Monte Carlo Simulation of Aircraft Evacuation Efficiency

Alex Zeng, Erika Lee, Jimmy Liu

IS 597

Background

Serious accident

- Time: 2 January 2024
- Location: Haneda Airport, Tokyo, Japan
- The first major accident and hull loss of an Airbus A350

Successful evacuation

- All 367 passengers and 12 crew members on board evacuated through 3 of the plane’s 8 evacuation slides.
- The plane was fully evacuated 20 minutes after landing.

Reference: https://en.wikipedia.org/wiki/2024_Haneda_Airport_runway_collision

Lesson learned: Insights and Questions

Insights incorporated in design

- **Exit Availability:** Not all the exits will be available during the accident.
- **Crew's quick response and passengers' discipline: no one left with hand luggage**
- Variety of Passengers might be slower in evacuation (due to the physical characteristics, panic level, other factors like foreigners' communication issue)

Questions to be tested

- **90 seconds rule (FAA) VS Full Evacuation within 20 minutes**
- **What factors should arise crew members' awareness? Higher occupancy rate? Groups of people who might need additional assistance?**

Reference:**90 seconds rule** https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_25.803-1A.pdf

Literature Review

- **Ching-Jui Chang et al. 2007** considered the narrow body vehicle (A320) and wide body vehicle(Boeing 777), as well as various doors' blockage scenario in their simulation design.
- **Yu Liu et al. 2014** pointed out the passengers' physical characteristics such as waist size, gender, age, and disabilities will statistically impact individual's movement and egress times.
- **A.Tinaburri 2022** mentioned how important the trained and active staff could be during the evacuations where occupants might need assistance.

Simulation Design

Randomized Variables

Configurable variable

Real Scenario	Baggage Delay Exit Availability	**Our Design** Emergency Level
Literature Review	Physical Characteristics Panic Occupancy rate	Different classes, speed_factor
Real Aircraft Seat Map	Aircraft seat configuration	Seat Distribution

Assumptions & Simplification

Passenger Seating and Behavior

- **Passengers remain in their seats during landing** and only evacuate after receiving crew instructions, no pre gathering near exits.
- **Passengers evacuate in an orderly manner,** using the aisle, without resorting to unconventional methods like climbing over seats.
- **Passengers will line closely next to each other if any jam happens.**
- **Passengers will evacuate individually, no group dynamics considered.**

Crew Interaction

- **Crew members have sufficient time to communicate evacuation instructions to all passengers**, including directing specific rows to the nearest exits (e.g., some rows to evacuate through the middle exits).

Airplane layout

- **Airplane layout based on A320 and Boeing 777**
- **the left and right sides are generally symmetrical**

Configurable Variables

Variable	Description
rows	Total rows in the plane
seats_per_row_front	Number of seats per row in first class/business class
seats_per_row	Number of seats per row in the economy section
front_rows	Number of rows in first class/business class
exits	List of exit row positions
speed_factor	Front rows movement speed (80% of normal time)
proportion_old	Percentage of elderly passengers (30%)
emergency_level	Severity of emergency situation (0.0–1.0, with 0.5 being medium)
occupancy_rate	Percentage of seats occupied (80%)

Randomized Variables

Passenger Characteristics

- **age**: Young or Elderly
- **panic_level**: 0-1 scale ~ Uniform
- **baggage_delay**: 0-1 impact ~ Uniform
- **move_time**: Young: 1-4 sec/unit; Elderly: 8-10 sec/unit ~ Uniform

Seat Occupancy

- Seat Distribution

Formulas

Base moving speed

$$moving\_speed = baggage\_delay + (panic\_level \times move\_time \times row\_speed\_factor \times distance\_to\_exit)$$

Emergency level

1. Panic Level:

$$panic\_level = \min(panic\_level \times emergency\_level, 1)$$

where $panic\_level \in [0,1]$ and $emergency\_level \in [0,1]$

2. Baggage Delay:

$$baggage\_delay = baggage\_delay \times (1 - emergency\_level \times 0.5)$$

decreases by up to 50% at maximum emergency level

3. Movement Time:

$$move\_time = move\_time \times (1 - emergency\_level \times 0.2)$$

decreases by up to 20% at maximum emergency level

Visualization

Individual Time (left)

The time needed for of an individual to evacuate if there's only him/her/they on the plane

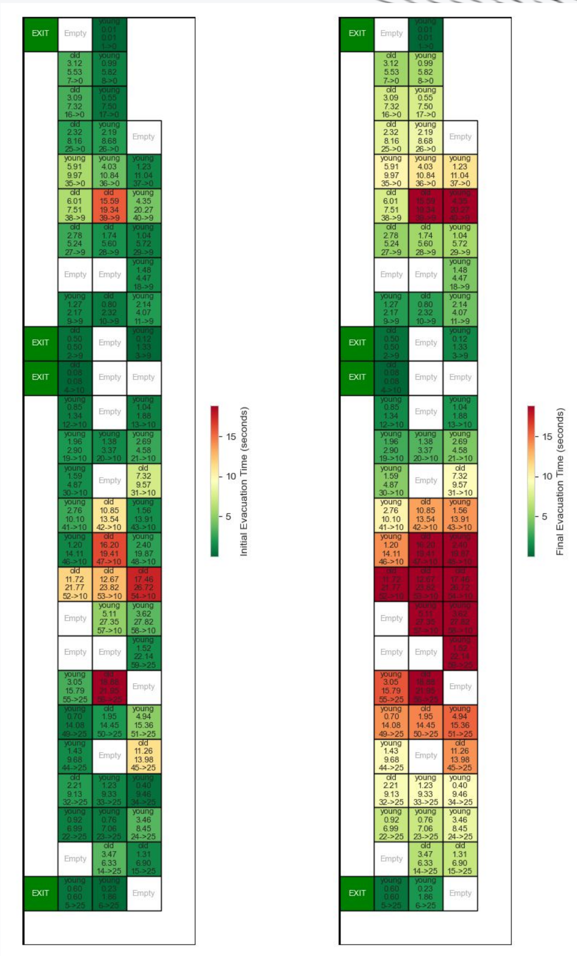
Final Time (right)

After considering the time needed for passengers in front of you in the line, your final evacuating time needed.

Coloring

Green: Fast, Red: Slow, Pale: Moderate, White: Empty

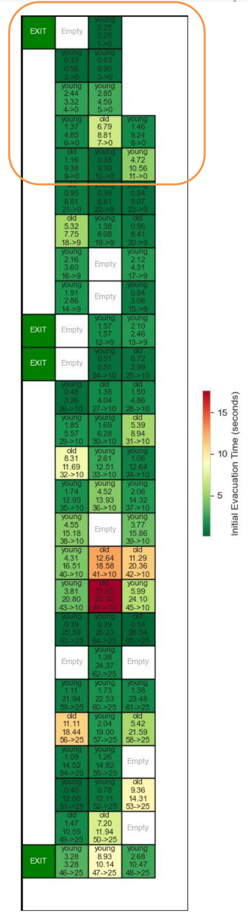
Exits are shown in green with white EXIT sign



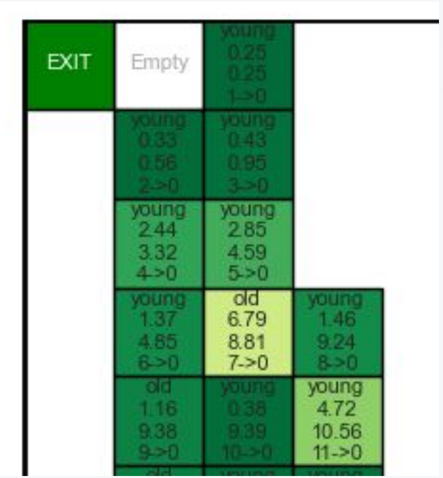
Seat map for A320

Evacuation strategy

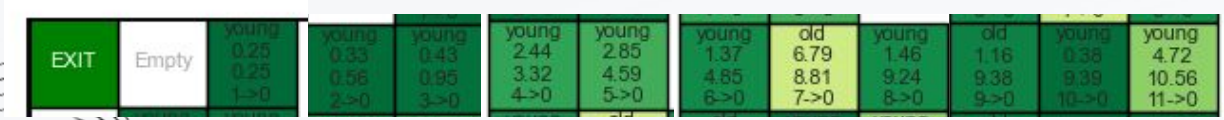
1. **Assigned seats**



2. Section near exit 0



3. Lined up for the exit



Downpits

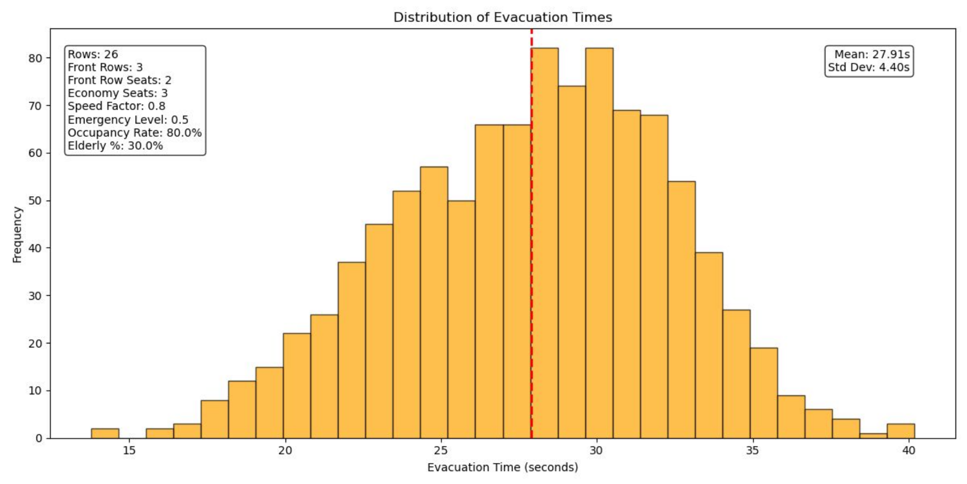
Congestion

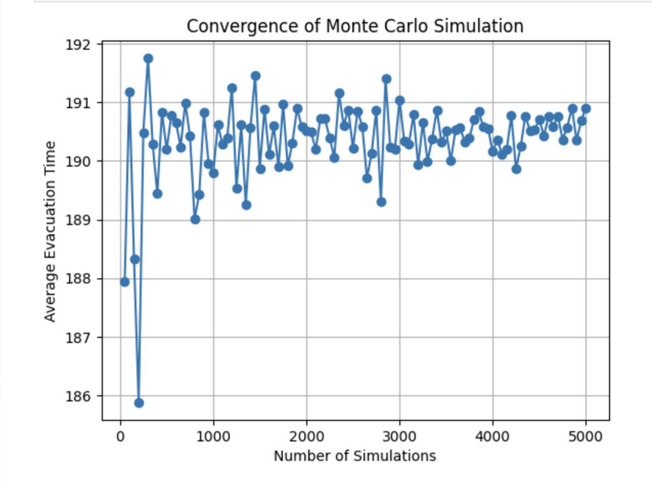
People would be blocked by slower people in front of them.

Lack of dynamic movement

After assigned to a exit at the start, passengers cannot move to other exits under any circumstances

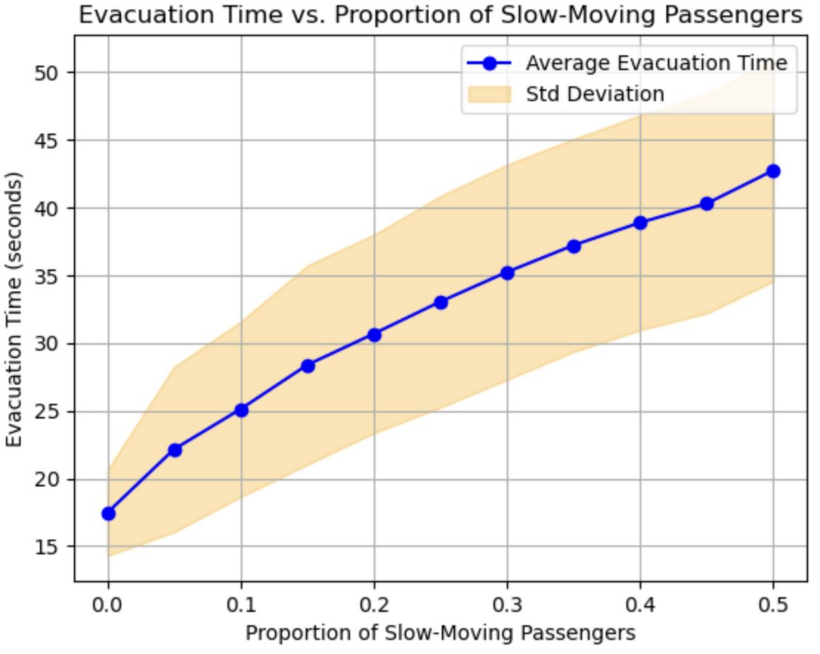
Model Validation





Hypothesis 1

H1: Increased proportion of slow-moving passengers significantly extends evacuation time due to slower movement



ANOVA Results:

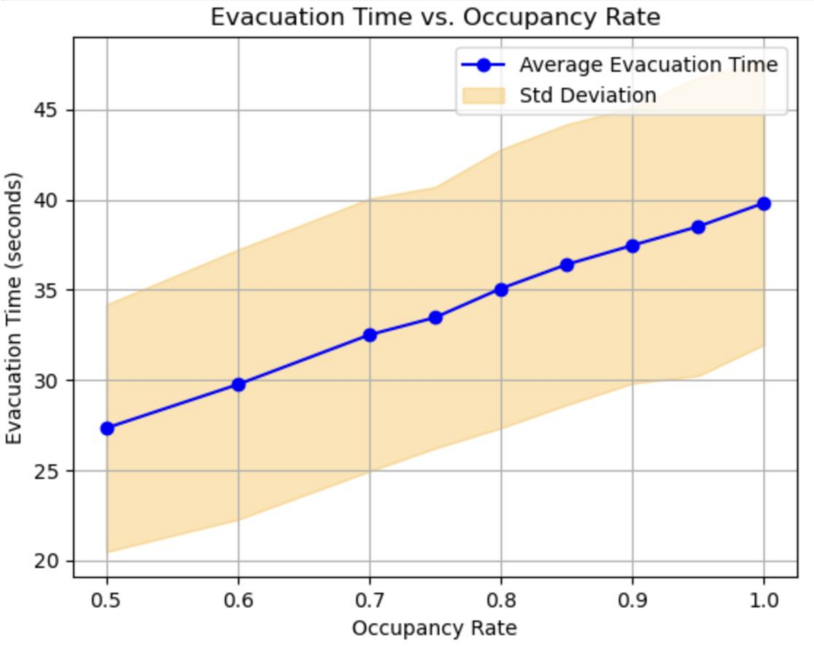
F-statistic: 1203.9991

p-value: < 0.0001

Evacuation time increases significantly with the proportion of slow-moving passengers

Hypothesis 2

H2: Higher seat occupancy leads to longer evacuation times due to congestion



ANOVA Results:

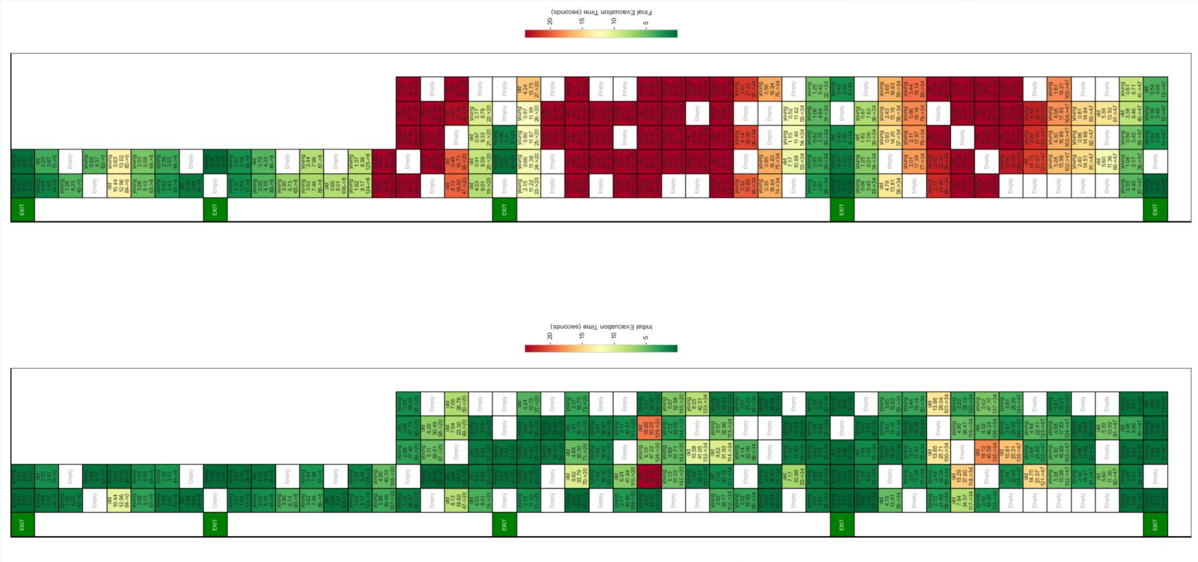
F-statistic: 120.7862

p-value: < 0.0001

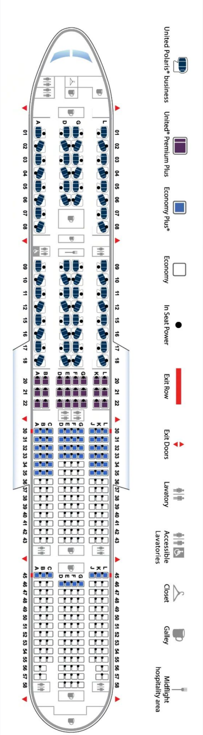
Higher occupancy rates significantly impact evacuation time

Hypothesis 3

H3: Larger aircraft (e.g., Boeing 777) require more evacuation time compared to smaller aircraft (e.g., A320)



Seat map for Boeing 777



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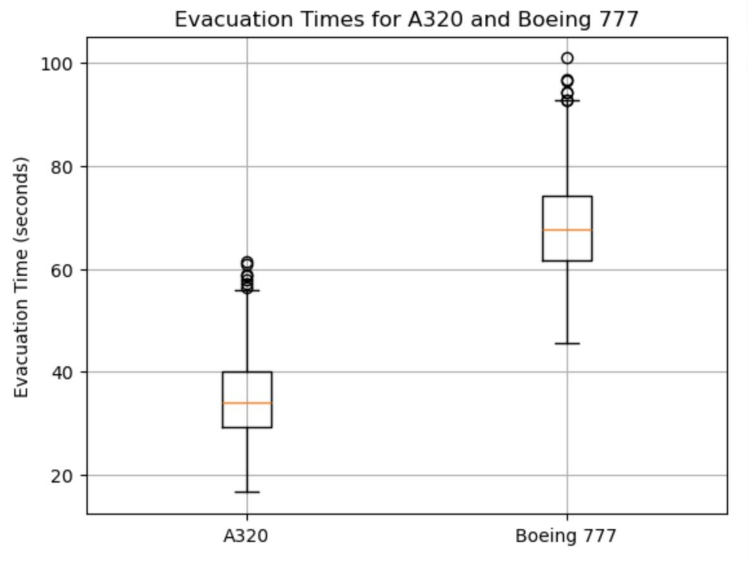


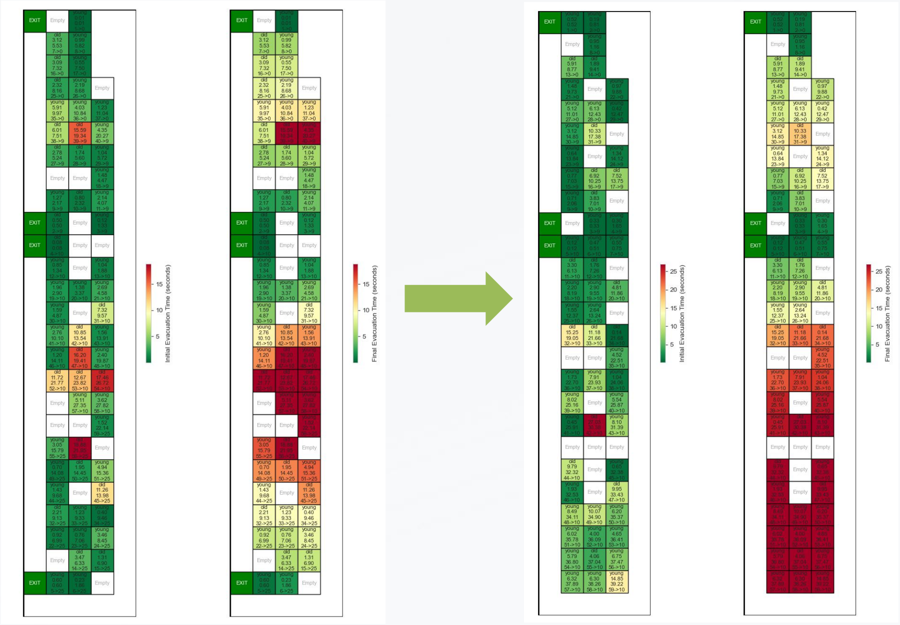
Average Evacuation Time:
A320: 34.95 sec
Boeing 777: 68.12 sec

T-test Results:
T-Statistic: -89.60
P-Value: < 0.0001

The evacuation time for the Boeing 777 is significantly longer than for the A320

Hypothesis 4

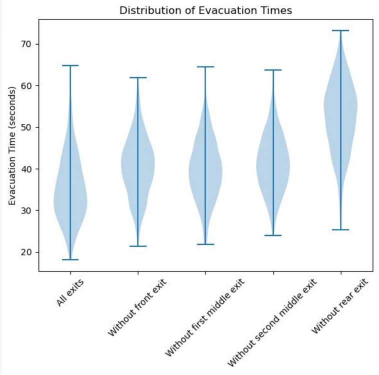
H4: With 25% of exits disabled (1 out of 4), the evacuation time will increase by more than 25%, indicating a non-linear relationship between exit availability and evacuation efficiency.

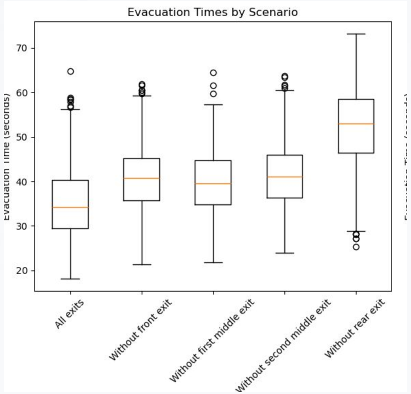


Hypothesis 4

H4: The evacuation time will increase by more than 25%...

Scenario	Mean Time	Std Dev	% Increase	p-value	Effect Size (Cohen's d)
Without front exit	40.51s	7.29s	15.0%	0.0000	0.70 (medium)
Without first middle exit	39.75s	7.22s	12.8%	0.0000	0.60 (medium)
Without second middle exit	41.29s	6.96s	17.2%	0.0000	0.81 (large)
Without rear exit	52.36s	8.57s	**48.6%**	0.0000	2.08 (large)





Conclusion

Hypotheses

- H1: Evacuation time increases significantly with the **proportion of slow-moving** passengers
- H2: Higher **occupancy rates** significantly impact evacuation time
- H3:The evacuation time for the **Boeing 777** is significantly **longer than** for the **A320**
- H4: The **rear exit is most critical** for the A320's evacuation efficiency, as its failure leads to the largest increase in evacuation time (exceeding 25%) compared to other exit closures.

Future Work

Panic Spread

Model how high panic levels in one passenger influence others nearby

Crowd Dynamics

Incorporate group evacuation dynamics

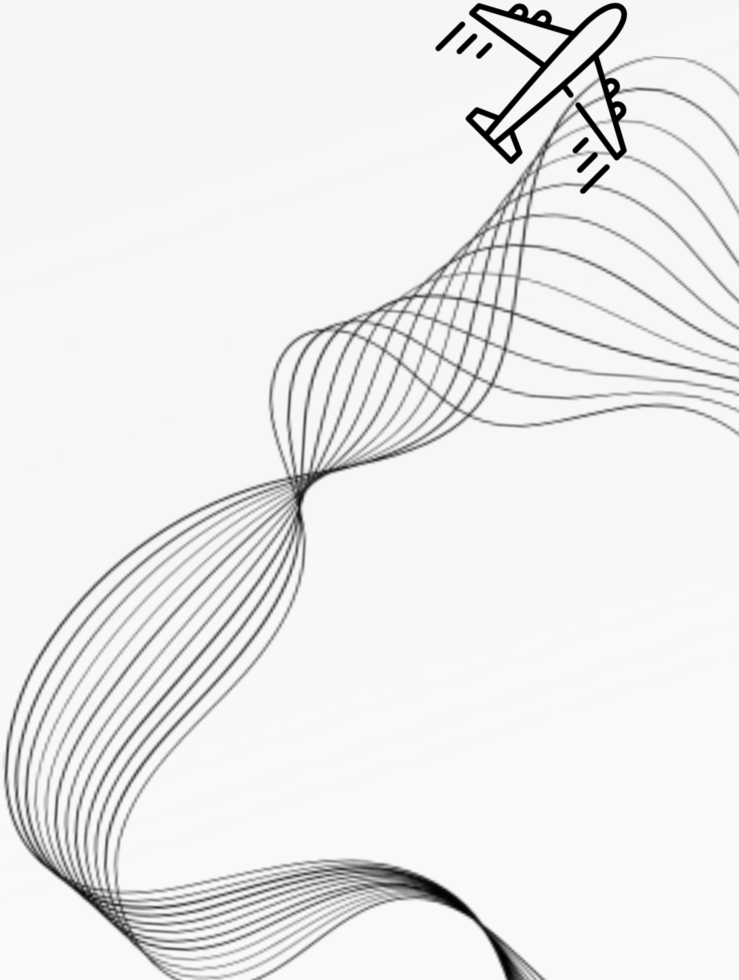
Injured Passengers

Simulate scenarios where injured passengers are unable to evacuate independently

Non-Compliant Behavior

Account for chaotic behaviors like climbing over seats, potentially causing delays

THANKS FOR LISTENING



Appendix

Github: https://github.com/jimmystereo/2024Fall_projects

Reference:

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