Florida HEALTH

"STORMSHIELD": A STRATEGIC MODEL FOR SAFE PATIENT RELOCATION AND DISASTER READINESS

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THE CONTEXT

Florida faces an average of **1-2** hurricanes per year, with some categorized as highly destructive (Category 4 or 5)

Hurricanes in Florida result in hundreds of injuries and dozens of fatalities annually (average: ~**64** deaths per year)

Vulnerable populations, especially ICU patients, face significant evacuation risks.

Economic Loss is estimated at $**17** billion, including damages to healthcare infrastructure.

THE CURRENT RESPONSE ~ HOSPITAL CHALLENGES

No Relocation:

- Overwhelmed emergency services due to lack of proactive evacuation measures.
- **Patients with critical needs (e.g., life-support systems) face life-threatening disruptions.**
- Average ICU utilization during hurricanes can exceed **85%**, leading to care delays.

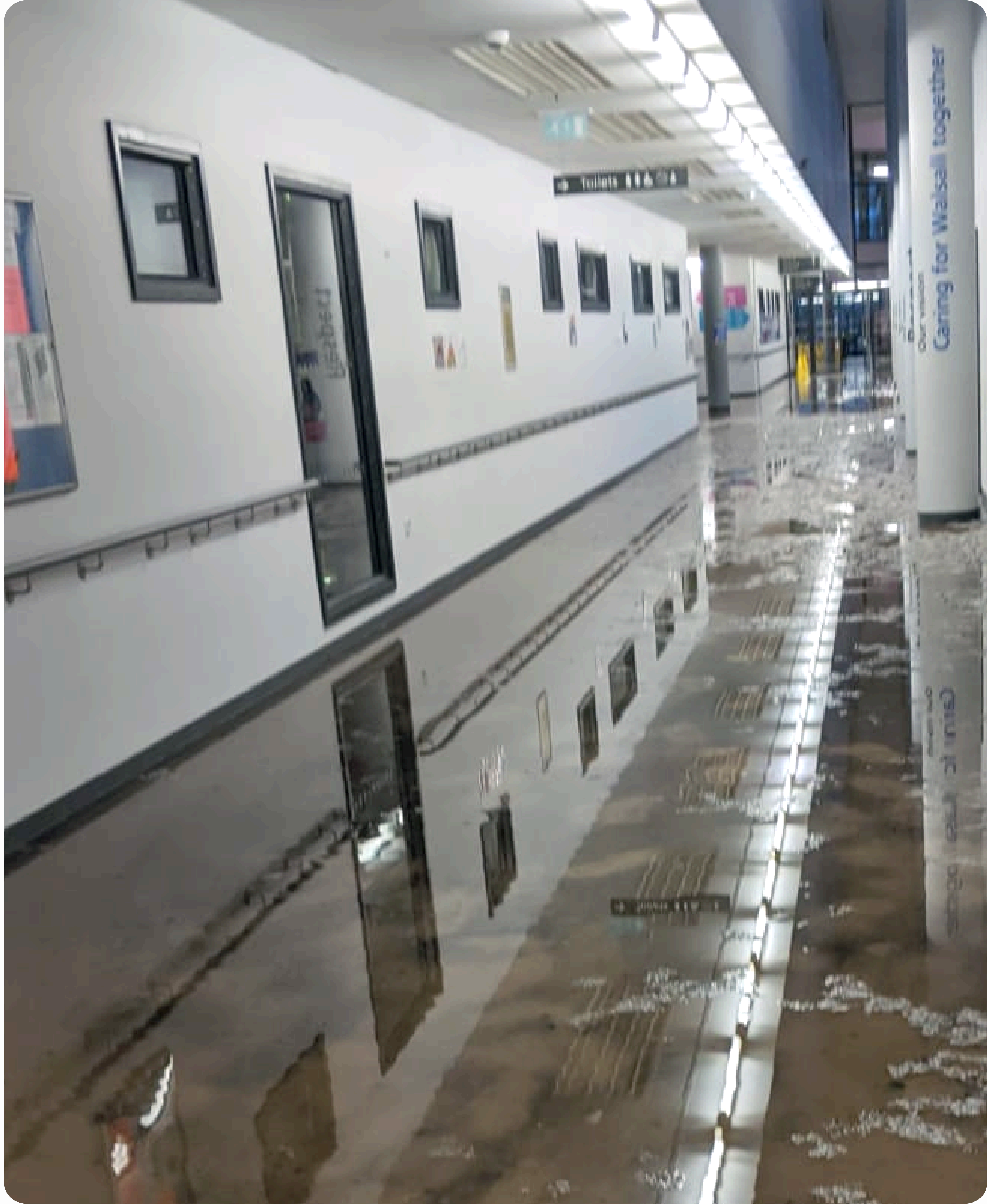
Barricading Hospitals:

- Leaves patients and staff at risk during severe storms.
- Leads to infrastructure damage led to power outages, equipment failure, and hindered access to critical supplies.

THE CURRENT RESPONSE ~ HOSPITAL CHALLENGES

Poor Planning:

- Patient are being relocated at the last minute, leaving them in the traffic on the realm of the storm
- Lack of preparedness can lead to prolonged hospital closures, affecting community access to healthcare services.
- Patient are only relocated at the aftermath of the flood



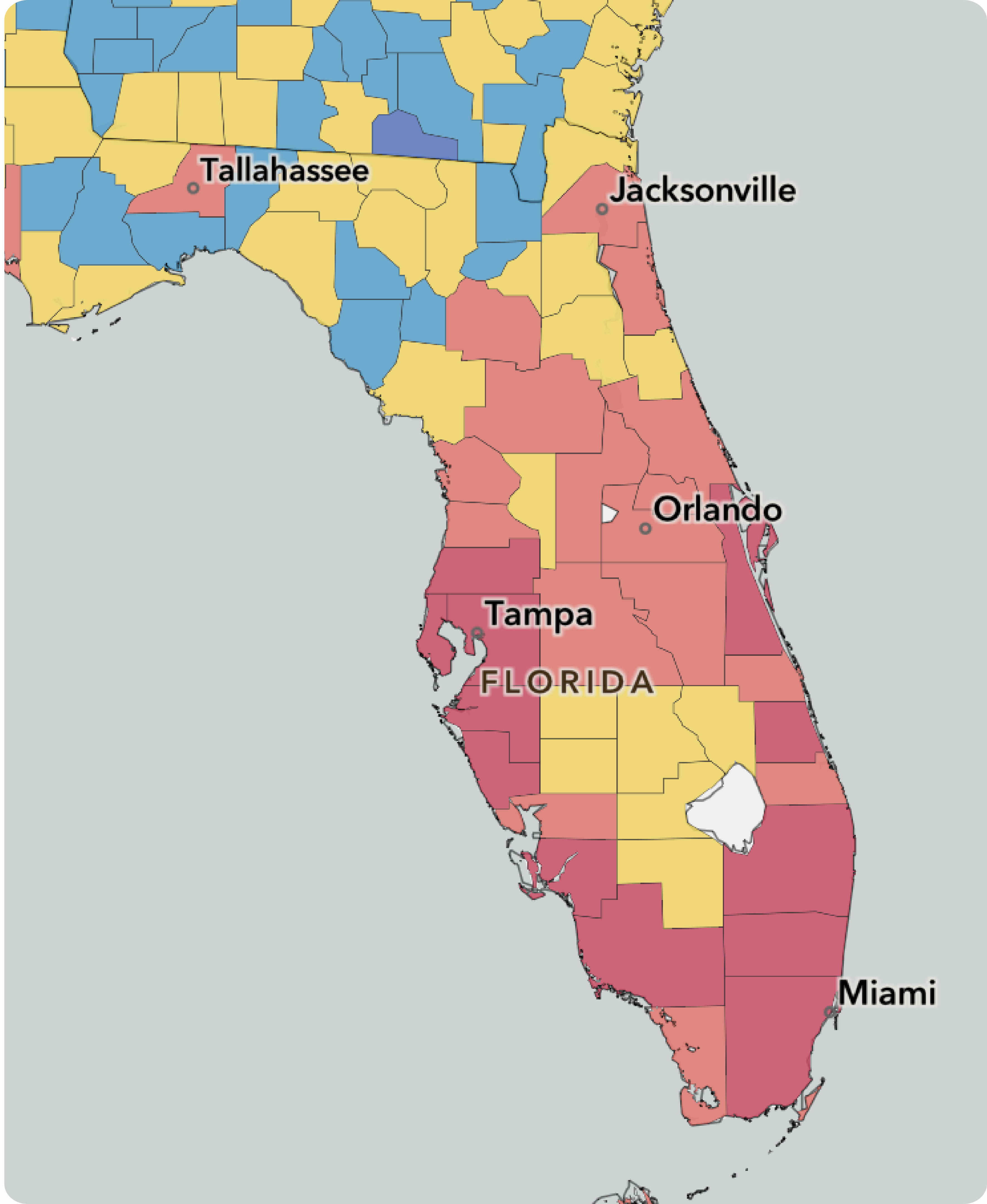
GEOGRAPHICAL VULNERABILITY

Miami-Dade, Broward, Monroe, and Palm Beach Counties are among the most hurricane-prone regions.

Over **40%** of Florida's population resides in these counties, amplifying the potential impact.

Costal Health facilities face greater risks due to storm surges, flooding, and infrastructure damage.

Limited transport options and infrastructure connectivity further complicate evacuations from these regions.



THE NEED FOR A PROACTIVE EMERGENCY PLAN ~THE OPTIMIZATION

“The aim is to relocate patients from hospitals in hurricane-prone regions to hospitals in safer areas, ensuring timely evacuations, patient safety, and efficient resource utilization.”

Evacuation Planning

Relocating non-critical and critical patients to safer regions before the hurricane strikes.

Sustainability

Ensuring that the routing is efficient to limit emmissions and costs.

Innovative Solutions

Leveraging school buses and air ambulance to transport people safely.

GATHERING THE INITIAL DATA

Hospitals Capacity
Last Updated: year 2024
Data records of all Hospitals in the State of Florida
Relevant Attributes: Total number of Beds, City, Coordinates

FEMA HURICAN RISK IN FLORIDA
Last Updated: year 2023
Data records of the risk of hurricane per county
Relevant Attributes: Risk index and loss ratio

EMS DATASET
Last Updated: year 2023
Data records of all the EMS dispatch centre facilities in the Florida Region
Relevant Attributes:
Coordinates, EMS Type (Ambulance, Fire Ambulance, Air Ambulance)

POPULATION RECORDS FLORIDA
Last Updated: year 2023
Data records of the population census per city in the Florida region
Relevant Attributes: City, Population

MODELING THE MISSING INFORMATION

Hospital Capacity Estimation

Total Beds

Data for total beds was obtained from hospital records.

Critical Care patient

Hospitals are classified by total beds:

- 100 beds: Assumed 13 ICU patients on average.
- 50–100 beds: Assumed 8 ICU patients on average.
- <50 beds: Assumed 6 ICU patients on average.

Vacancy Rate

The average hospital bed vacancy rate is estimated between 30% and 40%, randomized and normalized for each hospital.

*All THE ESTIMATIONS HAVE BEEN CALCULATED BASED ON U.S NATIONAL AVERAGE CENSUS (THAT CAN BE FOUND IN THE REFERENCES)

MODELING THE MISSING INFORMATION

Estimating Vehicle availabilities

AMBULANCE

1. Per Population: Assumed 1 ambulance per 21,057 residents.
2. Workload: Each ambulance handles approximately 2,408 calls annually, averaging 6.5 calls per day.

FIRE STATION AMBULANCE

1. Populations <2,500: 1.13 per 1,000 population.
2. Populations >1,000,000: 0.03 per 1,000 population.

AIR AMBULANCE

Allocation: Florida’s 19 cities providing air ambulance services are each allocated 5 air ambulances, totaling 95.

SCHOOL BUS

- Cities with >200,000 residents: 3 buses per EMS
- Cities with 50,000–200,000 residents: 2 buses per EMS
- Cities with 10,000–50,000 residents: 1 bus per EMS
- Cities with <10,000 residents: 0 buses per EMS

***AIl THE ESTIMATIONS HAVE BEEN CALCULATED BASED ON U.S NATIONAL AVERAGE CENSUS (THAT CAN BE FOUND IN THE REFERENCEMENT)**

MODELING THE EVACUATION PROCESS

General Path Forecast provided around 5 days before landfall, the Evacuation efforts begin.

Multi-Objective problem

Objective 1

Evacuate as many non-ICU patients as possible

- Evacuating all ICU Patients is a requirement (constraint)
- To be done before landfall

Objective 2

Minimize CO2 emissions in the process

Objective 3

Minimize costs of transportation (Fuel, Manhours)

MODELING THE EVACUATION PROCESS

Evacuation Tactic

EMS dispatch centres located across the state of Florida hold all emergency vehicles, each having its own capacity.

Stage 1: Allocate the optimal amount of each type of vehicle taken from EMS stations, assigned to hospitals in hurricane prone regions

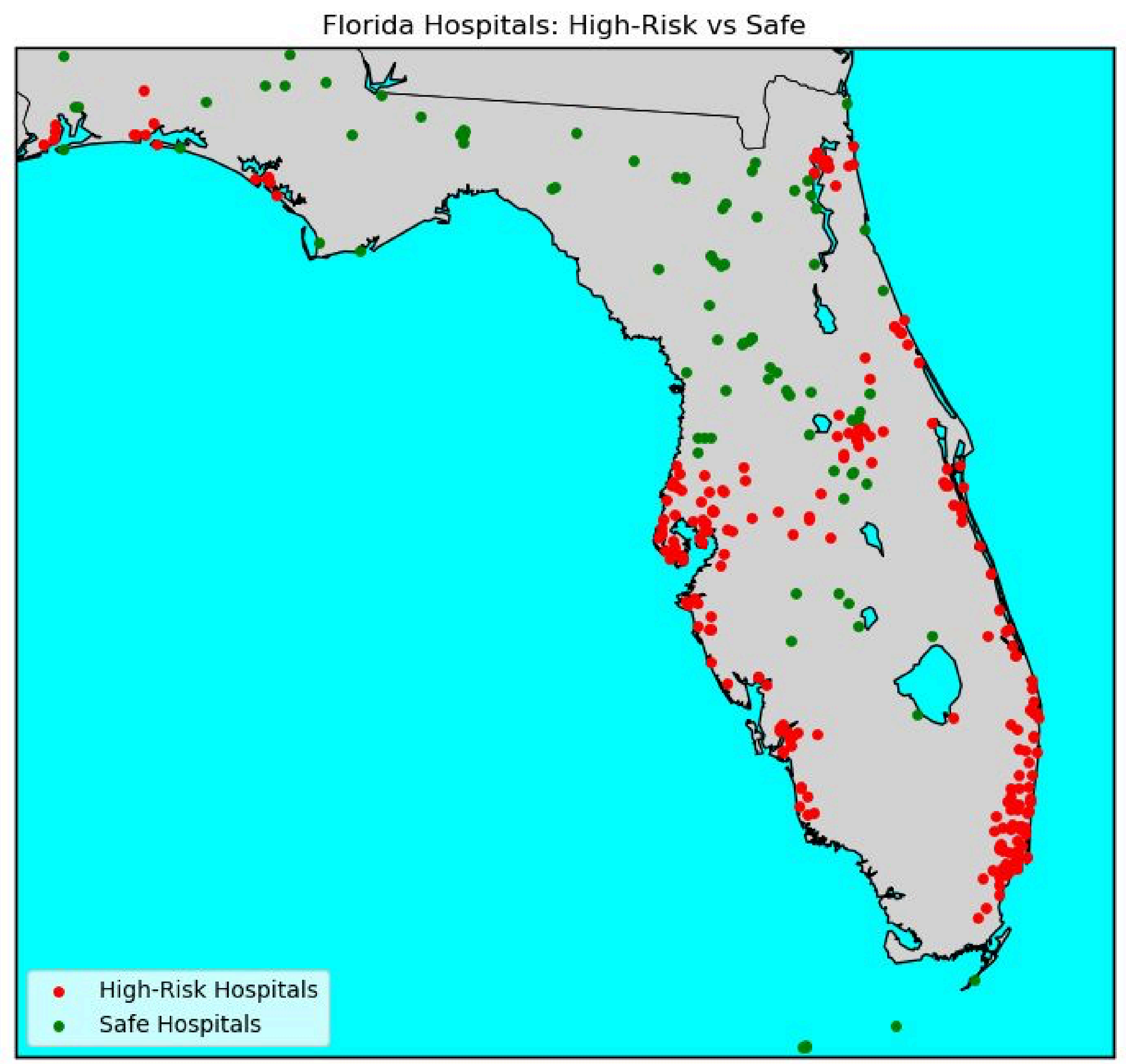
- Allocation must consider the optimal usage of these vehicles in stage 2.

Stage 2: Determine the optimal evacuation routes to be taken from risk zone to safe zone hospitals:

- How many of each type of vehicle to send on each route
- The number of round-trips to be taken by each type of vehicle on each route

For both stages: The distance traveled & time taken by each vehicle type will dictate fuel consumption (emissions, fuel costs), manhours needed for various types of evacuation workers (wages)

Allocations in Stage 1 are driven by how these vehicles are used in Stage 2.
At the same time, evacuations in stage 2 are constrained by the capacity of allocations in stage 1.



High Risk: Hurricane Risk Index above 0.98

- **Expected Annual Loss (People, Infrastructure)**
- **Social Vulnerability**

CONSTRAINT 1 : EMS VEHICLE CAPACITY LIMITS

For each EMS station, the sum of vehicle allocations to high risk hospitals must not exceed its capacity of each vehicle type

$$\sum_{r \in R} u_{e,r,v} \leq p \cdot VC_{e,v}$$

$$For\ e \in E$$

$$and\ v \in V$$

Parameters:

$VC_{e,v}$: Vehicle Capacity of EMS station e for vehicle type v

p : Percentage of emergency vehicles used for evacuation efforts

Decision Variables:

$u_{e,r,v}$: First stage assignment of vehicle type v from EMS center e to risky hospital r

Sets:

E : EMS dispatch centers

R : Risky hospitals

V : Vehicle types

CONSTRAINT 2 : CONTINUITY BETWEEN STAGES

Number of vehicles provided from all EMS stations to each risk hospital is equal to the number of vehicles dispatched from that hospital for evacuations

$$\sum_{e \in E} u_{e,r,v} = \sum_{s \in S} x_{r,s,v}$$

for all $r \in R$, and $v \in V$

Decision Variables:

$u_{e,r,v}$: First stage assignment of vehicle type v from EMS center e to risky hospital r

$x_{r,s,v}$: Second stage assignment of number of vehicle type v from risky hospital r to safe hospital s

Sets:

E : EMS dispatch centers

R : Risky hospitals

S : Safe hospitals

V : Vehicle types

CONSTRAINT 3 : EVACUATION TIME LIMIT

With 5 days between the general path forecast and landfall, and 1 day for preparations, evacuation efforts must not exceed 4 days (96h) accounting for turnaround time.

$$z_{r,s,v}(2 \cdot t^{v}_{r,s} + \text{turnaround}_v) \cdot \leq 96 \cdot x_{r,s,v}$$

$$\text{for all } \text{r} \in R, \text{ for all } s \in S, \text{ for all } v \in V$$

Parameters

t^{v}_{rs} : Travel time (hours) from risky hospital r to safe hospital s by vehicle v

turnaround_v : Turnaround time of vehicle type v

Decision Variables:

$x_{r,s,v}$: Number of vehicle type v assigned from risky hospital r to safe hospital s

$z_{r,s,v}$: Second stage vehicle round trips

Sets:

R : Risky hospitals

S : Safe hospitals

V : Vehicle types

CONSTRAINT 4 : ALL ICU PATIENTS MUST BE EVACUATED

The sum of the product of round trips and vehicle patient capacity must be at least equal to the number of ICU patients of each risky hospital

$$\sum_{s \in S} \sum_{v \in V} PC_v \cdot z_{r,s,v} \geq ICU_r$$

$$\text{for all } r \in R$$

Parameters:

ICU_r : Number of ICU patients at risky hospital r

PC_v : Patient capacity of vehicle type v

Decision Variables:

$z_{r,s,v}$: Second stage vehicle round trips

Sets:

R : Risky hospitals

S : Safe hospitals

V : Vehicle types

CONSTRAINT 5 : SAFE HOSPITAL CAPACITY LIMITS

The sum of the product of round trips and vehicle patient capacity must be at most equal to the number of available beds at the receiving hospital

$$\sum_{r \in R} \sum_{v \in V} PC_v \cdot z_{r,s,v} \leq AS_s$$
$$\text{for all } s \in S$$

Parameters:

PC_v : Patient capacity of vehicle type v

AS_s : Available space at safe hospital s

Decision Variables:

$z_{r,s,v}$: Second stage vehicle round trips

Sets:

R : Risky hospitals

S : Safe hospitals

V : Vehicle types

OBJECTIVE 1: MAXIMIZE NON-ICU PATIENTS EVACUATED

$$\text{Maximize: } B = \sum_{r \in R} \sum_{s \in S} PC_{v=bus} \cdot z_{r,s,v=bus}$$

Variables:

$z_{r,s,v=bus}$: Number of round trips by buses from risky hospital r to safe hospital s

Parameters:

$PC_{v=bus}$: Capacity of a bus (vehicle type 3)

Sets:

R : Risky hospitals

S : Safe hospitals

OBJECTIVE 2: MINIMIZE CO2 EMISSIONS

$$\text{Minimize: } P = 2 \cdot \sum_{e \in E} \sum_{r \in R} \sum_{v \in V_g} \left(\frac{d_{er}^{\text{ER}}}{f_v} \cdot p_d \cdot u_{e,r,v} \right) +$$

$$2 \cdot \sum_{e \in E} \sum_{r \in R} \left(t_{er}^{\text{air}} \cdot f_{\text{air}} \cdot p_j \cdot u_{e,r,1} \right) +$$

$$2 \sum_{r \in R} \sum_{s \in S} \sum_{v \in V_g} \left(\frac{d_{rs}^{\text{RS}}}{f_v} \cdot p_d \cdot z_{r,s,v} \right) +$$

$$2 \sum_{r \in R} \sum_{s \in S} \left(t_{rs}^{\text{air}} \cdot f_{\text{air}} \cdot p_j \cdot z_{r,s,1} \right)$$

Sets:

E : EMS locations

R : Risky hospitals

S : Safe hospitals

V_g : Ground vehicle types (e.g., ambulances, buses) $\{0, 2, 3\}$

Parameters:

f_v : Fuel efficiency of ground vehicle v (miles/gallon)

p_d : Diesel pollution factor (pounds of CO_2/ gallon)

p_j : Jet fuel pollution factor (pounds of CO_2/ gallon)

f_{air} : Fuel consumption rate for air vehicles (gallons/ hour)

t_{rs}^{v} : Travel time from risky hospital r to safe hospital s by vehicle v (hours)

t_{er}^{v} : Travel time from EMS location e to risky hospital r by vehicle v (hours)

d_{er}^{ER} : Distance from EMS to risky hospital (miles)

d_{rs}^{RS} : Distance from risky to safe hospital (miles)

Variables:

$u_{e,r,v}$: Vehicle type v assigned to risky hospital r from EMS location e

$z_{r,s,v}$: Round trips by vehicle type v from risky hospital r to safe hospital s

OBJECTIVE 3: MINIMIZE COSTS

$$\text{Minimize: } C = 2 \cdot \sum_{e\in E}\sum_{r\in R}\sum_{v\in V_g}\left(\frac{d_{er}^{\mathrm{ER}}}{f_v}\cdot c_d + t_{er}^{v}\cdot w_{emt}\right)\cdot u_{e,r,v} +$$

$$2 \cdot \sum_{e\in E}\sum_{r\in R}\left(t_{er}^{\mathrm{air}}(f_{\mathrm{air}}\cdot c_j + w_{\mathrm{pilot}})\right)\cdot u_{e,r,1} +$$

$$2\sum_{r\in R}\sum_{s\in S}\sum_{v\in V_g}\left(\frac{d_{rs}^{\mathrm{RS}}}{f_v}\cdot c_d + t_{rs}^{v}(w_{emt} + w_{paramedic}\cdot NP_v)\right)\cdot z_{r,s,v} +$$

$$2\sum_{r\in R}\sum_{s\in S}\left(t_{rs}^{\mathrm{air}}(f_{\mathrm{air}}\cdot c_j + w_{\mathrm{pilot}} + w_{paramedic}\cdot NP_1)\right)\cdot z_{r,s,1}$$

Sets:

$E:$ EMS locations
$R:$ Risky hospitals
$S:$ Safe hospitals
$V_g:$ Ground vehicle types (e.g., ambulances, buses) $\{0, 2, 3\}$

Parameters

$f_v:$ Fuel efficiency of vehicle v (miles/ gallon)
$c_d:$ Diesel fuel price (dollars/ gallon)
$c_j:$ Jet fuel price (dollars/ gallon)
$w_{emt}:$ EMT wage (dollars/ hour)
$w_{paramedic}:$ Paramedic wage (dollars/ hour)
$w_{\mathrm{pilot}}:$ Pilot wage (dollars/ hour)
$NP_v:$ Number of paramedics required for vehicle$v$
$f_{\mathrm{air}}:$ Fuel consumption rate for air vehicles (gallons/ hour)
$t_{rs}^{v}:$ Travel time (hours) from risky hospital r to safe hospital s by vehicle v
$t_{er}^{v}:$ Travel time (hours) from EMS location e to risky hospital r by vehicle v
$d_{er}^{\mathrm{ER}}:$ Distance from EMS to risky hospital (miles)
$d_{rs}^{\mathrm{RS}}:$ Distance from risky to safe hospital (miles)

Variables:

$u_{e,r,v}:$ Vehicle type v assigned to risky hospital r from EMS location e
$z_{r,s,v}:$ Round trips by vehicle type v from risky hospital r to safe hospital s

MODEL RESULTS

Number of Integer Decision Variables: 288,868 Integers

Vehicles Used

177 AMBULANCES
1596 PATIENTS

126 FIRE STATION AMBULANCES
1208 PATIENTS

32 AIR AMBULANCES
34 PATIENTS

18 SCHOOL BUSES
1706 PATIENTS

Objective Values

Non-ICU Patients Evacuated: **1760**

Pounds of CO_2 Emitted: **1,524,680**

Total Costs: **759,017 USD**

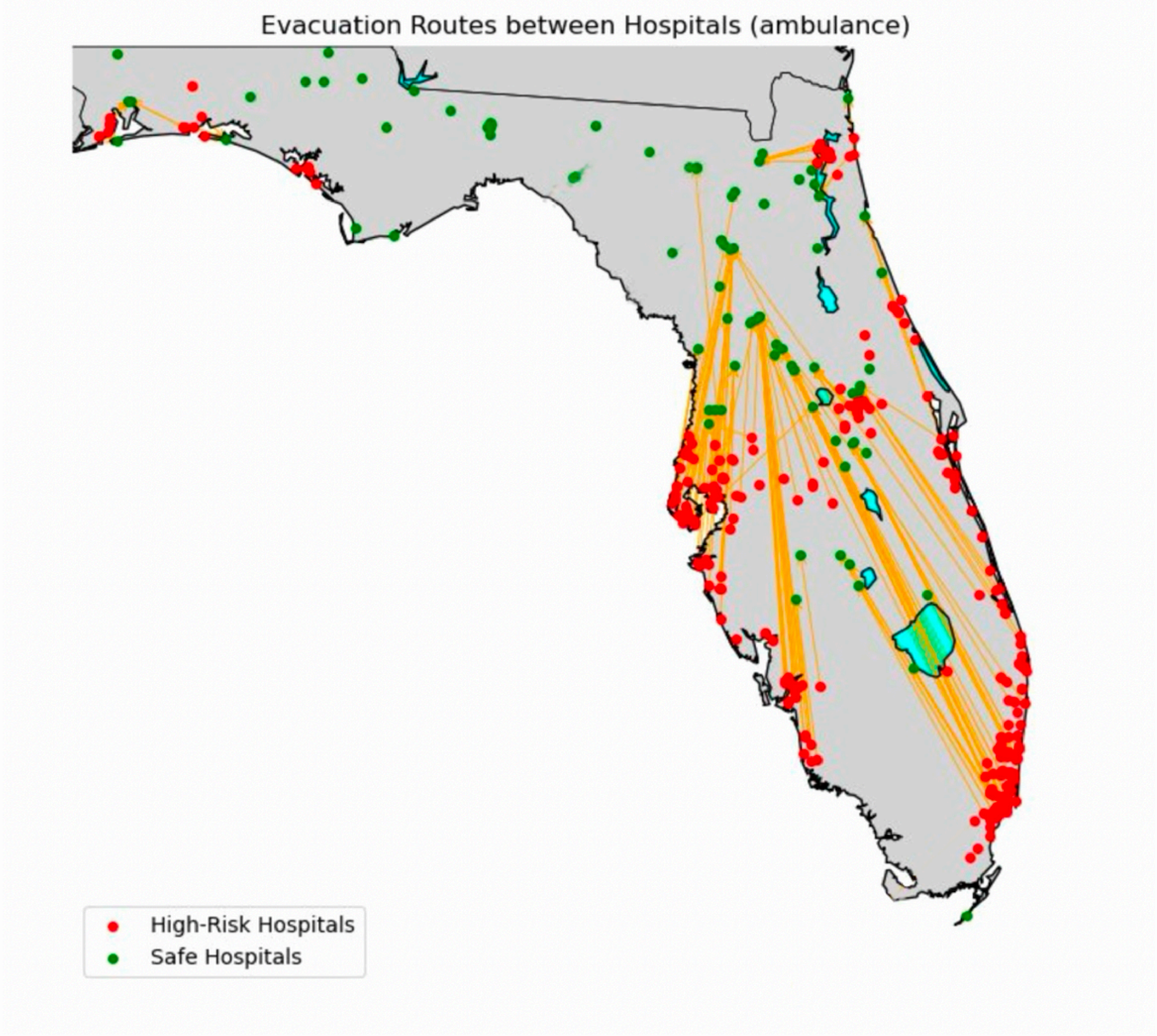
Total Evacuated Patients: 4598
All ICU Patients Evacuated

Example Allocation & Route

EMS Station	Risk Zone Hospital	Vehicle Allocation
EMS HOLLY HILL FIRE RESCUE	FL HOSP OCEANSIDE	1 Fire Ambulance

Risk Zone Hospital	Safe Zone Hospital	Round Trips
FL HOSP OCEANSIDE	FLAGLER HOSP	4 Fire Ambulance Round-Trips

EXAMPLE: AMBULANCE EVACUATION ROUTES



MODEL ASSUMPTIONS & LIMITATIONS

Fuel Cost:

Assumption: Fuel cost were estimated on 2023 prices
Limitation: The use of real time price variation would be more accurate

Danger Zone Mapping:

Assumption: Risky hospitals are defined according to the historical risk index at a **98%** threshold (Very High)
Limitation: The Use of real-time data driven information on the path and location of the current hurricane would provide more accurate insights

Routing Distance:

Assumption: We used straight line to model the different possible routes in Florida
Limitation: Lack of distances of real routes due to limited cost and the impossibility to leverage Google Maps or another API free of cost for the scale of our project.

Travel time:

Assumption: The travel time was calculated using the average speed of each vehicle and the route distance, turnaround time was accounted for **30 - 60** minutes.
Limitation: The model might not account for additional stop time, traffic using leveraging the google api could mitigate that issue

BUSINESS APPLICATION/RECOMMENDATIONS

1) Establish Temporary Shelter in “Safe Zone”

- Designate and equip hurricane-safe zones with temporary modular shelters in vulnerable regions prone to evacuation during hurricanes.
- Would allow to save more people by rerouting remaining non critical patients there

2) Real-Time Database for Patients and Emergency Capacity

- Develop an integrated, real-time database tracking ambulance locations, hospital bed availability, and patient status among all the hospital and EMS in Florida and leverage weather forecast.
- Scale our optimization model and make it readily available for the next hurricane.

3) Sustainability Measures to Reduce Environmental Impact

- Starts using and converting existing vehicles into electric ones, to further reduce CO_2 impacts in future events
- Continue the effort of pre-planning hurricane storms in order to reduce the risk of traffic in Florida and congestion hours before the storm strikes

4) Create a Sate-Level Emergency Task Force

- Establish a Florida Emergency Resilience Task Force (FERT) that includes representatives from state agencies, local governments, and private sector partners.
- Integrate community leaders from vulnerable populations to ensure equitable disaster response policies and maximize the number of patient saved

CONCLUSION

The model supports the government in crafting regulations that balance allocation productivity with environmental safety.

By mitigating disaster impacts through predictive planning and better resource allocation, the state can reduce financial burdens from lawsuits, cleanup costs, and healthcare expenditures.

Increased transparency and data accessibility can rebuild trust in government actions, showcasing proactive efforts to protect residents and the environment.

Position Florida as a national leader in hurricane response and environmental justice, using this model to demonstrate cutting-edge data-driven decision-making.

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