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MODELING HUMAN BEHAVIOR IN AIRCRAFT EVACUATIONS

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ABSTRACT

The overall objective of the project was to create an aircraft evacuation (AIREVAC) computer model that simulates aircraft evacuation behavior. The model will be used by the Air Transport Association (ATA) as a tool for obtaining input to help answer a variety of questions concerning evacuation safety. The model is unique because for each individual passenger, the program successively a) perceives/assesses the situation, b) on the basis of individualized physiological, cognitive, social, and motivational attributes decides a primary goal, and c) selects and executes a behavior consistent with that goal. The model accounts for a wide variety of behaviors found in actual evacuations ranging from negative panic to altruistic behavior.

1 INTRODUCTION

This paper summarizes the results of a completed design phase (see Schroeder and Tuttle, 1991), and provides an overview of the resulting structure of a model intended to simulate human behavior during an emergency aircraft evacuation (AIREVAC). The primary objectives of the design-stage effort were to a) search the literature and identify/prioritize the most critical variables in aircraft evacuations, b) identify areas where data are currently available or lacking to support such a model, and c) confirm or modify the general structure of the model as set forth in the original proposal. In the second-phase, the initial version of AIREVAC was created using SIMSCRIPT II.5.

A number of authors have cited the need to develop models of human behavior in an emergency evacuation settings. One such appeal was made by Janis (1954):

> "What the point essentially boils down to is this: there is an obvious need for general theoretical categories and constructs that will help to delineate central problems of disaster behavior that should be investigated."

Janis attributed the reluctance of theorists to address emergency situations partially to the fact that most scientists do not want to address such uncontrolled, "dirty" situations. More recently, Bickman, Edelman, and McDaniel (1977) similarly concluded that "little empirical information exists concerning human behavior in fires," and cited nine reasons for the lack of data, theory, and models. Stahl (1979) also described the general lack of systematic treatment of human behavior in fire emergencies:

> "Taken as a whole, for example, the body of research on egress behavior and human responses during fires was not guided by any single set of objectives. Consequently, individual efforts were neither cumulative nor purposefully directed toward theory development. What we do have is a collection of discrete studies in which it is often difficult to even compare results for ostensibly similar variables."

Despite the numerous excellent reasons to postpone the construction of such a model, several recent trends suggest that it is time to take the initial steps toward building such a model, especially if it is understood that the resulting model must be specified in detail and constantly subjected to comment, criticism, and revision based on new data as they become available. One fact that supports this conclusion is the increased reluctance of responsible scientists and organizations to subject human volunteers to studies which have any possibility of resulting in physical or mental injury. While theorists of three decades ago could argue that construction of a model should be delayed until more data were available from laboratories or controlled field studies, today, few persons familiar with the restrictions and limitations involved in the use of human subjects are likely to hope for such data in the future. It should be noted that relatively few data were collected even when such research was less scrutinized by institutional review boards. In fact, it is highly unlikely that data from controlled experiments or field studies creating "realistic" emergency settings will ever be available.

A second reason to proceed with the construction of such a model is that important questions constantly arise concerning aircraft-evacuation safety; these questions will probably never be answered with empirical data. For example, the safety implications associated with establishing guidelines for number and location of physically immobile passengers involves a set of questions which could be partially addressed through computer modeling. Such questions are important; peoples lives depend on the answers. However, it is highly unlikely that such answers will ever derive from controlled laboratory or field studies. Nevertheless, we owe it to all passengers to work toward answering such questions. Other important questions that could be partially addressed with such a model deal with the relative safety-effectiveness of different emergency procedures, safety devices, regulations (e.g., restrictions on the amount and size of carry-on luggage), and alternative aircraft configurations.

A third reason for proceeding with such a modeling effort concerns a family of issues dealing with current standardized procedures used to certify aircraft by the Federal Aviation Administration (FAA). While traditional FAA evacuation tests are very important and help insure that a given aircraft configuration meets safety standards, such exercises are often recognized in the literature for not truly simulating the intense environment and resulting diversity of behaviors that occur in an actual emergency (e.g., Snow, Carroll, and Allgood, 1970). For example, the probability of extreme "panic" behavior and negative panic (freezing) are virtually nonexistent, due to the very nature of the testing procedure. Rather, a cooperative, team-spirit attitude is evident in many of the evacuation tapes.

Recent research conducted by Muir, Marrison, and their colleagues at the Cranfield Institute of Technology in England support this conclusion and demonstrated the importance of considering motivational variables in evacuation studies (e.g., Muir and Marrison, 1989a, 1989b). They demonstrated that evacuation outcome depends on level of passenger motivation; in some cases very different outcomes were found under low (FAA-like) and high (emergency-like) motivation conditions.

Finally, concerns also exist that, while using healthy volunteers, participants in such exercises are subject to possible injury. It is possible that a well-designed computer model of aircraft evacuation could create a safer and more realistic emulation of actual aircraft evacuations than traditional certification tests.

Initial steps toward modeling human behavior in an emergency have already been taken by a several teams of scientists. Most of these deal with the topic of human behavior in building fires. Bickman et al. described the work of Breaux, Canter, and Sime, in which a model was created describing the factors thought to influence behavior in fire emergencies. Three stages were identified: detection of cues, definition of the situation, and coping behavior. Stahl (1979) described the BFIRES project in which a computer simulation of building egress during fires was developed. The resulting model included information-processing components and is similar in many respects to the human-behavior portion of the AIREVAC model developed independently by the present first author, except there appear to be fewer psychosocial variables.

In the BFIRES model, two-dimensional matrices were used to depict the original architectural configuration. The probabilities of an individual moving from cell to cell in the matrix changed over time, making it a non-stationary Markov model. The three major components in the BFIRES program were the a) information gathering component, b) information interpretation/processing component, and c) action component, in which the most probable move is selected.

Finally, one very recent computer model of aircraft evacuation was constructed by Gourary and Associates, working under contract to the FAA. Their effort provided a notable first-step in the right direction. In the following sections, many of the findings from the first-phase effort are presented in the context of an overview of the resulting structure of the AIREVAC model.

2 OVERVIEW OF THE STRUCTURE OF AIREVAC

A very general overview of AIREVAC is shown in Figure 1. After logging on, the user defines the evacuation situation and the passenger characteristics. For both situational and passenger variables, options exist for values to be assigned by AIREVAC (based on existing data), or by the user (to address specific situations of interest). After characteristics of the situation and passenger attributes have been established, the user executes a "run," usually comprising a large number of individual tests. After a run is executed, statistical analyses are performed and the results made available to the user. In the following sections, more detailed discussions of each of these four major modules are provided.

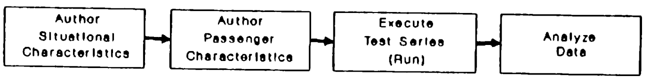

Figure 1: Four primary segments of AIREVAC.

2.1 Authoring Situational Characteristics

The review of the literature identified a number of important situational variables. Conceivably, all of these variables could be important and, eventually, AIREVAC will be extended to include all or most of these variables. However, for the initial effort, only the following variables were addressed:

Situational Attributes

- Total Number of Passengers
- Number of Passengers to be Defined by User
- Location of Passengers
- Number/Location of Functional Exits
- Amount and Location of Debris
- Flight Attendants (number and original location)
- Situation Index ("actual" severity of the situation)

Number and probable location of passengers as well as number and location of flight attendants are based on data provided by the airlines or by the guidelines set forward by the FAA for evacuation demonstrations, depending on the target application. Because the initial validation target for AIREVAC was to simulate an FAA evacuation demonstration, number and location of functional exits and amount and location of debris were randomly assigned based on FAA guidelines for such tests. Other variables to be included in the future are presented below. Information in parentheses indicates the condition adopted for the first test runs.

Other Situational Attributes

- Smoke Presence/Location/Density (none)
- Fire Presence/Location/Intensity (none)
- Planned/Unplanned Evacuation (planned)
- Aircraft Characteristics (Boeing 727-200 Series)
- Authority and Competence of Flight Attendants (high)
- Interior Cabin Environmental Characteristics
  - Light/Dark (emergency lights)
  - Amount of Water (none)
  - Orientation of Aircraft (horizontal)
- Exterior Environmental Characteristics
  - Light/Dark (emergency lights)
  - Land/Water (land)
  - Smoke/Fire (none)
  - Weather Conditions (excellent)
  - Geographic Conditions (excellent)

2.2 Authoring Passenger Characteristics

As with situational characteristics, the AIREVAC user is allowed to "construct" different individual passenger profiles. Following are the physical characteristics of passengers which can be assigned by the user or by AIREVAC based on existing data.

Passenger Physical Attributes

- Age
- Sex
- Original Seat Location
- Anthropometry (Weight, Shoulder Breadth, Chest Depth, Height)
- Authority Figure (Flight Attendants only)
- Physical Disability
  - Vision Disability
  - Hearing Disability
  - Arm/Hand Control Disability
  - Mobility Disability
  - Recognizability of Disability
  - Personal Attendant Present
  - Recognizability
- Reaction Time
- Dexterity Time (time to unfasten seat belt)
- Locomotion Speed (maximum velocity in aisle)
- Distressed or Not Distressed
- Physiological Level of Functioning

Within the overall AIREVAC model, a number of independent sub-models exist. For example, if not assigned by the user, AIREVAC assigns the above physical attributes to each passenger based on existing data or specified assumptions. For example, once sex and age are determined, weight, shoulder breadth, chest depth, and height are assigned (in that order) based on known relationships among those variables.

Until more accurate data are available, the various physical disabilities listed are all defined in terms of functional disability. For example, an individual with a 50% mobility disability would move in the aisle at half the velocity of a theoretical counterpart with the same physical characteristics but not mobility disabled. For the most part, the disability variables will not be included in the earliest AIREVAC tests, because the FAA excludes such individuals from being included in evacuation exercises. However, sensitivity analyses will be conducted for assessing the effect of number and degree of mobility disability on overall evacuation time.

Reaction time, dexterity time, and locomotion speed are assigned based on knowledge of the physical variables and known relationships among physical and performance variables. The "Distressed" variable is a flag indicating that an individual is in need of assistance. The "Level of Functioning" variable is a theoretical numeric index of the physical state of the individual ranging from awake/unhurt/alert at one end (1.0) through unconscious, to deceased at the scale's other end (0.0).

In addition to physical characteristics, several psychosocial variables were proposed in the early behavior model and supported in the literature as being important in determining the outcome of an evacuation. As with physical variables, values are assigned to these variables either by the user or by the program. One family of such variables concerns the knowledge the individual brings or acquires during the evacuation (cognitive variables).

Cognitive Attributes

Knowledge of Aircraft Exits and Routes
General Intelligence
Knowledge of Evacuation Protocol
Perception of Severity of Situation
Current Planned Escape Route

The first three attributes are constants, assigned by the user or program before the test run. They impact a number of other variables and indirectly influence resulting behaviors. For example, Knowledge of Aircraft Exits and Routes and General Intelligence partially determine whether individuals have a planned escape route and whether individuals have a realistic "Perception of the Severity of the Situation." Knowledge of Evacuation Protocol will partially determine whether an individual yields to another or does not under different circumstances. Perception of Severity of the Situation is an index ranging from 1.0 to 0.0 which, in a knowledgeable individual, is perfectly correlated with the Situation Index, (described above as an objective index of the situation) and which greatly influences the individual's motivation level (described below). Finally, "Current Planned Escape Route" is a representation of the individual's current planned route expressed in terms of a series of critical nodes (e.g., intersections of rows and aisles, rows and doors, or aisles and doors). Depending on the sophistication of the individual, the passenger might be assigned none, one, or a prioritized family of such routes.

The following motivational variables are included in AIREVAC.

Motivational Attributes

Motive to Escape
General Anxiety
Frustration Index
Phobic Drive
Modeling
Motive to Submit
Dispositional Submission
Altruistic Motive
Dispositional Altruism

Motive to Escape represents the overall strength of the motive to escape the situation. It is the pooled composite of General Anxiety, Frustration Index, Phobic Drive, and Modeling. General Anxiety is the dispositional level of motivation brought to the situation. Values are randomly assigned; individuals receiving higher values correspond to individuals who are generally more anxious. During an evacuation, Motive to Escape is influenced by the Frustration Index (which is influenced by a number of incidents including blocked responses, delays, and an increased Perception of the Severity of the Situation), Phobic Drive (which is triggered by sensing smoke or fire and influenced by distance to and intensity of the smoke or fire), and Modeling (which is determined by being close to another individual engaging in extreme (asocial) behavior.

Possibly competing with Motive to Escape (depending on the situation) are two other general motivations. First, the Motive to Submit is the strength of the tendency yield in an encounter with another individual. Such a "block" occurs when two or more individuals are competitors in determining who occupies a space or who goes first. Blocks are most likely to occur at intersections of rows and the main aisle and at doors. The strength of the Motive to Submit is influenced by Dispositional Submission (i.e., the tendency to submit that an individual brings to the situation), Knowledge of Aircraft Protocol, the physical characteristics of the other individual(s) (especially sex and age), and social variables (especially Anonymity and Role - discussed below).

The third general source of motivation is represented by the Altruistic Motive. Like the Motive to Submit, it is only triggered in specific situations. Specifically, whenever a distressed person is sensed, then the Altruistic Motive will be activated and compete with the other active motives. The strength of the Altruistic Motive depends on Dispositional Altruism (i.e., the tendency to help others, that the individual brings to the situation), the physical characteristics of the distressed individual (especially, sex, age, and weight), and social variables (especially Anonymity and Role).

Finally, the following social variables are considered important for the AIREVAC model. (It should be noted that the categories used here are somewhat arbitrary. For example, the altruism, submission, and modeling variables discussed above could also be classified as social variables.)

Social Variables

Current Social Role (Protector/Dependent/Neutral)
Anonymity
Number/Location of Family/Friends on Flight

The Current Social Role variable is initially assigned by the user or AIREVAC. For example, passengers traveling alone are initially assigned a "Neutral" role; passengers traveling with small children are assigned "Protector" role and the child they are with is assigned a "Dependent" role. During an evacuation, if an individual with a neutral role senses and physically approaches a distressed person, then the role of the person offering help is changed to "Protector" and the role of the person being helped is changed to "Dependent." Once a Protector, several dimensions of the behavior of that individual could change. For example, he/she is more likely to assert when confronted with a "block," and is more likely to disregard other encountered distressed passengers.

2.3 Executing a Test Series (Run)

Users are allowed several options when authoring a run. The primary variable is the number of tests to be conducted during the run. In addition, the user is requested to specify whether or not a graphic portrayal of the evacuation is desired. This graphic depiction is accurately spatially scaled, but, because of the computer system selected, is not currently a real-time display. Consequently, if the graphic option is selected, a clock is provided, indicating true evacuation time. Finally, the user is allowed to specify whether the passenger attributes assigned by AIREVAC are to remain the same for the entire run or whether they are to be reassigned characteristics for each new test. AIREVAC assumes that passengers specially created by the user are to retain the same characteristics throughout the run.

During a test, the program addresses the situation of every passenger every "instant" (0.2 sec), and updates the individual passenger's status, location, motives, and behavior. After each instant, relevant situational variables are updated (e.g., the Situation Index). During a test, the user can use a mouse to "click on" an individual icon to determine its identity, status, current motive, and current behavior.

2.4 Data Analysis

At the end of a run, summary data for that run are presented on the monitor and stored in a file. Summary data include mean, standard deviation, minimum, maximum total evacuation times and flow rates for that run. In future versions, individualized "diary" files will be stored to allow the user to track the progress of selected individuals.

3 OVERVIEW OF THE PERFORMANCE MODEL

The performance model is believed to be unique with regard to the number of situational, psychological, and social variables addressed. In general, the model is designed to determine for an individual of specific characteristics, a) what the situation is, b) the relative strengths of three possibly competing motives, c) whether the three motives are competing and, if so, which motive is currently dominant, and d) the resulting behavioral outcome. A condensed version of the performance model is presented in Figure 2.

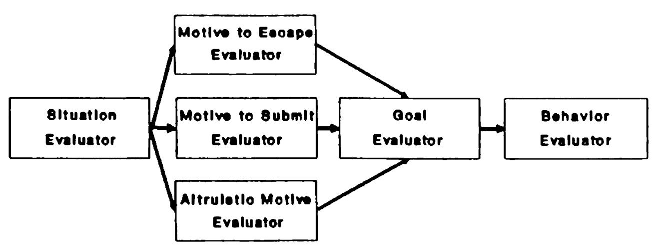

Figure 2: Overview of the AIREVAC behavior model.

3.1 Situation Evaluator

The Situation Evaluator provides the sensory and perceptual functions for an individual. Primary segments include a) updating the Perception of Severity of the Situation; b) checking for blocks by comparing current velocity and location of self on the current planned escape route with those of other passengers either on or about to enter the same path; c) "looking" for smoke and fire, gestures from distressed individuals, and extreme escape behavior in other individuals; d) "listening" for instructions from Flight Attendants and pleas from distressed individuals; e) "feeling" for physical contact with other passengers; f) if a block is detected, activating the Motive to Submit Evaluator and obtaining the physical characteristics of other person in the block (primarily location, age, sex, and weight); and g) if a distressed person is detected, activating the Altruistic Motive Evaluator and obtaining physical characteristics of the distressed individual (primarily location, age, sex, and weight).

3.2 Motive to Escape Evaluator

This module computes the current level of Motive to Escape by pooling the strengths of the relevant component variables. The primary variables contributing to the Motive to Escape are General Anxiety (constant for the individual), Phobic Drive (determined by detection and distance from smoke or fire, and dispositional level of phobic drive for the individual), the Frustration Index, (increased or decreased by situational events and length of time in the situation), and Modeling (influenced by witnessing extreme social behavior in others).

3.3 Motive to Submit Evaluator

If a block is sensed, then the Motive to Submit is calculated based on several dispositional and situational variables. The most important variables include the location and physical characteristics of the other person in the block, Knowledge of Evacuation Protocol, Anonymity, Current Social Role, and the individual's Dispositional Submission (tendency to yield in a confrontation situation).

3.4 Altruistic Motive Evaluator

If a distressed individual is detected, then the Altruistic Motive Evaluator module is called and computes a general tendency to help a distressed individual. Primary determinants of the Altruistic Motive include Dispositional Altruism, the location and physical characteristics of the distressed individual (especially sex, age, recognizability, and weight), Current Social Role of the distressed person (whether that person is already being helped by another), Current Social Role of self, and Anonymity.

3.5 Goal Evaluator

The Goal Evaluator determines which of the three motives (escape, yield, or help) is the stronger at that instant. However, because there is evidence for behavioral "inertia," and to provide some stability of motive across time, mechanisms exist that resist a currently dominant motive from being easily displaced.

3.6 Behavior Evaluator

Depending on the current dominant motive, one of several behavioral hierarchies are set in place. Following is the sequence or hierarchy of behaviors that accompany normal evacuation. Once a behavior is completed, the next behavior is addressed.

React
Unfasten Seat Belt
Move from Seat
Move to Aisle
Movement in Aisle
Move Through Door

In addition to the above hierarchy of more normal evacuation behaviors, the following behaviors are also possible under certain specified conditions.

Push
Pass
Negative Panic (freezing or tonic immobility)
Aggressive Escape (creating unconventional route)

According to the model, if the Motive to Submit is weaker than the Motive to Escape, then the individual will proceed with the current escape behavior sequence. On the next instant, the situation will be reevaluated and it will be determined whether the other person has yielded or whether the block still exists.

Two thresholds are used to determine extreme "panic-like" behaviors. If the Motive to Escapes reaches the first threshold, then, depending on the situation, asocial behaviors such as Push, Pass, and Aggressive Escape are invoked. If the second threshold is exceeded by Motive to Escape, and no strong evacuation path exists or competing responses exist, then Negative Panic occurs and the person becomes immobile.

If the Altruistic Motive dominates, then another sequence of behaviors is inserted before returning to the primary escape sequence:

Move to Distressed Individual
Address Distressed Person (e.g, position, lift)
Coordinate with Second Protector
Return to Escape Path at Slower Speed
Turn/Position Distressed Individual at Door

There are also specific behavioral hierarchies assigned to distressed individuals:

Call and Gesture for Help
Stop when Helped

Flight Attendants also have specific behavioral hierarchies, determined by Federal and airline training and procedures. Flight Attendants are generally assigned to Open a Door, while the other passengers might or might not be required to open doors, depending on the situation. Another difference between a Flight Attendant and other passengers is that Flight Attendants can give instructions which, depending on ambient noise, distance, and situational variables, are likely to be heard and followed by passengers.

Another set of behaviors were included because they were shown to be likely during some evacuation situations.

Fall
Open Door
Seeking/Carrying Belongings
Follow Instructions
Seek Family Members (e.g., see Sime, 1983)

Finally, another important function of the Behavior Evaluator is to increase or decrease the Frustration Index. Frustration is primarily influenced by Perception of Severity of the Situation and by other situational variables including stopping or slowing of movement on the path, failure of a block to be resolved as expected, failure of a door to open, etc.

4 VALIDATION STRATEGY

It is useful to conceptualize the severity of aircraft evacuations as a continuum, proceeding from one extreme involving relatively orderly situations, creating relatively low stress, and yielding relatively predictable human behavior (e.g., an FAA evacuation demonstration exercise), to the other extreme involving very lethal situations with fire and smoke. The strategy for initial validation and calibration of AIREVAC was to begin by conducting sensitivity analyses and testing the low-motivation end of this scale. Subsequent extensions and tests of the AIREVAC model will then attempt to slowly ascend this continuum.

There are five reasons for selecting the FAA evacuation setting for the initial validation setting. First, this end of the continuum is of more immediate interest to the sponsor of this research - the Air Transport Association. Second, because tests already have been conducted by the FAA, many more data exist for that setting than for the other extreme. Third, if laboratory or field studies are conducted to provide data for the model, it is easier to simulate the low-motivation end of the continuum. Fourth, many of the more intractable and theoretical variables/relationships which predict effects of high levels of motivation on escape, panic, yielding, and altruistic behavior are minimized in the traditional FAA-style evacuation exercise. Hence, some of the complicating and difficult situations/variables that make actual evacuations more unpredictable can be postponed until the model has a more sound foundation. Fifth, the relative incidence of non-hazardous aircraft evacuations is much greater than that for extremely lethal evacuations. Brunetti (1972) reported that a National Transportation Safety Board (NTSB) listing of incidents involving evacuations from 1962-70 (including 26,466,365 flights) found that only 18 percent of the 119 flights that involved emergency evacuations involved fire (overall probability = .00000083). The vast majority (82 percent) did not involve fire. Consequently, the model is likely to have greater external validity for the majority of actual evacuation situations.

Unfortunately, as one departs the world of the FAA evacuation test trial and moves to more hazardous evacuations, the complexity of resulting human behavior increases almost as fast as the available objective data decrease. Due to the work of Muir and her associates at the Cranfield Institute, there are data from at least one more scenario that more closely approximates the real world of aircraft evacuation. Consequently, the second general extension of the model will be to simulate the conditions imposed by Muir and her colleagues when they determined the effect of increased motivation on evacuation time and behavior. To predict the behavior and evacuation outcomes found in the Cranfield studies, much more of the model will be activated, specifically, those variables affected by high motivation. Again, sensitivity analyses will be conducted for variables or combinations of variables presumed or known to affect evacuation outcome.

In the final stages of the AIREVAC model, other psychosocial variables and relationships will be added. Because of the paucity of data, many of these extensions will be based in theory. Again, sensitivity analyses can be conducted to determine whether or not the theoretical variables/relationships affect evacuation in a predictable manner and the model can be modified as new facts and theories are identified. The ultimate goal of the final model is to predict (or recreate) actual evacuation outcome under different situations. Eventually, the model will become a very useful tool for assessing the effects of various regulations, procedures, devices, and configurations on aircraft evacuation safety.

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