RESEARCH OPPORTUNITIES ON

“AIRCRAFT EMERGENCY EVACUATION”

Presented by:

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3. Passenger Behaviour Analysis
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INTRODUCTION AND OBJECTIVE
A320 runway overrun in Honduras (30/05/08)
Is it realistic to say: **SAFETY IS NO ACCIDENT?**

**Accident** On February 1, 1991
- USAir Boeing 737 (737) and a Sky West Metroliner collided on the runway at Los Angeles International Airport
- 20 Passengers died.
- Two factors caused exit delays by several seconds
Introduction

- 600 passengers die in technically “survivable” accidents.
  - Half due to impact; other half due to other reasons

<table>
<thead>
<tr>
<th>Injuries</th>
<th>Crew</th>
<th>Passengers</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>2</td>
<td>53</td>
<td>-</td>
</tr>
<tr>
<td>Serious</td>
<td>-</td>
<td>15</td>
<td>-</td>
</tr>
<tr>
<td>Minor/none</td>
<td>4</td>
<td>63</td>
<td>1 (Fireman)</td>
</tr>
</tbody>
</table>

Injuries to Person in the Manchester Accident

Manchester Accident
Introduction

- Goal of **Cabin Safety**:
  - In Flight
  - In a **Crash Landing**

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**Diagram Explanation**

- **Prevention** and **Airworthiness**
- **Recovery**
- **Attenuation** and **Crashworthiness**

**Accident**

- **Stable & Safe**
- **Non Stable & Unsafe**
Introduction

- What is Cabin Safety?

- Focus of the Study: Emergency Evacuation

Impact Protection  Fire Survivability  Emergency Evacuation

- Focus of the Study: Emergency Evacuation
Main safety issues pertaining to emergency evacuations are as follows:

- Certification issues.
- Operational aspects
- Communication
- Effectiveness of evacuation equipment
- Air carrier and Airport Rescue & Fire Fighting (ARFF)
- Behaviour aspect during egress
- Interaction
AIRCRAFT EVACUATION EMERGENCY:

ANALYSIS OF MAIN ISSUES & REGULATION
Main Factors affecting Aircraft Emergency Evacuation:

- Configurational
- Environmental
- Procedural
- Behavioural
AIRCRAFT EVACUATION EMERGENCY: MAIN ISSUES

- Emergency Evacuation Demonstration for Certification

A 380 Emergency Evacuation Demonstration
Emergency Evacuation Demonstration for Certification

- To provide a benchmark
- Other acceptable means can be judged sufficient rather than conduct a new test
- Comply with specific requirements
AIRCRAFT EVACUATION EMERGENCY: MAIN ISSUES

- **Limitation of Full Scale Demonstration**
  - Reduced acquired knowledge
  - Partial lack of *realism*
  - Range of *injuries*
  - Hazardous and costly
  - Only once
  - Absence of *behavioural aspects*

- Provided consistent level of safety
Emergency Evacuation: Operational View

- Clear and precise procedures
  - Actual efficiency and training
  - Clarity of the rules and regulations
  - Adequacy of the existing regulations
- Crew Resources management (CRM)
  - “Passenger flow control”
  - Communication problem

Communication between Crew members
AIRCRAFT EMERGENCY EVACUATION: MAIN ISSUE

• USEFULNESS OF AIRCRAFT EVACUATION MODEL
  - Evacuation Certification Models
  - Accident/Incident Reconstruction Models
  - Modelling for Cabin Crew Training
PASSENGER BEHAVIOUR ANALYSIS
AIRCRAFT EMERGENCY EVACUATION

- **Passenger Response** during stress situation

  - Fear, Anxiety
  - Other Characteristic
  - Presentation of Safety Information
  - Passenger Training
  - Cultural and Language differences
  - Survival Perception
AIRCRAFT EMERGENCY EVACUATION

- Passengers Psychological Aspects at Egress
  - Individual
  - Interactions
  - Group

Competitive Behaviour
PASSENGER BEHAVIOUR ANALYSIS

Passengers Behaviour Aspects in Aircraft Evacuation

Queuing Behaviour

Herding Behaviour
Cabin Crew Behaviour in Aircraft Evacuation

Duality of Safety and Service Roles
PASSENGER BEHAVIOUR ANALYSIS

- Crew Members Decision Making Behaviour:
  - Good Understanding
  - Communication
  - Crew Synergy
  - Stress

Communication Barrier between Flight Crew and Cabin Crew
PASSENGER BEHAVIOUR ANALYSIS

- Interaction Between Crew Members & Passengers
  - Exit Row Passenger Task
  - Role of Pre-flight Briefing and Safety Briefing:
  - Communications With Ground Teams

<table>
<thead>
<tr>
<th>Reason</th>
<th>Number of Passenger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saw it before</td>
<td>247</td>
</tr>
<tr>
<td>It’s basic knowledge</td>
<td>70</td>
</tr>
<tr>
<td>Others</td>
<td>44</td>
</tr>
<tr>
<td>Reading</td>
<td>28</td>
</tr>
<tr>
<td>Sleeping</td>
<td>15</td>
</tr>
<tr>
<td>Obstructed View</td>
<td>10</td>
</tr>
<tr>
<td>Distracted by Other people</td>
<td>8</td>
</tr>
<tr>
<td>Distracted by Children</td>
<td>2</td>
</tr>
<tr>
<td>Listing to music/tapes</td>
<td>1</td>
</tr>
<tr>
<td>Too Long</td>
<td>1</td>
</tr>
</tbody>
</table>

Reasons: Passengers not watching entire pre-flight safety briefing
Conclusion

- Very complex phenomenon

- Threat to life
  - Complexity of the cabin environment

- Reaction of passengers

- More research required as no clear rules exist
AIRCRAFT EVACUATION MODELS
AIRCRAFT EMERGENCY EVACUATION

• Computer Based Evacuation Models

ARCEVAC model – Graphical Representation
• **Modelling Methodologies**: Two categories of model

  - Consider human movement
  - Link movement with behaviour

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**Air EXODUS Model**

**Discrete Element Method**
AIRCRAFT EMERGENCY EVACUATION

• Aircraft evacuation models
  › Cabin space representation, passengers modelling and behaviour perspective.
  › General Purpose Simulation System (GPSS)
  › Gourary Associates (GA) model
  › AIREVAC/ARCEVAC model
  › Macey’s Risk Assessment Model
  › Oklahoma Object Orientated (OOO) model
  › EXODUS Model
  › Robbin’s Discrete Element Method (DEM)
• Modelling Approaches for Emergency Evacuation

- Three modelling approaches
  - Optimisation Models
  - Simulation Models
  - Risk Assessment Models

- Essentially- Enclosure geometry, Passengers and Crew behaviour
• **Cabin Representation**

  ‣ Cabin space is an **important characteristic** of a model

  ‣ Cell networks

  ‣ Continuous space
AIRCRAFT EMERGENCY EVACUATION

• **Passenger Representation**

• **Microscopic**

• **Macroscopic**

Submodels Interaction (MACEY)
• Behaviour Perspectives
• Appropriate methods for determining passenger’s behaviour

- Functional analogy behaviour
- Implicit behaviour
- Rule based behaviour
- Artificial based behaviour
- No behavioural component.

Model-Behavioural Traits-Individual Passengers

Functional Analogy
Main Application Fields

- Simulation of the 90-seconds trial (4 models)

<table>
<thead>
<tr>
<th>Aircraft Type</th>
<th>Seats</th>
<th>Actual Time</th>
<th>Model Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>A320</td>
<td>179</td>
<td>79s</td>
<td>85.0s</td>
</tr>
<tr>
<td>A321</td>
<td>224</td>
<td>-</td>
<td>81.2s</td>
</tr>
<tr>
<td>B757</td>
<td>219</td>
<td>73.5s</td>
<td>77.8s</td>
</tr>
<tr>
<td>B737-800</td>
<td>189</td>
<td>-</td>
<td>91.8s</td>
</tr>
</tbody>
</table>

Validation history of Macey Model

Screen shot of the output from Macey’s model
• Simulation of real accident scenarios (3 models)

- Another Area Cabin Crew Modelling (No Models currently developed)

Fire Hazards During Modelling
- Different modelling methodologies to represent evacuation model (Six different aircraft evacuation models).

<table>
<thead>
<tr>
<th>Model</th>
<th>Objective of Study</th>
<th>Cabin Representation</th>
<th>Behaviour Modelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPSS</td>
<td>SIMULATION 90-SECONDS</td>
<td>COARSE</td>
<td>INDIVIDUAL AND STOCHASTIC</td>
</tr>
<tr>
<td>GA</td>
<td>ANALYSIS OF REAL EMERGENCY OCCURENCES</td>
<td>DETAILED</td>
<td>INDIVIDUAL AND STOCHASTIC</td>
</tr>
<tr>
<td>ARCEVAC</td>
<td>SIMULATION FOR BOTH</td>
<td>DETAILED</td>
<td>INDIVIDUAL STOCHASTIC AND</td>
</tr>
<tr>
<td>EXODUS</td>
<td>SIMULATION FOR BOTH</td>
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<td>MACEY</td>
<td>RISK ASSESSMENT FOR BOTH</td>
<td>DETAILED</td>
<td>INDIVIDUAL DETERMINISTIC AND</td>
</tr>
</tbody>
</table>

Aviation Evacuation Model Methodologies
• Conclusion

▷ Different modelling attempts
  – Represent realistically behaviour of passengers
  – Calibrating and validating
  – “black box” character of the models
  – Large amount of data
  – Introduce new data processing techniques such as Fuzzy representation and Logic
PROPOSED APPROACH FOR EGRESS MODELLING (SEEM-F)
PROPOSED APPROACHES FOR EGRESS MODELLING (SSEM-F)

Enhanced Solution Approach through Fuzzy Logic

- Major difficulty in modelling aircraft emergency evacuations
  - Overall behaviour of passengers and crews during emergency evacuation
  - Physical representation of passengers competing with each other

- Fuzzy Logic is a convenient way to map a linguistic input space into a numerical output space

- Powerful tool to deal quickly and efficiently with?

- Fuzzy modelling can provide a good flexibility in the representation of individual behaviours
PROPOSED APPROACHES FOR EGRESS MODELLING (SSEM-F)

• Conceptual model SEEM-F (Simulation of Emergency Evacuation Model with Fuzzy techniques).

• Usefulness:

  ▶ Not only to contribute to the validation of certification exercise
  ▶ Optimizing positioning of the crewmembers
  ▶ Represent uncommon but realistic situations such as:
    – Large groups of scholars or of elderly people
    – On-going tentative of on board hijacking
    – Bomb alert in a grounded aircraft
    – Emergency evacuation after ditching
    – Emergency evacuation in other very hostile environments
• General features of SEEM-F
  - Simulator should be able to integrate in a complex process physical and behavioural considerations
    - Physical environment
    - Health state of passengers and crews
    - Mental state of passengers and crews
  - Mental state: passengers and crews will perceive differently their current situation
  - Specificity of SEEM-F no previous model adopts fuzzy logic as a driving tool for passengers and crew behaviour
PROPOSED APPROACHES FOR EGRESS MODELLING (SSEM-F)

• General features of SEEM-F

Interactions between Passengers, Crew, Cabin and Hazard
PROPOSED APPROACHES FOR EGRESS MODELLING (SSEM-F)

• General features of SEEM-F

- Provides an instant situation of the emergency evacuation of a grounded aircraft (here case of a tail fire progressing forward).

- Crew members are positioned according to airline emergency procedures:

Emergency Evacuation situation
PROPOSED APPROACHES FOR EGRESS MODELLING (SSEMF)

- General organisation of SEEM-F
PROPOSED APPROACHES FOR EGRESS MODELLING (SSEM-F)

• Modelling of Crew

• Different types of cells considered
  - Economy class seat cells
  - Business class seat cells
  - Economy class aisle cells
  - Business class aisle cells
  - Emergency exit rows cells
  - Common areas cells
  - Main exit cells

Different types of cabin cells
PROPOSED APPROACHES FOR EGRESS MODELLING (SSEM-F)

• Accessibility matrix $A$ provides the information about accessibility from one cell to the others by passengers and crews

$$A(i, j) = 1 \text{ if cell } j \text{ is reachable from cell } i, \quad A(i, j) = 0 \text{ otherwise}$$

• Even if the capacity of a cell is given by an integer number, its occupancy can be represented using fuzzy numbers.

Example of cell of capacity equal to three and crossing by a passenger.
• Disaster Modelling
  ▸ Cabin cells are classified as:
    - Undamaged
    - Partly damaged but transitable
    - Destroyed or non transitable
  • Propagation models of the present hazards:

\[
F(t), \ t \in \{t_0, \ t_0 + \delta t, L, \ t_0 + k \ \delta t, L, \ t_f\} \\
S(t), \ t \in \{t_0, \ t_0 + \delta t, L, \ t_0 + k \ \delta t, L, \ t_f\} \\
W(t), \ t \in \{t_0, \ t_0 + \delta t, L, \ t_0 + k \ \delta t, L, \ t_f\}
\]

Propagation of fire (red) and smoke (blue)
Passenger and Crew Generation

- Passengers are classified according to different parameters, which have consequences on their behaviour during egress.

- Each passenger is assigned a seat through a random process:
  - Individual
  - Leader of a group

Example of Fuzzy Occupancy in a cell
PROPOSED APPROACHES FOR EGRESS MODELLING (SSEM-F)

• Passengers and Crew Health Modelling
  
  ‣ Passenger and crewmember are assigned with a state
  ‣ State does not change except if new environment conditions appear

![Diagram showing the evolution of passengers and crew health states](image)
PROPOSED APPROACHES FOR EGRESS MODELLING (SSEM-F)

• Passengers and Crew Processing

- At each time period each passenger (alive and inside the cabin)
- Determine his new health state, exit choice, new position
- Represent realistically queue processing at the different exits
  
  - Several subsets of passengers are defined at period $t$, their instantaneous characteristic property is to have a common exit as target
  
  - Each subset the passengers are ranked according to their increasing distance to the common target exit

- Passengers are processed according to their rank within the subset
- Same procedure is applied for crewmembers present in the cabin
• Behaviour Modelling

- Main decisions taken by passengers and crewmembers before and during emergency evacuation

Decision sequences during emergency evacuation
• **Behaviour Modelling**

• Passengers behaviour *in the cabin, at the exit, on the slide, and on the ground*

  ‣ Performance *in the cabin*

  ‣ Performance *at the exit*

  ‣ Performance *on the slide*

  ‣ Performance *on the ground*
PROPOSED APPROACHES FOR EGRESS MODELLING (SSEM-F)

• Crew member **Positioning before Emergency Evacuation**

• **Objective:** Crewmembers take position

• **Description:**
  - Positioning of Crew member **at the time of event**
  - Delay due to communication between the crew members
  - Operational state of cabin communication system
  - Other delay to reach the planned exit depends on:
    - State of injury of the cabin crew
    - State & length of the path leading to that planned position

• Passengers queues can form before
  - Opening of the exit doors introduces new

• Delays are chosen randomly according to given probability
• **Crew member Positioning before Emergency Evacuation**

  • **Objective:** Crewmembers take position

  • **Description:**
    - Positioning of Crew member at the time of event
    - Communication between the crew members (delay) & Operational state of cabin communication system
    - The state of injury of the cabin crew & State and the length of the path leading to that planned position

  • Passengers queues can form before
    - Opening of the exit doors introduces new delay

  • **Exceptions:** Crewmember is dead or severally injured & planned position is unreachable for the cabin crew

  • **Post-conditions:** The cabin crew has reached planned position
• **Crew members way out choice**

  • **Objective:** Crew makes a choice with respect to the exit to propose to passengers

  • **Pre-conditions:** Crewmember wounded or dead & if choice by crewmember unfeasible

  • **Description:** Crewmember makes a choice for the exits based on
    - Relative position with respect to the available exits
    - Difficulty to access effectively feasibility & availability of exits
    - Reachability to each of these exits & depends on factors:
      - Dangerousness of the path
      - Congestion of the path leading to the exit;
PROPOSED APPROACHES FOR EGRESS MODELLING (SSEM-F)

- **Crew members way out choice**

  - Expert module based on fuzzy logic is designed to take into account realistically all these factors:

  ![Expert Decision Module for Crew Exit Choice](image)

  - **Post-conditions**
    - Possible exits are identified
    - Crewmembers give directives to use these exits
    - Path is assigned to the crewmember towards his selected exit
• **Passengers decision to leave their seat**

  • **Objective:** Passenger makes choice to leave seat to start egress motion
  • **Pre-conditions:** Passenger is able to move
  • **Description:** Make up mind to prepare egress motion
    ‣ Indications by cabin crew
      – Are imperative & Cabin crewmember must be “not far” from the passenger if cabin communication is out
    ‣ State of injury, Difficulty to access the criticality of the situation, Apparent choice made by neighbours
  • **Post-conditions:** Passenger has got up & ready to start emergency evacuation.
  • **Exceptions:** Dead or not able to make choice
• **Passengers way out choice**
  
  • **Objective:** Passenger makes a choice with respect to the exit
  
  • **Pre-conditions:** Able to move, has not made a choice & choice made appears unfeasible to him
  
  • **Description:** Makes a choice for his exit
  
  ‣ Indications by cabin crew if any, Imperative & Cabin crewmember must be “not far” from the passenger if cabin communication is out
  
  ‣ Relative position with respect to the available exits
  
  ‣ Difficulty to access effectively the feasibility of the path & availability of exits
  
  ‣ Reachability of each of these exits
  
  ‣ Apparent choice made by neighbors
PROPOSED APPROACHES FOR EGRESS MODELLING (SSEM-F)

- **Passengers way out choice**

  ![Diagram showing expert decision module for passenger exit choice](image)

  **Expert Decision Module for Passenger Exit Choice**

- **Post-conditions:** Passenger has chosen an exit & dependents (group) & path is assigned to passenger since it is supposed that there is a single possible path from his present position to the chosen exit
• Passenger motion towards exit

❯ **Objective:** Determine position of given passenger at time \( t + dt \).

❯ **Pre-conditions:** Passenger has mobility

❯ **Description:** Position of a passenger is given by a fuzzy set

Representation of the fuzzy position of a passenger
PROPOSED APPROACHES FOR EGRESS MODELLING (SSEM-F)

• **Passenger motion towards exit (Cont…)**

• Passengers in a same cell may try to reach different exits

• Speed of displacement of passenger depends on different things
  
  - State and nature of the current passenger
  - Qualitative reasoning (fuzzy logic), to define a potential speed measured in fractions of cells per second
  
  - Position of the passenger in the cabin (cells)
  - Qualitative reasoning (fuzzy logic) is used to defined the position increment

• **Post-conditions:** Passenger has got either a new position or a recovery delay at his current position
• Decision case: Passenger rush out

• Objective: Passenger performs extraction from aircraft

• Pre-conditions: Passenger positioned before an emergency exit

• Description:
  - If passenger is alone proceeds without any delay
  - Duration of his extraction depends: State of injury, age, nature of the crash, state and occupancy of the slide raft

• Passenger is a member of a group, the group gathers in front of the exit and start extraction one after the other.

• Exceptions: External event

• Post-conditions: Passenger achieved or remains inside the aircraft
• **Crew Member motion towards exit**

• **Objective:** Determine the position of a crewmember

• **Pre-conditions:** Crewmember is alive and not seriously injured.

• **Description:**
  - Crewmember remains at a fixed position near a feasible exit
  - Crewmember tries to escape the exit after last passenger

![Diagram showing membership function](image)

Representation of the position of a crewmember by square fuzzy
• Crew member leaves behind passenger to common exit

• Speed of displacement of a crewmember:
  – State of injury, Vision of the scene, Speed of the preceding passenger or crew member if any, Nature of the cell

• **Post-conditions:**
  ‣ Crewmember remains at the same location, or has got a new position
  • Crew member tries to use the same exit
• **Crew member rush out**

• **Pre-conditions:** Crewmember positioned right before an emergency exit & no passenger left to exit

• **Description:** Proceeds to evacuate without any delay
  
  ‣ Duration of evacuation depends on:
  ‣ State of injury
  ‣ Nature of the crash
  ‣ State and occupancy of the slide raft

• **Post-conditions:** Crew member achieved evacuation or remains still inside
• **Scenario composition**

• Different scenarios must fix parameters related with:
  ‣ Composition and state of the cabin at the initial time (start of simulation) and further
  ‣ Composition and state of passengers at initial time
  ‣ Composition and state of crew at initial time

• Behavioural parameters **may be fixed to characterize different assumptions about passengers and crews comportment**

• Should be run many times so that statistical data is generated and confidence intervals can be built for better assessing the performance of the emergency evacuation system.
• **Simulation Evaluation**

  - For each simulated scenario, a visualization of the whole process is possible, but may be more important are the many performance indexes that can be computed. They are related with:

  - Delays

  - Physical damage to passengers and crews:
• Conclusion

› Conceptual model of the proposed emergency evacuation simulator named SEEM-F

› Egress cornerstone decisions have been identified and linked together

› Quite favorable to the design of realistic decision processes, which is a multidisciplinary exercise where Psychology takes a central place

› Importance:
  – Simulation of dynamical systems, involving human behaviour in complex environments is a never-ending task
  – New scenarios are tackled since in general they induce new improvements to broaden the scope of application of the simulator
CONCLUSION AND FUTURE WORK
AIRCRAFT EMERGENCY EVACUATION

- Improvement of safety within air transportation aiming with priority to accident avoidance
- Cabin Safety (impact protections, fire survivability, aircraft emergency evacuation measures)
- Importance of development of aircraft emergency evacuation technology
- Usefulness of simulation tools (building and ship evacuations)
- Design of Emergency Evacuation Model for aviation have been considered in this thesis
- New modelling approach, based on the use of fuzzy sets and fuzzy logic decision-making has been proposed
- Coherent way to deal with the critical issues of modelling passengers and crews decision making and resulting passengers motions during egress
• Well adapted to catch complex decision-making processes where behavioural aspects have a central importance.

• To develop acceptable egress simulation models, is the non-availability of accurate quantitative or qualitative information on human performance during emergency evacuation situations.

• Device may be activated by the cabin crew or automatically from the alarm systems.

• Reactive guidance systems for passengers either at the personal level or by cabin sections.

• Developed modelling tool for training of cabin crews.
FOR MORE DETAILS PLEASE CONTACT:

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