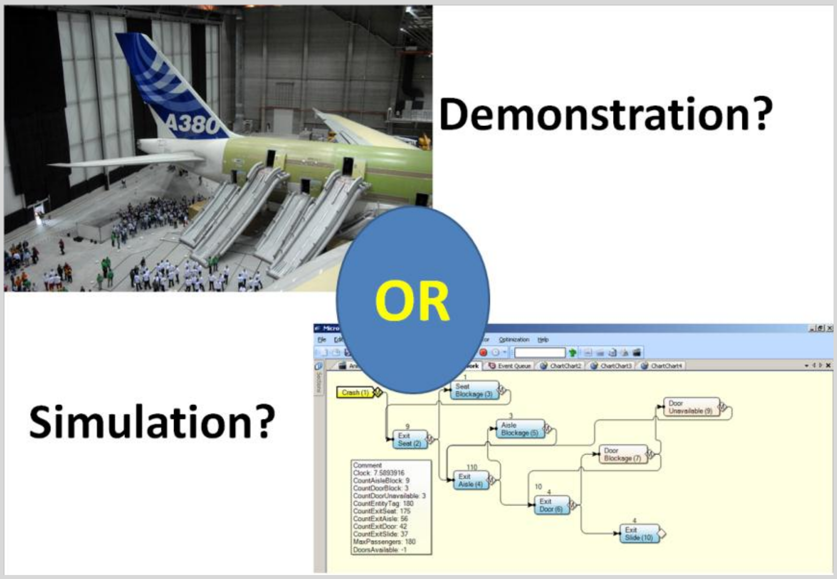
Simulation of Emergency Evacuation from Transport Category



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Simulation of Emergency Evacuation from Transport Category Aircraft

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Abstract

The certification of transport category aircraft requires an emergency evacuation demonstration mandated by both FAR Part(s) 25 and 121. There are many constraints on the demonstration, including gender, age, exit availability, and time. There are no provisions in the regulations concerning use of simulation for emergency egress; yet, simulation is widely used in design considerations for buildings, roads, manufacturing processes etc. Muir et. al. (1989, 1994, 1996, 2004) have written extensively on emergency evacuation of transport category aircraft and suggested the use of simulation, as an alternative to demonstrations, in order to better understanding the influence of variability in emergency egress situations.

The simulation approach adopted here involved the development of models with varying levels of detail, such as movement durations through the sequential evacuation stages – from the seat and aisle, to the door and use of the exit slide. These times were modeled by the Gamma and Lognormal statistical distributions with parameters estimated from observations and data related to human movement in constrained evacuation situations. Constraints were placed on the activities to simulate blockages at various stages of the evacuation. These constraints were intended to represent handicapped passengers or "kin" behaviors in which groups of passengers attempt to stick together. The results of the preliminary simulations indicated the viability and validity of the approach and showed the expected effects of passenger movements and delays. More extensive investigations, planned over the coming months, will focus on the cause and effect of blockages and passenger behavioral variability.

Introduction

Aircraft accidents are relatively rare events. However, the context of high (but survivable) impact forces, release of volatile fuels, ignition sources and flammable materials is such that successful evacuation is a very time critical issue. There are examples of successful evacuation of large airplanes in a very short time – both from demonstrations and from actual accidents (e.g. the Toronto runway excursion accident involving an Air France A-340 in August of 2005; and the recent British Airways 777 in London), with minimal casualties. There are also records of unsuccessful evacuations (e.g. the Air Canada DC-9 at Cincinnatti in 1983 in which 23 of 46 people died due to the effects of fire, and the British Airtours B-737 at Manchester, England in 1985 in which 55 people perished in an aircraft that never left the ground). New airplanes are being designed with greatly increased capacity, but the time available for evacuation is unlikely to increase. The solutions to this problem are an increase in the capacity of the escape routes, improved procedures and training. Discrete event simulation approaches will provide important contributions to these designs.

Background

The requirements for emergency evacuation demonstrations by operators were first established in Part 121.29 of the Federal Aviation Regulations by Amendment 121-2, effective March 3, 1965. Operators were required to conduct full-scale evacuations within a limit of one-hundred twenty seconds using fifty-percent of the available exits. In 1967, this established time limit was reduced to ninety seconds as Amended by Section 25-46. This exercise demonstrates the operator's ability to execute the established emergency evacuation procedures, and ensures realistic assignment of functions to the crew.

The requirements for the emergency evacuation demonstrations by manufacturers were established in Part 25.803 by Amendment 25-15, effective October 24, 1967. With seating capacity of aircraft exceeding 44 passengers, manufacturers were required to conduct full-scale evacuations within a ninety second time limit. It was considered that the manufacturer's demonstration illustrated the basic capability of a new airplane before the Part 121 requirement intended to account for crew training and adequate crew procedures developed by the individual operator. Hence, the test conditions were somewhat different. These demonstration tests provided data on (a) evacuation rates, (b) escape system performance, and (c) behavior of evacuees during the demonstrations.

It was proposed in Notice 75-26 that analysis, or a combination of analysis and tests, be used to show evacuation capability. By dropping the provision which allowed analysis alone and requiring a combination of analysis and tests through Amendment 25-46, this was meant to assure approvals would be based on sufficient test data since data may not be available in the case of a completely new airplane or model which had major changes or a considerably larger passenger capacity than a previously approved model. This design stage presents an ideal opportunity for simulation.

The preamble to Amendment 121-176 from the FAA study of evacuation demonstrations states, "that with rare exceptions, the rates of passenger egress are not significantly different for the same type of exit and that changes in the passenger cabin configuration, seat pitch, and aisle width have no significant bearing on the egress rates if the airplane type certification requirements for minimum aisle width and exit accessibility are met."

However, Muir, Bottomley and Marrison (1996) found that all increases in aperture width up to 30 inches produced significantly beneficial flow rates, but further width increase provided no additional benefits. Moreover, when comparing different aisle widths they concluded that, "more bottlenecks occurred in the 24 inch configuration tests than in the 20 inch tests, even though the mean evacuation time for the former condition was less than that of the latter." This suggests that aisle widths have a possible significant bearing on egress rates even when the type certification requirements for minimum aisle width are met. Therefore, the possibility for modeling or simulating the emergency evacuation with aisle variations could prove useful in understanding human behavior and safety design.

The 1985 FAA Public Technical Conference held in Seattle, Washington discussed the conduct of emergency evacuation demonstrations and the use of analysis in lieu of full-scale demonstrations. The rationale of such discussions was to discuss policy formulation on when to conduct evacuation demonstrations or analysis. However, no consensus could be reached concerning the analysis in lieu of full-scale demonstration's and the FAA issued AC 25.803-1 "Emergency Evacuation Demonstrations." So, the analysis used to ascertain if an evacuation needs to be conducted, as well as, the procedures used in conducting the evacuations are explained in the Advisory Circular. Ultimately, though, there is no mention of the use of alternative means of evacuation demonstrations, such as modeling or simulation, in the AC 25.803-1.

Modeling or simulation of emergency evacuations could provide understanding of aircraft designs without the costs, injuries, or mock-ups required in full-scale demonstrations. Muir and Thomas' study (2004) supports this perspective when they investigated passenger safety and very large transportation aircraft. In their landmark study of passenger survival factors they concluded that, "In view of the numbers of passengers and , as a consequence, the potential for injury, consideration could be given to the use of a combination of modeling and partial testing rather than a full-scale evacuation test."

Methods

Evaluation of Physical Factors

The first task was to to assess the physical, geometrical and temporal nature of the evacuation situation including seat configuration and location, restraint system, seat pitch, distance to aisle, width of aisle, number of available exits, distance to nearest exit, headspace in front of exit, configuration and operation of the exit, as well as associated evacuation slides. An additional set of variables will be developed regarding the environmental factors in post-impact situations. Evidence regarding environment factors will be obtained from the literature and include such things as fire ignition, development and propagation, exit availability and post-impact condition or the occupants. Additional factors relate to the condition of the fuselage (intact, partially intact, or fragmented) and compromise to survival such as smoke, toxic gases, and heat. Data will be obtained from previous accidents to identify evacuation conditions, times, failure modes and escape probabilities. Next informed assumptions will be made regarding the numbers, characteristics and behaviors of the passengers. Finally detailed evacuation performance requirements will be obtained from industry and FAA documents.

Flight Attendant Training

The capabilities and actions of flight attendants are important factors in successful evacuation. Given that the hardware on most passenger aircraft is unchangeable, the next line of defense is through the development of facilitators (instructions, warnings, labels and procedures) and training of both flight attendants and passengers. Regulations already require that only capable passengers are seated in the exit rows; these passengers must follow flight attendants commands and then open the exits. The first challenge for flight attendants is the variability among aircraft regarding exit hardware function and procedures. Next flight attendants are assigned different responsibilities around the aircraft when the need for evacuation occurs; these different responsibilities, together with the different exit operating procedures can be a cause for confusion. The familiar duty of the flight attendants is to carry out a pre flight safety briefing, including what should happen in the case of an evacuation. This briefing supplements the largely pictorial information on the passenger safety card which is located in all the seat back pockets. Although this instruction process is well intentioned and very familiar to frequent flyers, it may not be adequate for many infrequent flyers, especially in the case of a real emergency. It is under these conditions that the flight attendants must be knowledgeable, assertive and flexible depending on the conditions. Hence there is no substitute for rigorous selection and training of flight attendants, whose actions may be critical in the very unlikely occurrence of an evacuation.

Video

Video technology is a very rich analysis and training aid. The U Tube video of the A380 evacuation demonstration provided a very good introduction to a highly orchestrated event in which 873 passengers evacuated in 77 seconds, but with one serious injury (a broken leg) and 32 minor injuries.

http://www.youtube.com/watch?v=XIaovi1JWyY

Video analysis can provide useful passenger behavior and time data for different situations, including maximum unobstructed movement speeds and speeds observed for less physically capable passengers and under more constraining conditions, such as blockages.

Simulation

The traditional methods of observing human behavior and performance, such as that in evacuation from transport aircraft, include outcome statistics (e.g accident, fatality, injury statistics), and controlled experimentation or demonstration. The former approach has considerable validity (the events actually happened) although the exact conditions are not easily replicated and analysis and therefore conclusions may be flawed by missing evidence. The latter approach has good repeatability, but often questionable validity owing to the cost and potential danger to which the participants are exposed. The current method of aircraft certification of related to evacuation is by constrained demonstration. The constraints include passenger demographic mix, exit availability and a time limit (90 seconds). Other factors affecting behavior and performance include the aircraft configuration (seat pitch, aisle width, door dimensions, blockages etc) and cabin crew training, behavior and performance. Also, these demonstrations are usually single, orchestrated events that are not subject to statistical controls to address the various combinations of configuration, passenger, flight attendant and situational variables, such as fire, smoke, aisle blockages, door and slide failures etc.

The alternative approach used in this investigation is discrete event simulation. This approach enables an infinite number of combinations of conditions, replications and outcome measures. It is also very inexpensive – only requiring the availability of software, sufficiently powerful computers, and the knowledge and time of the investigators. For the present investigations the Micro Saint Sharp discrete event simulation tool is used, although there are alternative simulation packages, such as Arena. The Micro Saint Sharp package works well on a high end desk top computer, provided the models are not too extensive or elaborate. There are two major shortcomings with the simulation approach. The first is the validity of the models – do they realistically represent the activities associated with evacuation? These problems are addressed by using a consensus of domain and simulation experts to develop and evaluate the models. The second shortcoming is the availability of accurate, reliable and valid data to drive the simulations. Most of the data needed relate to the times taken to execute various activities and the probabilities of different branches in the model logic, such as the probability that an aisle or exit will be blocked. This shortcoming is addressed in two ways. First it is necessary to obtain data from appropriate sources, such as actual evacuations or demonstrations, or from similar operations, such as evacuation from buildings, laboratory experiments of movement in constrained conditions etc. The second approach to the application of data is through statistical assumptions and sensitivity analysis. For example one may assume Gamma or Log Normal statistical distributions (Evans et al 2000, Doane and Seward 2007, Elizandro and Taha 2008, Konz and Johnson 2000) of movement times and manipulate the parameter values in repeated simulation runs to explore worst and best case scenarios. This approach is widely used in PERT / CPM analysis.

The simulation study development includes the following levels of sophistication:

1. The basic models developed in this study included seat exit, aisle exit, door exit and slide exit. Each of these activities was further broken down into sub activities, such as moving from one location to the next in a seat row or aisle. At this level it is possible to simulate normal, orderly evacuation behavior, assuming fixed or variable movement times.
    a. The movement time variability can assume a Rectangular, Exponential, Log Normal or Gamma Distribution
2. The next level involves creating limited resources such as seat, aisle, door or slide "slots", which forces queues to develop preceding the egress activity.
3. Blockages are simulated either by a probabilistic branch back into the current activity or by simply removing the availability of an exit, seat or aisle slot resource and an activity ending effect.
    a. This feature may be modeled by having a resource branching into an "occupied" state for a variable time, or permanently.
4. Probabilistic branching to other pathways is introduced when a blockage (queue) develops.
    a. This may involve back tracking along the aisle if an exit becomes unavailable.
5. The final level of sophistication involves the introduction of aberrant behaviors by passengers
    a. There may be very large, old or handicapped passengers whose movement times are significantly slower and who may be the cause of temporary (or permanent) blockages
    b. There may be passengers who choose to take luggage with them, which can be simulated by slowing them down or by having them occupy multiple resources (e.g. aisle slots.
    c. A third behavioral feature is "kin behavior" in which groups of people, such as families stick together. This is simulated by linking individual entities (passengers) and having a group take up multiple spatial resources and / or move more slowly. This behavior will also increase the probability of blockages

d. The fourth group of behaviors can generally be called ‘panic behavior’. These are characterized by irrational acts, such as freezing or pushing or going in the wrong direction, and hysterical outbursts. As far as evacuation is concerned, these behaviors can be very disruptive and cause time consuming blockages.

Each of these variants is set up in Micro Saint Sharp by creating “Scenarios”. Furthermore each scenario or combination of scenarios needs to be arranged according to an appropriate experimental design and each experimental combination needs to be replicated multiple times to understand the effects of residual random variability in the implementation of the model, whose building blocks are based on classical statistical distributions (Evans et al 2000).

Results

Micro Saint Sharp enables the investigator to display time unit to time unit status (snapshots, watches) of the various model parameters, either in a digital or graphical way (charts). The charts that are displayed at the end of a simulation run show the progress of the various parameters as the evacuation progresses, including a final status when the simulation ends by time (e.g. 90 seconds) or number of passengers processed (e.g. 180). These parameters include queue length, number of entities in service or number of entities served. Other output variables include the time spent in a queue or service activity or the time taken for an entity (passenger) to move through a part of or the whole system.

Another feature of the program (OptQuest) enables a complete simulation run to be executed which searches for an optimum level of performance given input or probabilistically occurring constraints. For example if passengers have the opportunity to choose among exits then it is possible to determine the best possible strategies given the flow through different aisle segments.

Results to Date

Three different models were developed during the first phase of this investigation as shown below in Figures 1, 2 and 3. Each of these models added a degree of sophistication to the simulation.

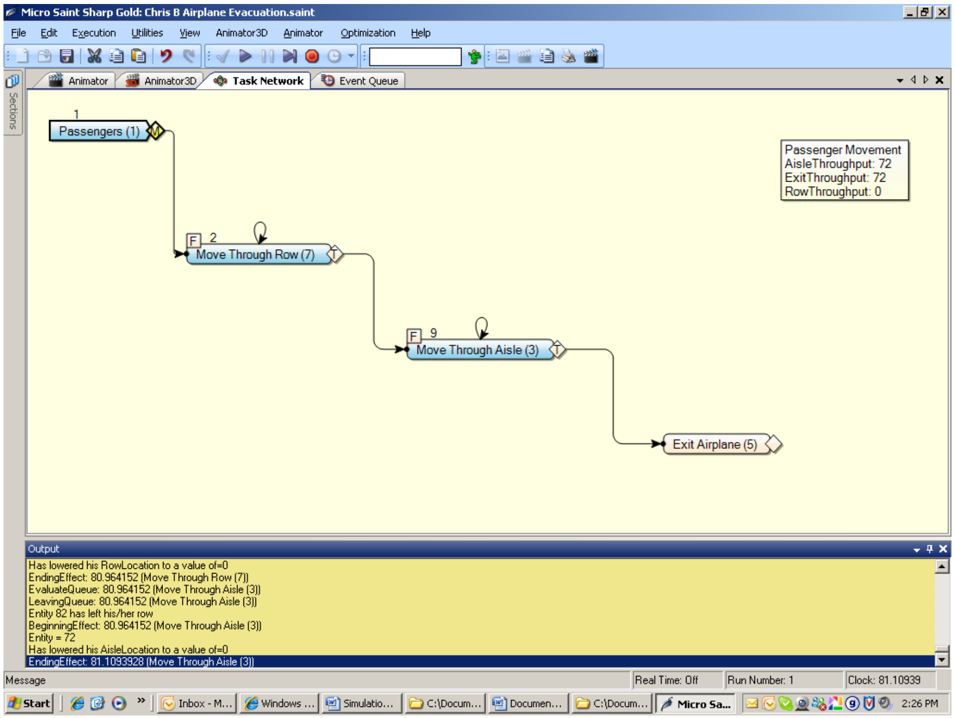

Figure 1 A basic model of evacuation processes

This basic model used exponential “service times” (Mean = 1 – 5 seconds per movement between “spaces”) for each row, aisle and door exit activities and updated the location of a passenger as he /she moved incrementally along a row or aisle, or exited the airplane. Queues were allowed to form if a service “resource” (space) was not available.

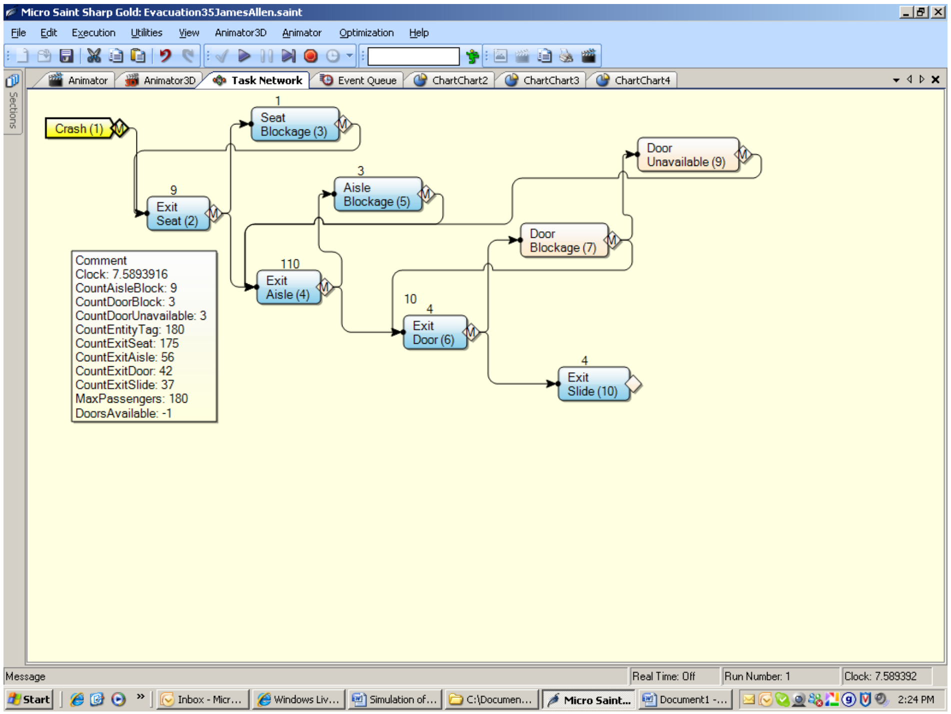

Figure 2 A model of evacuation that allows probabilistic branching to blockage conditions.

The model in Figure2 includes a probabilistic branch to a series (seat, aisle and door) of blockage conditions. Furthermore the door blockage may develop into a “door unavailable” condition, again on a probabilistic basis. Manipulation of the activity throughput times, using a Gamma distribution with means and standard deviations calculated based on the distance of the seat from the aisle and the distance of the seat row from the door. The probabilities of seat, aisle and door blockages were systematically increased from 0.0 to 1.0.

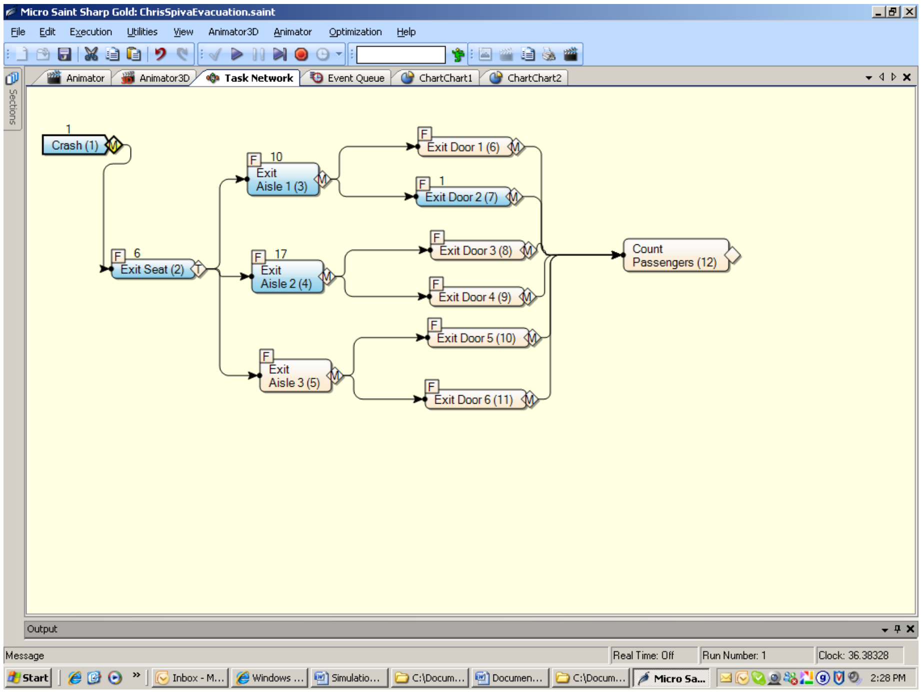

Figure 3 A model that overtly separates the different evacuation pathways

This model explored specific exit path assignments based on seat location. Exit times were related to position in row and location of row. An extension of this model addressed looping back to alternative routes if a resource became unavailable or the waiting time for the resource exceeded an assigned amount.

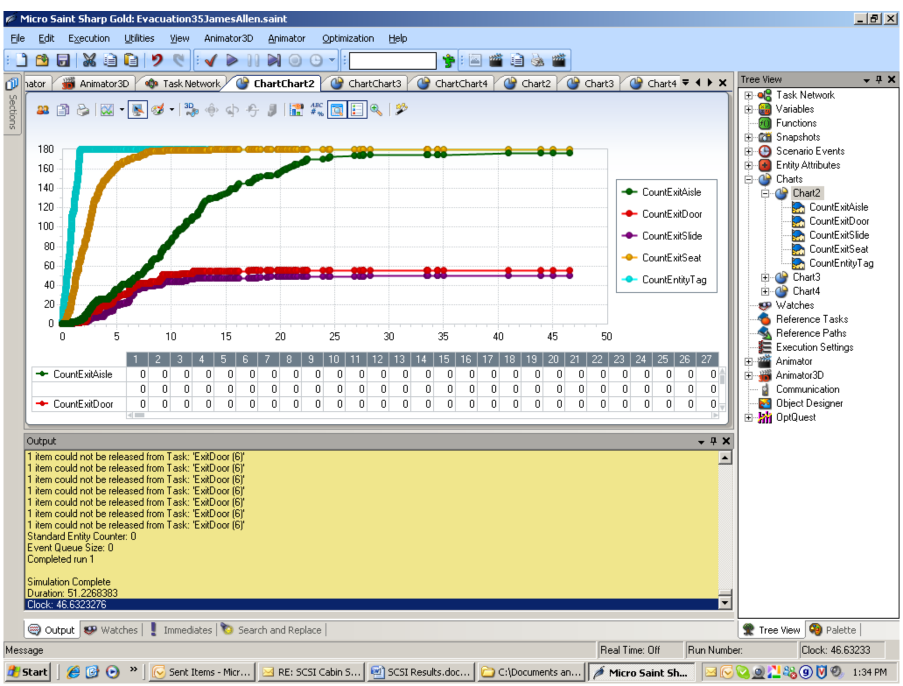

Figure 4 Typical evacuation graphs

Figure 4 shows the timeline of movement from rows, aisles, doors and slides. In this run, it can be seen that there were 180 passengers who all exited the seats after 5 seconds and the aisles after about 25 seconds. However, apparent congestion at the doors indicated that only about 50 passengers exited the doors and slides.

Discussion

The project to date has reviewed a considerable amount of the extensive literature available on this topic and this activity is ongoing. The modeling effort to date has focused on the development of representative models although the scarcity of actual passenger movement times in these situations is a barrier. Despite this shortcoming, and using estimated movement times and movement time variability from evacuation and industrial engineering literature, the models behave as expected. A second aspect of the modeling effort is to develop an adequate representation of passenger behavior and the resulting blockages at various locations in the exit pathway. This project is at the midway stage and further refinements of the simulation will be forthcoming over the next few months. One particular value of this approach is the ability to explore a wide range of conditions, such as movement times and resource (aisles, doors etc.) capacities. This demonstrated a considerable advantage over traditional demonstrations which are costly, dangerous and present only a snap shot of one single set of conditions.

Conclusions

Successful emergency evacuation from large transport category aircraft is affected by the configurations, the conditions (fire, lighting etc.) and the capabilities and behaviors of the flight attendants and passengers. Actual demonstrations are costly, inflexible and possibly dangerous, and furthermore do not give a reliable representation of real events. Conversely computer simulations, given valid models and appropriate data, are safe, inexpensive and flexible so that many replications of different conditions may be investigated. Simulations are therefore valuable aids to the design of hardware and procedures and evacuation performance evaluation. The current project so far has focused on the evaluation of the many factors – configurations, regulations, training, conditions and actual evacuations of large aircraft. Moreover exploratory models have been developed to demonstrate the utility of the simulation approach using Microsoft Excel and Micro Saint Sharp software. It is concluded that this simulation approach is both flexible and useful, warranting further research in the hopes of achieving more robust results.

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