Resilient Transportation Systems: Moving from Risk to Resilience

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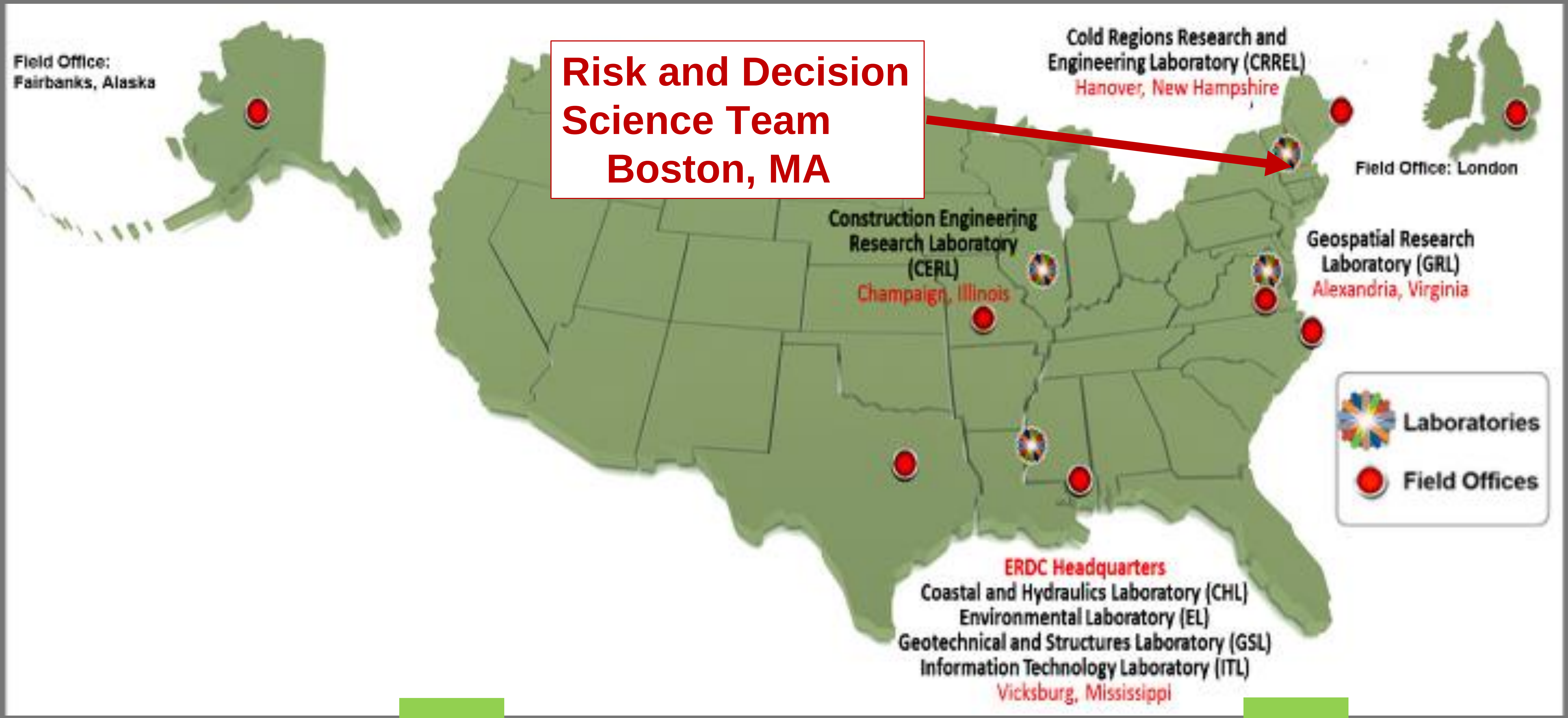

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Academia
68 EPAs with top engineering schools
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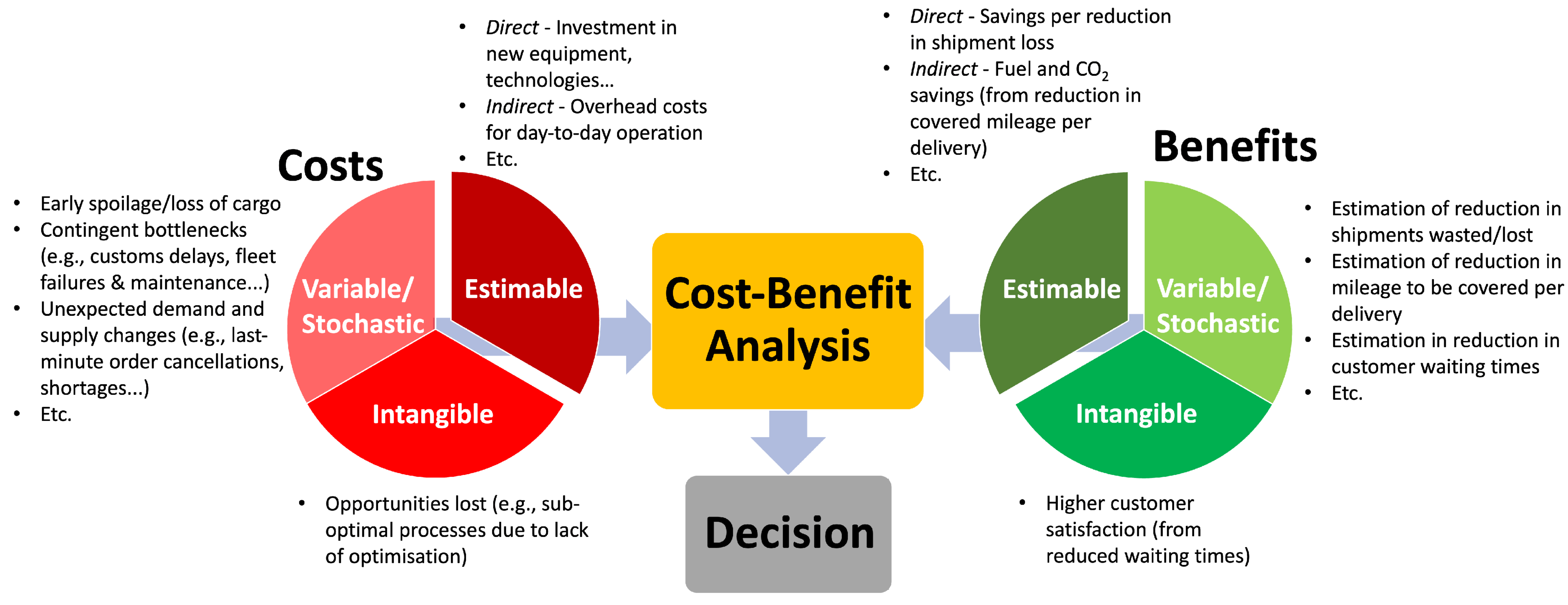
172 CRADAs
International
14 international agreements with 7 countries

Traditional Approaches: Risk Assessments & Cost-Benefit Analysis

- Identity risks and manage those risks: Threat, vulnerability, consequence



Schiffmann, O. et al., A Cost–Benefit Analysis Simulation for the Digitalization of Cold Supply Chains. *Sensors* **2023**, *23*, 4147. https://doi.org/10.3390/s23084147

Risk vs Resilience: Definitions

Risk -- "a situation involving exposure to danger [threat]."

Security -- "the state of being free from danger or threat."

Resilience -- "the capacity to recover quickly from difficulties."

*Definitions by Oxford Dictionary

30 | NATURE | VOL 555 | 1 MARCH 2018

Don't conflate risk and resilience

'Risk' and 'resilience' are fundamentally different concepts that are often conflated. Yet maintaining the distinction is a policy necessity. Applying a risk-based approach to a problem that requires a resilience-based solution, or vice versa, can lead to investment in systems that do not produce the changes that

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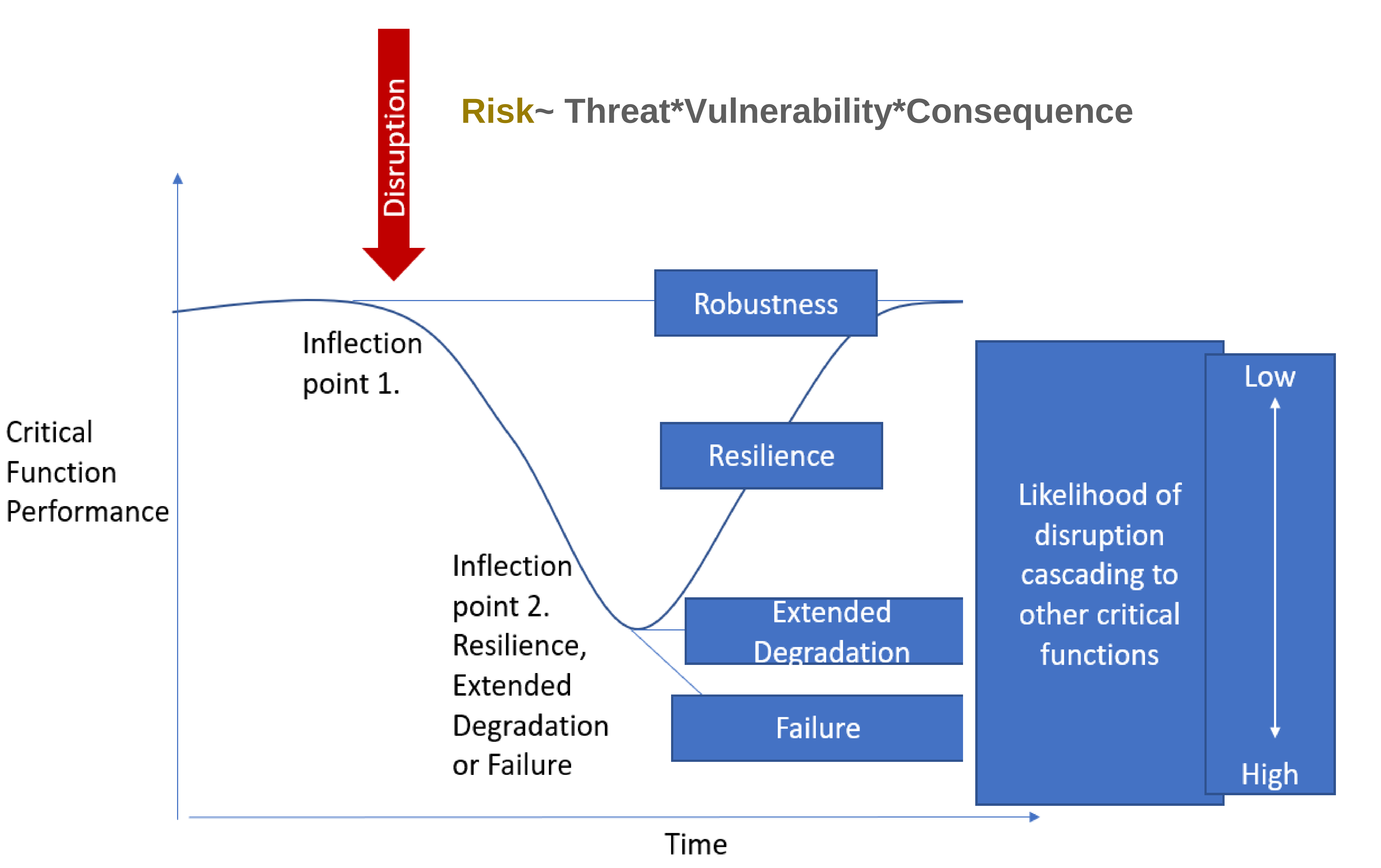
Risk vs Resilience: Definitions

Risk Management Strategy:
- Aim: Predict risks & either:
  - Prevent the from impacting system
  - Planning around them (insurance)
- Threat*Vulnerability*Consequence

Resilience Strategy:
- We can't predict all threats a company will face
  - Especially in a dynamic and changing world
- Reduce severity, time and/or extent of the disruption
- Prepare, absorb, recover, adapt from disruption

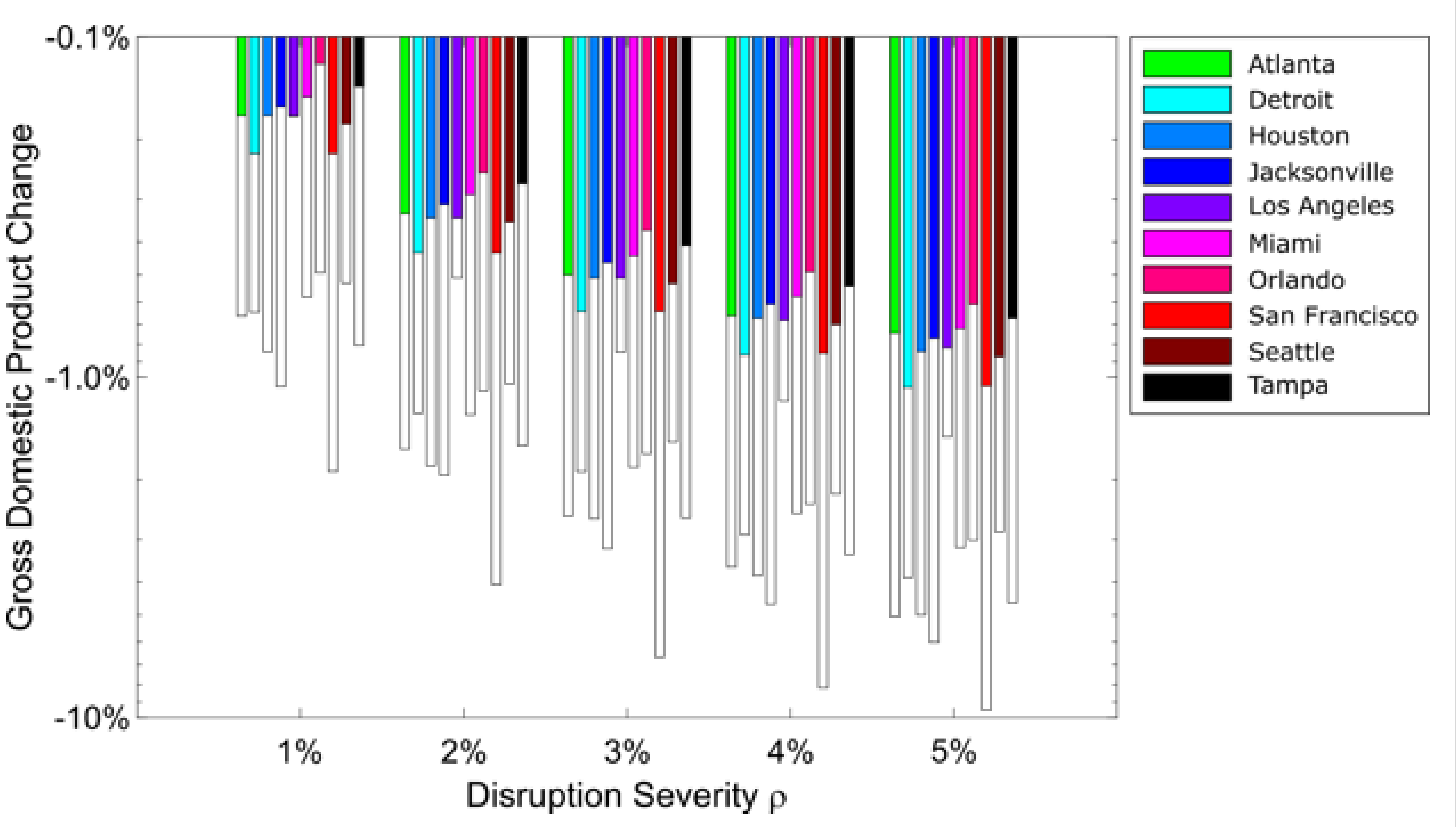


After Galaitsi, Linkov et al, 2022

Risk vs Resilience:
Random Disruptions are Much More Consequential

Risk:
- Identity risks and manage those risks
  - Only as good as your risk estimates
  - Doesn't address system response or un-anticipated disruptions

Resilience:
- Improving system's ability to:
  - Absorb, Recover, Adapt
- Threat agnostic
  - Addresses both anticipated & unanticipated disruptions



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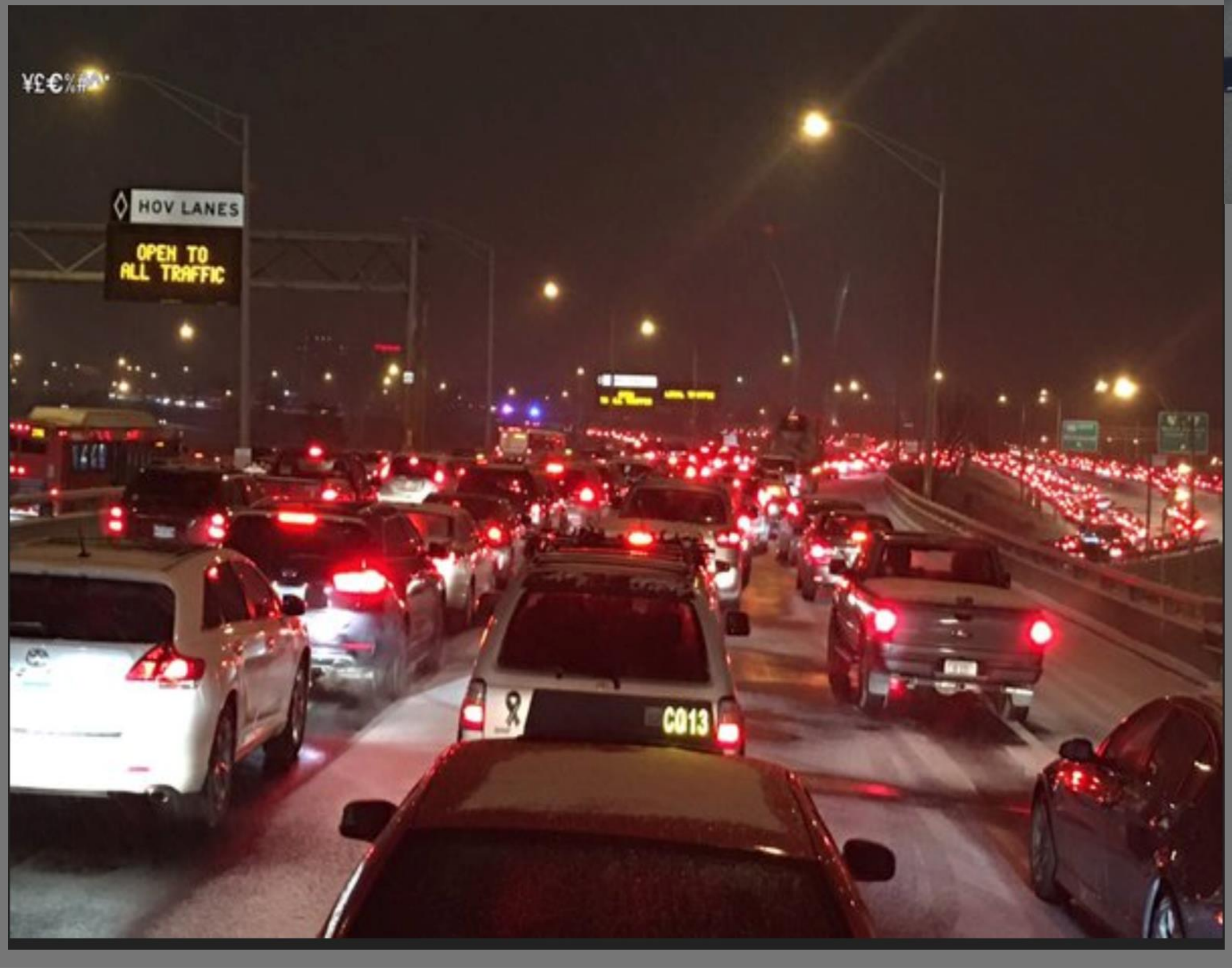
What does it mean to have a resilient transportation network?

Poor Efficiency:

System cannot not accommodate a large volume of commuters driving at the same time.

Traffic congestions are predictable and are typically of moderate level.



Lack of Resilience:

System cannot recover from adverse events (car accidents, natural disasters)

Traffic disruptions are not predictable and of variable scale.

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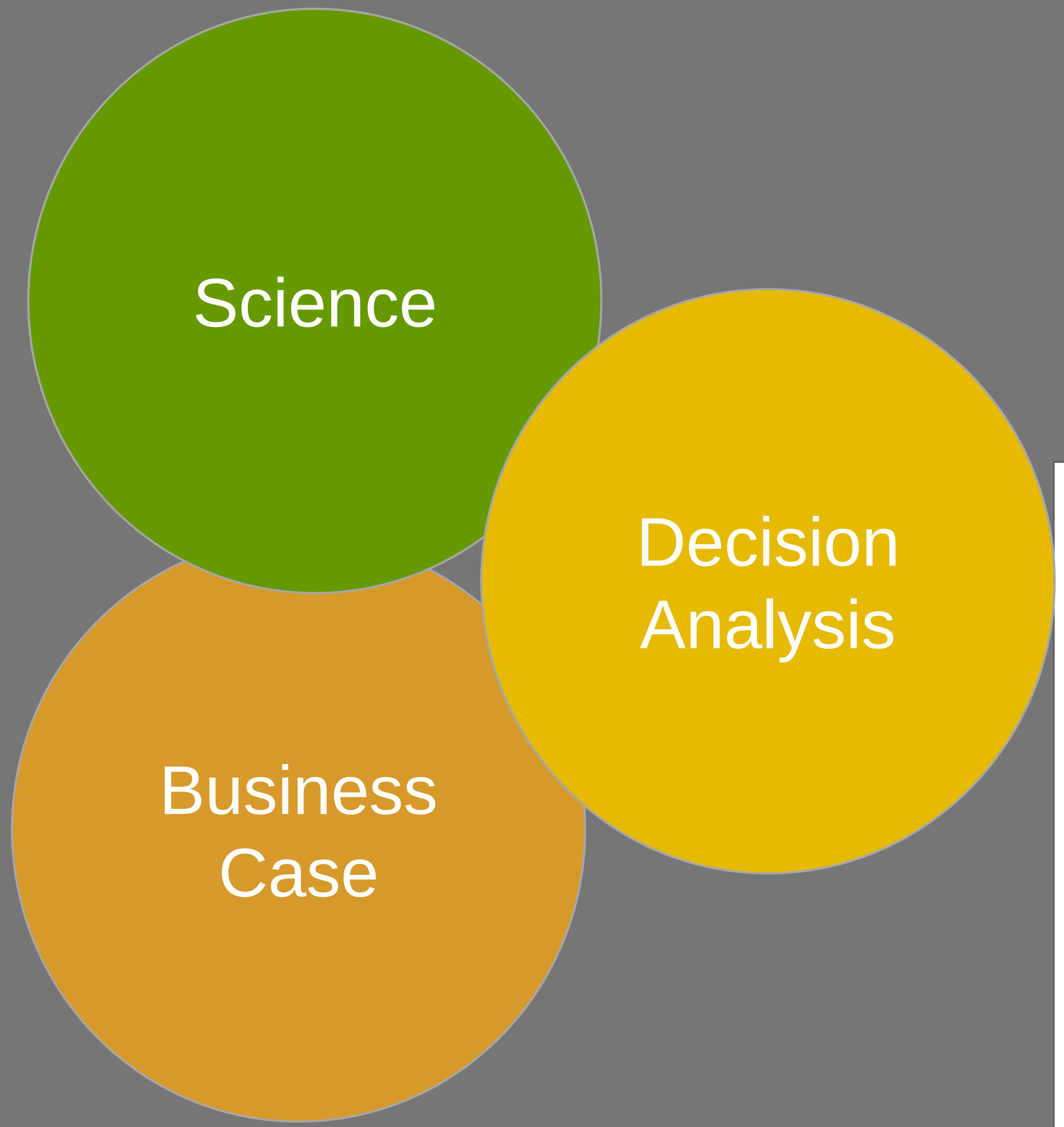
What does it mean to have a resilient transportation network?



Transportation Network Model
+
Regional Economic Models, Inc.

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Transportation Research Part D
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Lack of resilience in transportation networks: Economic implications

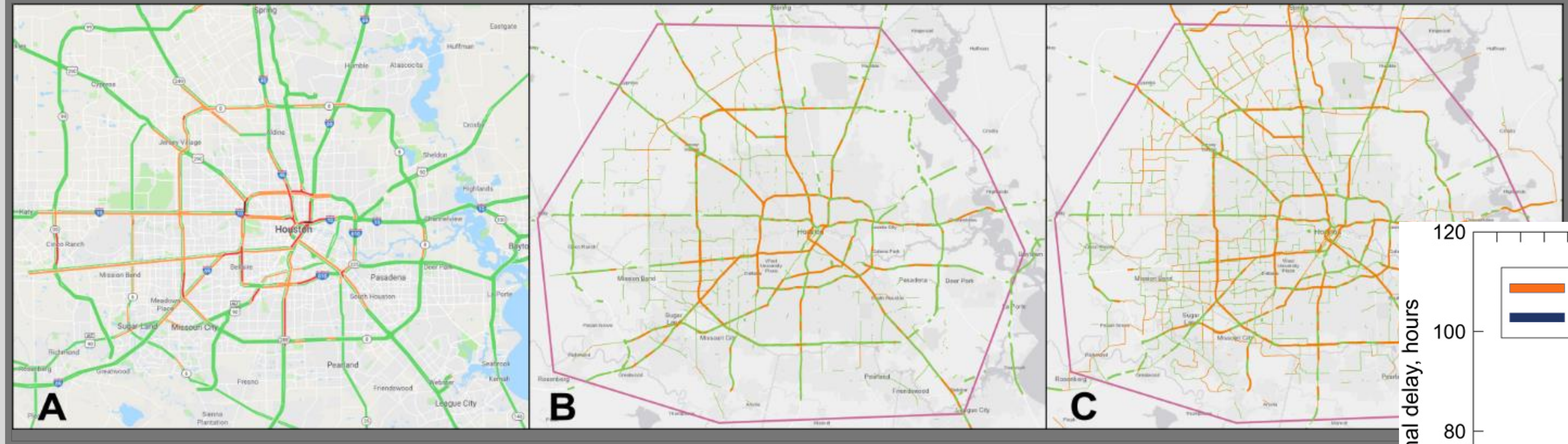
SCIENCE ADVANCES | RESEARCH ARTICLE

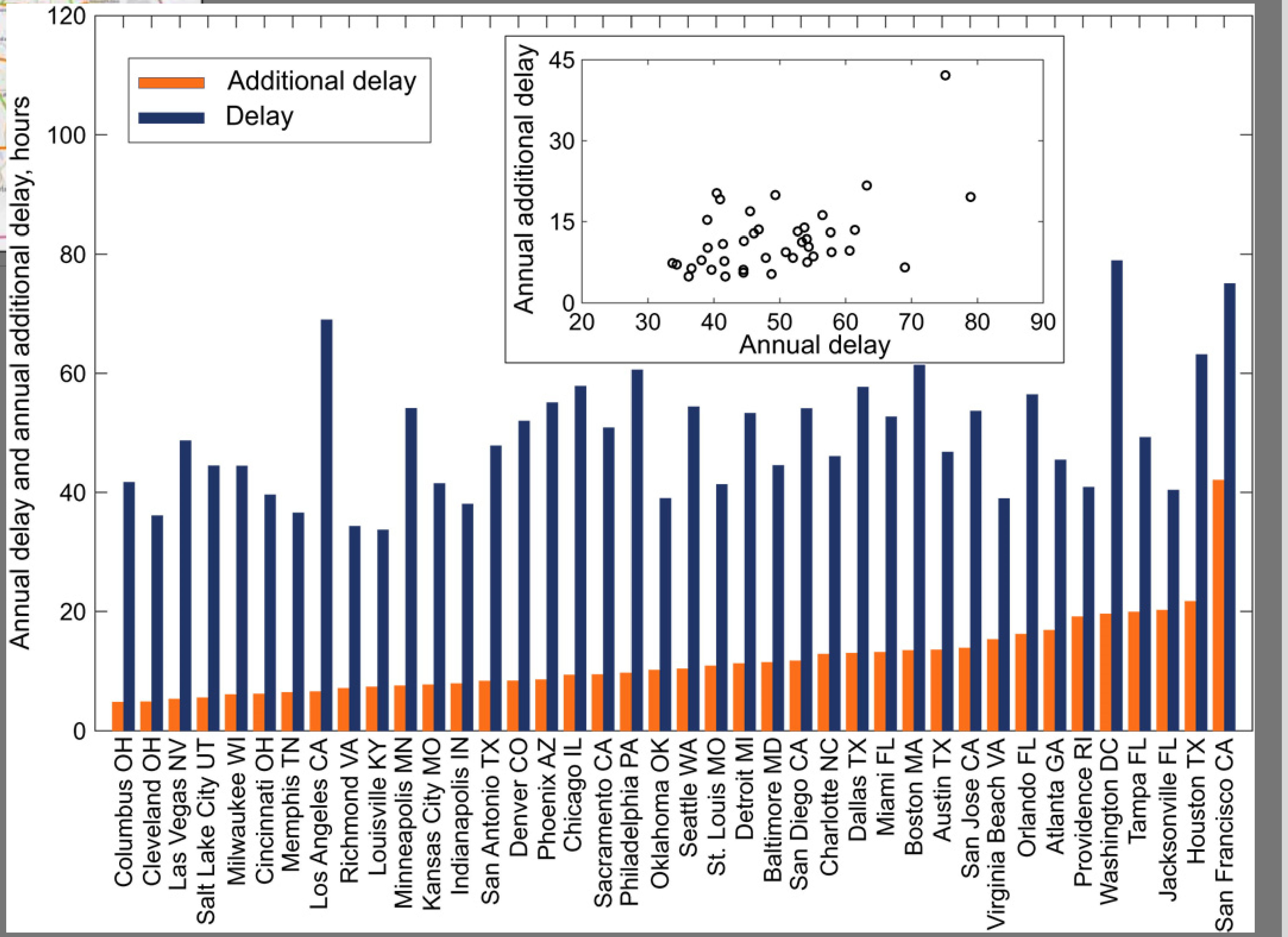
NETWORK SCIENCE

Resilience and efficiency in transportation networks

Alexander A. Ganin,[1,2] Maksim Kitsak,[3] Dayton Marchese,[2] Jeffrey M. Keisler,[4] Thomas Seager,[5] Igor Linkov[2]*

What does it mean to have a resilient transportation network?: Impact of Transportation Network Disruptions on Travel Time

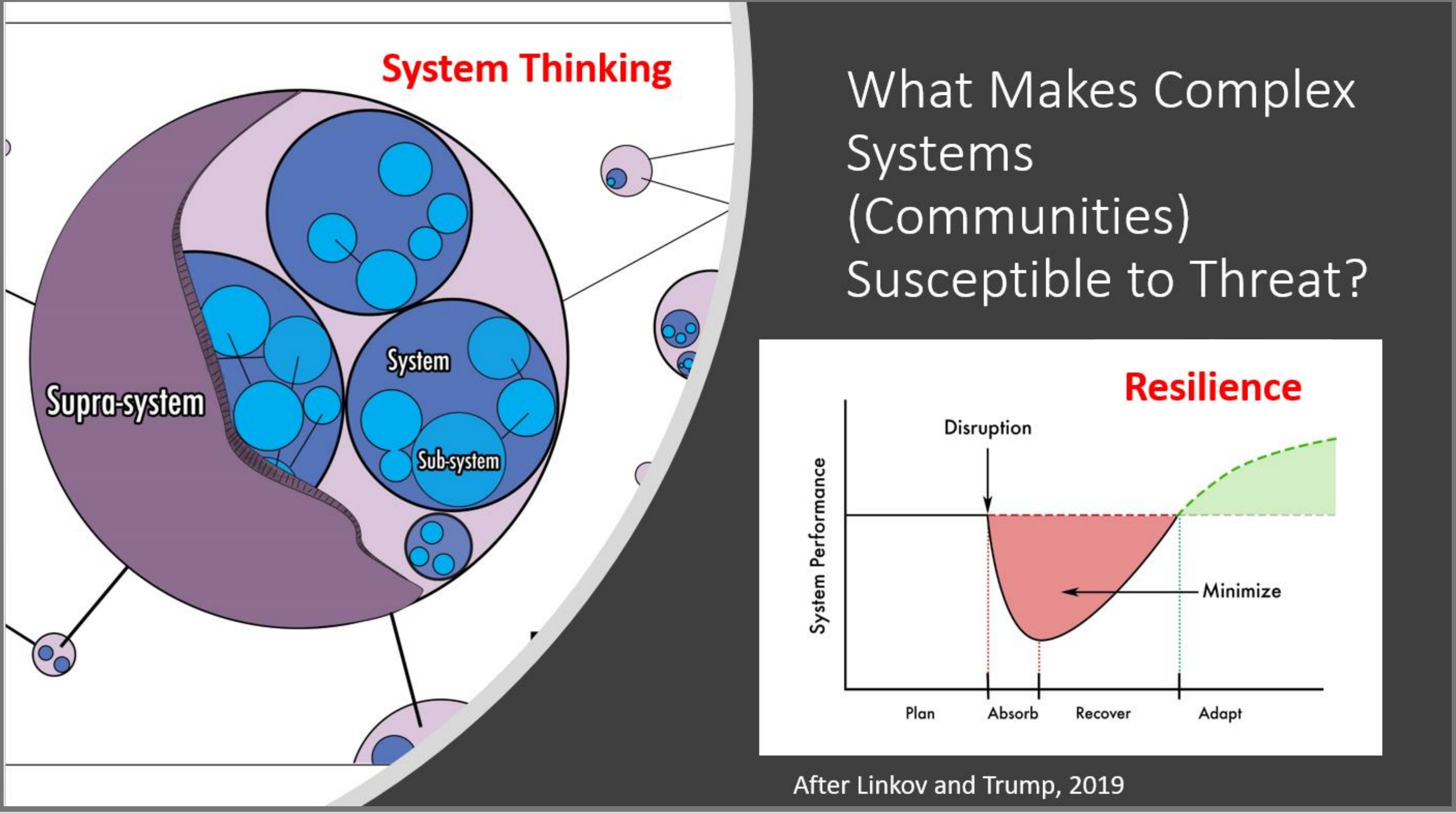




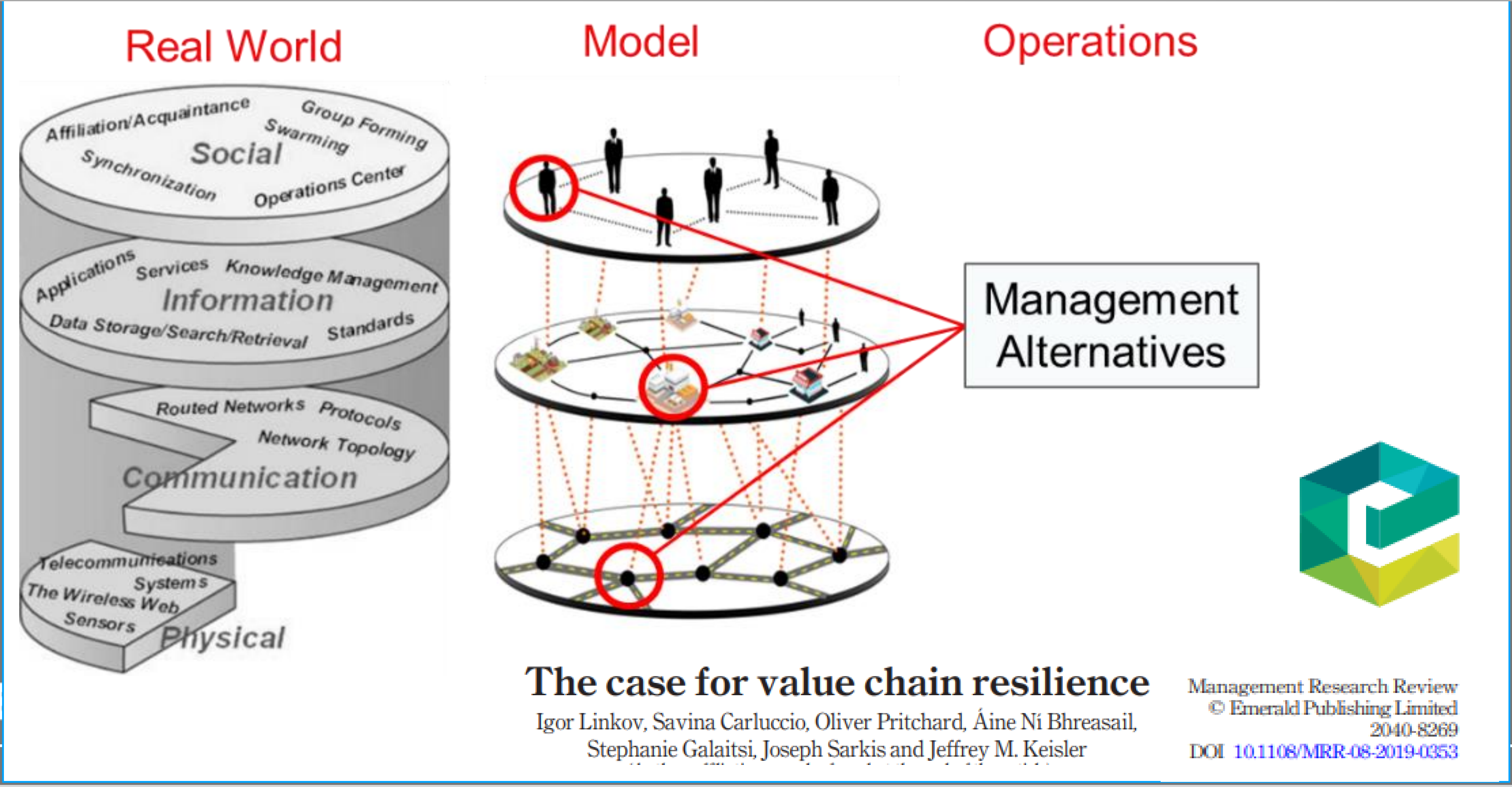
1) Build networks comprise of road links and intersection nodes
2) Assign travelers and routes
3) Calculate free flow travel times and actual travel times
4) Calculate normal delay
5) Calibrate model to data

$$\langle \Delta T \rangle = \frac{1}{N_c} \sum_{\{ij\} \in \text{all roads}} L_{ij} \ell_{ij} \left(\frac{1}{v_{ij}} - \frac{1}{v_{ij}^0} \right)$$

ERDC Approach: System-Level Approach to Resilience



ERDC Vision for System Resilience



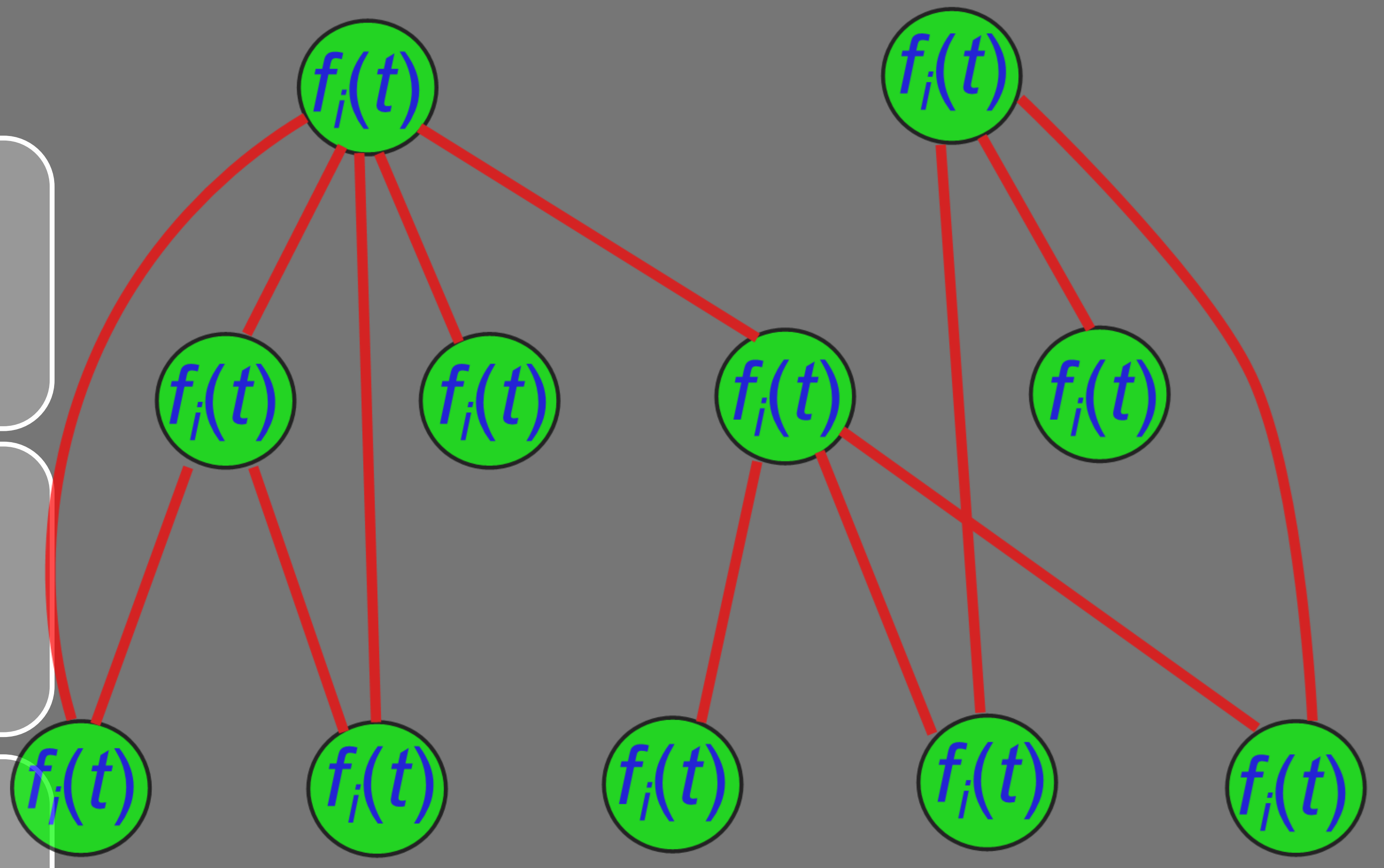
ERDC Approach: System-Level Approach to Resilience

System's *critical functionality* (K)

Network topology: *nodes* ($\mathcal{N}$) and *links* ($\mathcal{L}$)

Network *adaptive algorithms* ($\mathcal{C}$) defining how nodes' (links') properties and parameters change with time

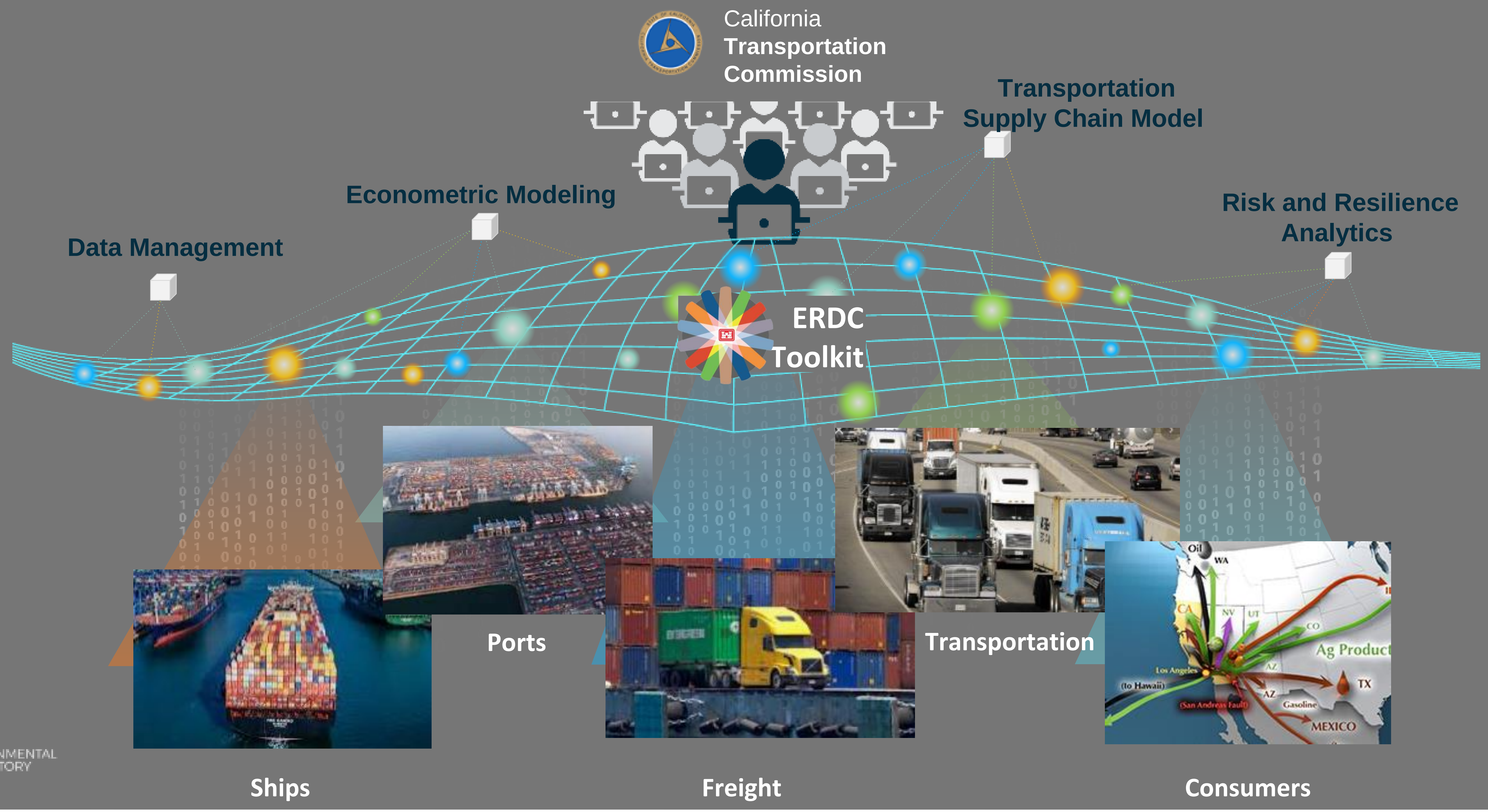
A *set of possible damages* stakeholders want the network to be resilient against ($\boldsymbol{E}$)



$$R = f(\mathcal{N}, \mathcal{L}, \mathcal{C}, \boldsymbol{E})$$

After Ganin et al., 2016

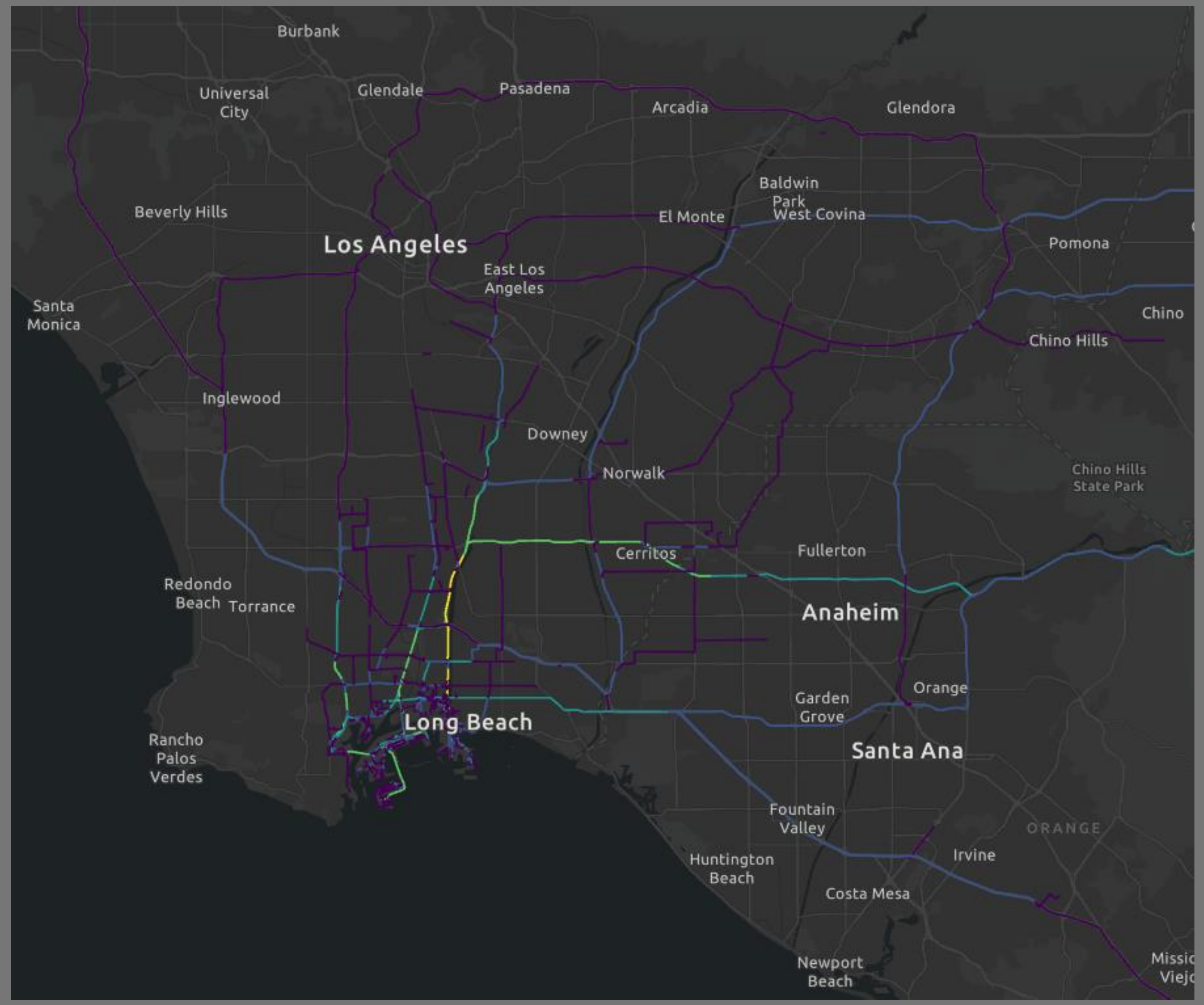
ERDC Approach: System-Level Approach to Resilience



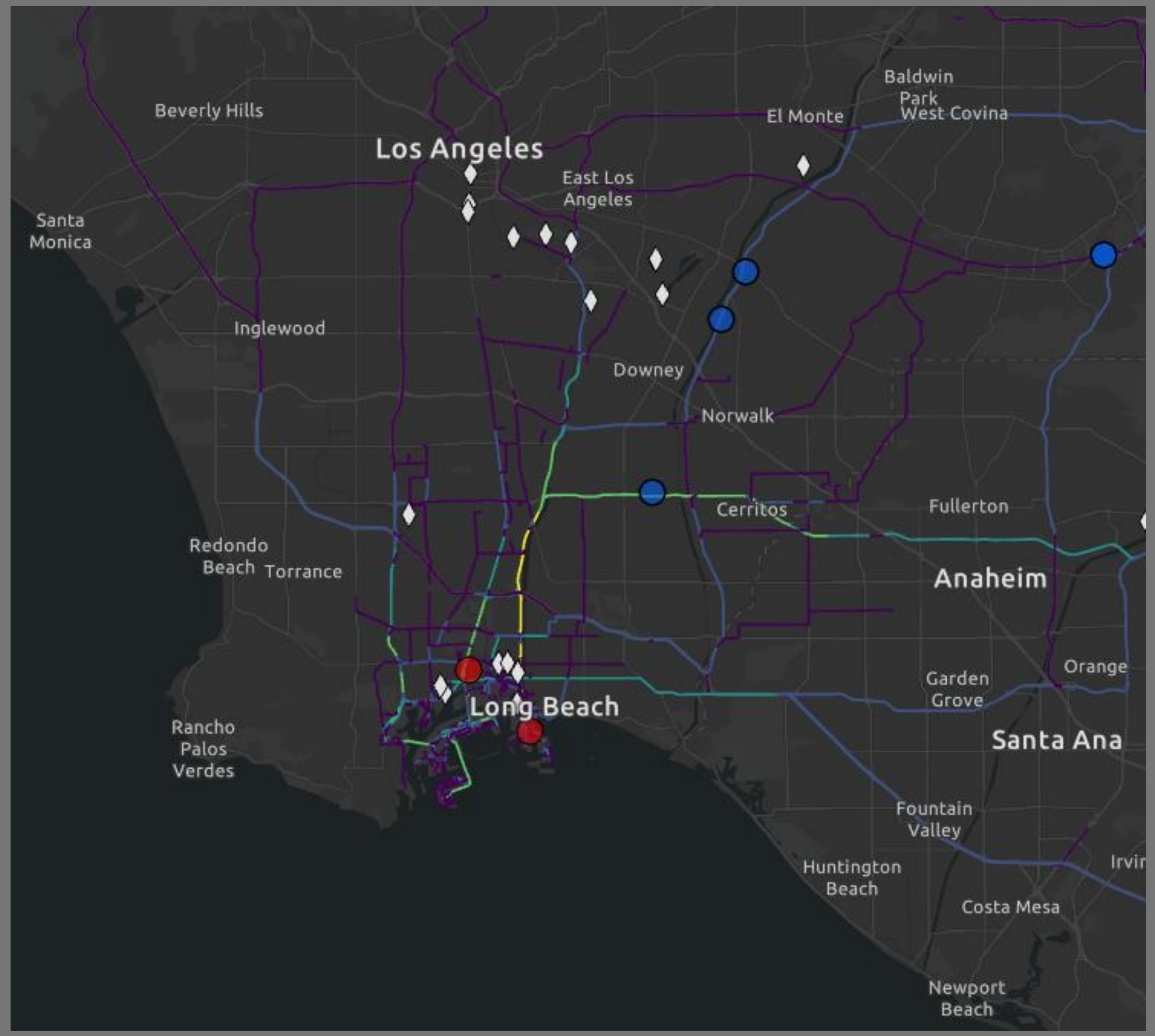
ERDC Approach: System-Level Approach to Resilience in Transportation Systems

- Problems that work sought to addressed:
    I. General Transportation/Supply Chain Resilience Quantification*
    II. Zero-Emission Refueling Station Prioritization

Supply Chain/ Transportation Resilience



Zero Emission Refueling Station



*proposed work

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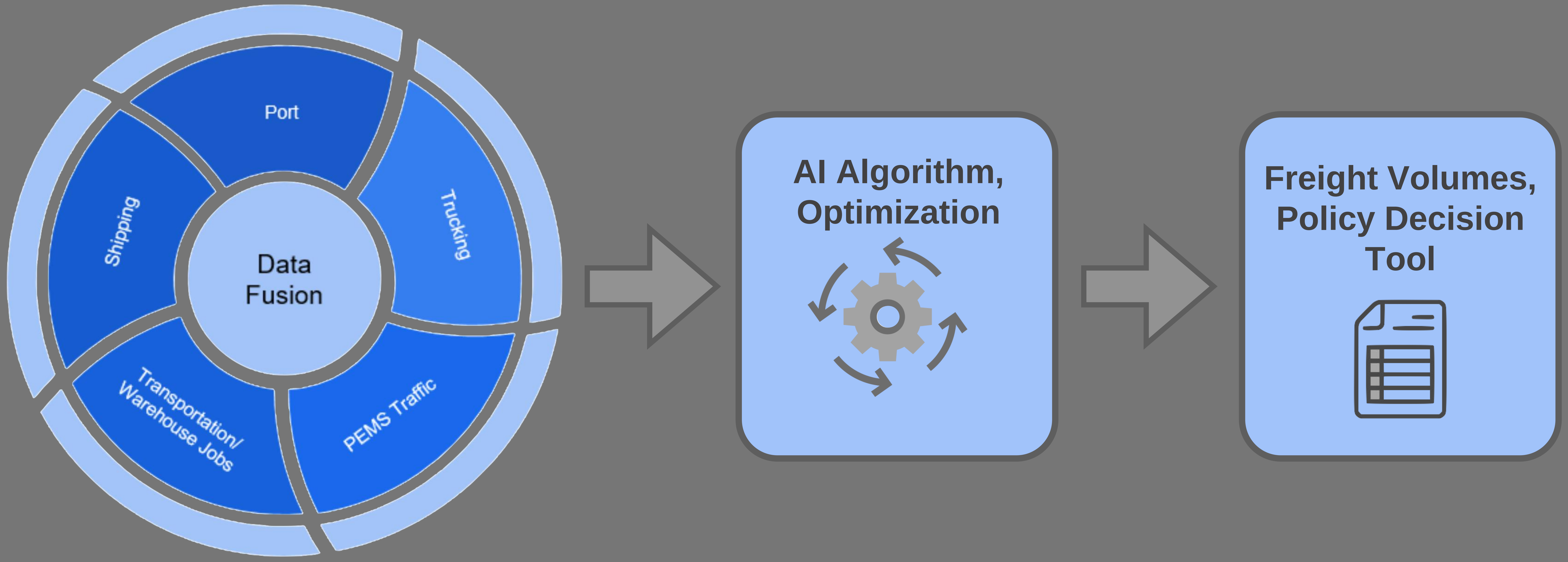
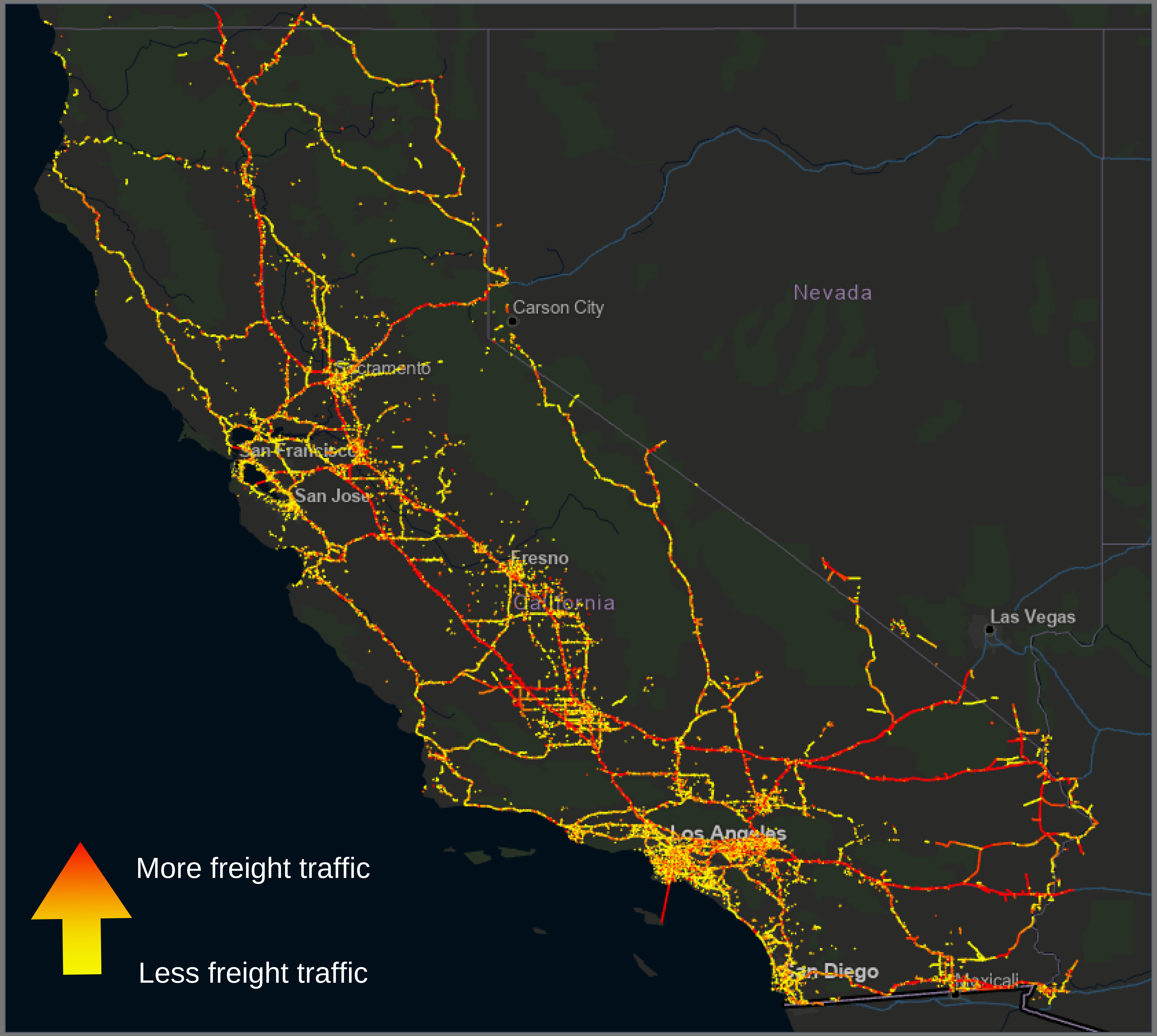
Methodology:
Data Fusion and Optimization Using AI and Resilience Modeling



Methodology:
Aggregate GPS

- Tools/Impacts can be understood for:
  - Aggregate Flows
  - Medium vs Heavy Trucks
  - Long Haul
  - CA External Goods:
    - Ports
    - Airports
    - Land Points of Entry



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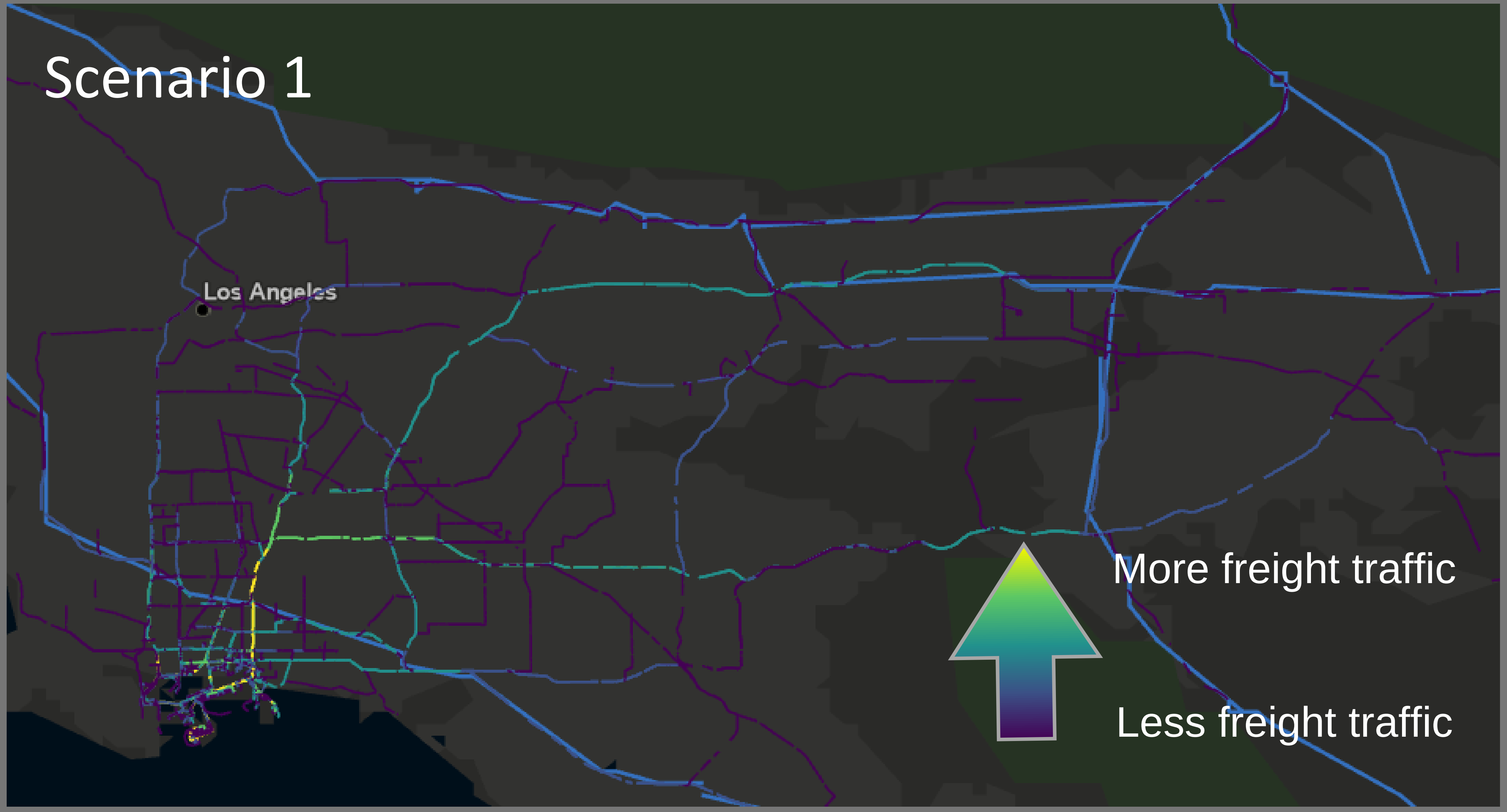
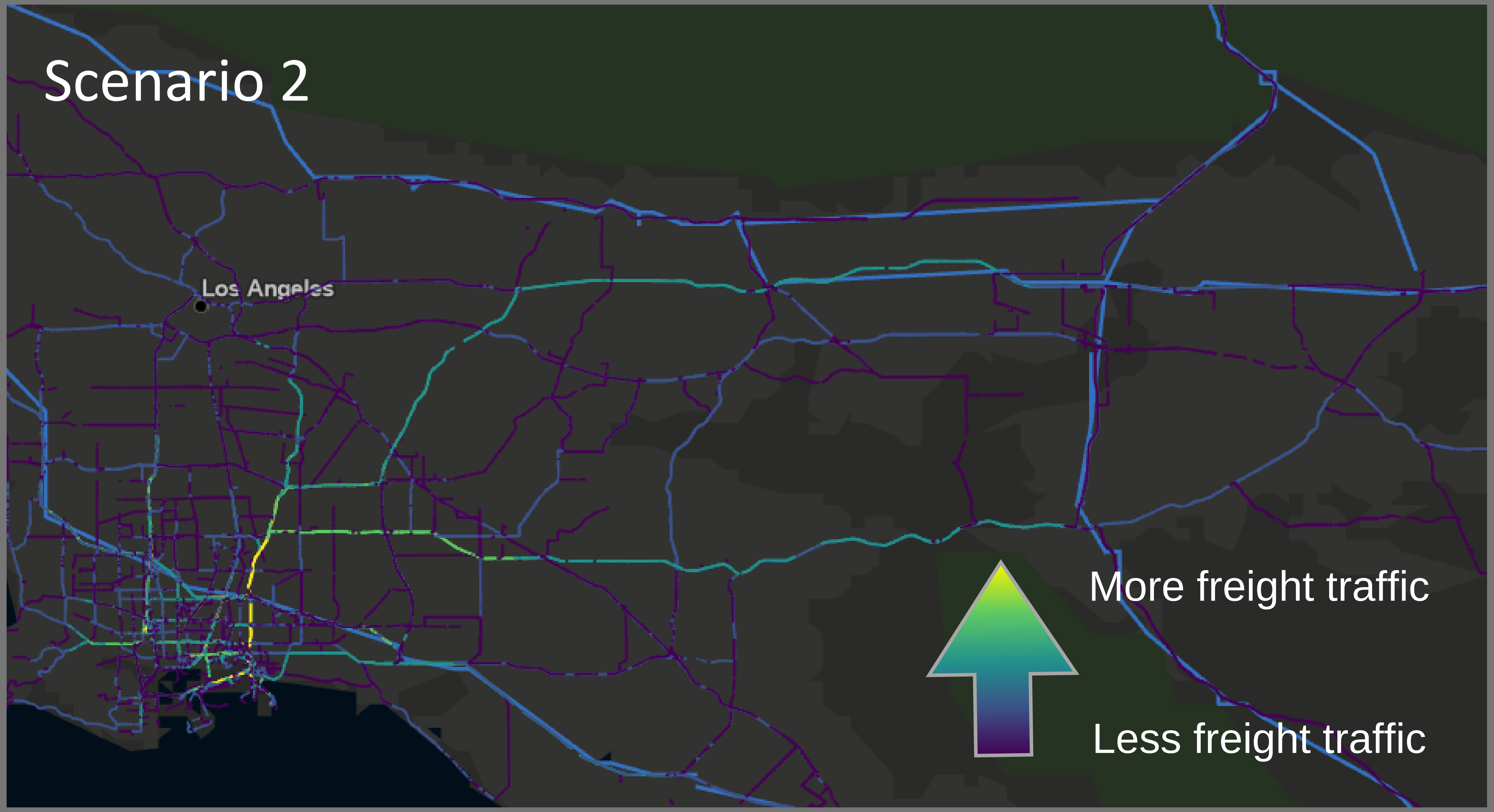
I. Problem 1: Resilience Policy Comparison Tool

- Scenario comparison tool compares new road volumes based on changes to roads
  - Does not: Recalculates by assuming cars will divert around the disrupted road
  - Does: Re-calculates by defining completely new routes for impacted vehicles
  - Finds added congestion and travel time
- Aim: Identify **single points of failure**





II. Problem 2:
Zero Emission Refueling Station

- **Challenge:**
  Minimize the diversion of freight routes caused by fuel conversion (disruption)

- **Solution:**
  Identify gas stations that could be converted to dispensing stations:

  - minimize freight displacement
  - scalable

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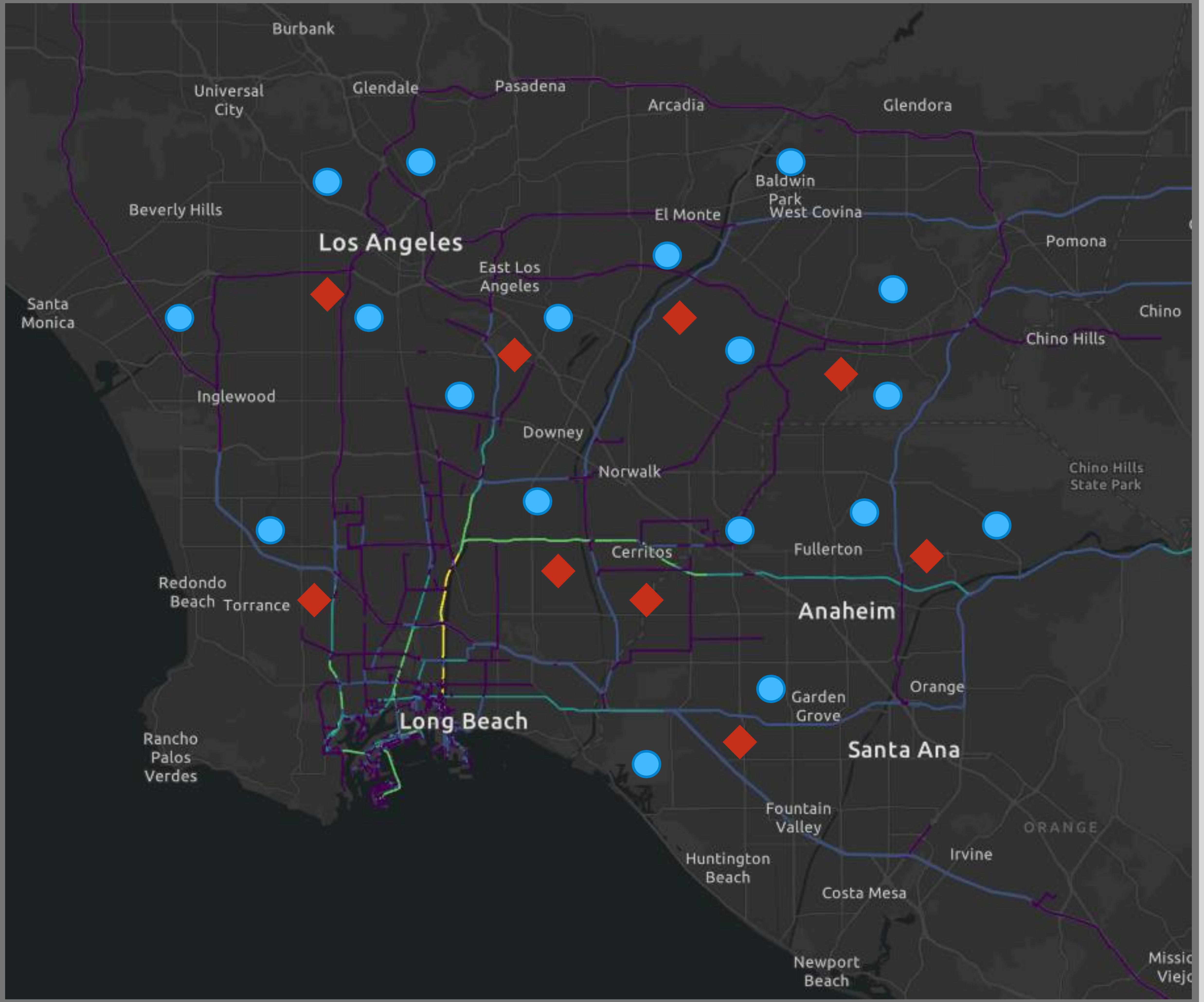
II. Problem 2: Methodology
Facility Location Problem

- Assigns Demand to Facilities such that an objective is minimized
  - Objective = **Total Travel Time**
- **Need:**
  - Demand Locations
  - Facility Locations
  - Travel Time between Demand and Facilities



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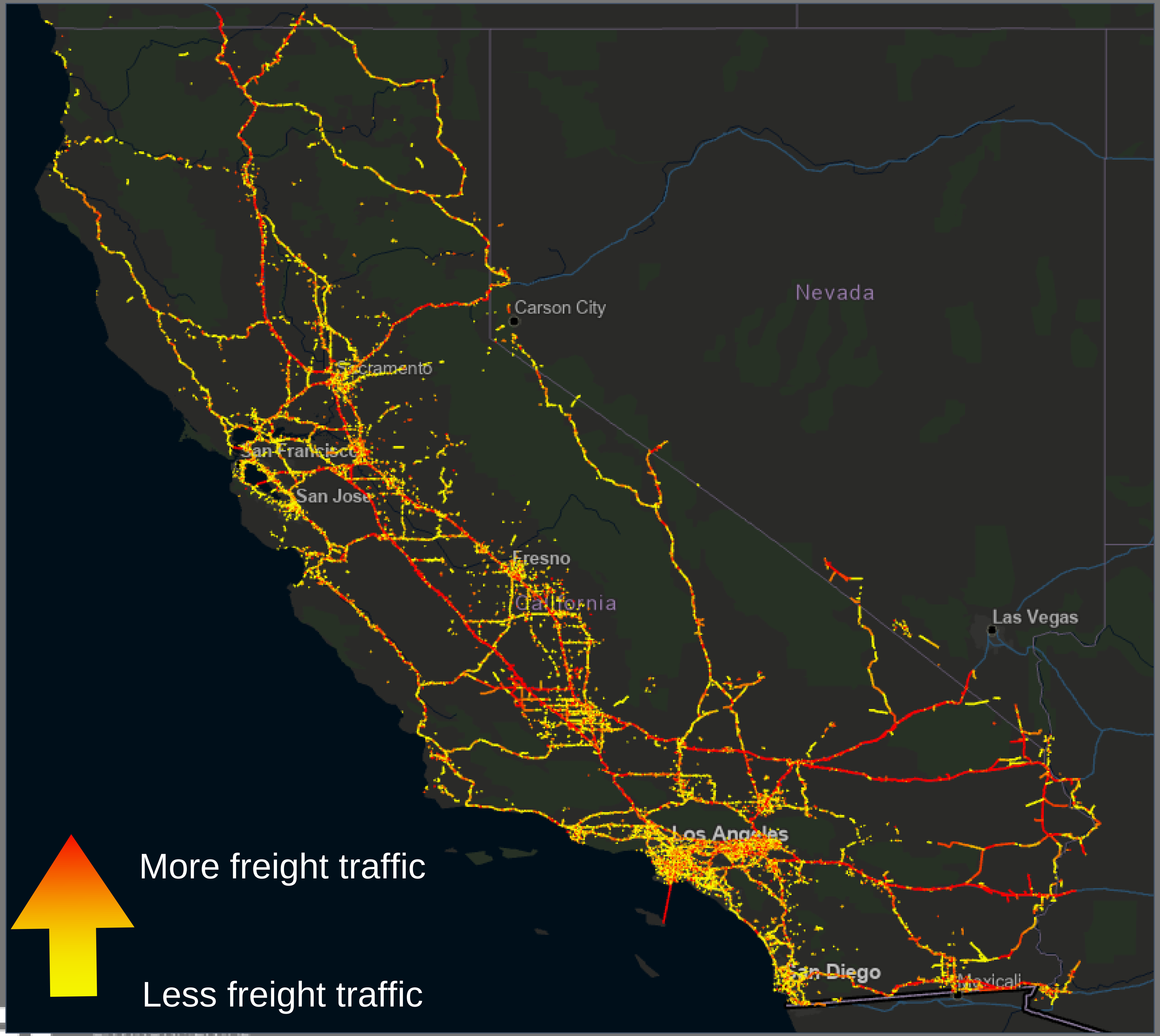
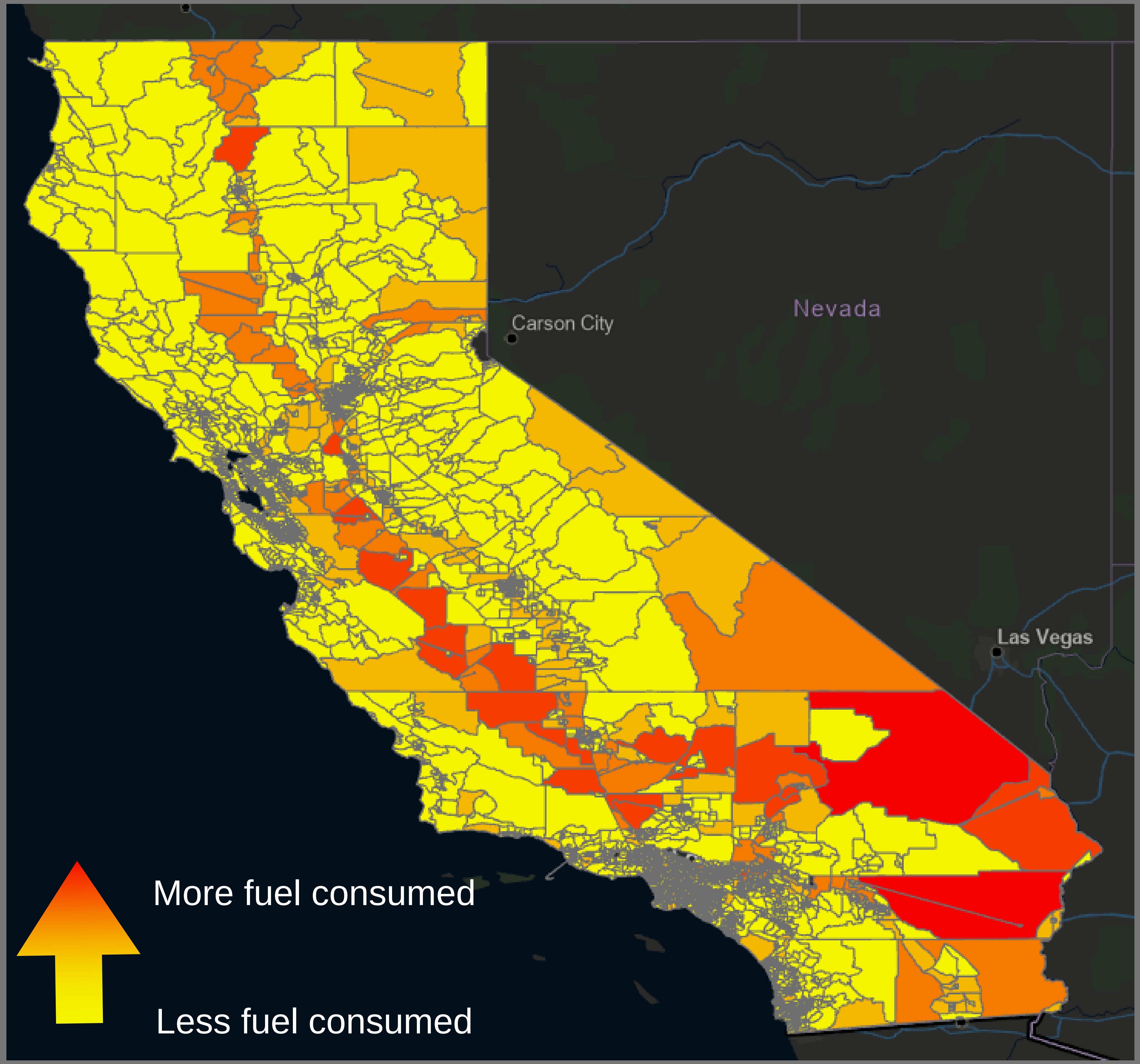
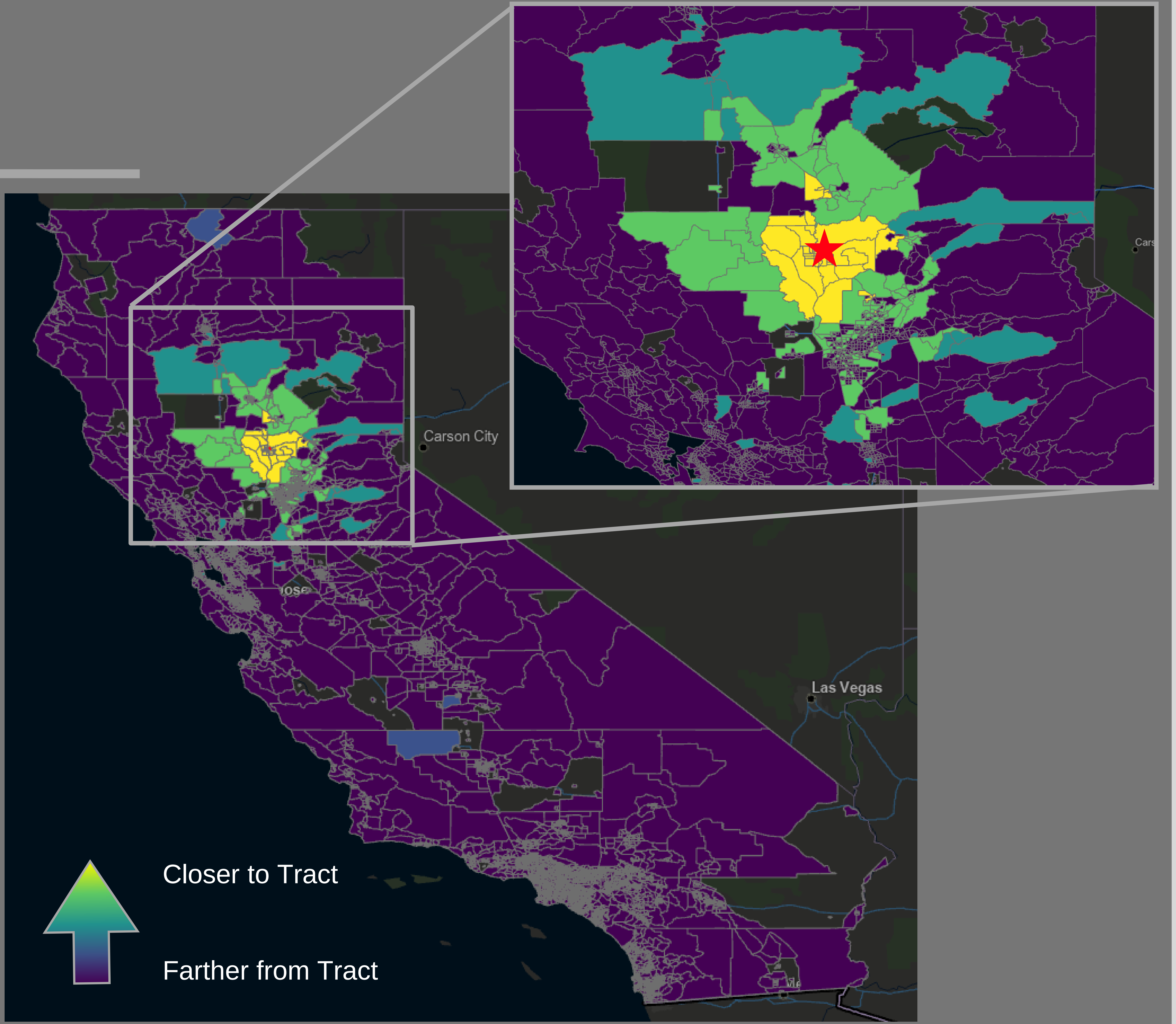




II. Problem 2: Methodology
Congestion Aware Travel Time

- **Distances:**
  Mean travel time between tracts from Replica freight trips data
- **Details:**
  - Trip data was used so that travel distances were 'congestion aware'
  - If no trips existed between blocks, travel time was set to 1 day



II. Problem 2: Optimization Results: Candidate Locations

- **Identified:**
  500 Candidate Census block which, together minimize freight diversion

- **Details:**

  - 500 block were identified based on CTC input

  - Gas and Service stations within census blocks were also identified

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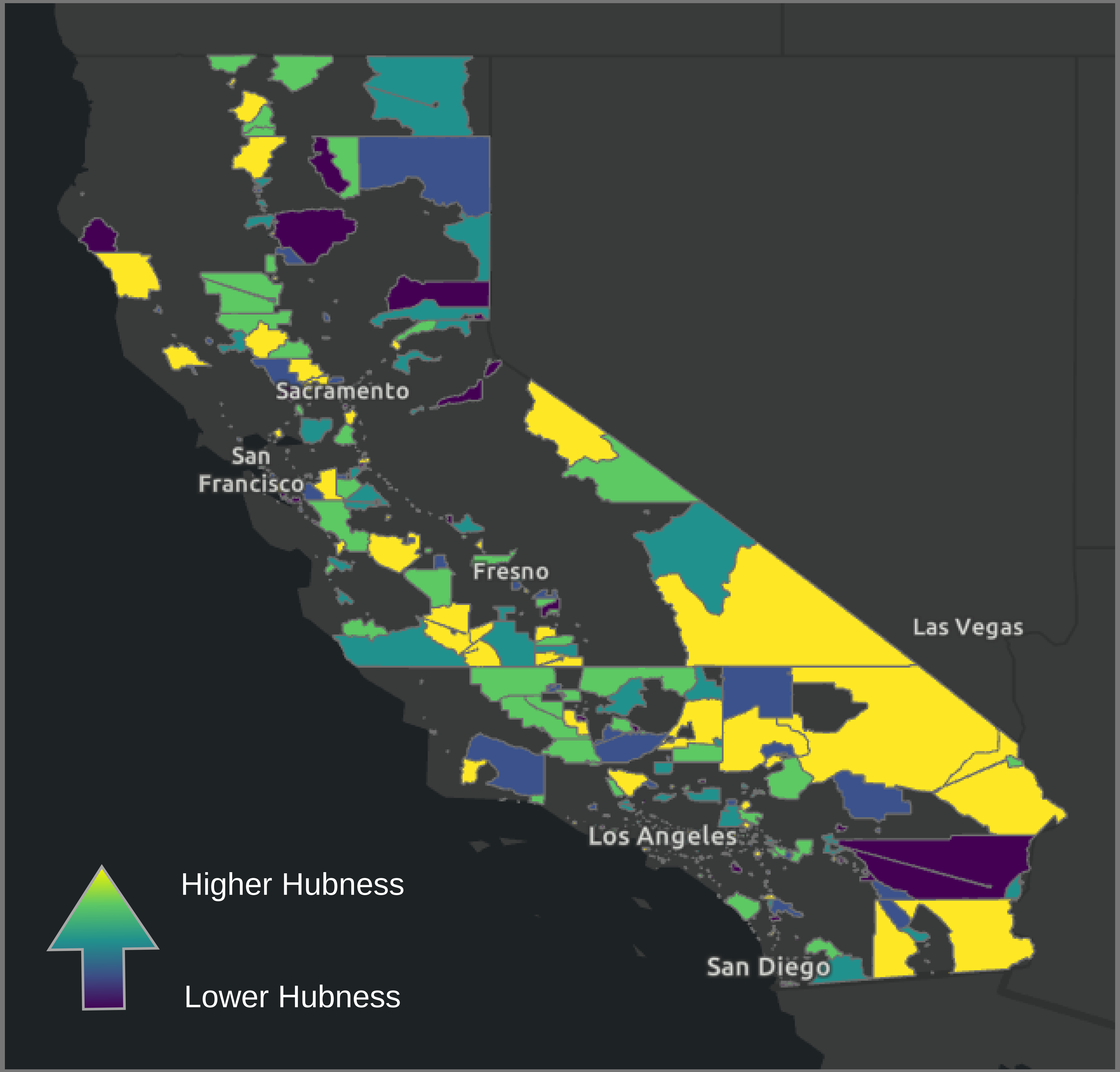
II. Problem 2: Optimization Results: Quantifying Location Scalability

Want: Quantify the Scalability of Locations

Solution: Rank solutions by hubness

Hubness:
1. Re-ran for sets of best (1, 2, …., 500) stations
2. Count of how many sets contain any location

- High hubness = Scales well as more are added
- Probably in a good, central location



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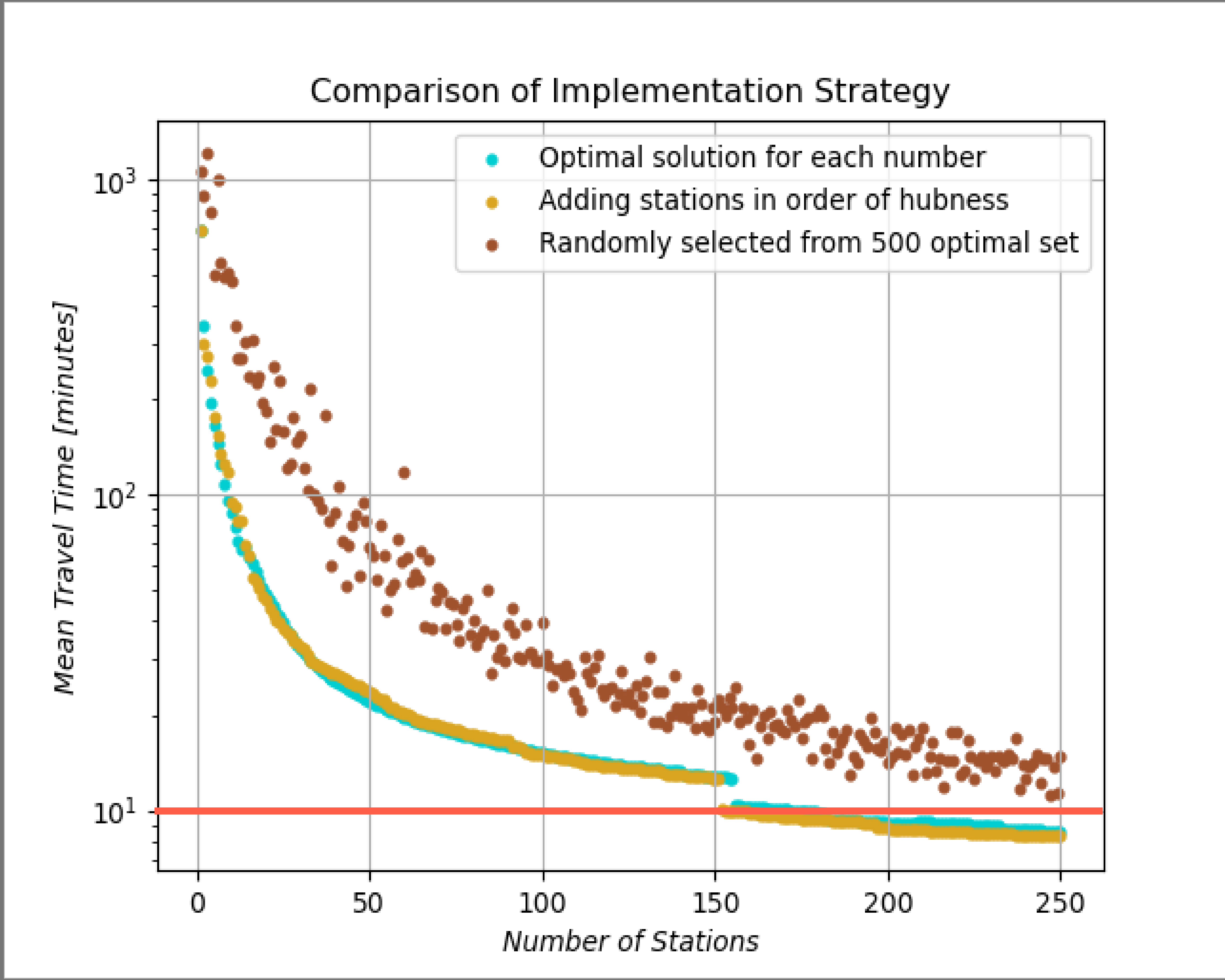

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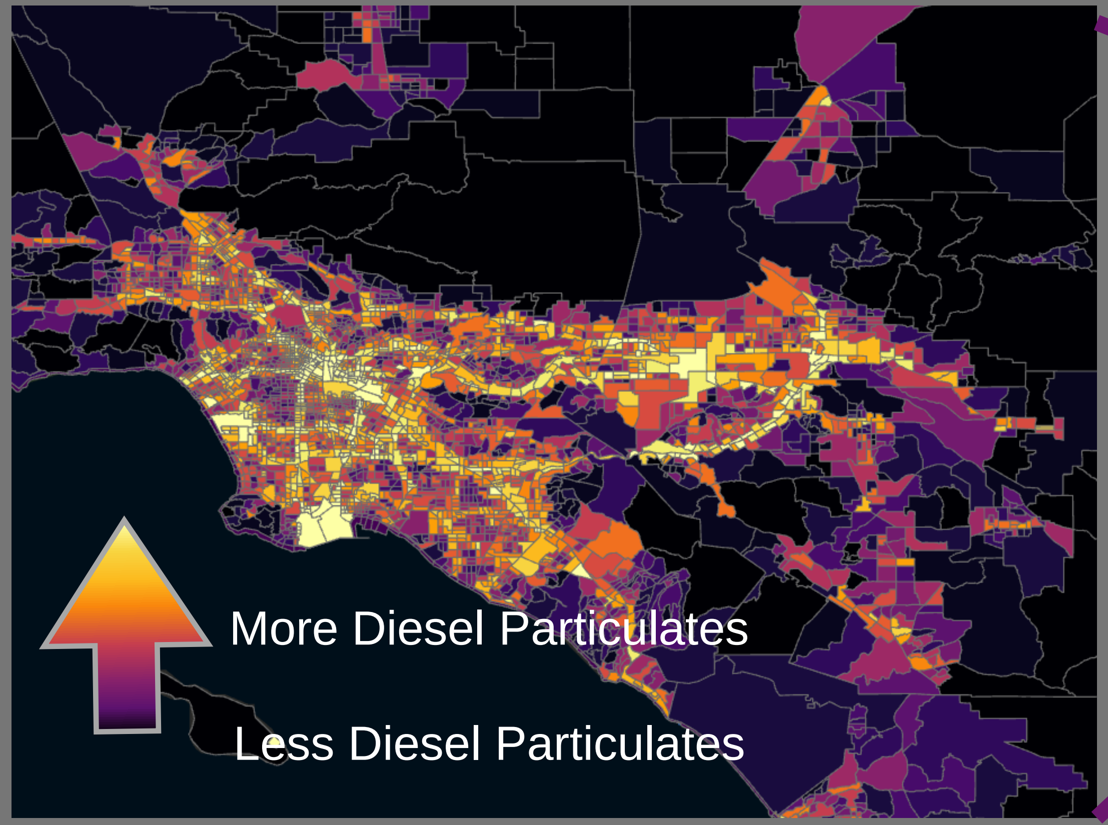
III. Extensions: Multi-Objective Optimization

- **Examined Concerns:**
  Define a set of equity concerns which can be weighed against each other

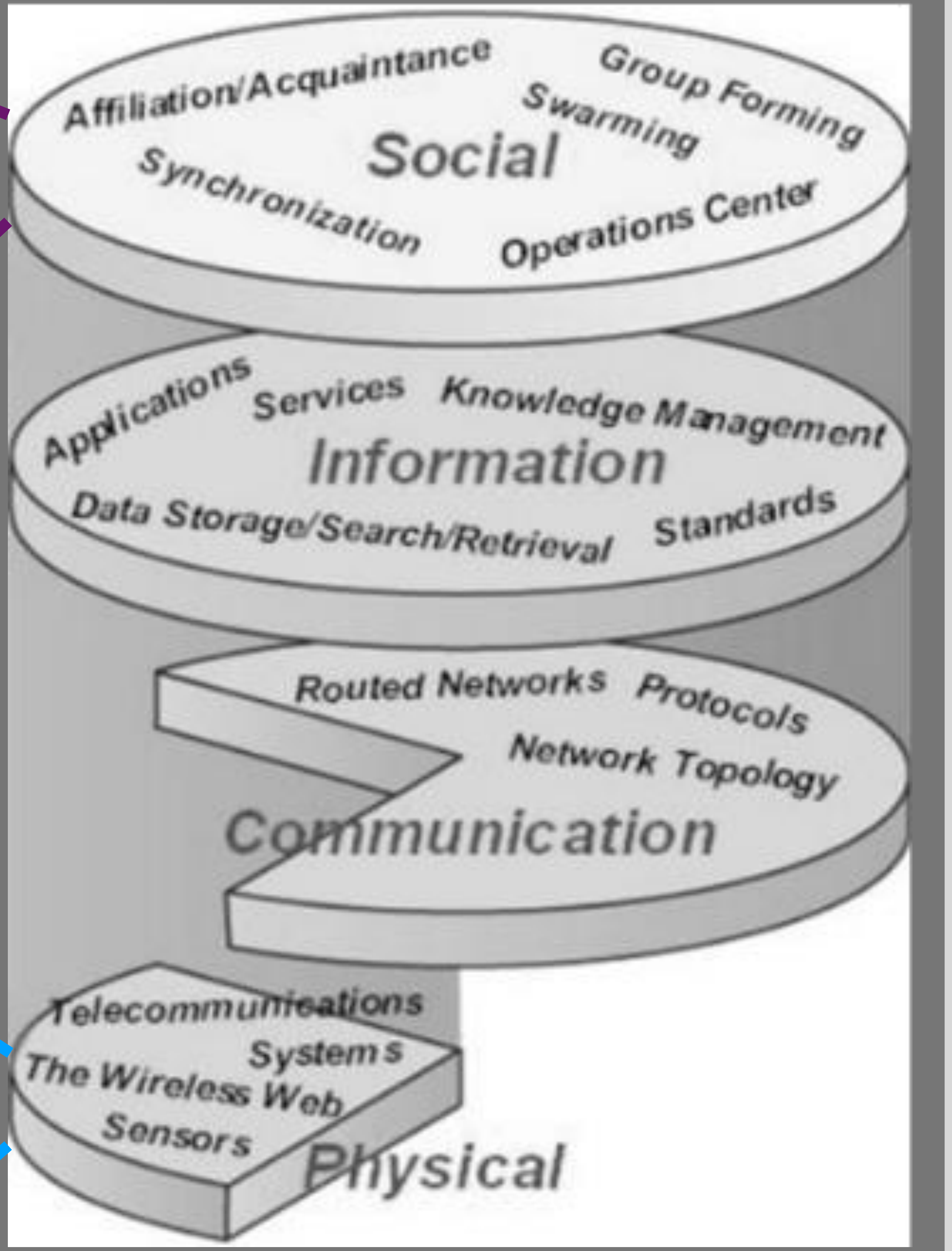
- **Solution:**
  Preform Multi-Objective Optimization:
  - Gets you a range of answers so decision makers can weight different options

Model



CalEnviroScreen 4.0
Diesel Particulate Matter - Percentage

Real World



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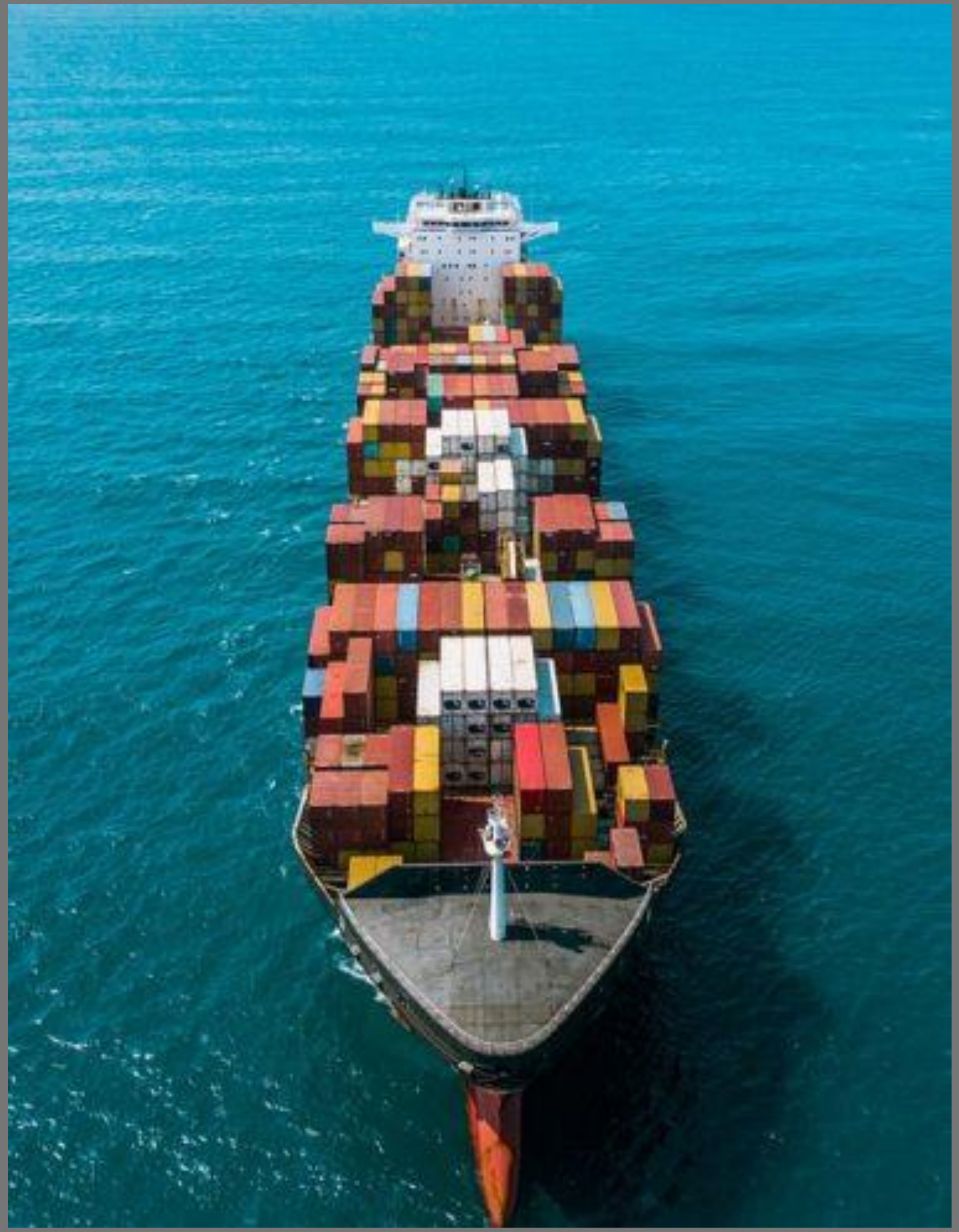
Where are we? Where do we want to go?

- **Where we are at:**
  - Growing call for resilience
  - Transportation Systems can be modeled
  - A lot of focus is still on risk, not resilience
- **Challenges:**
  - Visibility
  - Multi-Domain Knowledge
  - Validation/Success is Hard to Measure



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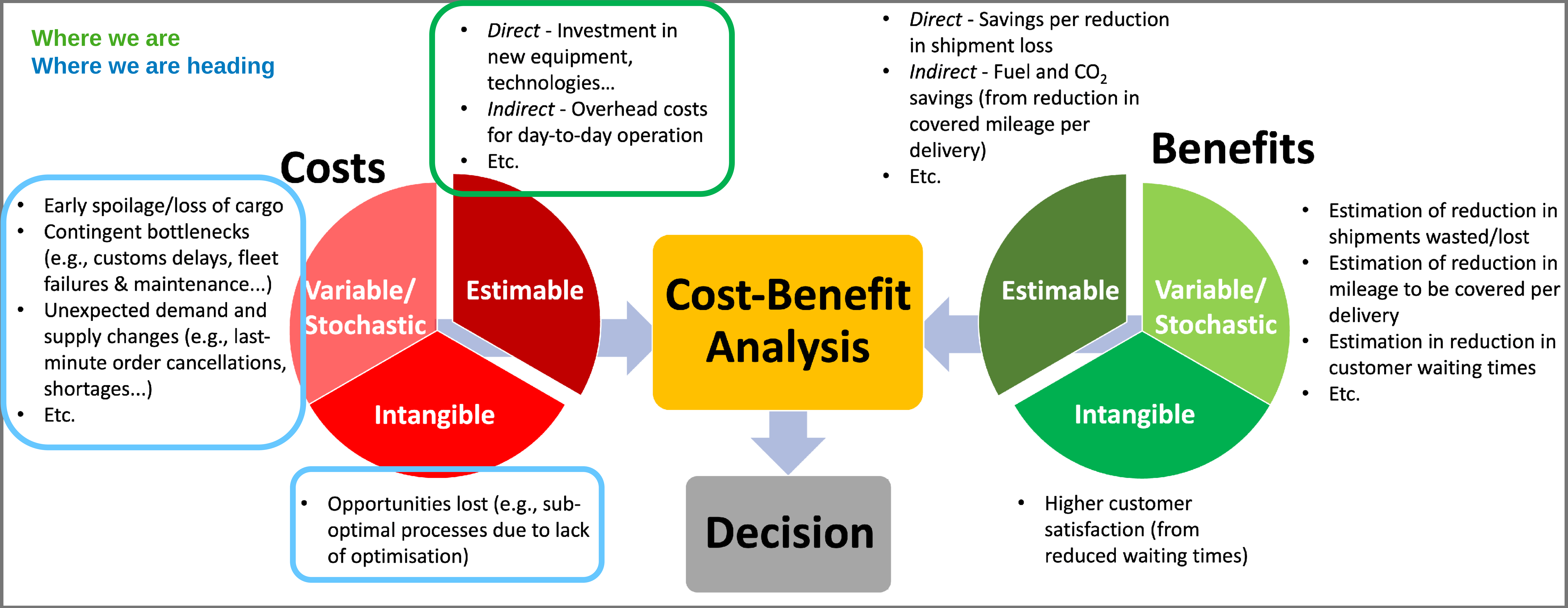
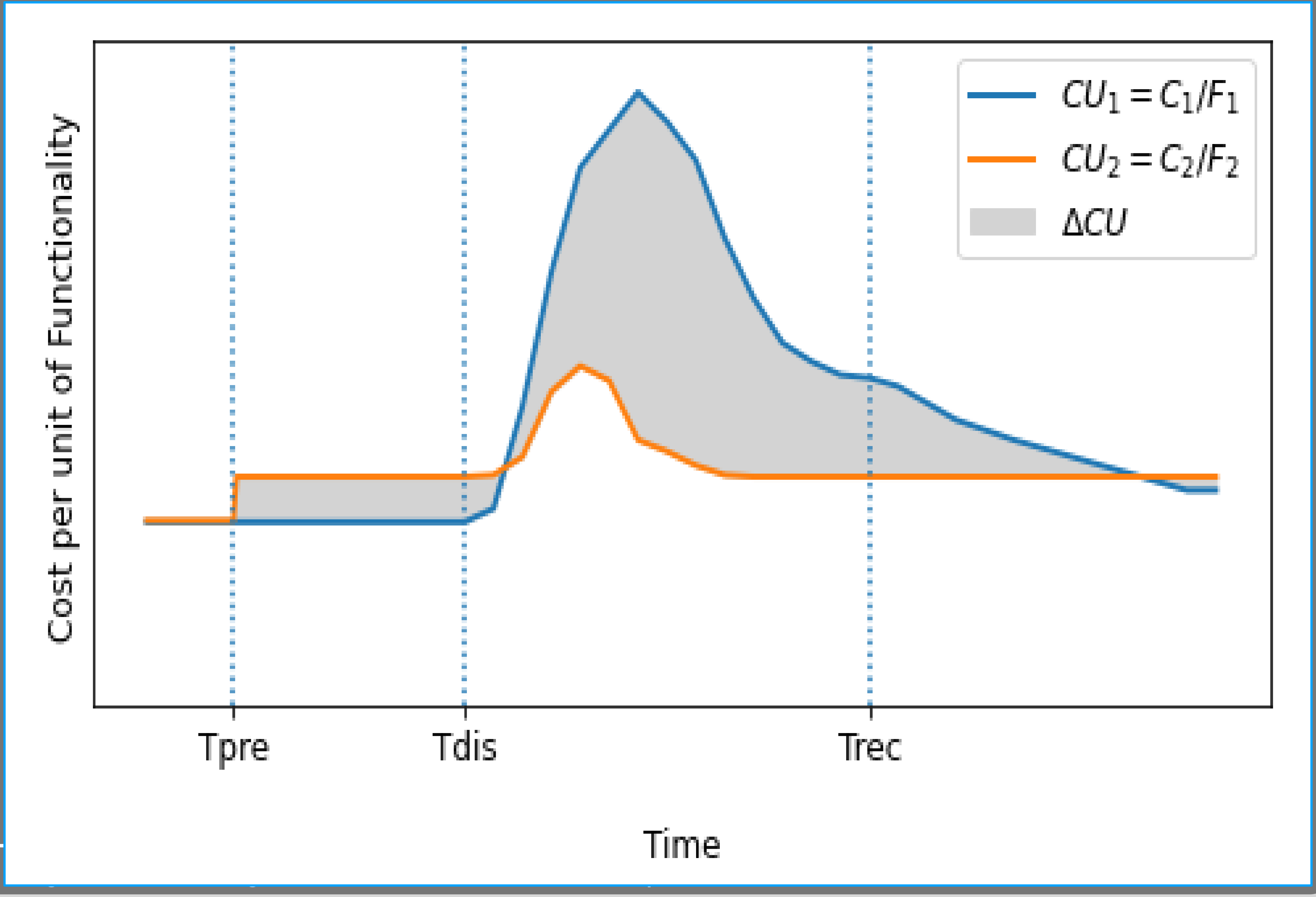
Where are we? Where do we want to go?



Schiffmann, O. et al., A Cost–Benefit Analysis Simulation for the Digitalization of Cold Supply Chains. *Sensors* **2023**, *23*, 4147. https://doi.org/10.3390/s23084147

Where are we? Where do we want to go?
Balancing Efficiency and Resilience

- Want to **maximize functionality across time over time**
- **Requires estimating both known and unknown risks**



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Where are we? Where do we want to go?

Summary:

- Resilience should be prioritized more
- Science emerging but needs to be developed
- We approach through data-driven, system-level modeling
- There are still challenges which need to be addressed:
  - Visibility
  - Multi-Domain Knowledge
  - Validation/Success is Hard to Measure

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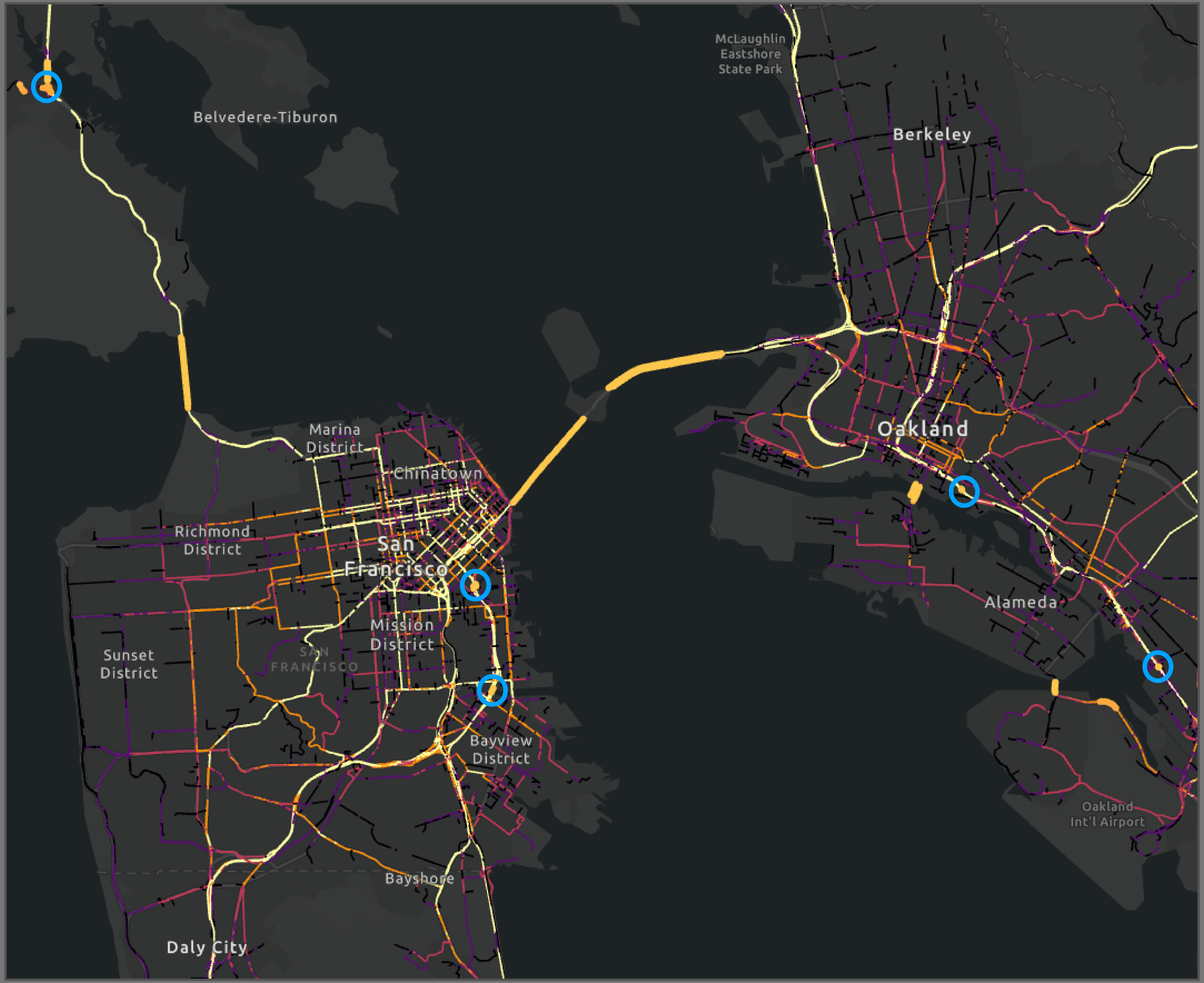
Questions



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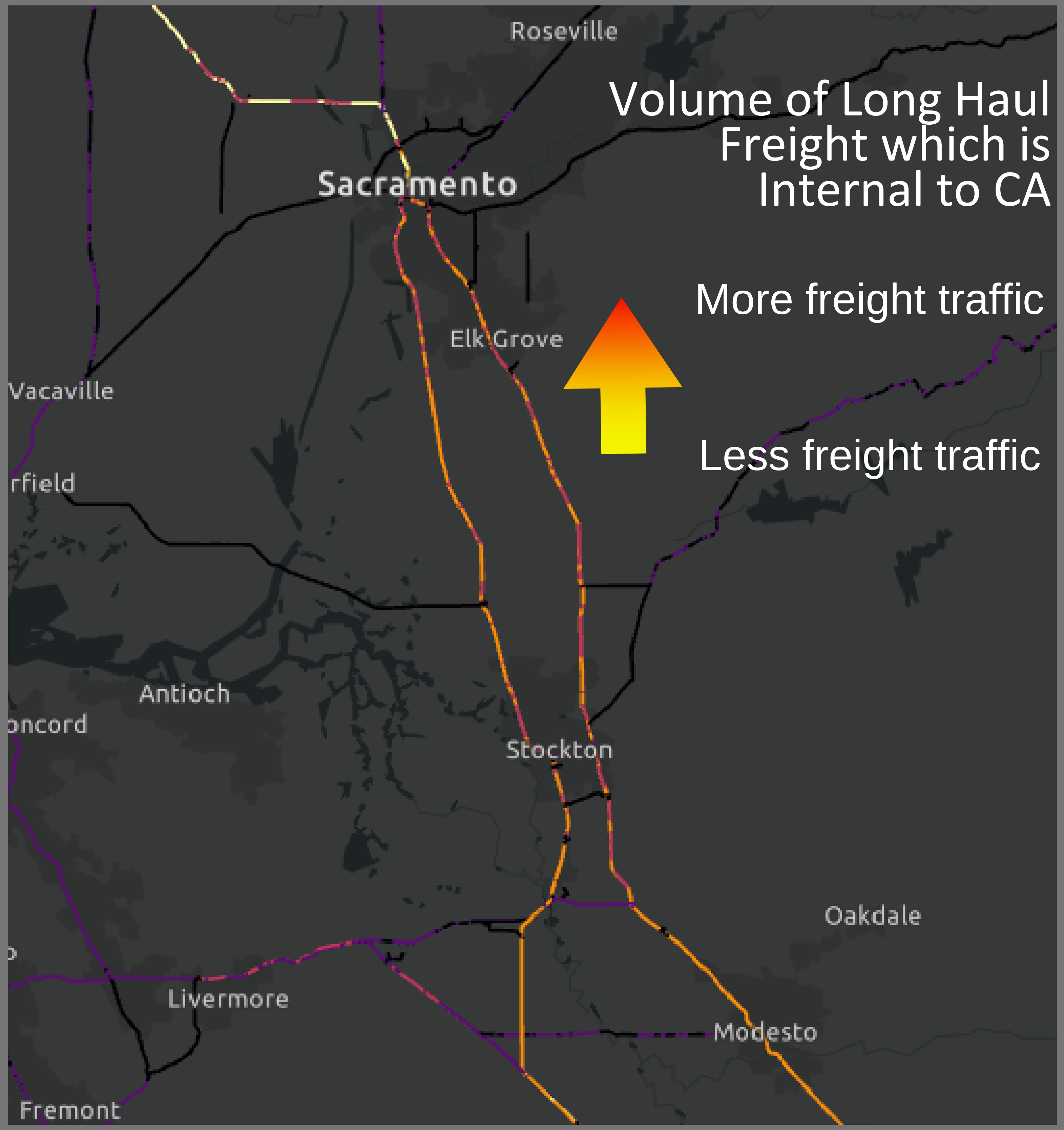
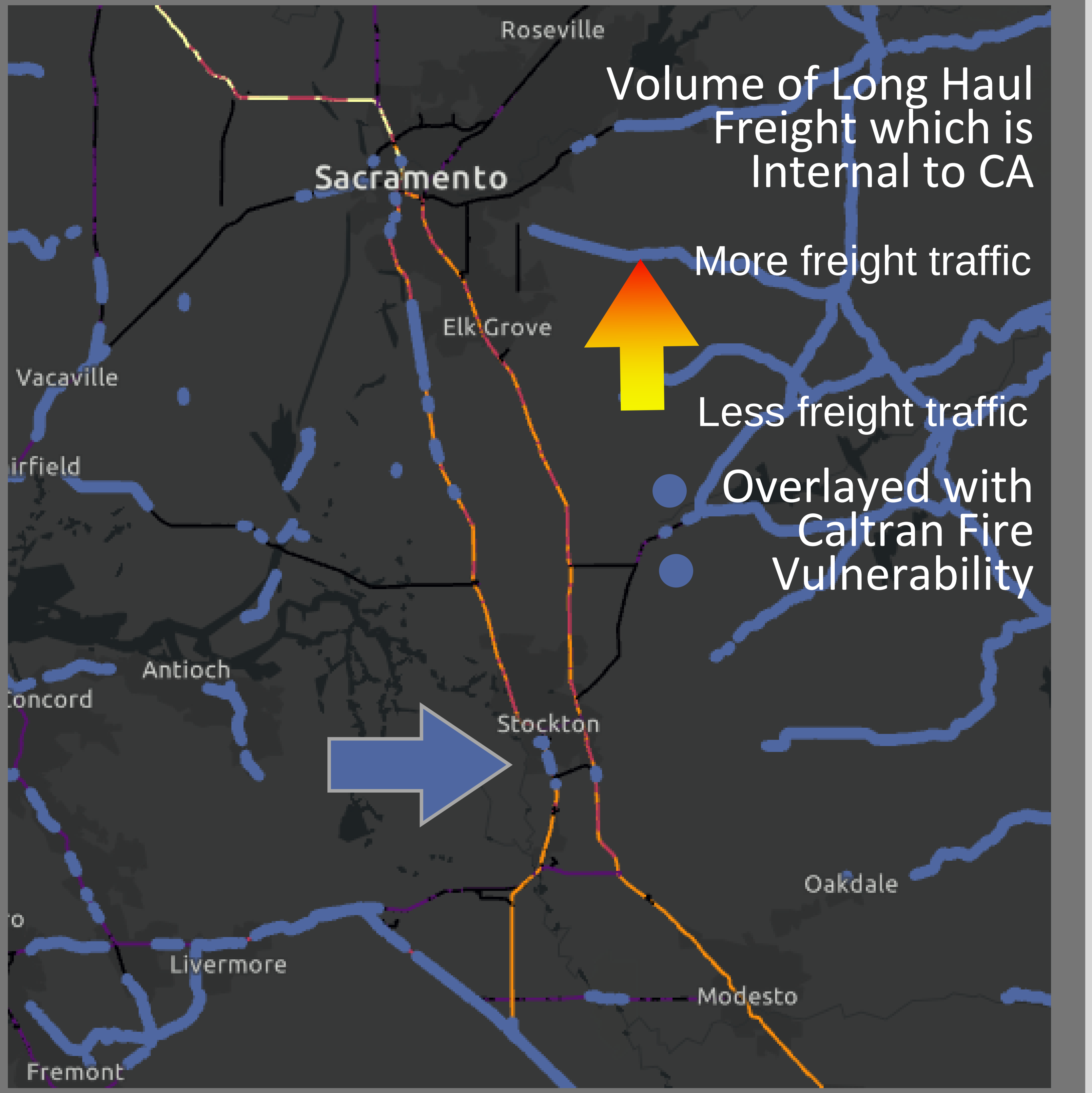
IV. Additional Results: Natural Disaster Overlays

- Overlaying freight volumes with climate change vulnerabilities:
  - Wild Fires - Early 2045
- Result: Near Stockton
  - N/S fright corridors are close
  - Near-term Fire Risk





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