTS</td>
<td>How did the goals shift through the course of the incident?</td>
</tr>
<tr>
<td>CAUSAL FACTORS</td>
<td>How did the situation evolve?</td>
</tr>
<tr>
<td>ERRORS</td>
<td>What errors are commonly made in this situation?</td>
</tr>
<tr>
<td>HYPOTHETICALS</td>
<td>What if...? If I changed a variable, how would it affect your actions or assessment?</td>
</tr>
<tr>
<td>MISSING DATA</td>
<td>What information was not available? What information would have been most useful?</td>
</tr>
<tr>
<td>COMPARISONS TO NON-EXPERTS</td>
<td>How would a less experienced person have handled this situation? What mistakes would a less experienced person make?</td>
</tr>
</tbody>
</table>

The interviewer uses the second sweep through the incident to fix the incident to a timeline. This helps the analyst gain a sense of the sequence of events and identify inconsistencies. The interviewer works with the expert to identify the time and duration of the incident and assemble the events in chronological order. At this time, the expert often begins to bring in more specific detail about the incident that was not remembered originally.

The third sweep through the incident comprises cognitive probes to detect shifts and elaborations to situation assessments and identify decision points. The cognitive probes examine goals, cues employed, missing and incomplete information, expectancies, and courses of action.

The fourth sweep through the incident sees the analyst searching for errors, either those committed by the expert or hypothetical errors that might be committed by people with less experience. The expert often will talk about mistakes that a novice would make or compares expert performance against that of a journeyman.
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Interviewers often rely on mining past experiences that stand out in the experts' memory. This is not always the best approach. Experts in some domains have difficulty remembering specific incidents, or they may be sufficiently removed in time that memory of the incidents is hazy. Furthermore, relying on personal experiences prevents analyzing the performance of more than one expert on the same incident. All incidents pull for somewhat different behaviors. It is difficult to make comparisons among multiple experts when the data collection process probes a different incident for each expert. Exposing experts to a standard scenario and probing their performance during this scenario enables the analyst to compare performance of more than one expert.

9.2.2 Developing procedures

Before beginning data collection, the analyst must establish a set of procedures to be followed through the analysis. Three phases are of concern: preliminary data collection, interviewing, and verification or validation.

Frequently, at the beginning of an analysis, the analyst will not have enough information about the domain or the tasks to shape data collection procedures. They must learn more about the nature of the tasks, the equipment needed, the vocabulary, documentation and procedures, and a variety of other points. A number of activities can be implemented to accomplish these goals. For example, the analyst can conduct observations of pilots performing the target tasks, or they can conduct non-structured or structured interviews with pilots experienced with the target tasks. The analyst can obtain verbal protocols from experienced pilots as they perform the task or get hands-on experience with the task by performing it himself.

During this preliminary phase, the analyst has at least two objectives. The first is to gain a perspective about the target tasks that will enable him to select effective interview probes for the CDM segment, and begin to develop some basic notions of the tasks' decision requirements and how decisions are made.

The analyst must also identify the probes that will be used during CDM interviewing, and determine the types of incidents that will serve as the subject of the CDM interviews. CDM interviews have two basic characteristics. First, they are based on the types of cognitive probes described in Table 9.1. Second, they are based on incidents experienced by the interviewee.

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All types of probes do not work for all tasks or in all interviews. The analyst must determine which are of primary interest and may be most successful, and be prepared to focus on these during the interviews.

The analyst must also determine which incidents to focus on during the interviews. They may be generated from a variety of sources. For example, they may be operational incidents experienced by the interviewee in the past. They may be training incidents experienced in the past. They may be a scenario prepared by the analyst and conducted in a simulator immediately prior to the interview.

In many cases, the latter method of generating the scenario is preferred, but also requires more preparation and resources. The analyst’s two major concerns are building a scenario that pulls for the desired behaviors, and gaining access to the necessary resources, such as a flight simulator. In many cases, generating the scenario is not a trivial issue and requires significant preparation and planning on the part of the analyst.

9.2.3 Selecting participants

Generally, CDM does not require as many participants as other methods. Most analyses elicit information from 8 to 12 decision makers for each condition. Their qualifications can vary, depending on the purposes of the analysis. Many studies explore the nature of proficient decision making and performance. Thus, they focus on the decision processes of experienced decision makers. Most air carriers can screen these experienced decision makers from its roster of pilots assigned to the relevant aircraft. Rather than relying on flight experience as an indicator of proficiency, the analyst may want to obtain some measures of proficiency on the target tasks prior to proceeding to the elicitation phases of the analysis.

The analysis may focus on differences between expert decision makers and novices or journeymen. In these cases, two samples of pilots must be drawn with at least 8 or more participants in each sample. Less experienced pilots may be drawn from the population of new hires or students enrolled in courses. Air carriers need to take care in identifying less experienced pilots. Even the least experienced pilot working for an American airline has a significant amount of flight experience. It would be useful to define the meaning of proficiency for each group, and to have proficiency measures that distinguish among the two groups of pilots.

9.2.4 Analyzing data

Analysis of CDM data is a qualitative analysis, multi-step process of extracting and interpreting information from interview notes and
transcripts. Content of the analysis varies across studies, depending on the focus and goal of each study. In most cases, analysis begins during interviews and other data collection. During the interviews, the analyst begins to learn what factors are important and how to elicit information about them. Thus, early interviews have an impact on which probes are used in subsequent interviews and how they are used.

The formal analysis of CDM data usually involves identifying the decision events in each scenario, building a model of the decisions in a way that describes the flow of the cognitive events, and identifying all the amplifying data. This involves categorizing data identified in the interview notes and transcripts. Multiple analysts should participate in this process in a way that facilitates indications of reliability among the analysts. The examples presented below provide some detail about how this kind of data can be analyzed and how this process can vary among studies.

9.2.5 Limitations and modifications of CDM

CDM requires experienced and skilled interviewers. The quality of the data obtained from these interviews is dependent on the ability of the interviewer to recognize opportunities when he hears them during the interview, and to extract information from the SME at these opportunities. It is difficult for less experienced interviewers to achieve these goals.

A streamlined version of the CDM process, targeted for practitioners in the field, is in development. Millitello and Hutton (in press) report a three-step interview process that enables the practitioner to extract information about the cognitive demands and skills required for a task. Millitello and Hutton call this new process the Applied Cognitive Task Analysis (ACTA). ACTA also enables the analyst to represent the information obtained from the analysis in a manner that will translate more easily into useful products, such as training scenarios and interface design recommendations.

9.3 Analysis of airport security personnel

This project examined the cognitive performance of security agents who use x-ray technology to screen passengers. These individuals work in teams, monitoring each piece of carry-on baggage as passengers move through a security checkpoint. The goal was to develop a model of decision making to support revision of the existing training program and the development of additional decision support features to be incorporated into the x-ray scanning equipment.

We defined the decision event for the screener, beginning when a bag is placed on the scanner belt and ending when the screener determines the appropriate action for the bag. The screener can take one of three actions. He can let the bag pass without stopping the conveyor belt; let the bag pass through the scanner, then stop the belt and conduct a hand search of the bag’s contents; or stop the belt immediately, trapping the bag inside the x-ray scanner. The action taken depends on the screener’s assessment of the image.

9.3.1 Procedures

The data collection process for studying the screeners involved several steps. First, screeners were interviewed regarding prior incidents where their skills had been challenged. The analysts assumed that these challenging cases would be memorable incidents where the screener detected some kind of threat in a piece of baggage. These interviews were conducted in quiet rooms away from the security checkpoints.

The screeners provided verbal protocols as they examined real baggage passing through the checkpoint. As bags flowed through an x-ray scanner, each screener described how he scanned the image of each bag, the cues that were relevant for each bag, the features that distinguished one item from another, and why he might be suspicious of one bag and not another.

Direct observations were also obtained as analysts stood behind the screeners as they examined baggage, observing the screeners and discretely asking questions. As the screeners viewed the display, the researchers applied the cognitive probes for specific items and bags, with the screeners clarifying points using the bag that had most recently passed through the x-ray scanner. When asked to describe how he would hide a weapon in a bag, for instance, one screener noted that he would hide a gun near the top of a bag, because dense objects (such as guns) are heavy and tend to settle toward the bottom of the bag, which is where he looks for them. He then pointed to the image of the most recent bag to indicate places that might conceal a weapon. When collecting data in a real-time operational setting such as this, the analyst cannot interfere greatly with job performance. Notes were taken during all interviews, and many were recorded on audio tape for subsequent transcription.

9.3.2 Analysis

The first step was to identify each assessment screeners make and the nature or purpose of these assessments. Second, analysts looked for information relevant to these assessments that would enable them to
construct a model of the decision process. The cues that screeners attend to in making these assessments were identified, as well as the factors they consider when applying meaning to these cues. The third step was to identify the function each assessment served and the cognitive process screeners invoke to make the assessments. Finally, the characteristics that make each judgment difficult, and how novices differ from experienced screeners, were identified. This information helped sharpen the understanding of proficient cognitive performance and provided a means of illustrating differences related to experience and training.

The analysis was designed to determine how competent screeners perform their jobs. Do they simply stare at a monitor to recognize an image pattern that matches one they learned during training, or is the job more complex than that? The screener’s job appears to be a fairly simple one. The screener has few motor actions to make (depressing several buttons). There are no complicated psychomotor or perceptual-motor tasks involved. The rules and procedures are relatively simple, but the important elements of the job are entirely cognitive in nature. What are these elements and how can we represent them in a way that communicates their importance to training and systems designers?

9.3.3 Findings

The screener’s function is to evaluate the image of a bag, and take one of three actions based on that evaluation. Experienced screeners have confidence in their judgments, and have developed strategies enabling them to handle high workload and angry passengers. They do not examine each bag closely, yet are confident that a prohibited object will not get past them. They gain confidence with experience in making judgments about bags. The company considers them good screeners because they never miss a test object, they get along well with passengers, and they do not create a backlog by searching too many bags by hand. How can they do all this? Perhaps it is a simple pattern matching task: the screener serially reviews the image of each item in the bag and compares it with a library of threat images memorized during training. If there is a positive match, the bag is stopped and the screener searches the bag by hand if there is an opaque image large enough to obscure a threat. In the absence of the other two alternatives, the screener lets the bag pass through.

But this model only explains the screener’s job from the perspective of what we see them do, not from their perspective as they perform the task. Rather than making a single judgment about the contents of a bag, experienced screeners make a series of judgments as they view each image. This series of filters ensures the screener will have a high hit rate for bags that contain threats, and requires that he examine closely only a small proportion of the bags that pass through the scanner (see Figure 9.1).

![Figure 9.1 Cognitive model of an experienced screener](image-url)
Initially, the screening process is almost entirely perceptual. Screeners begin their assessment by looking very globally for items that are dark or draw their attention (see Step A). With extensive experience, they are simply looking for something that does not "feel right." The image is evaluated as a whole rather than identifying individual items in a serial fashion. It is often done without conscious awareness, relying on a sense of typically developed over repeated trials of experience.

If a dark or unusual object is discovered, the screener begins to evaluate it (see Step B) by attempting to recognize individual items in the area of interest. The screener compares the observed image with a library of images stored in his memory. If the area of interest is cluttered, the screener evaluates items in the area serially to "weed out" recognized harmless objects. This evaluation takes place rapidly because experienced screeners have developed a very complete mental catalog of images of what is commonly found in bags. This mental library contains images of prohibited items, but it is predominately a library of common, innocuous items. A screener working at a busy airport might view as many as 10,000 bags in a single month. With each bag serving as a learning trial, screeners have many opportunities for overlearning from exposures to images of innocuous items (e.g., hair dryers, shavers, computers, notebooks, wine bottles). In rare cases when a screener detects a prohibited item, he may stop the belt; but usually he passes the bag to Step C for further evaluation. If the screener cannot positively identify the item at Step B, then he must determine if the item can obscure the view of a threat item (Step C). At this point, the screener will hand-check the bag under either of two conditions: if the unknown item is large enough to obscure a threat item, or if the screener simply does not know what the item is.

The accumulation and accessibility of the mental image library provides the basis for proficiency at Steps A and B. Rapid recognition of what is typical facilitates Step A, and minimizes the number of bags that must receive additional scrutiny. In many cases, the screener's sense of typicality has become implicit rather than explicit knowledge. Experienced screeners often make the assessment without being aware of it. In addition, a large image library facilitates recognition at Step B. The more items the screener recognizes, the fewer bags he must submit to a hand search.

At Step B, the primary skill required is to rapidly recognize common, innocuous items. The enabling knowledge base for this skill is an extensive library of mental images of these innocuous items, developed through extensive experience on the line. Experienced screeners rarely pause to examine a bag more closely. However, when questioned about the contents of a bag that has just passed, they can reliably describe the contents and location of various items within the bag. Though it appears they are not paying attention, in reality they are continuously evaluating information.

This multi-step filtering process has a dramatic effect on how quickly passengers move through a security checkpoint. It enables screeners to maximize the number of bags passing through by minimizing the number of bags they search by hand. Each step of the process enables the screener to progressively weed out those bags that definitely do not pose a threat while maintaining confidence of detecting a threat item when it appears.

How does a novice differ from an experienced screener? Figure 9.2 illustrates the cognitive process employed by novice screeners, which is very similar to that for experienced screeners, with two major exceptions. First, the initial judgment of typicality made at Step A is different. Novice screeners do not possess the extensive mental image library to enable a holistic judgment at this step. Thus, novice judgments are more deliberate and serial: novices examine each item in the bag and attempt to identify it. This serial evaluation requires a significant amount of time and results in failure to recognize many items in many bags. As a result, they divert more bags to Step B, with the net effect being to slow the screening process. The next major distinction occurs at Step B where the screener scans the area of interest to recognize the object of concern. It is a simple process of comparing images and patterns stored in with the observed image. Novices often experience considerable ambiguity at Step B because they simply do not know what is in the bag. Therefore, novice screeners hand search far more bags at this stage of the process than more experienced screeners.

Novice screeners are much slower than experienced screeners. They take longer to evaluate each bag, ask for help from their team, and hand search a higher proportion of bags. These factors slow the flow of bags through the checkpoint, creating lines of passengers.

In summary, this analysis employed CDM data collection techniques to identify three cognitive tasks experienced screeners perform as they evaluate baggage. These high-level decision tasks are summarized in a decision requirements table presented in Table 9.2. First, screeners make judgments about whether a bag requires closer examination because it contains dark or unusual items. Second, they make serial evaluations of some objects to eliminate common, innocuous items through a pattern recognition process. Third, they evaluate the relative size of some objects to determine if they may obscure a potentially threatening item. Each of these tasks requires that the screener attend to certain cues and pieces of information. Furthermore, there are distinct differences between the processes invoked by experienced screeners and those invoked by novices.
9.4 Analysis of en route air traffic control

The second example, the development of a cognitive model of Air Traffic Control (ATC) decision making, provides some significant contrasts with the first. Although the basic approach to obtaining data was similar to the approach described in the first example, implementation was quite different and produced a different type of data.

9.4.1 Procedures

Again, the primary sources of data were semistructured interviews with SMEs following the CDM format. These interviews employed the same sets
of probes (see Table 9.1) as in the first example, and were focused on incidents experienced by the SMEs. The source of the incidents, however, was different. In the previous example, incidents were generated as the screeners worked on the line with real passengers and bags. In this study, the incidents were generated by scenarios conducted by the controller SMEs on a high fidelity training simulator. The simulator provides a fully functional workstation with Primary Visual Display (PVD), Flight Progress Strips (FPS), and voice communications with flight crews, all relevant agencies, and control sectors. Each scenario is scripted, with trained “ghost pilots” playing the roles of pilots, relevant agencies, and controllers in adjacent sectors. The simulator does not provide the “puke factor” of moving real airplanes across a real sky, but it does provide a challenging and realistic environment for training controllers and studying their skills and performance.

Two scenarios were developed for this study, and they replicated realistic conditions within a fictitious airspace. The goal was to generate a model of “normal” decision making for the controllers. Therefore, the scenarios were designed to study how controllers make decisions in their everyday work. The scenarios required about thirty minutes to complete, and represented generally two different types of problems. One presented a sector in which the primary task for the controller was to accept numerous aircraft from many directions and sequence them onto a single airway fifteen miles in trail. The sequencing problem continued throughout the scenario. In addition, a number of events involving potential conflicts and departing and arriving aircraft occurred during the scenario. The second scenario required controllers to maintain separation for multiple aircraft originating from a variety of directions with a variety of needs. In addition, the controller had to contend with numerous departures and arrivals.

Eight SMEs participated in the study. As the SME performed a scenario, two analysts observed, taking notes and recording on audio tape. The analysts did not interpret the SME during the scenario. After the scenario, the SME was given a short break before the interview. Using the same set of probes, the analysts structured the interviews around the problem sets contained in the scenarios. The analysts did not have to search for the problem embedded within a story recalled by the SME. Having constructed the scenarios and having observed the SMEs perform them, the analysts knew which problems they wanted to investigate and how the SME had reacted. The analysts used the simulator displays as stimuli for conducting the interviews, “fast forwarding” the simulator to specific points around a problem of interest to stimulate the SME’s memory. After completing both scenarios, two SMEs were interviewed together about both scenarios and their thoughts in general. Such team interviews often produce a more complete discussion of topics begun in the individual interviews.

9.4.2 Analysis and findings

Similar to Example 1 above, the analysis conducted on these data was a qualitative, multi-step process of extracting and interpreting information from the interview and observation notes. Some studies used multiple analysts to code the data from notes and transcripts. They would select coding categories and proceed through the transcripts independently to categorize assessments, tactics, goals, etc. Following their initial cut, these categorizations, the analysts worked collaboratively to resolve conflicts in their interpretations and assess their coding reliability. (In the present case, resource limitations dictated that the analysts work collaboratively on the first effort to extract and categorize the data.)

These analyses produced a table of decision requirements for the two scenarios taken together, a detailed listing of specific tactics controllers employ in the decision process, and several examples of common controller errors. These findings are discussed below.

9.4.3 Decision requirements

The analysts’ first goal was to identify the decision requirements to provide a broad view of the cognitive tasks and ancillary information that may support development of training or decision supports. It does not refer to the buttons that must be pushed or the movements that need to be made. Rather, decision requirements address the goals to be accomplished, decisions or judgments to be made, cues and information needed, and the factors that tend to make each task difficult. Taken together, these pieces of information can provide an accurate overview of the controller’s job.

Several major cognitive tasks were identified for controllers:

- Perform situation assessment
- Recognize significant events
- Monitor progress
- Prioritize scanning and actions
- Resolve conflicts
- Direct traffic for sequencing
- Manage workload and organize tasks.
Applied cognitive task analysis in aviation

The last requirement, manage workload and organize tasks, is discussed in detail in Chapter 10. A brief description of the others follows.

The controller must constantly gather information to build an understanding of what is occurring in the airspace. He utilizes information from the FFS, the PVD, and from voice communications with other controllers and flight crews. From the FFS, the controller obtains the call sign, assigned altitude, airspeed, destination, filed route, and predicted time the aircraft will arrive over a specified navigational fix. From the PVD, the controller will learn about the aircraft’s real altitude, airspeed, two-dimensional position in the airspace, heading, and dynamic information such as vertical airspeed and intermediate altitudes. Developing this awareness is difficult for a variety of reasons. Much of the data is presented in text format, and does not facilitate rapid and accurate conversion of the data into meaningful information. The controller must monitor multiple tracks, often creating screen clutter and obscuring some information. The controller also must divide his attention between the PVD and the FFS. This can seriously disrupt the controller’s concentration and cause him to become disoriented regarding the PVD.

These types of requirements can be summarized usefully in a table known as a Decision Requirements Table (Table 9.3). It presents the requirements for a selected sample of controller cognitive tasks.

### 9.4.4 Tactics

Decision requirements tables provide some interesting information about the controllers’ cognitive tasks. But how do they go about completing the tasks?

A controller must make many judgments and decisions rapidly. It is important that the controller project into the future, quickly formulates a viable plan, and recognizes when a plan is failing and modifies it quickly. Controllers have experienced these tasks many times and know what works in certain situations and what does not. They have learned numerous tactics to accomplish these essential cognitive tasks. Tactics might be shortcuts, rules of thumb, or simple procedures for specific situations. The primary objective for them is to recognize the situation and implement the appropriate tactic.
Some tactics are learned from other controllers; other tactics are learned through experience. Controllers can describe some tactics readily, and they may not even be aware they are implementing other tactics. These implicit strategies pose a challenge for the analyst. Frequently they will be revealed during observations. The analyst can note how the controller handles a particular situation and then probes later how, why, and what the controller noticed.

The following is a short list of tactics used by controllers as they completed the two scenarios. The tactics are arranged by the specific cognitive task they support.

**Recognizing events**

- Use mental simulation to project an aircraft’s course and future location relative to other aircraft and airspace.
- Use mental simulation to envision concentric arcs on the display to judge distance and order of arrival at a fix.

**Resolving conflicts**

- Disrupt as few aircraft as possible.
- Perform calculations mentally (e.g., 1 minute = 6 miles, change in altitude x 12 = ft/min).
- Hold crossing traffic at temporary altitude until clear of traffic. Remember to come back and issue clearance for final altitude.
- Wait to see how the aircraft order evolves for sequencing or conflicts.

**Sequencing traffic**

- Envision which aircraft is closer.
- Disrupt as few aircraft as possible.
- Envision relative distance using extended leader lines.
- Once you have the sequence set up, what you do to one you do to all.
- When changing speed of aircraft in trail, speed up from first to last and slow from last to first.
- Start with last aircraft in line to turn away from airport; start with first to turn toward airport.
- Place aircraft away from cluster either first or last in line.

**Determining decision making skills**

9.4.5 Error sources

The SMEs committed many errors while performing the scenarios, including operational errors as defined by the Federal Aviation Administration (FAA) (loss of separation) and other clear mistakes such as failure to descend an aircraft to its final destination airport. To determine how and why these errors occurred in this relatively controlled and normal setting, researchers focused part of their post-scenario interviews on these errors when they were detected. The resulting data produced interesting findings regarding the sources of mistakes for controllers.

There were generally two kinds of errors: errors of omission and errors of commission. Table 9.4 provides a brief description of some of these types of errors. Several factors led to the failure of the controller to act. In some cases the controller did not see the aircraft and the accompanying data on the PVD, and thus took no action to resolve the potential for conflict. Several factors often led the controller to take the incorrect action. Most frequently, the inability of the controller to correctly anticipate how the events would unfold contributed to their failure to identify and implement the correct course of action. In the controller's world, this is described as projection or planning with the underlying skill being mental simulation.

For each event, controllers have a window of opportunity to intervene and prevent a loss of aircraft separation. This window reduces with time, requiring the controller to eventually transition from an anticipatory mode to a reactive one. But controllers vary in their skills for projecting into the future: some have shorter time horizons than others. That is, some can accurately see how the situation will evolve over the next few minutes and can implement actions to control the situation for the near future. Novice controllers cannot see as far into the future as the more experienced ones. Furthermore, different scenarios require different horizons. A 20-mile-in-trail sequencing, for example, may require a long time horizon for the controller to envision the effect of his actions.

When studying controller errors it is important to remember that no error is an isolated event. Errors (as all actions) occur within the context of an evolving situation; a series of judgments, decisions, and actions that ultimately lead to an error. Imagine that a controller sees a potential tie between two aircraft; in a few minutes they will want to be at the same point in space, at the same altitude, at the same point in time. However, the controller's initial assessment is made when the two aircraft appear at opposite sides of the display. Since he has little else to do, the controller decides to wait and see what will happen before taking an action. A few minutes later, several aircraft that need to be sequenced onto a single
airway appear. The controller creates a plan and begins to execute it. During the challenge of sequencing he forgets the other event, and just as he remembers to check it, he notices that the symbols for the first two aircraft cross within one mile of each other. There was no single point in this scenario when the controller made an error. Rather, a series of events, actions, and judgments conspired to create the problem.

Table 9.4
Types of controller errors

<table>
<thead>
<tr>
<th>ERROR</th>
<th>CAUSE</th>
<th>CONTRIBUTING FACTORS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did not see aircraft or data.</td>
<td>* Did not see aircraft were at same altitude.</td>
<td>* Clutter on the display.</td>
</tr>
<tr>
<td></td>
<td>* Confused leader lines.</td>
<td>* Distractions.</td>
</tr>
<tr>
<td>Did not hear.</td>
<td>* Missed a readback error or request by flight crew.</td>
<td>* Complacency.</td>
</tr>
<tr>
<td>Did not perceive a problem.</td>
<td>* Misevaluate information or its implications.</td>
<td>* Inaccurate projection of future positions.</td>
</tr>
<tr>
<td>Did not solve a continuing problem.</td>
<td>* Failed to return to complete the action after a planned delay.</td>
<td>* Distraction.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* Work overload.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* Memory overload.</td>
</tr>
<tr>
<td></td>
<td>* Planning inaccurate.</td>
<td>* Did not consider wind.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>* Inaccurate projection of how events would unfold.</td>
</tr>
<tr>
<td>Created additional problems.</td>
<td>* Did not anticipate ripple effects of action.</td>
<td>* Inaccurate projection of how events would unfold.</td>
</tr>
</tbody>
</table>

9.5 Chapter 9 key points

This chapter provides a detailed view of methods designed to identify higher level cognitive tasks and the types of information needed to support proficient decision making in aviation. Although researchers have developed a variety of analytic techniques for investigating decision points, few, if any, address the breadth of information concerning decision tasks and produce information directly applicable both to training and systems design. Thus, this chapter focuses on the procedures for applying CDM. The chapter stressed several key points, which follow:

- When determining decision making skills, the analytic goal is to identify the task’s decision requirements.
- CDM is the focal point for the analysis.
- Incorporates other methods and techniques (e.g., observations, verbal reports) as well.
- A primary task for the analyst is to adapt and incorporate methods to address specific goals of the available analysis and resources.
- Two examples demonstrate how the methods can be tailored to address different analytic goals and task settings.