

Ahead of the Curve: Emergency Logistics

SCL Affiliated Faculty Member Mathieu Dahan shares insights from his research on how service systems and workforce models perform under stress

LUNCH AND LEARN

Thursday, February 6, 2026 | 12pm ET

Thank you for attending!



Mathieu Dahan

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for upcoming session dates

Ahead of the Curve: Emergency Logistics and Rapid Response Systems

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Georgia Institute of Technology

Joint work with Pichamon Anukulkarnkusol, J. Haden Boone, and Bobak McCann

SCL Lunch and Learn, February 5, 2026

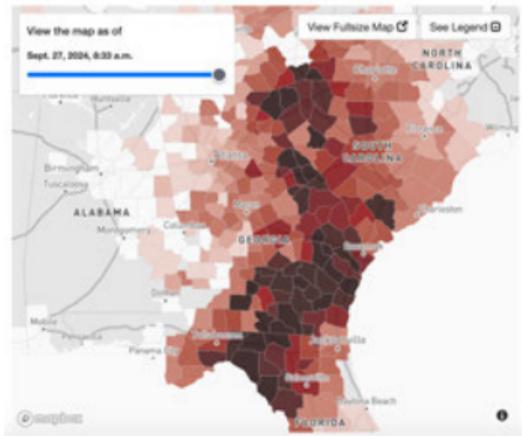


Reliability and Security Failures in Distribution Networks



Georgia power outage map

In Georgia alone, more than a million people were without power as of about 7:30 a.m. Friday, according to USA TODAY's tracker. Chatham County had the most residents without power, at 113,212 reported outages.



Cyberattack cost Maersk as much as \$300 million and disrupted operations for 2 weeks



Ukraine targets Russian oil pipeline installations with drones - Russian media

By Guy Faulconbridge and Alexander Marrow

May 27, 2023 11:41 AM EDT - Updated a year ago



Somalia: Pirates attack UN aid ship, prompting call for action

THE EVER-CHANGING LOGISTICS OF DRUG SMUGGLING

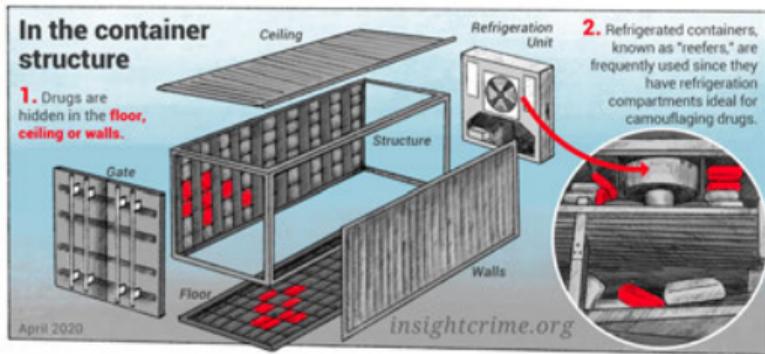
BY PETER S. GREEN

WSJ

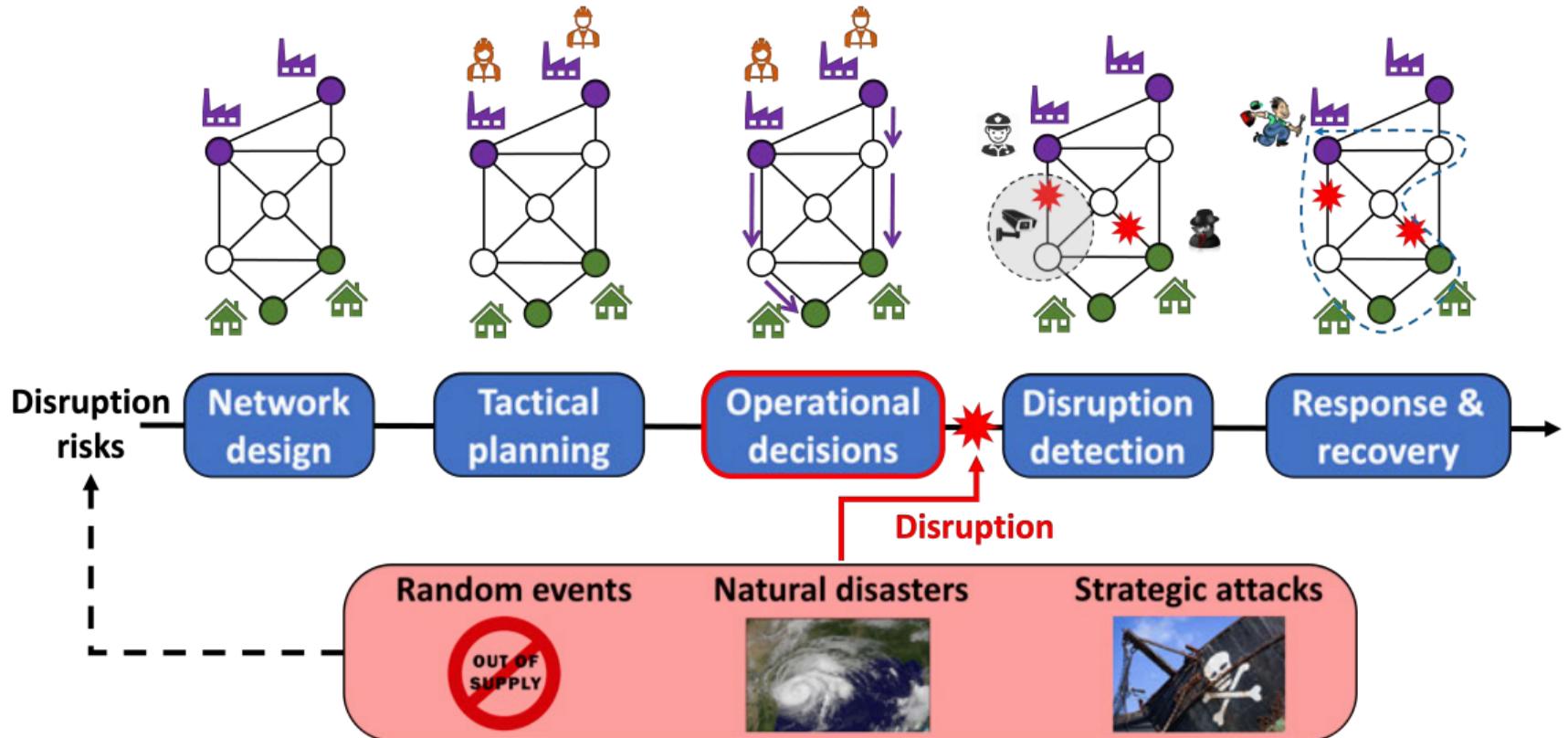
Latin America Smugglers Opt for Commercial Flights

by Juliana Manjarrés 3 Jun 2024

InSight  Crime



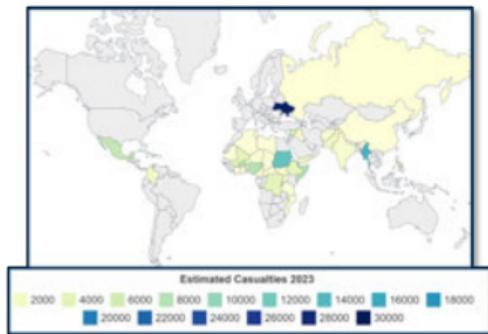
Improving Network Security and Resilience



Expeditionary Logistics

Movement of supplies and personnel to support military operations in challenging environments

- Rapid deployment of supply lines during military conflict
- Delivery of relief supplies to communities impacted by disaster
- Evacuating refugees or wounded soldiers from unsafe areas



Countries at war in 2023



Supplies being delivered to Hurricane Helene survivors in North Carolina

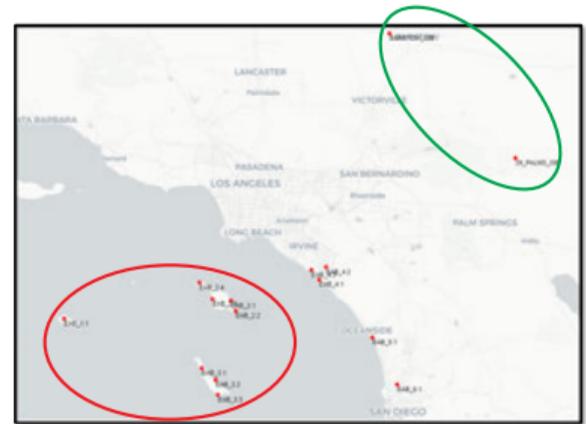


Air Force evacuating Hurricane Katrina victims

Expeditionary Logistics

Main Features

- Priority on **meeting as much demand as possible on time**
- Remote **demand locations**
- Distant **supply hubs**
- Specialized multimodal fleet
 - Heterogeneous speeds and capacities
 - Constraints on location access
 - No possibility to outsource vehicles



Current Practices

- Wargaming and tabletop exercises
- Presentations and spreadsheets show strategies at high level
 - Limited quantitative evaluation of logistic capabilities

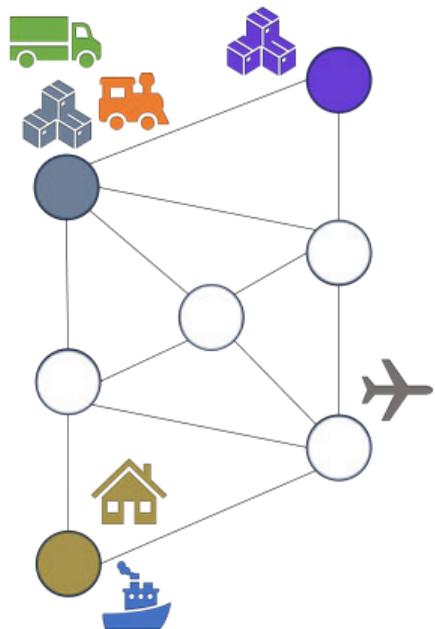
How to efficiently develop logistics consolidation plans in expeditionary environments?

Our Work

- Formulate an optimization model for multimodal scheduled service network design
- Develop a large-scale optimization algorithm to efficiently manage transportation assets
- Validate our approach on instances provided by the U.S. Marine Corps
- Integrate model into military software



Problem Description



Flat Network:

- Sets of locations and vehicle-specific arcs

Commodities:

- Multiple commodity types
 - Various weights, volumes, and transportation requirements
- Supplies and requests become available throughout the time horizon

Vehicles:

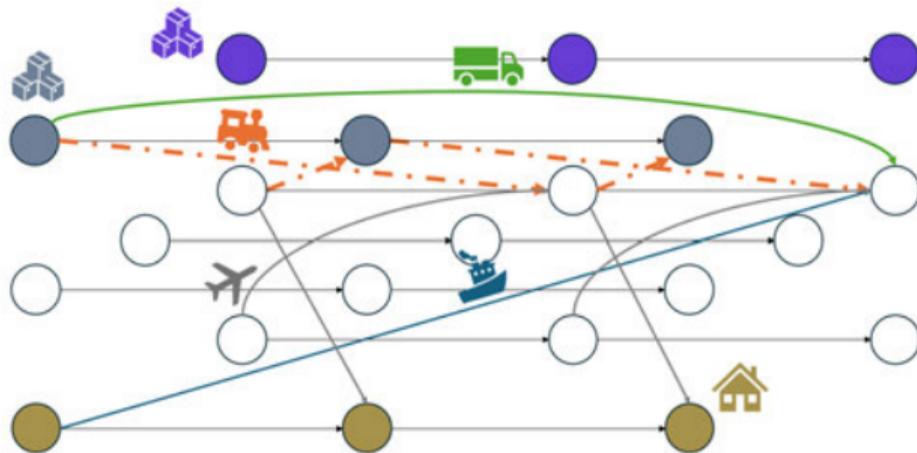
- Multiple vehicle types
 - Various domains, speeds, and weight/volume capacities



Time-Space Network

To model temporal decisions (e.g., dispatch times), we construct a time-space network:

- 1 Create a set of decision points of time interval Δ
- 2 Duplicate locations for each epoch
- 3 Add arcs that move across the time horizon:
 - Arcs that symbolize waiting at a location
 - Arcs that symbolize traveling on a vehicle



Mixed-Integer Programming Formulation

$$\begin{aligned} \max \quad & \sum_{k \in K} \sum_{\tilde{i} \in D} v_{\tilde{i}}^k \cdot \theta_{\tilde{i}}^k \\ \text{s.t:} \quad & \sum_{a \in \delta^+(\tilde{i})} x_a^c - \sum_{a \in \delta^-(\tilde{i})} x_a^c = \begin{cases} n_{\tilde{i}}^c & \text{if } \tilde{i} \in S \\ -\sum_{\tilde{j} \in S} n_{\tilde{j}}^c & \text{if } \tilde{i} = \tilde{i}_{end} \quad \forall \tilde{i} \in L, c \in C \\ 0 & \text{otherwise} \end{cases} \end{aligned}$$

$$\sum_{k \in K} w^k \cdot f_a^k \leq u^c \cdot x_a^c, \quad \forall c \in C, a \in A$$

$$\sum_{a \in \delta^+(\tilde{i})} f_a^k - \sum_{a \in \delta^-(\tilde{i})} f_a^k \begin{cases} \leq b_{\tilde{i}}^k & \text{if } \tilde{i} \in I \\ = -\theta_{\tilde{i}}^k & \text{if } \tilde{i} \in D \\ = 0 & \text{otherwise} \end{cases} \quad \forall \tilde{i} \in L, k \in K$$

$$0 \leq \theta_{\tilde{i}}^k \leq d_{\tilde{i}}^k, \quad \forall k \in K, \tilde{i} \in D$$

$$x_a^c \in \mathbb{Z}_{\geq 0}, \quad \forall c \in C, a \in A$$

$$f_a^k \geq 0, \quad \forall k \in K, a \in A$$

Maximize value of on-time demand fulfillment

Vehicle flow balance constraints

Capacity constraints

Commodity flow balance constraints

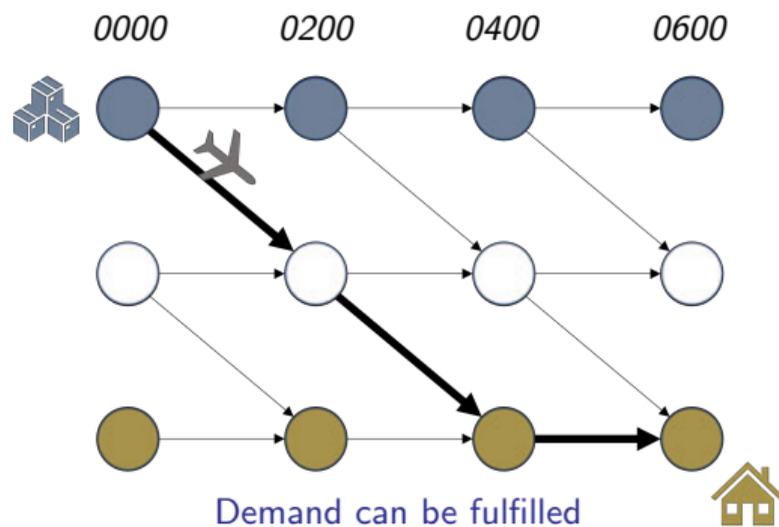
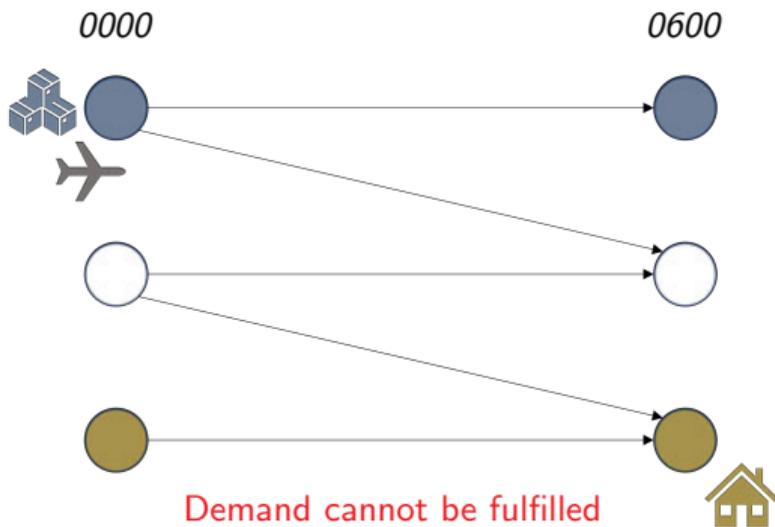
Demand fulfillment

Vehicle flow

Commodity flow

Time Discretization

- Performance of expeditionary logistics is impacted by the granularity of the time discretization



**Dynamic discretization
discovery (DDD) algorithm**

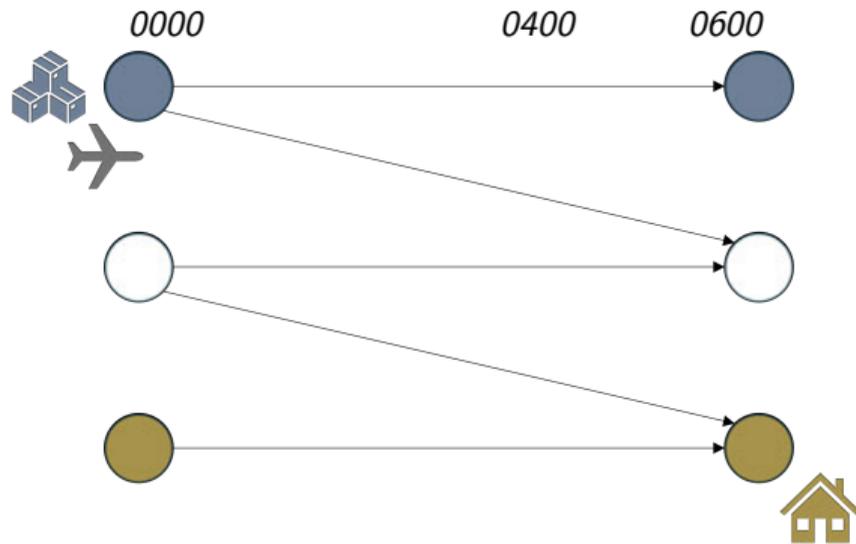
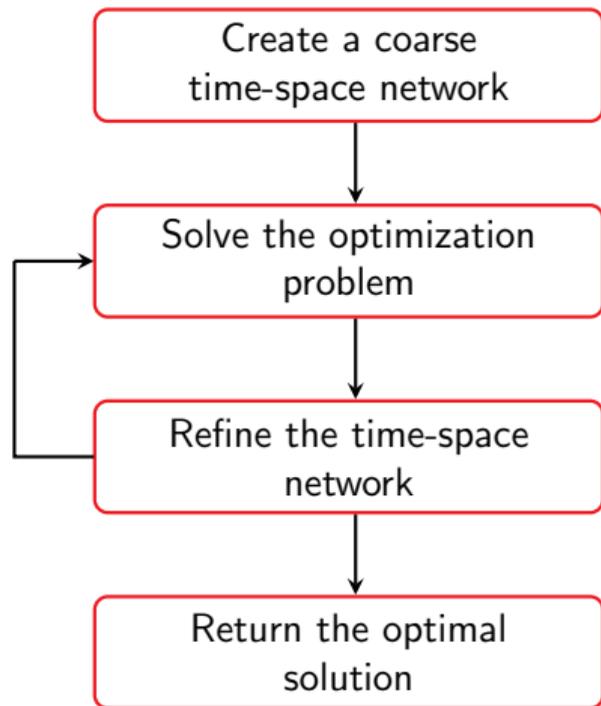


Finer Time Discretization:

- + Better management of assets
- + More consolidation and deliveries
- Significantly harder problem to solve

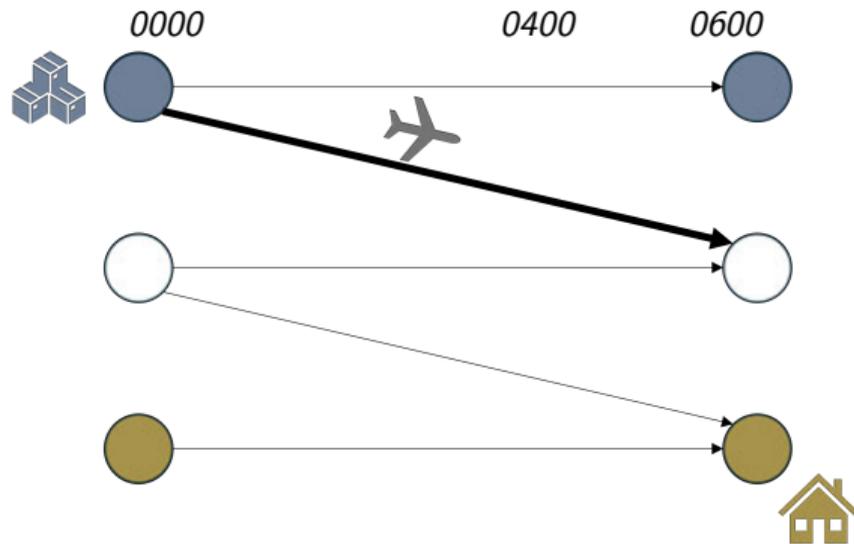
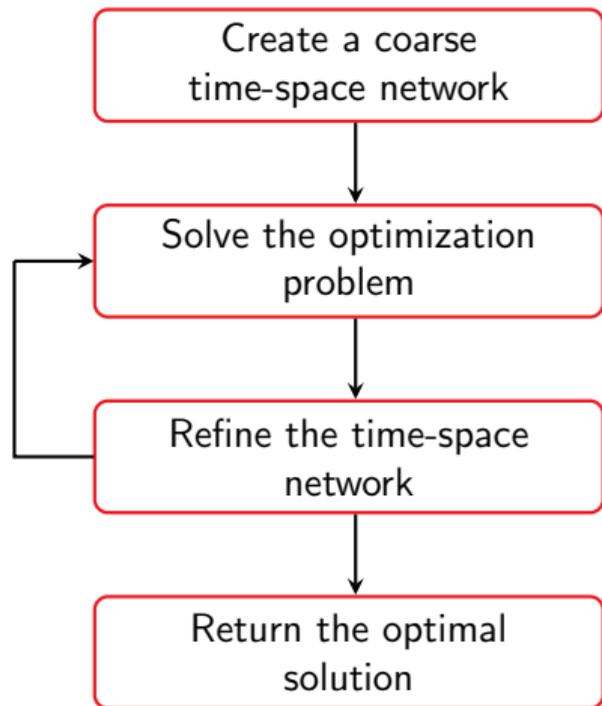
Dynamic Discretization Discovery

Iterative Algorithm



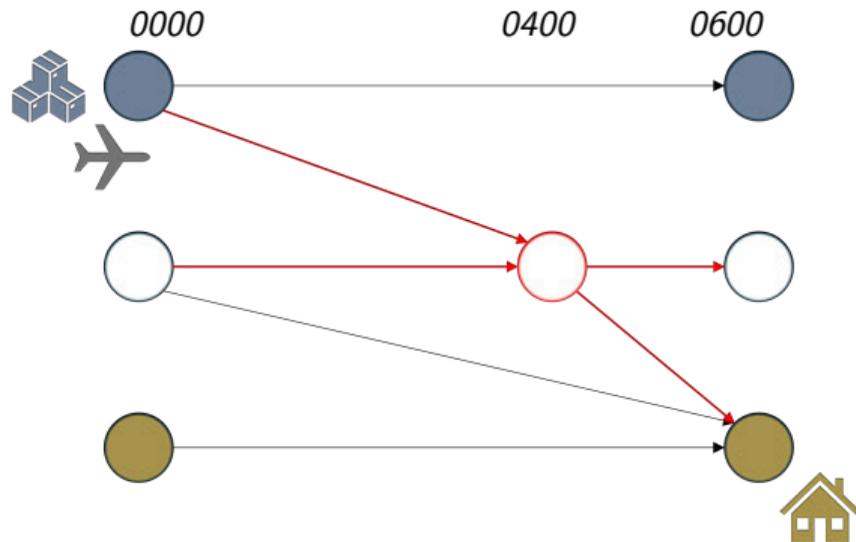
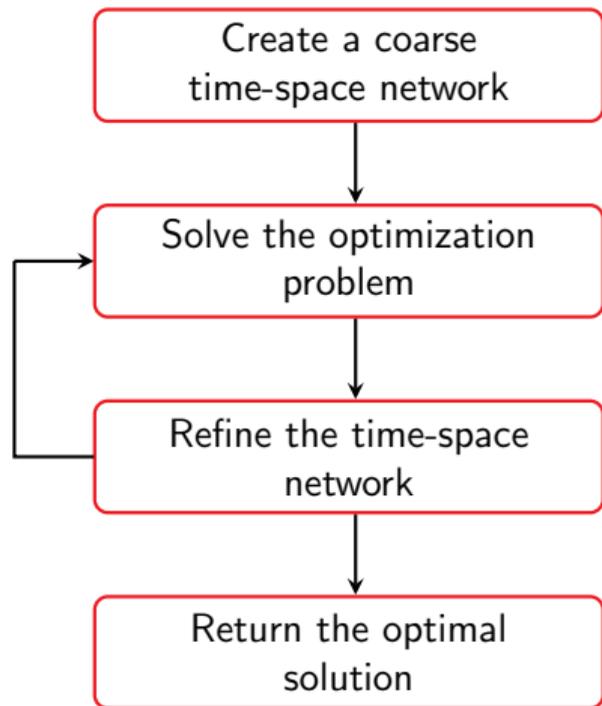
Dynamic Discretization Discovery

Iterative Algorithm



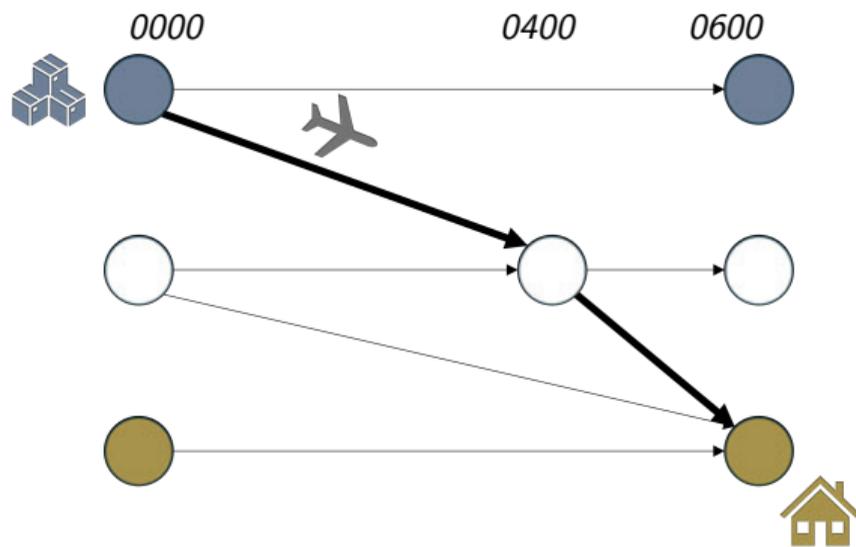
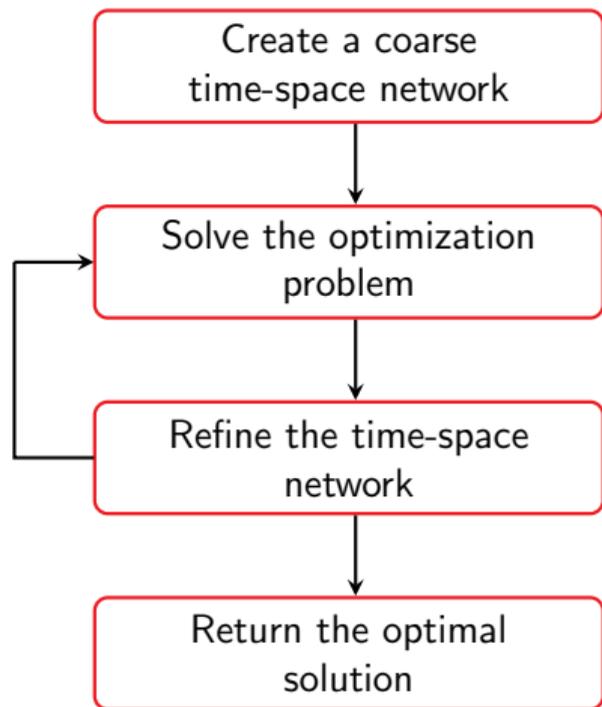
Dynamic Discretization Discovery

Iterative Algorithm



Dynamic Discretization Discovery

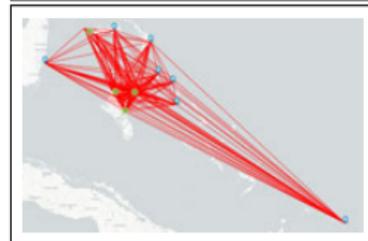
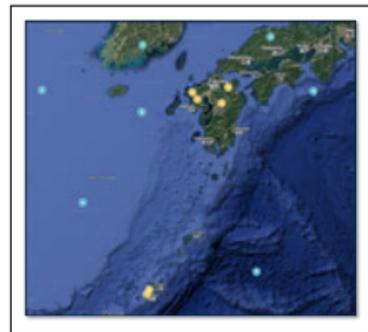
Iterative Algorithm



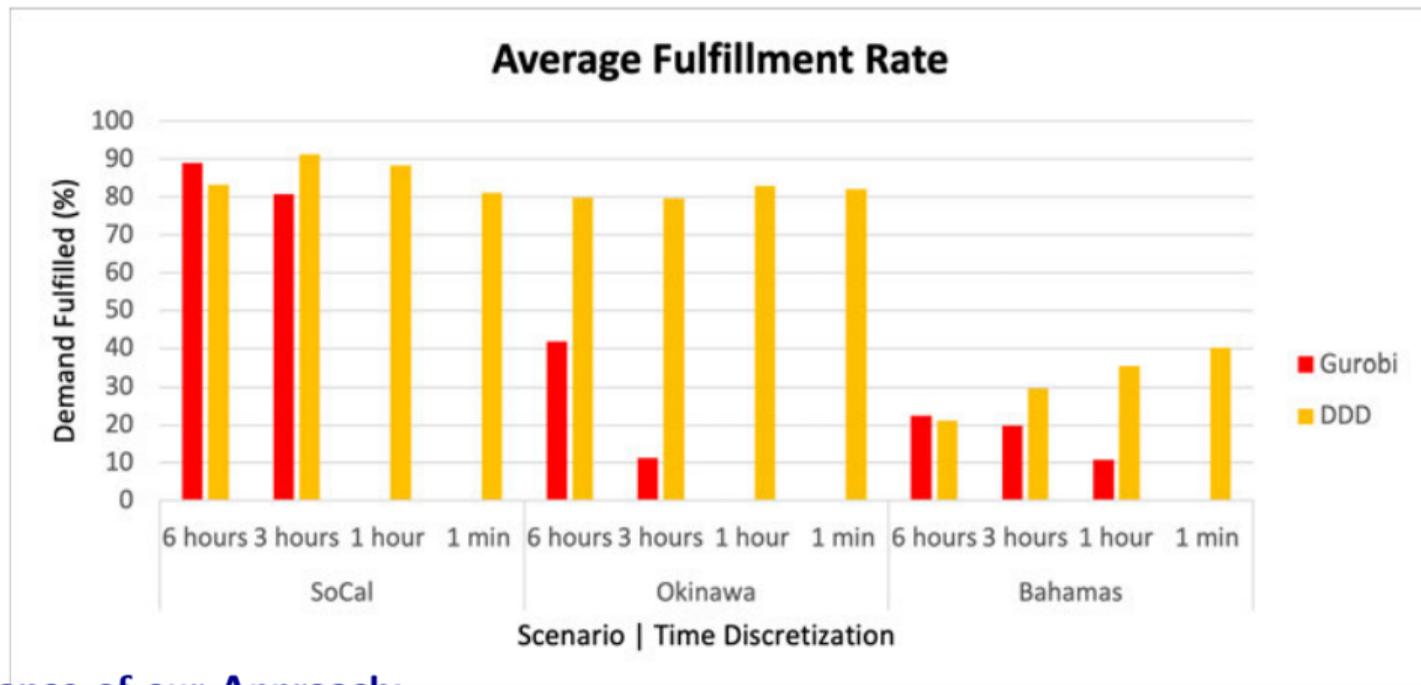
Case Study

- Scenarios validated by the US Marine Corps

Region	Okinawa	SoCal	Bahamas
# Instances	24	13	16
Time horizon	31 days	5 days	3 days
# Locations	[3, 6]	7	[12, 25]
# Vehicles	[12, 32]	[27, 58]	[13, 95]
# Vehicle-specific arcs	[24, 150]	[54, 72]	[336, 2080]
# Commodity types	[23, 53]	[27, 57]	3
# Demand requests	[29, 60]	[55, 70]	[33, 60]
# Total demand units	[27k, 191k]	[37k, 125k]	[5.7M, 17M]



Computational Results

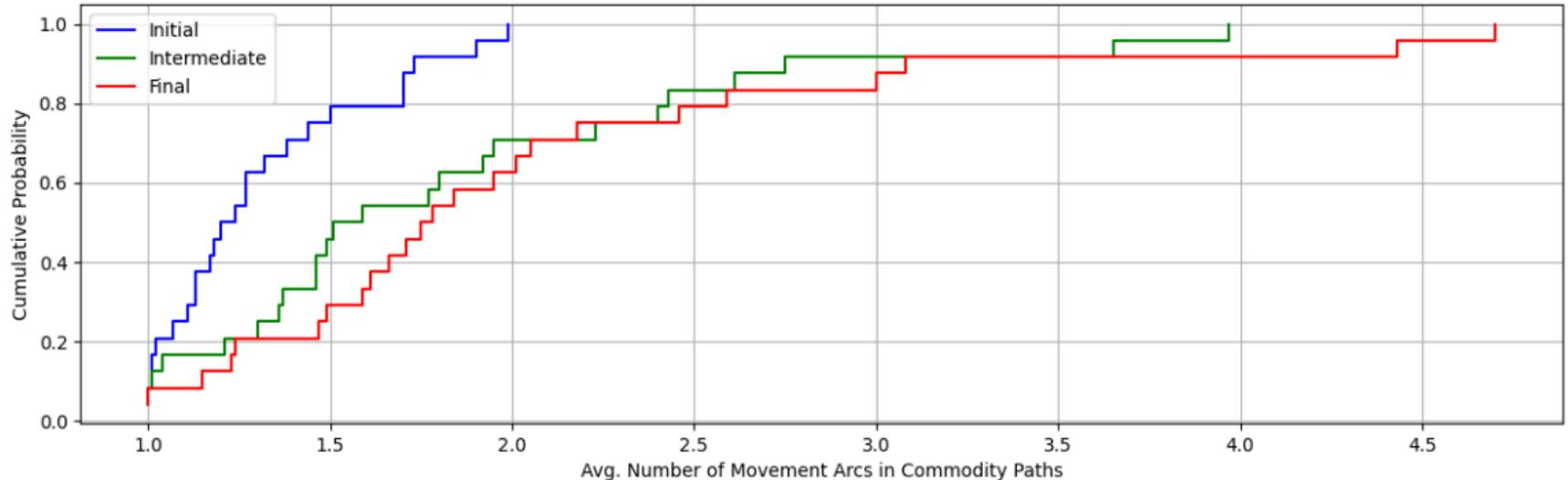


Performance of our Approach:

- Average optimality gap: 16.4%
- Demand fulfillment increases by 106% compared to benchmarks

Managerial Insights

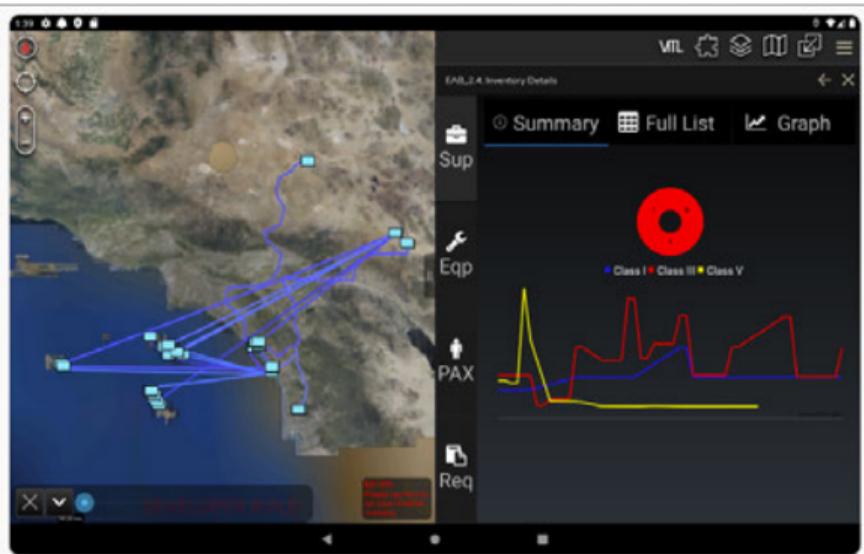
Distribution of Average Number of Movements for Each Commodity in the Okinawa Scenario



- Earlier deliveries use fewer movements to reach destinations
- Air connectors are heavily utilized due to speed and versatility

Software Integration

- Visually Integrated Tactical Logistics – Battle Management Aid (VITL-BMA)



EAB Bases and Connector Utilization

Utilization Rate (% of Max Time Capacity). Green = [0-90], Yellow = [90,95], Red = [95, 100]

Connector	03-24	03-25	03-26	03-27	03-28	03-29	03-30
KC-130	100	100	100	100	100	100	100
MV-22	94	100	100	100	100	90	90
MTVR	0	0	0	0	0	0	0
MTVR-Trailer	70	100	90	91	95	90	100
LAW	70	100	90	70	50	50	100
LCU-1700	50	0	100	92	0	92	70
Railway	100	50	20	70	0	50	70
Truck-5	100	100	100	100	100	100	70
Truck-6	100	100	100	70	50	50	90

Logistics Risks

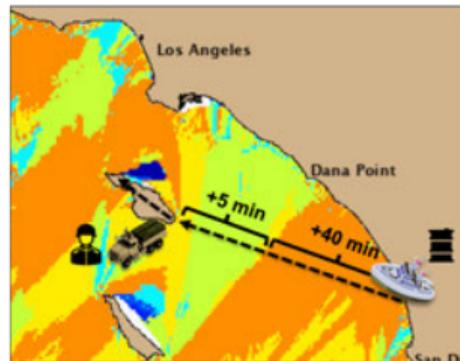
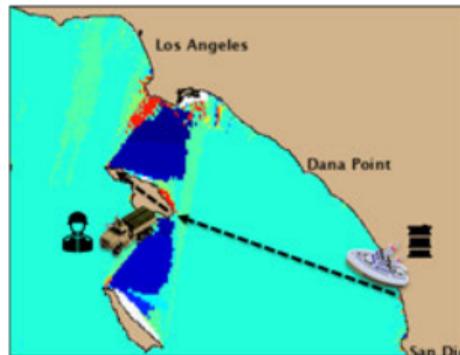
Challenge

- Expeditionary logistics plans face significant uncertainties:
 - Weather-induced delays
 - Vehicle maintenance
 - Enemy presence
- Very large number of potential disruptions



Objective: Evaluating and mitigating the impact of unplanned disruptions affecting logistics plans

Monte Carlo Simulation



Logistics plan

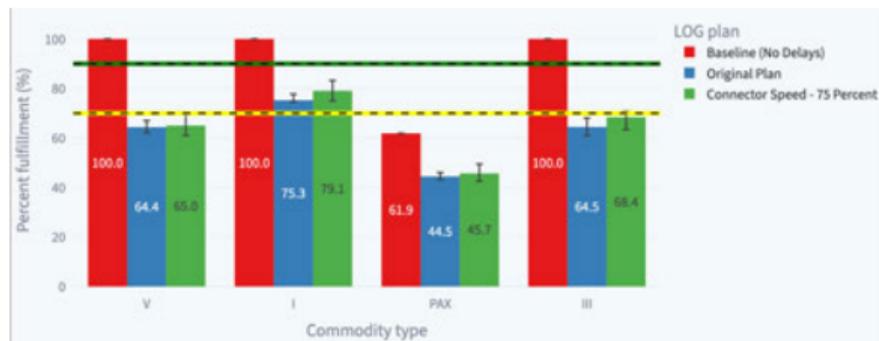
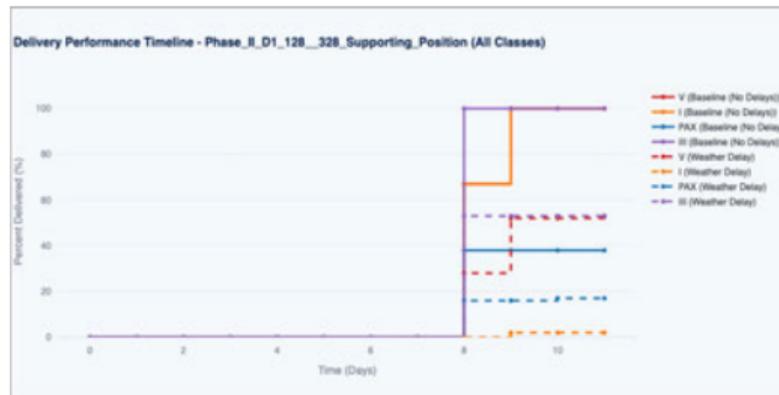
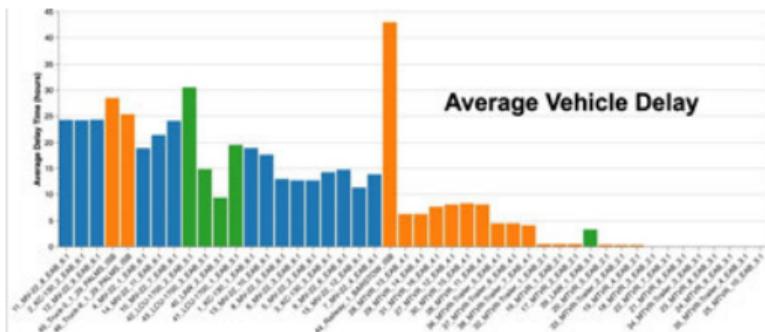
Risk scenarios

Risk impact

Logistics performance

Value Generated

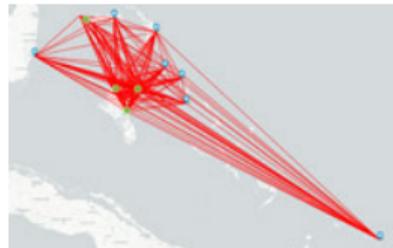
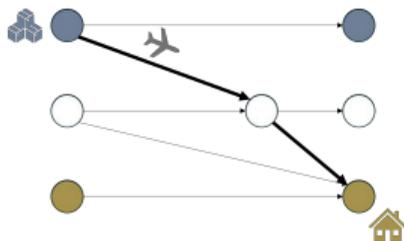
- Quantifies the impact of risks on logistics plans
- Identifies logistics bottlenecks
- Supports resilient, risk-aware planning for expeditionary logistics



Summary

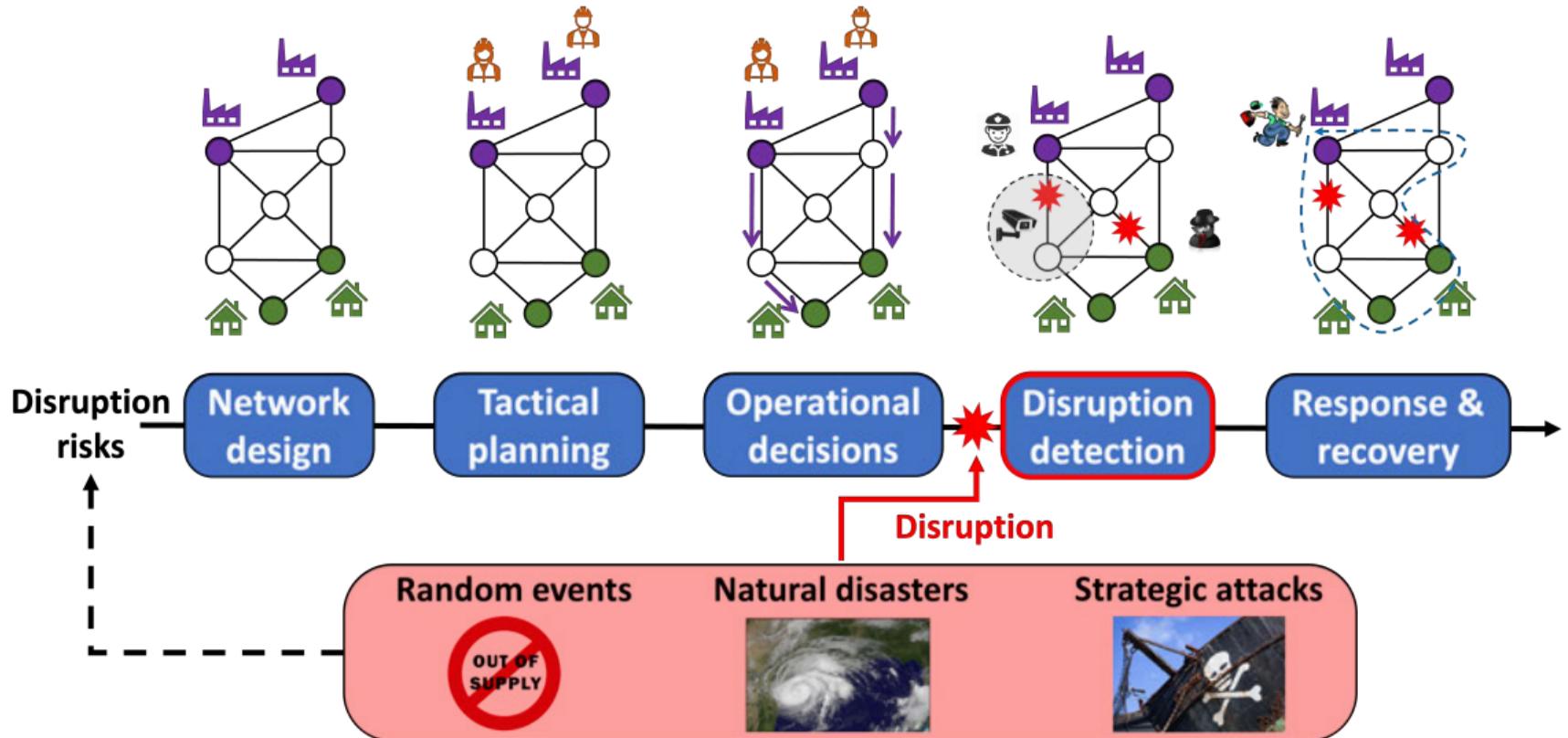
Contributions:

- Developed a new service network design model for multimodal expeditionary logistics
- Designed a new dynamic discretization algorithm with explicit fleet coordination
- Showed 106% increase in average demand fulfillment over benchmarks on instances validated by the US Marine Corps
- Developed a Monte Carlo simulation tool for estimating and mitigating logistics risks



Preprint

Improving Network Security and Resilience



Challenges in Inspection Operations



Seizure of smuggled goods

Inspection Resources

X-rays scanners
Canine units
Manual inspection teams

Challenge

Imperfect detection



Criminal deterrence

Police officers
Undercover agents
Surveillance cameras

Partially known criminals



Critical infrastructure security

Smart sensors
Unmanned aerial vehicles
Thermal imaging cameras

Limited resources

How to coordinate heterogeneous inspection resources to detect partially known illegal activity?

Inspection Game with Heterogeneous Resources

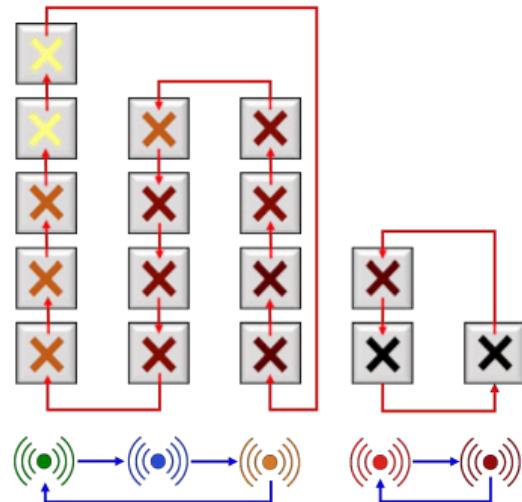


Problem features:

- Zero-sum inspection game
- Randomized allocation of heterogeneous resources
- Incomplete adversarial information

Contributions

- Analytical characterization of equilibrium strategies
- Optimal acquisition and coordination of inspection resources
- Drug-seizure case study using records from U.S. ports



Problem Formulation

Critical System:

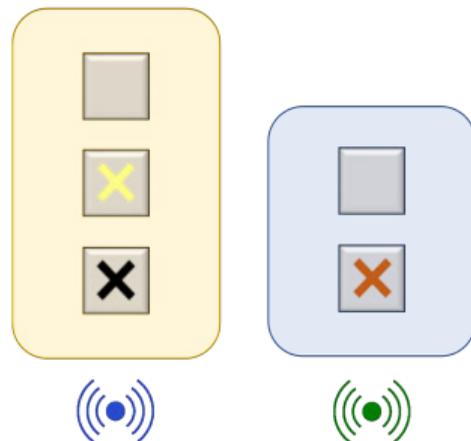
- Capacitated locations (containers)

Players:

- **Adversary** hides illegal resources
 - Damage values (monetary or societal)
- **Inspector** allocates inspection resources
 - Detection probabilities

Uncertainty:

- Stochastic player types
 - Model resources available to each player



Payoff:

- Expected damage value of detected illegal resources
 - **Inspector** maximizes
 - **Adversary** minimizes

Zero-Sum Game

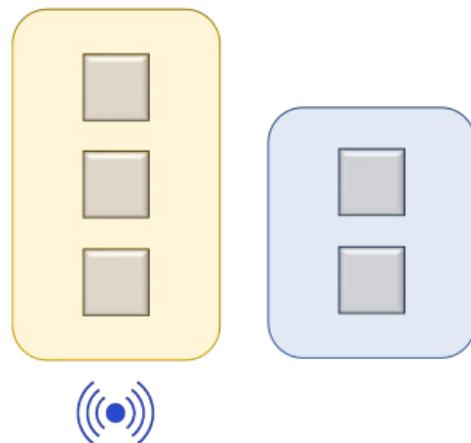
Mixed Strategies:

- Each player type selects a probability distribution over allocation plans
 - Inspection strategy: σ_I
 - Hiding strategy: σ_A
 - Expected payoff: $u(\sigma_I, \sigma_A)$

Solution Concept:

- (σ_I^*, σ_A^*) is a Nash equilibrium if

$$u(\sigma_I, \sigma_A^*) \leq u(\sigma_I^*, \sigma_A^*) \leq u(\sigma_I^*, \sigma_A), \quad \forall \sigma_I, \sigma_A$$



No improvement by
unilateral deviation

How to compute Nash equilibria for this large game of incomplete information?

Zero-Sum Game

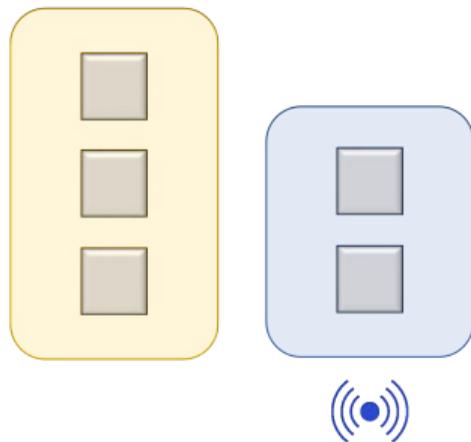
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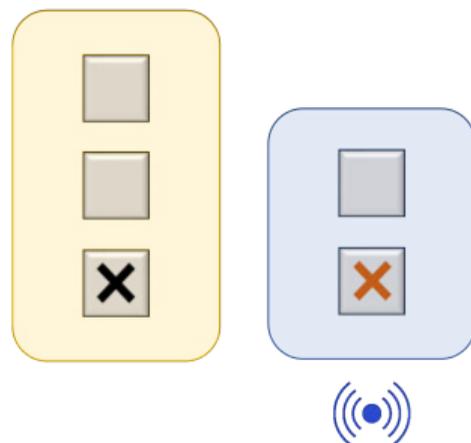
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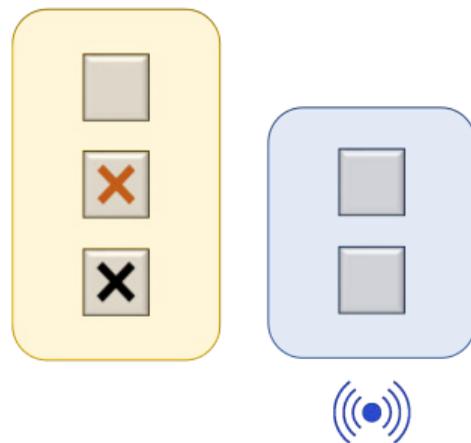
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No improvement by
unilateral deviation

How to compute Nash equilibria for this large game of incomplete information?

Equilibrium Analysis: Preliminary Results

Adversary's Strategy:

- Each adversary type allocates resources with higher damage values in smallest locations

Special Case:

- Expected damage values are increasing with location capacities

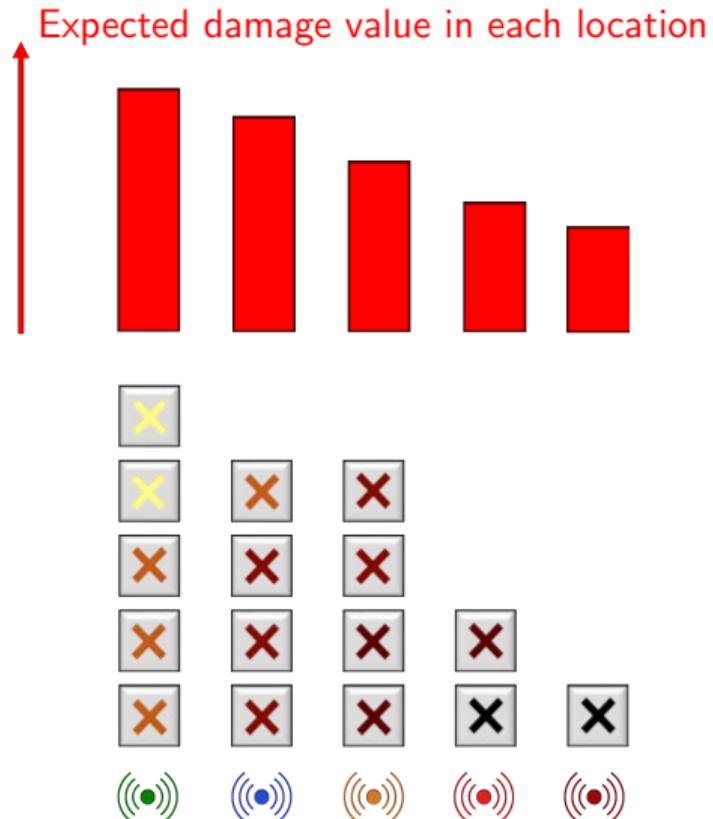
Inspector's Best Response:

- Each inspector type allocates best resources to largest locations

Lemma

Strategy profile is a pure Nash equilibrium

- Swapping **inspection** resources decreases detected damage value
- Swapping **illegal** resources increases detected damage value



Equilibrium Analysis: General Case

Algorithm for Adversary's Strategy:

- Randomize the allocation of illegal resources to ensure that expected damage values are nondecreasing with location capacities
- Partition locations into zones

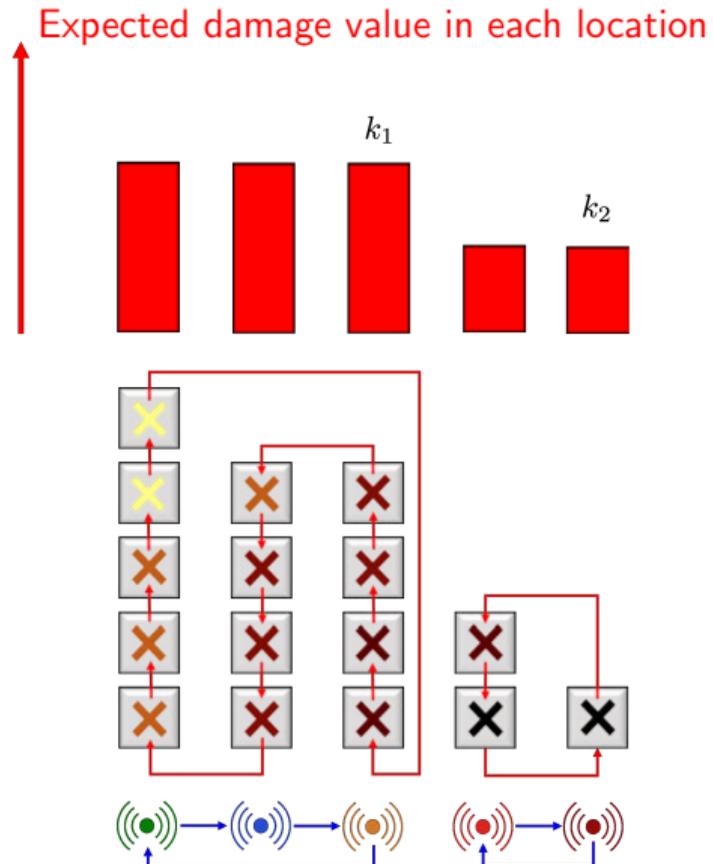
Inspector's Strategy:

- Randomize best inspection resources within zones with largest expected damage values

Theorem

Strategy profile is a Nash equilibrium

- Proof ensures homogenization feasibility
- More valuable illegal resources remain in locations with lowest expected damage values



Equilibrium Implications

Value of the Game:

$$\sum_{i=0}^{r-1} \underbrace{\frac{1}{k_{i+1}^* - k_i^*} \cdot \left(\sum_{k=k_i^*+1}^{k_{i+1}^*} \mathbb{E}_{\theta_I \sim \pi_I} [d_k^{\theta_I}] \right)}_{\text{Detection probability in each zone}} \cdot \underbrace{\left(\sum_{k=k_i^*+1}^{k_{i+1}^*} \sum_{s \in \psi^0(k)} \mathbb{E}_{\theta_A \sim \pi_A} [v_s^{\theta_A}] \right)}_{\text{Expected damage value in each zone}}$$

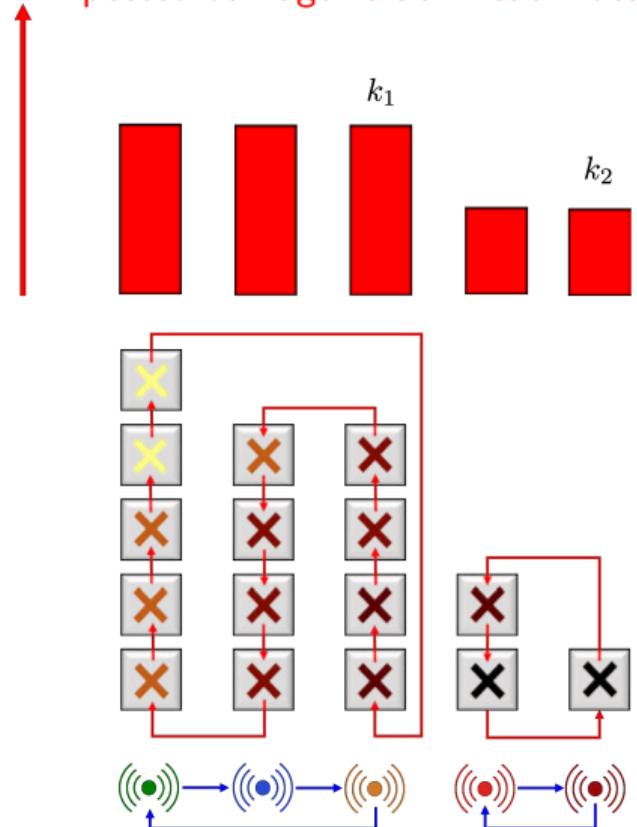
Player Insights:

- **Inspector** sacrifices more valuable illegal resources to detect more resources that are less valuable
- **Adversary** allocates less valuable illegal resources in larger locations to ensure that more valuable resources are less detected

Proposition

- **Adversary's** equilibrium strategy is *independent* of the inspector's resources
- No advantage from concealing inspection resources

Expected damage value in each location

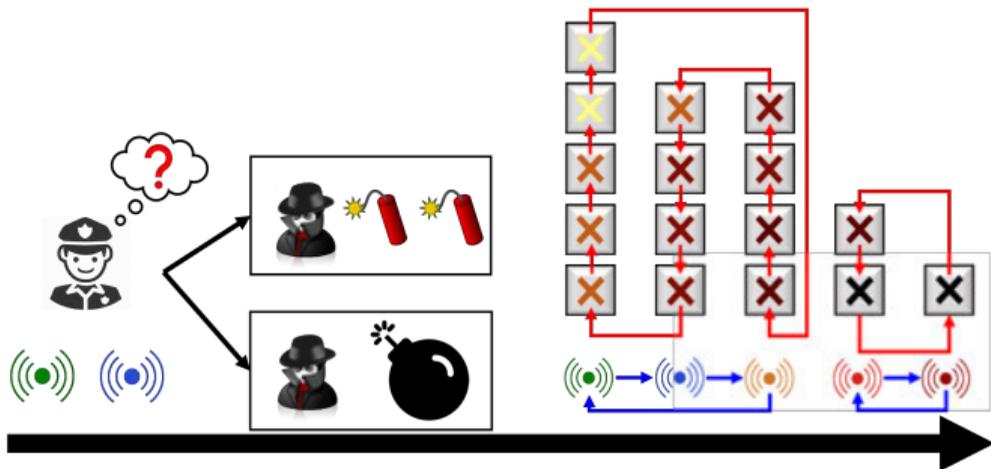


Inspection Resource Acquisition

Research question: Which inspection resources should the inspector purchase?

Features:

- Purchasing costs and budget
- Adversarial uncertainty



Theorem

This reduces to a Multiple-Choice Knapsack Problem

$$\min \sum_{t,i} \mathbb{E}_{\theta_A} [V_i] \cdot d_t \cdot x_{t,i}$$

$$\text{s.t. } \sum_{t,i} C_t \cdot x_{t,i} \leq B$$

$$\sum_t x_{t,i} = 1, \forall i$$

$$x_{t,i} \in \{0, 1\}, \forall t, i$$

- Efficiently solvable

Case Study

Port Inspection for Seizing Illegal Drugs:

- Two case studies
 - Florida (8 ports)
 - California (10 ports)
- Volume data

Port	# Containers/week
Long Beach, CA	38,451
Los Angeles, CA	27,634
Richmond, CA	7,364
Oakland, CA	5,877
Stockton, CA	2,483
Oxnard Harbor District, CA	1,573
Redwood City, CA	1,037
San Diego, CA	977
San Francisco, CA	920
Sacramento, CA	811

- Drug data
 - Damage value = Average selling price
 - *U.N. World Drug Report (2024)*

Coast Guard offloads more than **29,000 pounds of cocaine** in San Diego



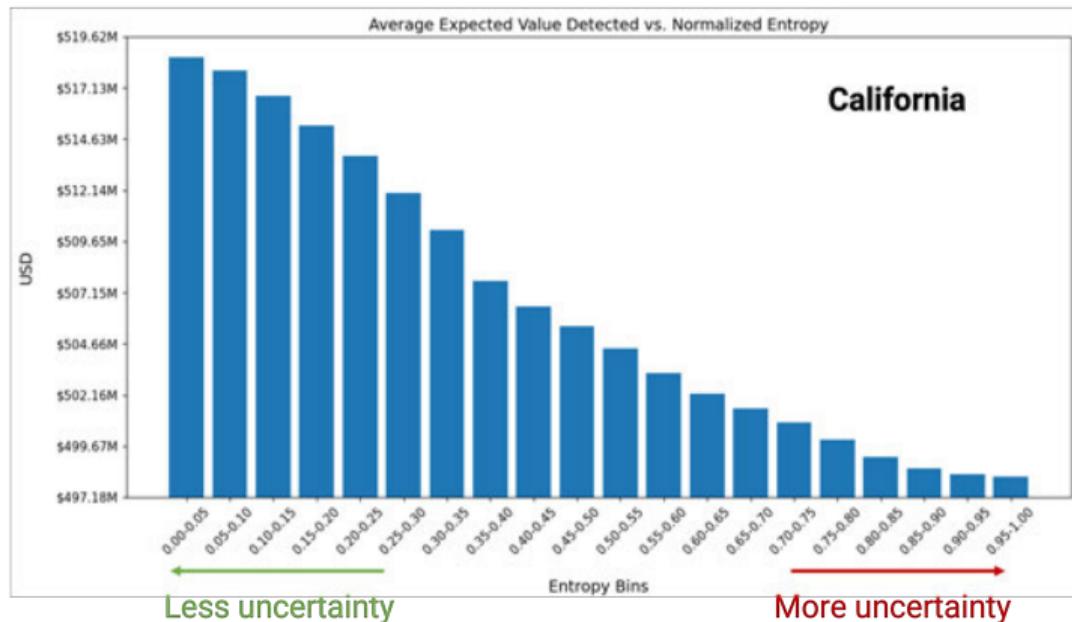
- Inspection resource data

Inspection Resource	Accuracy	Cost (USD)
German Shepherd Dogs	86.8%	400,000
X-ray Scanners	80%	330,000
Junior Officers	50%	115,000
⋮	⋮	⋮

Value of Intelligence

Adversarial uncertainty:

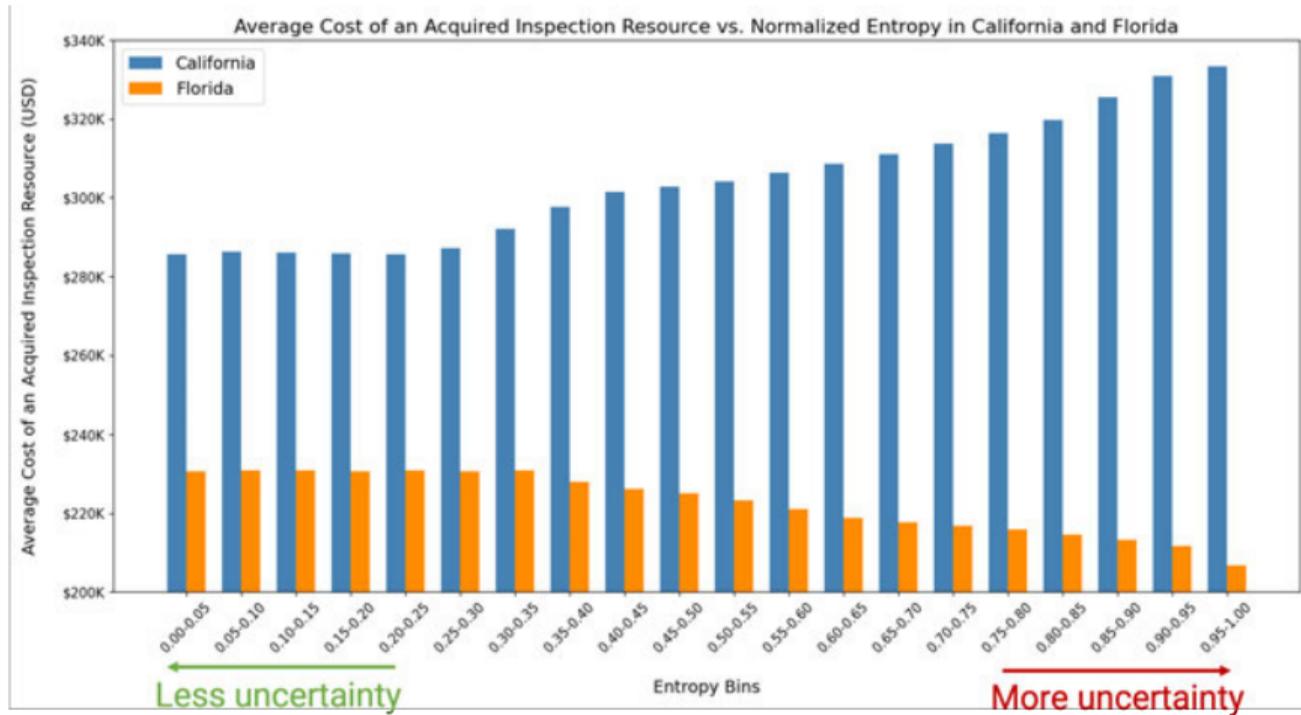
- Adversary types computed from historical data
 - Occurrence probabilities generated synthetically
- 1 million replications:
 - Uncertainty characterized by *normalized entropy*



Main Finding

\$20M increase in seized drugs by gathering adversarial intelligence

Uncertainty vs. Inspection Resource Acquisition



Main Finding

Purchasing profile highly depends on the dispersion of location capacities

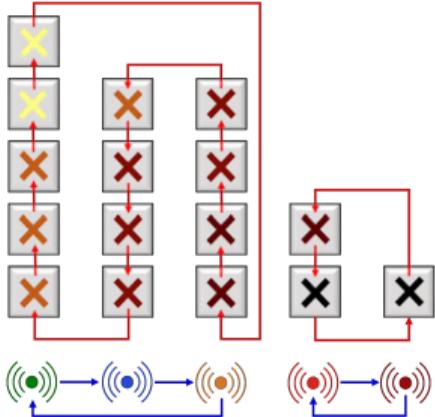
Summary

Contributions:

- Incomplete-information inspection game with heterogeneous resources
- Analytical characterization of equilibrium allocation strategies
- Fast algorithms for heterogeneous resource selection and coordination
- Quantitative value of adversarial intelligence for U.S. port inspections



Preprint



Resilience Analytics Framework

Infrastructure Networks



Health & Humanitarian Systems



Network Resilience

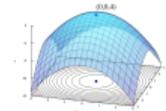
Supply Chains



Military Operations



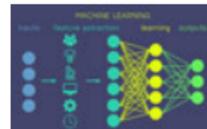
Optimization



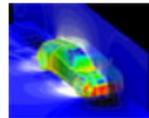
Game Theory



Machine Learning



Simulation



Thank you!

Questions: mathieu.dahan@isye.gatech.edu

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