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List Models of Procedure Learning

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TABLE OF CONTENTS

LIST MODELS OF PROCEDURE LEARNING

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1. INTRODUCTION

This paper presents a new theory of the initial stages of skill acquisition and then employs the theory to model current and future training programs for flight management systems (FMSs) in modern commercial airliners like the Boeing 777 and the Airbus A320. The theoretical foundations for the theory are a new synthesis of the literature on human memory and the latest version of the ACT-R theory of skill acquisition (Anderson, Bothell, Byrne, Douglass, Lebiere, and Qin, in press; Anderson and Schunn, 2000; Taatgen and Lee, 2003).

The models derived from the theory describe training programs where to-be-learned procedures are formally trained, and trainees must demonstrate mastery before they can achieve journeyman status or go on to more advanced on-the-job training. Airline transition training programs are examples of this paradigm. The models generate estimates of the training time required to master the procedures specified in the training program syllabus. These estimates and the underlying theory are used to evaluate current and future training programs and support construction of business cases justifying investments in training-program modifications.

1.1 Problems and Solutions

Numerous studies have documented operational and training problems with the modern autoflight systems, in particular the FMS and its pilot interface, the control display unit (CDU). During the last few years, more attention has been given to the limitations of current autoflight training methods. Many studies have concluded that current training programs are inadequate in both depth and breadth of coverage of FMS functions (Air Transport Association, 1997, 1998, 1999; BASI, 1998; FAA Human Factors Team, 1996).

This paper argues that the inadequacies of the programs are due to airline training practices that encourage pilots to master FMS programming tasks by memorizing lists of actions, one list for each task. Treating FMS programming skills as lists of actions can interfere with acquisition of robust and flexible skills.

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Blackmon and Polson (2002) argue that a solution to these training problems is to develop new training programs based on an intelligent computer-aided instruction technology, cognitive tutors (Anderson, Corbett, Koedinger, and Pelletier, 1995; Corbett, Koedinger, and Anderson, 1997). Blackmon and Polson claim that cognitive tutors can dramatically increase the depth and breadth of autoflight skills while maintaining the same training footprint. However, airlines will not even consider radical changes to current training practices until the research community provides sound business cases justifying large capital investments and radical modifications to the pilot training culture.

A critical step in building a defensible business case is estimating the time required for both current and proposed training programs. This paper presents a new method for estimating training time based on a theory of the initial states of skill acquisition that is analogous to the Card, Moran, and Newell (1983) Keystroke Level Model for estimating skilled performance by characterizing procedures as sequences of actions and drastically simplifying descriptions of the underlying cognitive processes. The new method is referred to as the Lists of Actions Model.

1.2 Outline of The Paper

The paper first gives the theoretical foundations for the new Lists of Actions Model and describes it in detail. Then the model is applied to the learning of FMS procedures. The model makes predictions about current training times that agree with times found in empirical research. The model is then used to analyze modifications to current training programs.

2. THEORETICAL FOUNDATIONS

The foundations of the theory are the Fitts (1964) three-stage model of skill acquisition that underlies almost all model analyses of skill acquisition and the latest ACT-R simulation models of skill-acquisition processes proposed by Anderson, et al. (2004) and Taatgen and Lee (2003). There is widespread agreement that the acquisition of a complex skill involves three stages, first described by Fitts (1964). The following description of these stages has been adapted from VanLehn (1996) to describe acquisition of the skills necessary to operate an autoflight system.

2.1 The Three Stages of Skill Acquisition

The *Cognitive Stage* involves learning enough about the interface of a system to be able to generate descriptions of the steps in a procedure that can be successfully memorized. Initial training on such systems includes learning descriptions for elements of displays and controls. The *Associative Stage* involves memorizing a description of the actions required to perform a procedure. This stage ends with the successful storage in memory of representations that can be used to reliably generate the actions necessary to perform the procedure. The third or *Autonomous Stage* involves refining, strengthening, and transforming the mental representation of the skill to improve both speed and accuracy of performance. The endpoint of the process is a mental representation of the procedure that supports rapid and accurate performance even in high-workload situations—automaticity.

2.2 The Representation of Skills at the End of Formal Training

The declarative representation of a procedure enables a newly trained operator to perform correctly but at some cost. The procedure is executed interpretively by retrieving description, decoding it, and generating the actions described by the retrieved information. These processes are error-prone, they take extra time, and they impose additional workload. In addition, declarative representations are easily forgotten. They can be maintained only by practicing the procedure at least every two or three weeks.

The ACT-R cognitive architecture assumes that all these limitations can be overcome by acquiring a procedural representation of the procedure that enables very rapid retrieval of the actions necessary to perform it. The procedural representation is generated, refined, and strengthened during successful execution of the procedure mediated by the declarative representation.

However, recent results (Anderson, et al., 2004) support the claim that achieving automaticity can take more than 100 repetitions of a procedure. The transformation from a declarative to a procedural representation of a skill is ACT-R's explanation of the processes that describe Fitts's Autonomous Stage. Thus trainees complete their formal training while they are still in the Associative Stage for all but the most frequently executed procedures.

It follows that training time is in large part determined by the number of repetitions of a procedure necessary to acquire a useful declarative representation that is resistant to forgetting, i.e., supports accurate recall after retention intervals of as long as two weeks. Most of the additional experience necessary to convert the declarative representation into the much more durable and flexible procedural representation occurs during a trainee's initial on-the-job experience. However, declarative representations enable a trainee to pass a qualifying exam and perform acceptably during on-the-job training.

2.3 Implications of the Human Memory Literature for Understanding the Associative Stage

Research on human memory during the last 100 years has focused on the learning and retention of a wide variety of declarative representations from serial lists of nonsense syllables (Ebbinghaus, 1888/1913) to expository and native texts (Kintsch, 1998). The theory presented in this paper assumes that it is possible to model a training program by analogy to one or more experimental paradigms that have been employed to study human memory, e.g., serial or paired-associates list learning. The three steps of constructing such a model by analogy are described as follows.

First, specify an experimental paradigm in the human-memory literature that has a structure analogous to that of the training program. Next, identify the features of tasks and training procedures that are analogous to variables that have been investigated in the context of the analogous experimental paradigm, e.g., mapping list length onto complexity of FMS procedures. Third, review the literature on the selected experimental paradigm to derive quantitative relationships between measures of learning and retention and the variables that are mapped onto important features of tasks and training methods, e.g., list length, distribution of practice, retention interval, and properties of list elements.

The list-learning literature contains extensive parametric studies of time and trials to mastery and retention for these and other variables. These quantitative relationships can be used to derive a model of a specific training program and make quantitative predictions of training time. It is also possible to propose change in existing training programs that are analogous to experimental manipulations in the memory literature that enhance both learning and retention, improving the efficiency of a training program.

2.4 The Loci of Expertise Effects in Skill Acquisition

The theory developed in this paper hypothesizes that the Cognitive and Associative Stages of skill acquisition are the loci of expertise effects in skill acquisition. The characteristics of the learning processes for these two stages are determined by the strategies employed by a trainee. The learning strategies are determined by interactions between 1) the properties of the system user interface, 2) the trainee's expertise acquired from experience with similar systems, and 3) the assumptions made by a trainee about how to learn and perform tasks using the system. These interactions also determine the experimental paradigm that best models the cognitive and associative stages of skill acquisition and the difficulties of these stages.

The Cognitive Stage involves learning how to encode descriptions that when retrieved from memory enable them to generate actions necessary to perform tasks. The Associative Stage involves memorizing lists of these descriptions that enable trainees to perform tasks that will be on a proficiency examination at the completion of a training program.

Catrambone (1995) has shown that novices in a domain—in the absence of explicit guidance on how to learn skills—assume that skill acquisition involves memorizing lists of actions required to perform tasks and that performing a task involves retrieving and performing each memorized action. It will be shown that for a novice pilot, learning a new FMS procedure is analogous to learning a serial list of nonsense syllables.

Experts in a domain have much more powerful encoding strategies and are able to impose meaningful structures on representations that are well integrated with their domain knowledge. Pilots with extensive experience with several different FMS-equipped aircraft show all the attributes of domain experts acquiring new knowledge in their domain. For example, they can successfully perform a moderately complex procedure after a single demonstration. In addition, experts' lists tend to be much shorter. Experts can generate descriptions that concisely describe a sequence of several actions. Finally, experts have specialized cognitive skills that enable them to generate actions when retrieval fails during execution of an infrequently performed task.

2.5 Current Airline Training Practices

Flight manuals, FMS pilots' guides, computer-based training (CBT) lessons, and other documents all contain very different descriptions of the steps in procedures, ranging from bare lists of key presses in flight manuals to detailed descriptions of each function invoked by a key press in a pilots' guide. A demonstration of a procedure in a CBT lesson or by an instructor pilot in a fixed-base simulator presents the series of required actions and resulting display changes that occur during successful execution of a procedure.

None of these methods for training FMS procedures provides pilots with much—if any—clear guidance on how to generate memorable—or even meaningful—descriptions of a FMS procedure. Pilots using a glass cockpit for the first time tend to focus on actions required to perform a procedure because they will be tested on their ability to reproduce the action sequence to demonstrate mastery of the procedure during later simulator sessions or on a check ride.

Learning FMS procedures involves both mastering a specific set of FMS programming tasks and acquiring specialized problem-solving skills. The ability to problem solve to use the FMS in an unfamiliar situation is based on knowledge of the CDU interface conventions, a retrieval structure that segments an action sequence into subsequences along with the knowledge of the purpose of each subsequence, and the skills necessary to use this knowledge and cues provided by the interface.

None of these skills and knowledge is provided to pilots in today's training programs. Pilots must induce them by making generalizations across procedures using the FMS. This induction problem is very difficult in the absence of explicit instructions. This is why clear evidence of reconstruction skills is seen only in pilots with experience with several different FMS-equipped aircraft.

In addition, Fennell (2004)[1] observed that pilots have strong default assumptions about learning cockpit procedures. Typical procedures are sequences of actions such as button presses, switch positionings, and observations of instrument readings and indicators. Memorizing lists is not an unreasonable approach to learning required short standard operating procedures (SOPs). However, it is a very poor model to apply to the acquisition of FMS programming skills.

Instructors' descriptions of their experiences with such trainees are certainly consistent with the hypothesis that these pilots try to learn FMS procedures as serial lists of actions. They require several repetitions of a procedure before they can perform it without errors. Trainees rapidly forgot newly learned procedures, and they must be retrained after a one- or two-day retention interval. Furthermore, these trainees' knowledge of these painfully acquired procedures is very brittle. They have trouble generalizing their skills to new procedures that are closely related to a trained procedure.

3. THE LISTS OF ACTIONS MODEL

A representation of a task must encode both item (actions and parameters) and order information. Anderson, Bothell, Lebiere, and Matessa (1998) assumed that item and order information is encoded in a hierarchical retrieval structure incorporated in their ACT-R model of serial list learning shown in figure 1. The order information is encoded in a hierarchically organized collection of chunks. The terminal nodes of this retrieval structure represent the item information.

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[1] Personal communication, K. Fennell, United Airlines, Oct. 1, 2004.

3.1 The Underlying Representation

The model assumes that pilots transitioning to their first FMS-equipped aircraft master a cockpit procedure by memorizing a serial list of declarative representations of individual actions or summaries of subsequences of actions. Learning this list takes place during briefings and demonstrations of the procedure, study of the procedure as described in a flight manual or other training materials, and attempts to execute the procedure as part of a CBT lesson or in a simulator session. It is assumed that each of these attempts to learn the list is analogous to a test-study trial in a serial recall experiment.

An interpretive process uses the list to perform the procedure. This process incorporates the knowledge necessary to understand each step description and to execute actions necessary to perform each step. Thus, an item such as “Press the LEGS key” would generate the actions required to locate the Legs key on the CDU keyboard and press it. A parameter such as a waypoint identifier would be represented in working memory as a sequence of letters. The interpretative process would generate the keystrokes necessary to enter the identifier into the scratch pad.

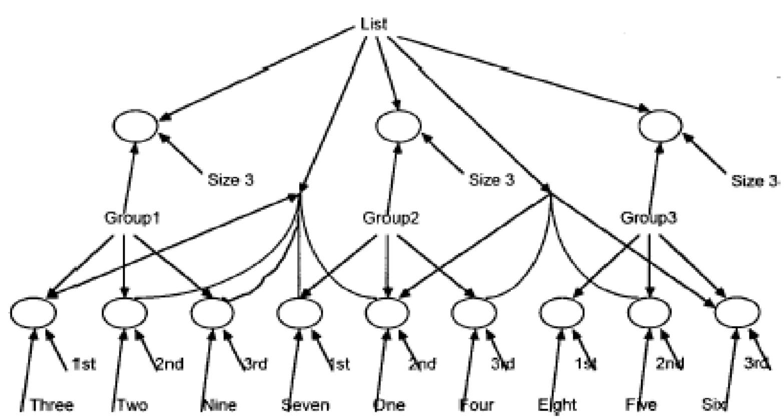

Figure 1. List Model Representation. The retrieval structure for a list of nine digits of Anderson et al. (1998).[2]

The list actions representation is a consequence of pilots’ decisions to treat the task of mastering FMS procedures as learning serial lists of actions. The retrieval structure shown in figure 1 is generated by processes that adults use to memorize any arbitrary serial list of items. It is assumed that a novice representation of a FMS procedure with nine actions would be represented by replacing the terminal-node chunks with chunks representing individual actions in the procedure.

The retrieval structure only encodes order information and supports access to the chunks representing individual actions. The groupings of the actions imposed by this structure have no

[2] Figure 1 is figure 2 copied from Anderson, et al. (1998, p. 348).

relationship to the underlying task structure. Because these retrieval structures are unique to each task, they block transfer of training.

3.2 An Example List

The following is a possible list describing an FMS procedure for the Boeing 777 for responding to the following hold clearance that would be generated by a pilot with limited glass-cockpit experience.

> NASA 1: Hold west of Haden on the 270^{O} radial. Right turns. 10 mile legs.
> Expect further clearance at 2130.

The list shown in figure 2 has undesirable properties and would be difficult to memorize. It is long—14 items—and it is organized as a linear sequence of actions that cannot be directly stored in memory (Anderson, et al., 1998). Some kind of idiosyncratic organization would have to be imposed on it to break it up into sublists before it could be successfully memorized. Furthermore, the representation of the procedure for programming a hold shown in figure 2 is specific to a particular clearance. It would be relatively easy to generalize this representation to clearances with identical parameters but with different values. However, generalizing this procedure to cover the entry of any hold clearance requires numerous nontrivial inferences.

1. Press HOLD Function/Mode Key.
2. Press LSK 6L, if a holding pattern is already in the route.
3. Line select waypoint identifier for Haden to scratchpad.
4. Press LKS 6L.
5. Enter the quadrant and the radial into the scratchpad, W/270.
6. Press LSK 2L.
7. Enter the turn direction into the scratchpad, R.
8. Press LSK 3L.
9. Enter the leg distance into the scratchpad, 10.
10. Press LSK 5L.
11. Enter expect further clearance time into the scratchpad, 2130.
12. Press LSK 3R.
13. Verify the resulting holding pattern on the ND.
14. Press EXECUTE.

Figure 2. A possible novice representation of a FMS procedure for responding to a hold clearance.

3.3 Using the Serial List Learning Literature to Make Training Time Predictions

The Lists of Actions Model assumes that learning a FMS procedure is analogous to memorizing serial lists of nonsense syllables for a pilot with limited FMS experience. Training times can be estimated using results of an experimental paradigm initially developed by Ebbinghaus (1888/1913, Chapter 8).

3.3.1 The Savings Paradigm

On the first day of the experiment, participants learn a serial list of items to a criterion of mastery of one perfect recitation of the list. Items are presented in a fixed order. During the presentation of an item in a list, participants must study it and attempt to recall the next item to be presented. Participants return to the laboratory 24 hours later and relearn the list to the same criterion of mastery. Training stops on the first day that participants perform perfectly on the first presentation of the list after a 24-hour retention interval.

3.3.2 The Relationship Between FMS Procedure Complexity (List Length) and Training Performance

Table 1 presents the number of retentions on each successive day and the number of days of training required to be able recall a list perfectly after 24 hours for lists of 4, 8, 12, 16, and 24 items. The numbers in the table were derived by synthesizing the results of several experiments from the list-learning literature starting with the data from Ebbinghaus (1885/1913, Chapter 8). The numbers are extrapolations generated by fitting power functions to Ebbinghaus's results and then adjusting them to account for the fact that he used a very rapid presentation rate.

Table 1. Average number of repetitions of a list required to reach a criterion of one perfect recall as a function of list length and days.

List Length	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Total
4	1.5	1.2	1.1	1					4.7
8	4.5	2.4	1.8	1.5	1.4	1			12.5
12	8.5	3.9	2.7	2.1	1.8	1.6	1		21.7
16	15.5	6.6	4.2	3.2	2.6	2.2	2	1.8	38.2
24	23	9.5	5.9	4.3	3.4	2.9	2	1.8	52.8

Table 1 makes clear that procedures described by long lists with 12 or more items are very difficult to master. The 16- and 24-item lists do not reach criterion even after 8 days of training. Furthermore, examination of the column for Day 2 shows that much is forgotten after initial mastery of lists on Day 1. Underwood (1957) showed that interference caused the large amounts of forgetting shown in table 1 and in the original results of the studies from which it was derived. Participants in these early studies of list learning participated in many different experiments. The forgetting is caused by interference between the representations of a current list and previously learned lists.

These interference effects are also present in FMS training. A transition training program is described by the List Model as involving concurrent mastery of from 20 to 30 lists describing various FMS procedures. Many days of practice are required to overcome the effects of interference between the memory representations of various procedures.

Recall that pilot instructors find that even moderately complex procedures are difficult to train and are rapidly forgotten. The impact of list length shown in table 1 and the very powerful interference effects found in this list-learning literature account for these problems.

3.4 Modeling a Training Program

This section illustrates the methods involved in using table 1 to construct a simplified quantitative model of a training program. In this training program, procedures for performing FMS programming tasks are introduced during CBT lessons and training sessions with nonpilot instructors. Then, these skills are further trained and practiced in briefings and simulator sessions conducted by pilot instructors. All actual practice of these skills takes place in fixed-base and full-motion simulators.

3.4.1 Estimating the Time Required to Train a FMS Procedure

The model assumes that the training of a specific FMS procedure is analogous to the serial-list-learning experiment described in Section 3.3.1. During any given simulator session, different examples of a procedure (e.g., a direction to clearance with different waypoints) are performed repeatedly until a pilot can execute the procedure without errors or hesitations. The number of required repetitions for a given simulator session and the number of days necessary to master the procedure are taken from table 1.

Training time is estimated by calculating the amount of time it would take to administer N repetitions of a procedure of length L during one session in a fixed-base or full-motion simulator. The model's description of the training processes has three time parameters: session setup time (SST), repetition setup time (RST), and step time (ST). SST is the time required to set up a simulator to begin training a specific procedure. RST is the time required to set up the simulator for the next repetition, and ST is the time required for a trainee to perform a step and receive feedback from the instructor if necessary. These values are then summed over days to generate a training- time prediction for a given procedure.

The time devoted to training a procedure on one day = SST + N*RST + N*L*ST.

The values for N, the number of repetitions on a day, are taken from table 1. Values for SST and RST were set to 120 seconds, and ST was set to 5 seconds. Current fixed-based and full-motion simulators were found to be ill-suited to this kind of training; they are designed to simulate the execution of complete missions.

Figure 3 shows the total time necessary to train a procedure plotted as a function of length, L. The function turns out to be linear with a slope of approximately 11 minutes per step.

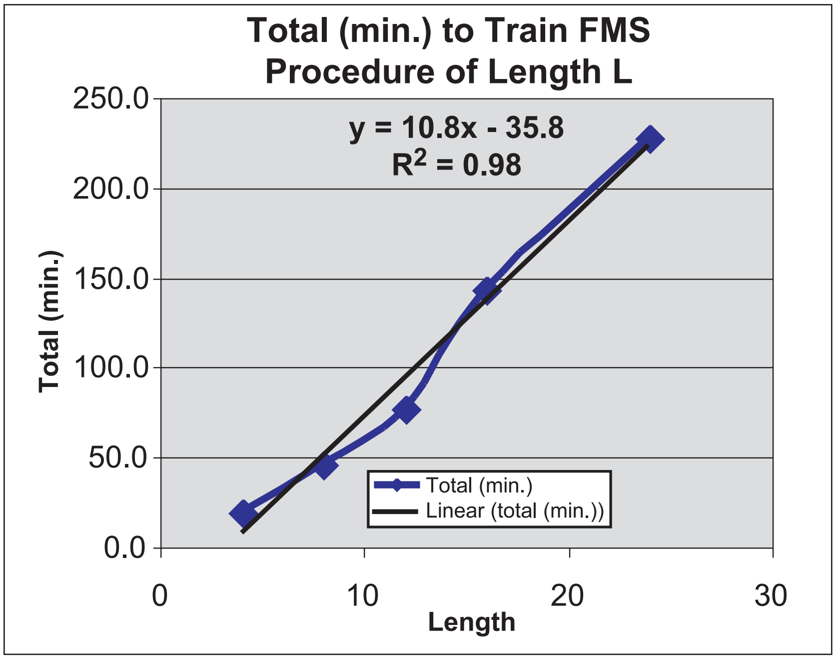

Figure 3. The time in minutes to train a procedure of length L.

Figure 4 shows the percentage of the total training time that was devoted to actually practicing a procedure and receiving feedback from an instructor. The figures plotted are the actual training times (N*L*ST) summed across days divided by the total training times plotted in figure 2.

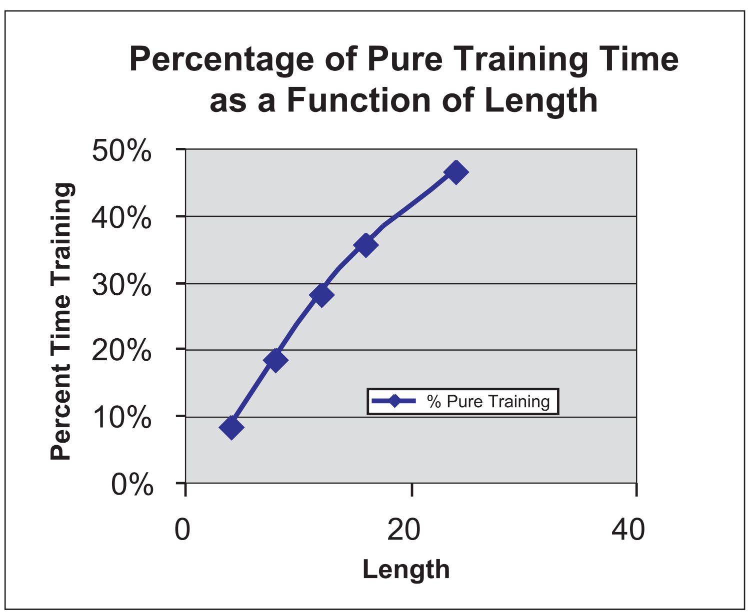

Figure 4. Percentage of training time devoted to actually practicing the procedure.

Figure 4 makes very clear the inefficiencies involved in using a mission-oriented simulator to train FMS procedures.

3.4.2 Approximate and More Realistic Models of a Training Program

A complete FMS training program is modeled by identifying the FMS procedures specified in the syllabus and describing each procedure as a list of items to be memorized. The complexity of a FMS procedure is represented in the model as the length of a serial list of items describing how to perform it. The lists are generated from examples of FMS procedure descriptions in airline and manufacture training and reference documentation. An example is shown in figure 1. Pressing a page/mode key (e.g., HOLD) or line select key is described as a single list item. Entries into the scratch pad, which may involve several keystrokes, are each described as single items. It is similar to descriptions of FMS procedures in an airborne flight manual for the Boeing 777.

An approximate model of a training program can be generated by computing the distribution of list lengths and then computing the total time required to train the complete collection of tasks. The function fitted to the data in figure 2 can be used to estimate training time for list lengths not included in table 1.

A more realistic model would be based on a description of an actual Boeing 777 FMS training program of a major airline, including a realistic syllabus that specifies the tasks introduced and/or practiced on any given day. This model would specify the tasks that are introduced or practiced on any day during a multiday training program during a reasonable length simulator session, e.g., four hours.

3.4.3 Using the Approximate Model to Analyze Training Program Modifications

The following examples assume that a FMS training program can be described as a collection of 30 lists. Based on a very preliminary study of an actual training program, a hypothetical distribution of list lengths was generated and is shown in table 2. In addition, no attempt was made to model a realistic syllabus specifying what tasks were introduced or practiced on a given day of the training program.

Table 2. Frequency distribution of list lengths for a hypothetical FMS training program.

List Length	Frequency
4	4
8	4
12	10
16	10
24	2

3.4.3.1 A model of a current airline training program

Using the list-length distribution of table 2, a model of a current training program was constructed using the same values, 120 seconds, for SST and RST used to compute the predictions shown in figures 2 and 3. The total training time was approximately 48 hours. Polson, Irving, and Irving (1994) reported that pilot instructors for the Boeing 737-300 fleet of a major airline estimated that pilots spent between 15 and 50 hours practicing FMS skills in a simulator.

This large value for total training time for FMS procedures—48 hours—is cause by two main factors. First, table 1 shows that successful training of complex FMS procedures—lists of 12 or more items—requires a very large number of repetitions distributed over at least 8 days. Second, figure 3 shows that a full mission simulator is a very inefficient—as well as very expensive—device for administering the necessary repetitions.

3.4.3.2 Introducing part-task trainers

Numerous studies have shown that PC-based, part-task simulators can be used successfully to train skills such as performing FMS procedures (e.g., Salas, Bowers, and Prince, 1998; Salas, Bowers, and Rhodenizer, 1998; and Polson, Irving, and Irving, 1994). The lesson planners incorporated into commercially developed simulators can be programmed to deliver the necessary repetitions while minimizing the SST and RST (Aerosim Technologies, www.aerosim.com; Tricom Technologies, www.tricom-tech.com/products.htm; CAE, www.Cae.com; and Wicat, www.wicat.com). Use of such a trainer was modeled by reducing the values of SST or RST to 5 seconds.

Total training time was reduced to 20 hours. This demonstration indicates that these trainers can very efficiently deliver the large number of repetitions necessary to master complex FMS procedures, leading to a large reduction in total training time—20 versus 48 hours.

3.4.3.3 Training pilots to generate shorter lists

Pilots do not receive an explicit instruction on how to encode FMS procedures in memory early in training. Furthermore, descriptions of procedures in airline training and reference materials are inconsistent. The example in figure 2 is consistent with some of the more detailed descriptions of FMS procedures in the Boeing 777 Flight Manual of a major airline. Catrambone (1995) has shown that novices tend to describe problem solutions in terms of actions used to solve the problem. In the case of FMS programming skills, this process leads to long lists that are very difficult to memorize.

Many studies in memory literature show that subjects can be easily trained to use more effective encoding strategies to enhance learning and retention of materials to be memorized. This model explores the consequences to teaching pilots methods for generating more concise descriptions of FMS procedures, leading to short lists.

This example assumes that a hypothetical encoding strategy would have little or no effect on description list lengths for 4- and 8-item lists, that 12-item lists would be reduced to 8-item lists, that 16-item lists would be reduced to 12-item lists, and that 24-item lists would be reduced to 16-item lists. This encoding scheme would change the distribution of list lengths shown in table 2 to the distribution presented in table 3. The column labeled Novice List Length is from table 2. The column labeled Trained List Length shows the results of the encoding strategy described previously.

Table 3. Frequency distribution of list lengths for a hypothetical FMS training program for two different method of encoding lists.

Novice List Length	Trained List Length	Frequency
4	4	4
8	8	4
12	8	10
16	12	10
24	16	2

The result of training these encoding skills is to reduce total training time from 48 hours to 29 hours, assuming the use of fixed-base and full-motion simulators. If we combine the use of part-task trainers with use of more efficient encoding strategies, total training time is reduced to 8.1 hours.

The encoding and decoding skills assumed in this example are not trivial, and there is no way at this point of estimating the amount of time required to train such skills or if they can be taught to pilots during the initial stages of transition training to their first FMS-equipped aircraft. However, these skills—if mastered early in training—would be useful during later stages of training and line operations in supporting more effective acquisition of new skills on the line.

3.5 Summary of Applications of the Lists of Actions Model

The examples presented in the preceding sections are illustrations of using results of the serial-list-learning literature to model existing airline training programs and suggest enhancements. Table 4 summarizes these results.

Mastering FMS procedures takes a large number of repetitions, especially for procedures longer than 12 steps (see table 1.) A training program should be set up to deliver the necessary repetitions as efficiently as possible by employing part-task trainers. Additional large gains in training efficiency can be achieved by teaching pilots to generate shorter descriptions of FMS procedures.

Table 4. Summary of four modeling experiments.

Approximate Model of FMS Training	Total Training Time for 30 FMS Tasks (hours)
All Practice in a Full-Mission Simulator	48
All Practice Using a Part-Task Trainer	20
Efficient Encoding Skills, Practice in Full-Mission Simulator	29
Efficient Encoding Skills, Practice with Part-Task Trainer	8.1

The serial-list-learning literature describes numerous robust phenomena that have important implications for airline training. These phenomena can guide the development of incremental changes to existing training programs that can improve pilot performance and reduce training time. The examples presented in the preceding section, introducing part-task trainers and more efficient encoding strategies, are good illustrations.

Many training programs introduce FMS procedures early in a three- to six-week transition training course. Focus of the program then switches to emergency procedures and other topics. Trainees can have very limited or no opportunity to practice flight plan modifications and other FMS procedures during the remainder of the program. Results shown in table 1 indicate that forgetting new learned procedures is a major problem. Rapid forgetting can be overcome only by distributing opportunities for practicing FMS procedures throughout a training program.

Airline training and reference documentation do not contain complete sets of detailed and consistently described FMS procedure descriptions. Thus, pilots new to FMS-equipped aircraft must invent their own encoding methods. The list-learning literature shows that providing subjects with efficient encoding strategies can facilitate learning. Providing pilots with consistent descriptions of procedures and strategies for memorizing them should reduce training time and improve pilot performance.

However, this literature also contains an important lesson. There is no “silver bullet” (Anderson and Schunn, 2000). Mastering a complex FMS procedure will require a large number of repetitions that must be distributed over many days and then practiced occasionally throughout the rest of a training program. Developers of training programs must recognize this fact and then deliver the necessary repetitions as efficiently as possible.

4. SUMMARY

This paper hypothesizes that initial mastery of an FMS or any other procedure is analogous to memorizing a serial list of items. Starting in 1888 with the publication of Ebbinghaus’s monograph on memory to the present, a huge collection of empirical and theoretical results has been published describing the learning and forgetting of such lists. This literature provides us with a rich collection of results that have enabled us to identify problems with current airline training practices and to propose many different solutions to these problems.

The goals of this research program are to validate these insights and develop useful solutions to known problems with existing training programs.

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14. ABSTRACT
This paper presents a new theory of the initial stages of skill acquisition and then employs the theory to model current and future training programs for fight management systems (FMSs) in modern commercial airliners like the Boeing 777 and the Airbus A320. The theoretical foundations for the theory are a new synthesis of the literature on human memory and the latest version of the ACT-R theory of skill acquisition (Anderson, Bothell, Byrne, Douglass, Lebiere, and Qin, in press; Anderson and Schunn, 2000; Taatgen and Lee, 2003).

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