

NATO CA2X2 Forum 2026

Graph Reinforcement Learning for Logistics Planning under Catastrophic and Adversarial Disruptions

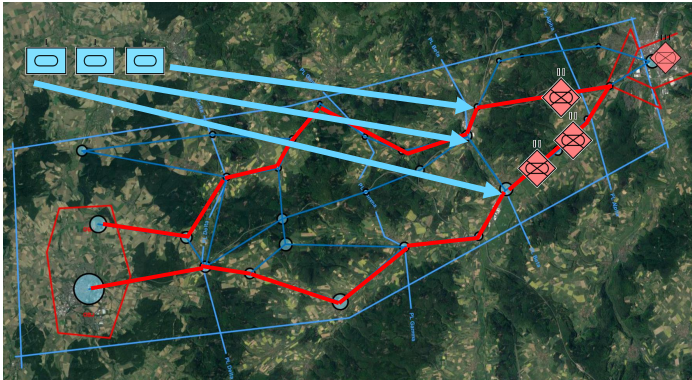
Jonathan Cawalla, Marvin Gülhan, Lasse Ruttert, [Hans-Christian Schmitz](#)

Introduction

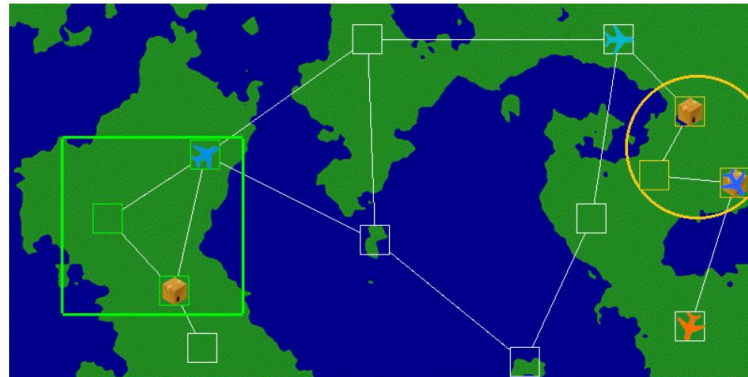
Motivation

- Dynamic planning is crucial when adversaries or natural events disrupt one's plans.
 - **Disaster response and civil defense:** Disruptions caused by natural events or hostile actors.
 - **Military operations:** The adversary attempts to disrupt logistics and maneuver.

Network Disruption: CoA analysis



Dynamic Routing: Airlift Planning

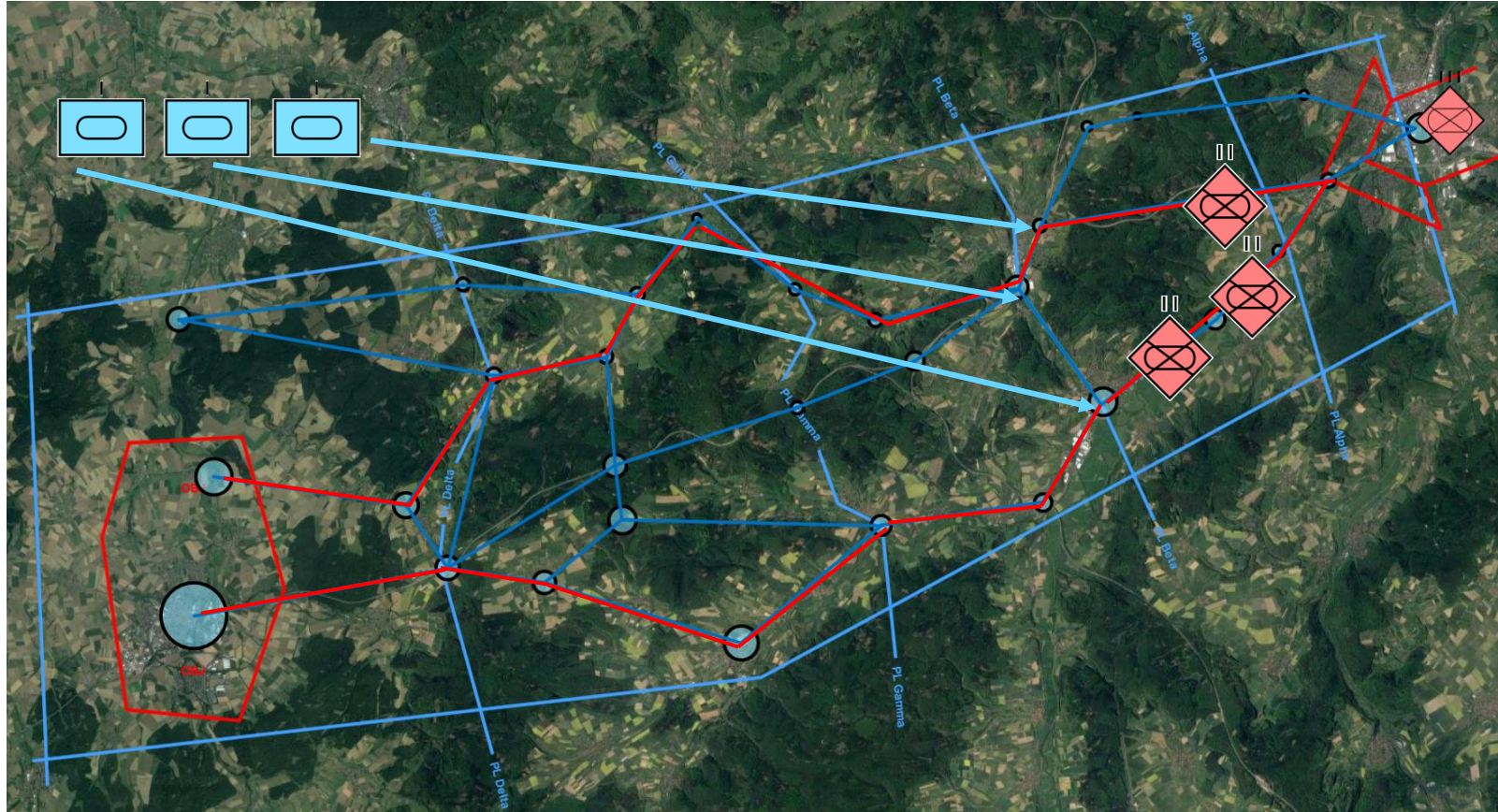


Routing under Adversarial Disruption



Network Disruption: Graph-based Analysis of CoAs

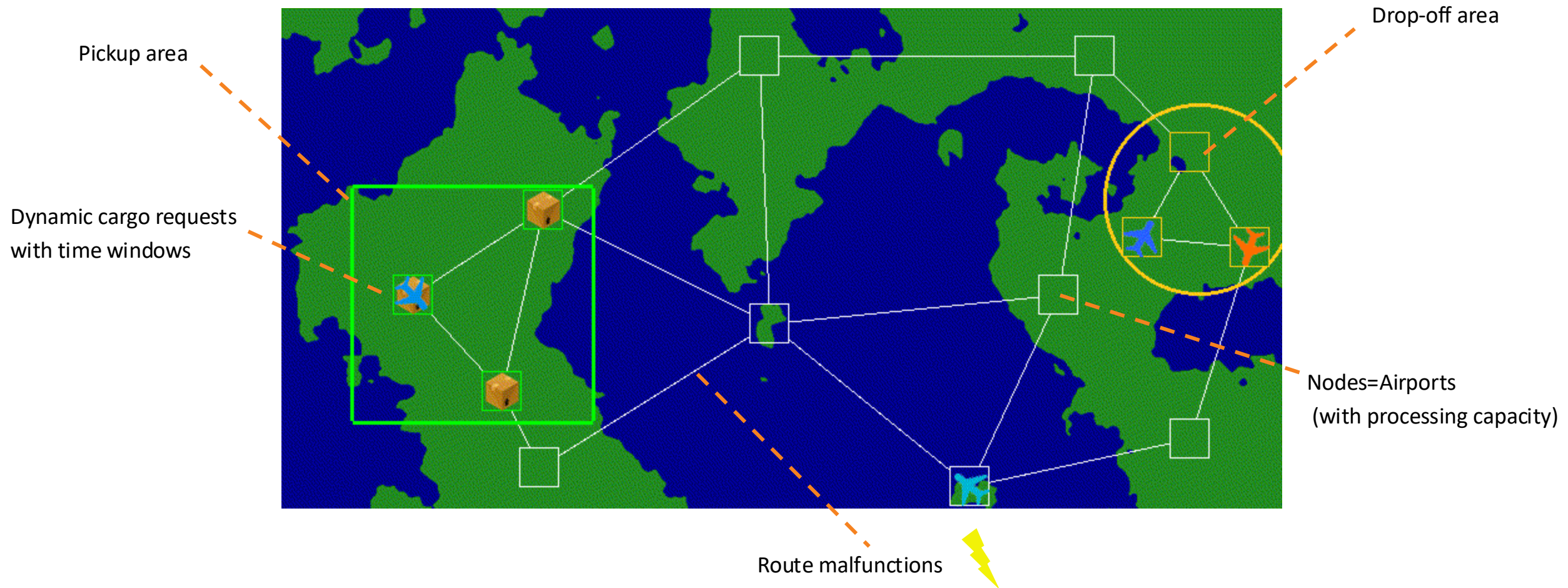
Concept



Goal: Identify areas where the deployment of own resources has the largest effect on stopping or delaying the red approach.

Dynamic Routing: Airlift Planning Problem (APP)

Objective: Deliver cargo items from pickup area to drop-off area using a fleet of aircraft



Classical planning methods struggle in dynamic C2 environments

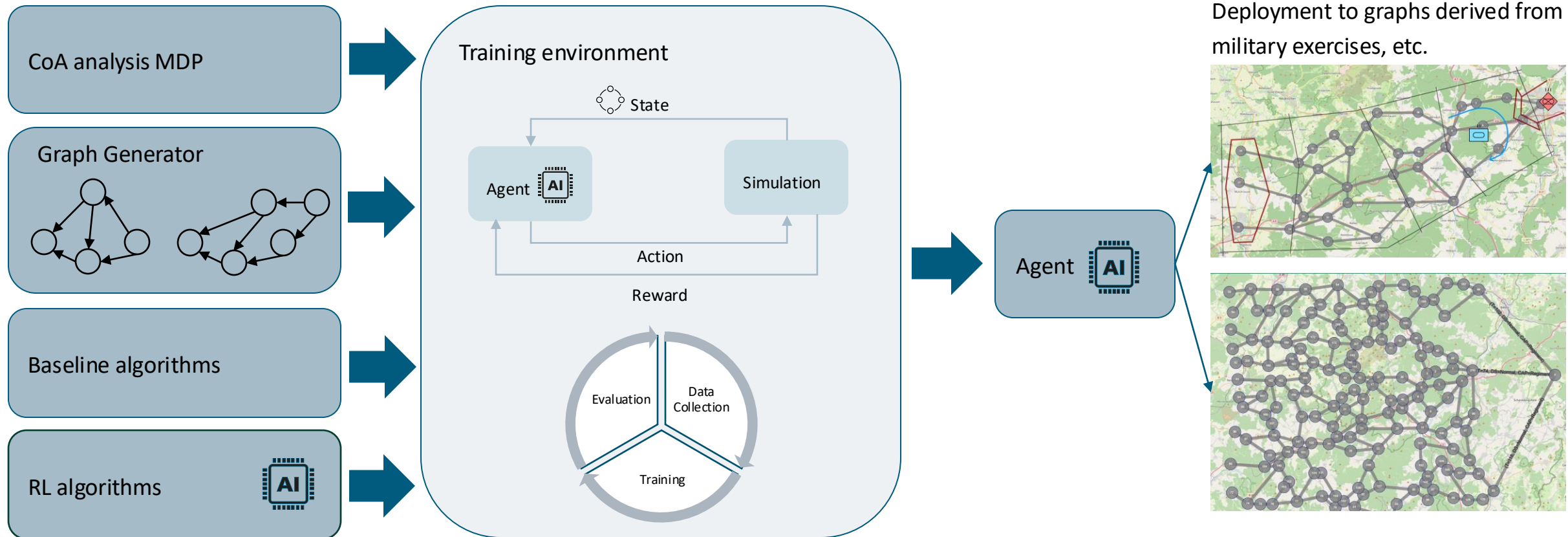
- **C2 environments are hard:** high complexity, operational constraints, uncertainty.
 - **Conventional approaches:** optimization models, heuristics, and metaheuristics (Operations Research).
 - **Problems:**
 - Exact optimization models become intractable due to runtime issues.
 - Hand-crafted heuristics need deep domain expertise and continuous tuning.
 - Changing requirements, which are common in military settings, requires costly re-engineering.
- ➔ These limitations motivate planning approaches that reduce manual modeling and adapt automatically

Graph Reinforcement Learning (GRL)

- **Learning-based alternative:** Graph Reinforcement Learning (GRL).
- **Core idea:** instead of hand-crafting heuristics, learn them from a simulator via Reinforcement Learning (RL).
- **Related Work:** existing GRL work has focused mainly on classic optimization problems and classic routing problems, such as the Traveling Salesman Problem (TSP) and the Vehicle Routing Problem (VRP).
- **Research gap:** GRL for C2 planning, especially for dynamic graph-based multi-agent problems

Reinforcement Learning Framework

Method



Results so far

Disruption (CoA analysis)

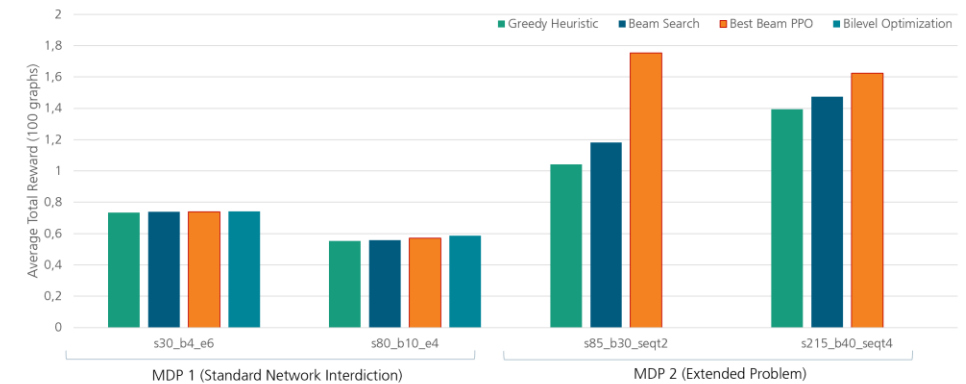
- Approach outperforms other heuristics
- Very close to classical optimization methods
- Applicable where optimization methods fail

Dynamic Planning (Airlift Planning)

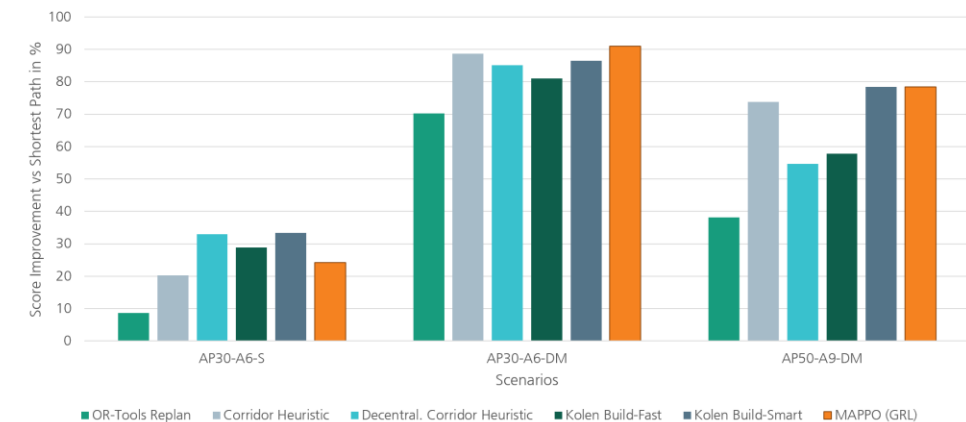
- A learned GRL policy matches or outperforms heuristics specifically designed for the problem, with the largest advantage in dynamic scenarios.

➔ GRL can reduce reliance on hand-crafted heuristics for dynamic, graph-structured planning problems.

Disruption Results (CoA analysis)



Dynamic Planning Results (Airlift Planning)



Project “Logistics under Catastrophic Conditions” (Lokab)



Bundesamt
für Bevölkerungsschutz
und Katastrophenhilfe

Lokab:

- Funding from the German Federal Office of Civil Protection and Disaster Assistance (BBK)
- Project period: 2025–2027

Lokab focuses on optimizing logistics under challenging, dynamic conditions in the field of civil protection and disaster response.

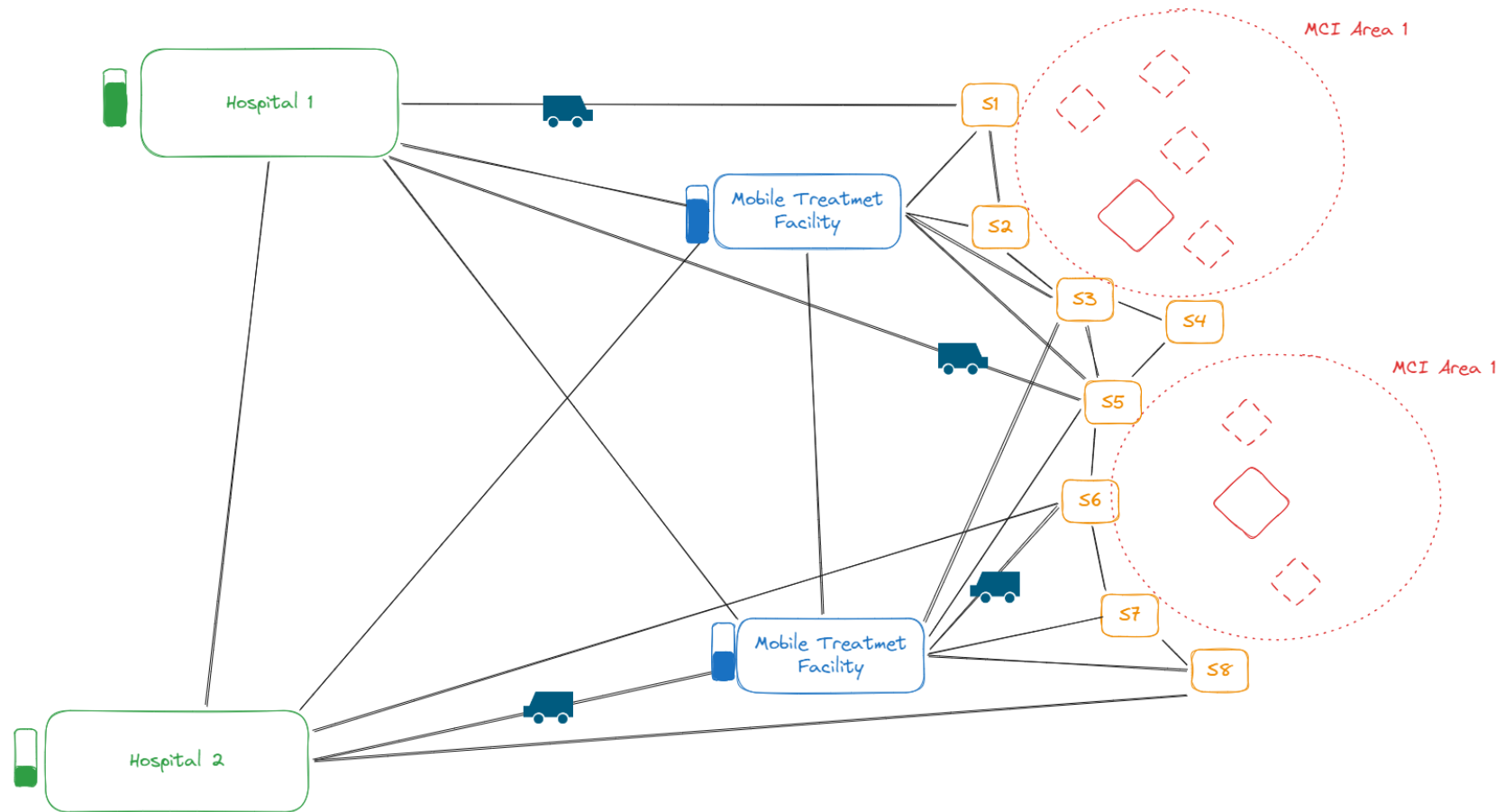
Objective: Develop methods that use Reinforcement Learning to learn heuristics capable of handling these adverse conditions.

Problems:

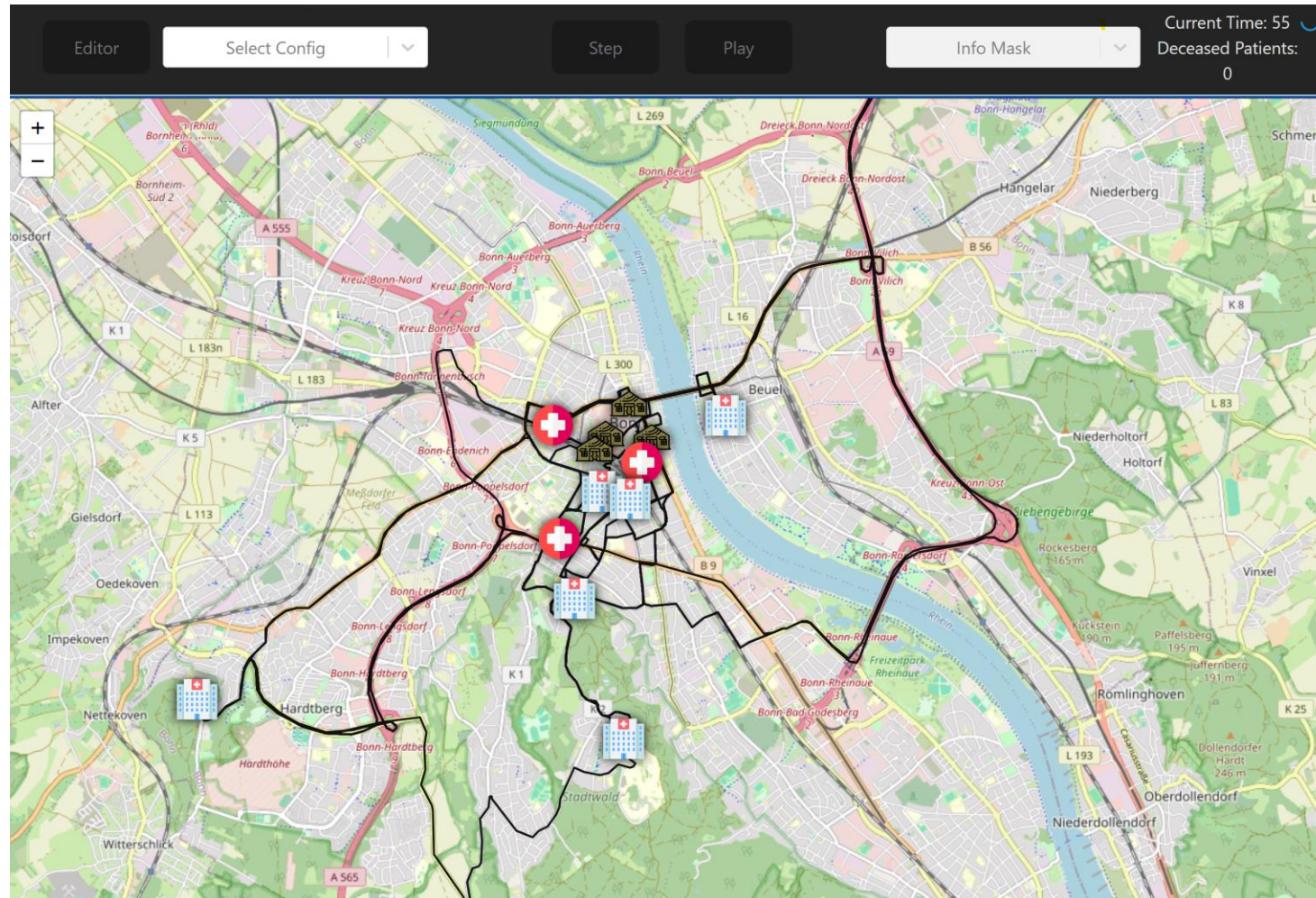
1. Local crisis logistics: mass-casualty incidents (Dynamic Routing)
2. National crisis logistics: supply management and risk analysis (Dynamic Routing under Adversarial Disruption)

Dynamic Routing: Mass Casualty Incident

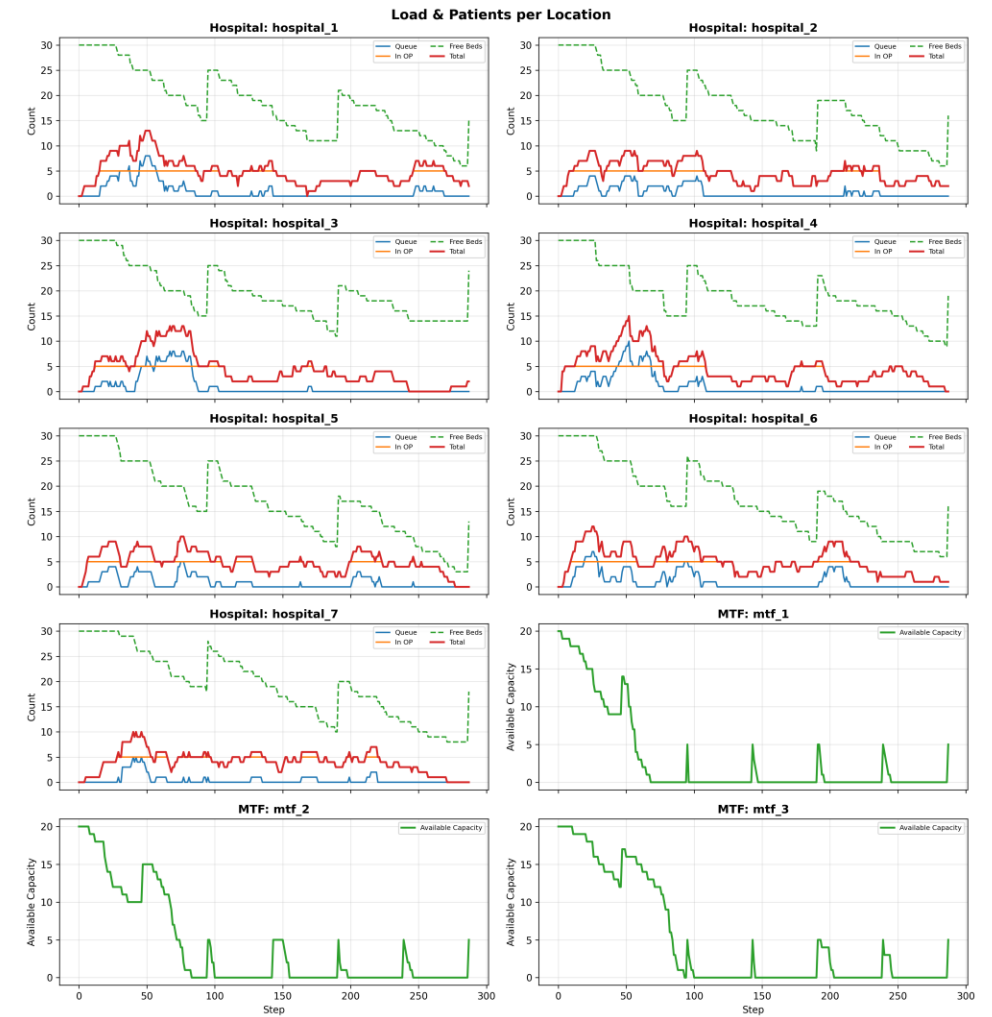
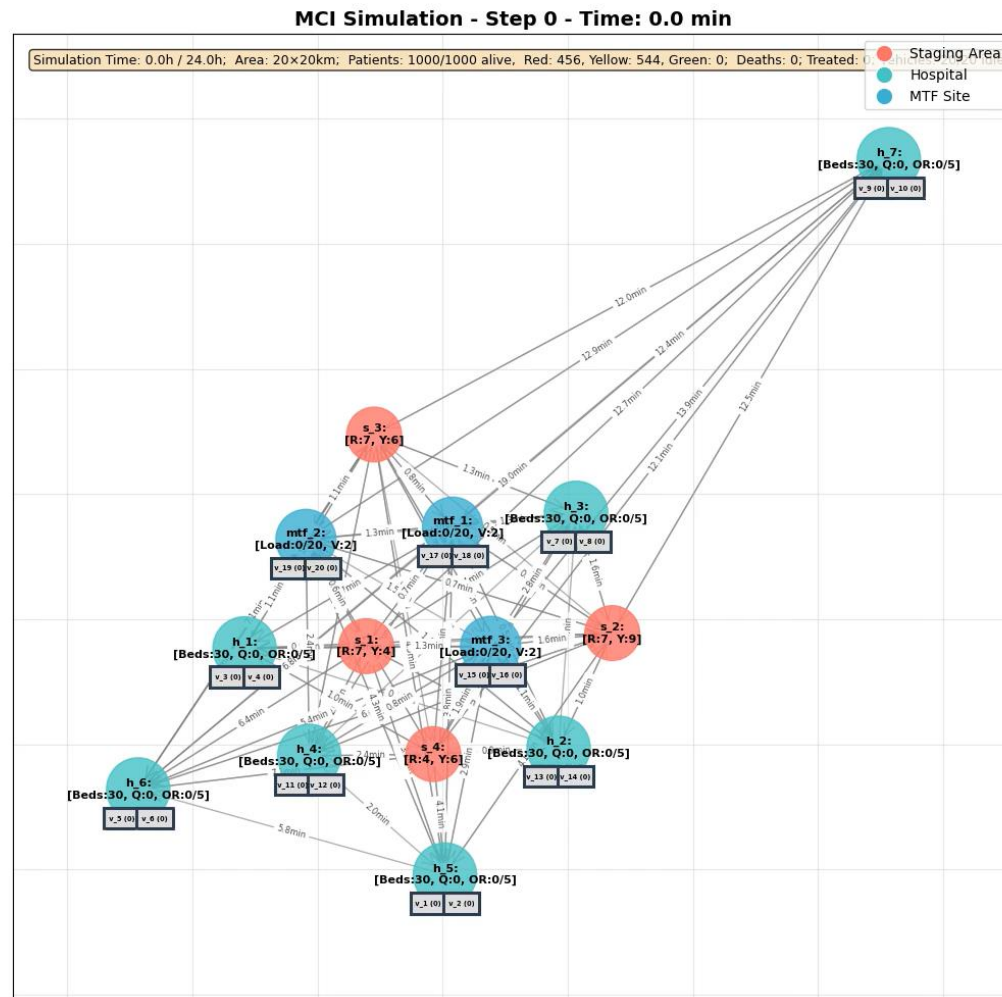
Problem Definition



Dynamic Routing: Mass Casualty Incident Demonstrator

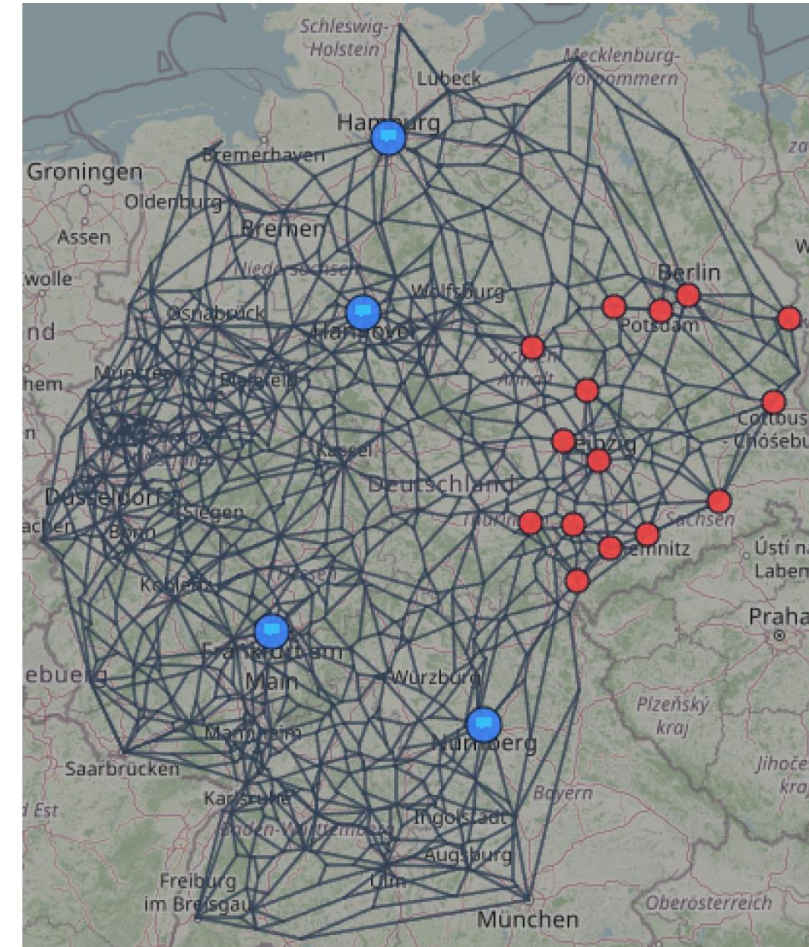
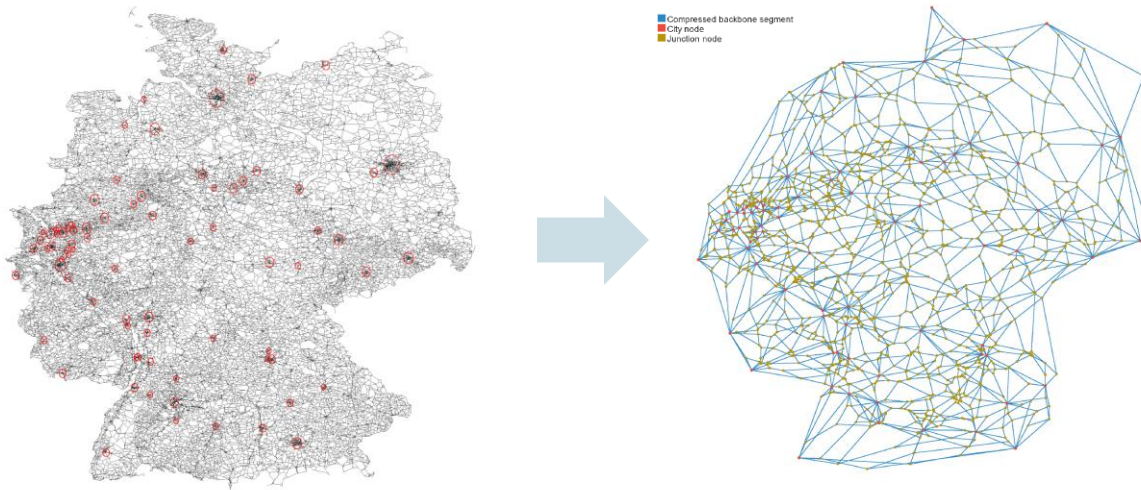


Dynamic Routing: Mass Casualty Incident



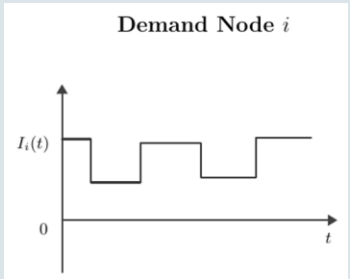
Dynamic Adversarial Routing: National Crisis Logistics

- **Objective:** supply the population with relief supplies (Focus of the civilian project Lokab)
- **Military perspective:** supply an area of operations with required materiel

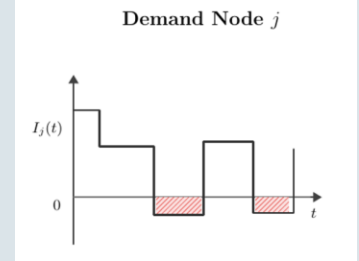
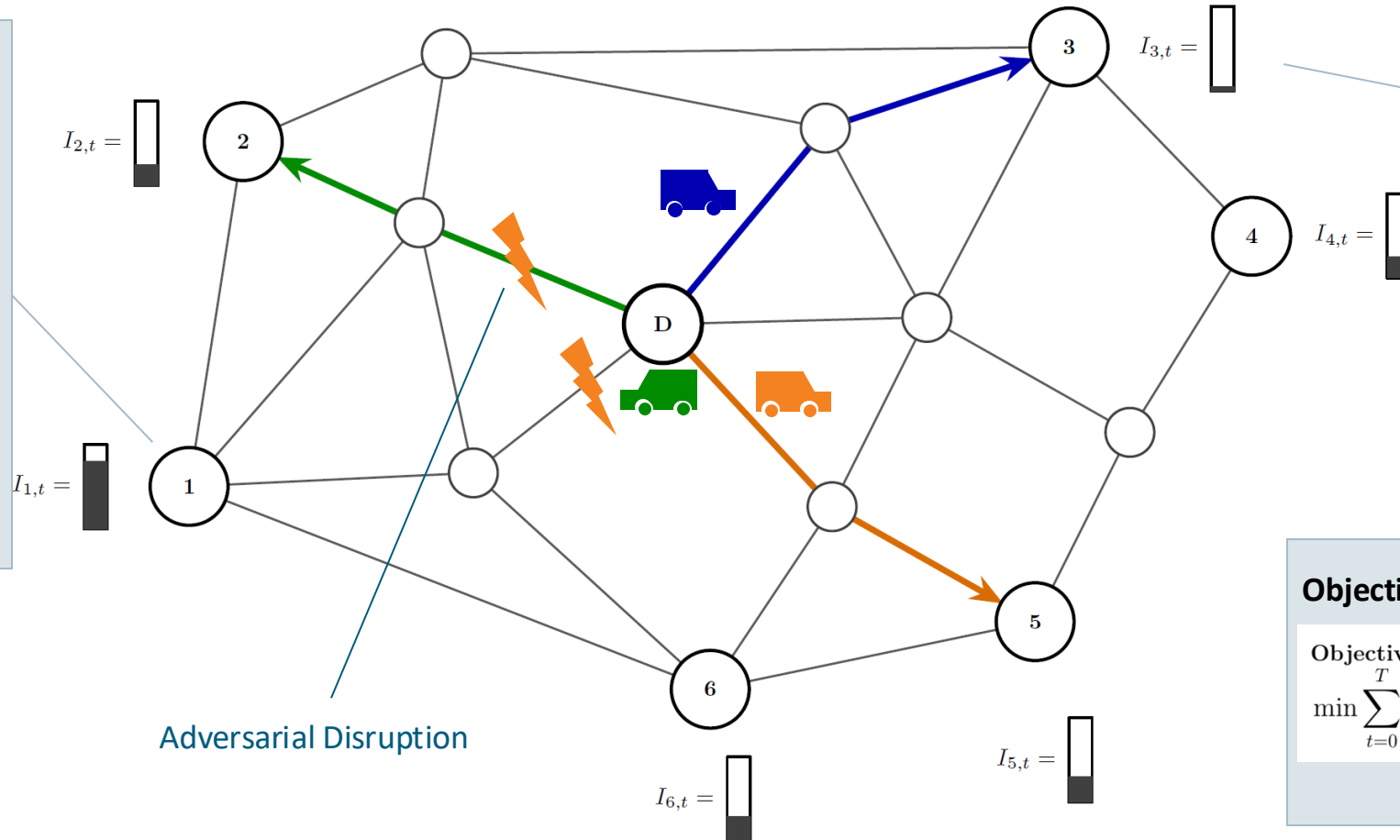


Problem Definition: Inventory Routing under Adversarial Disruption

Demand node inventory



Goal: demand nodes have always enough supply



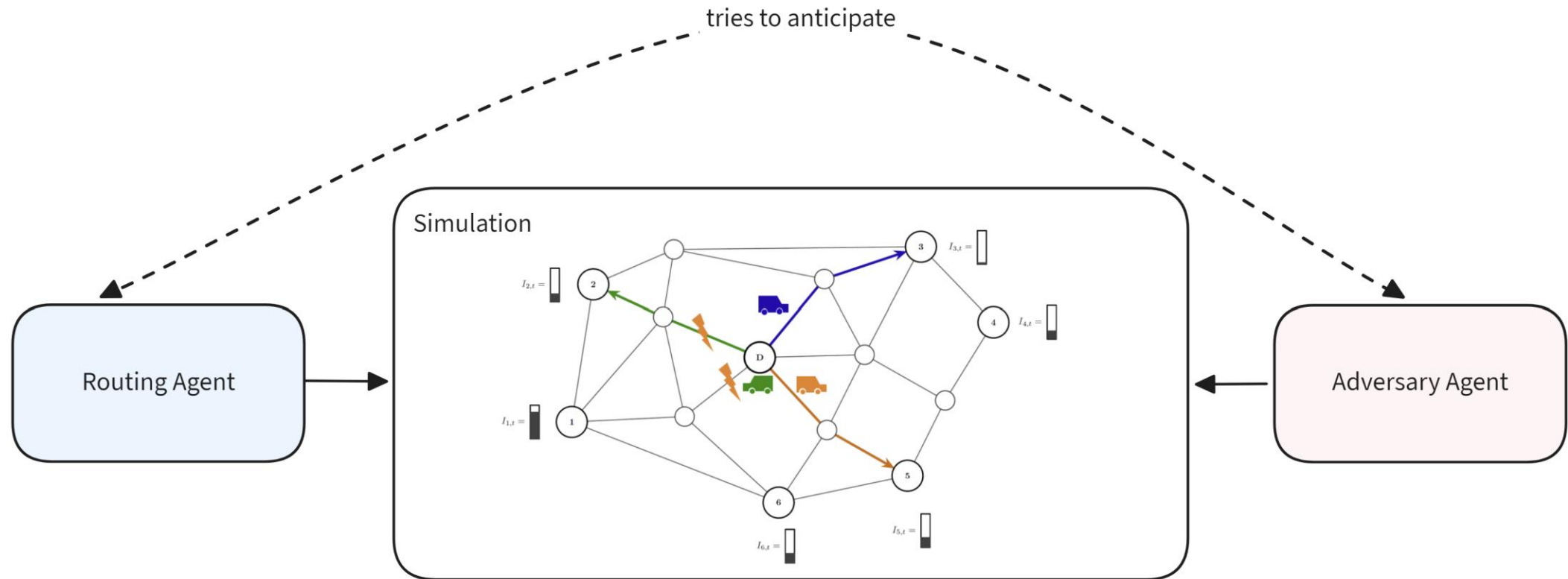
Problematic case:
multiple Stockouts

Objective function

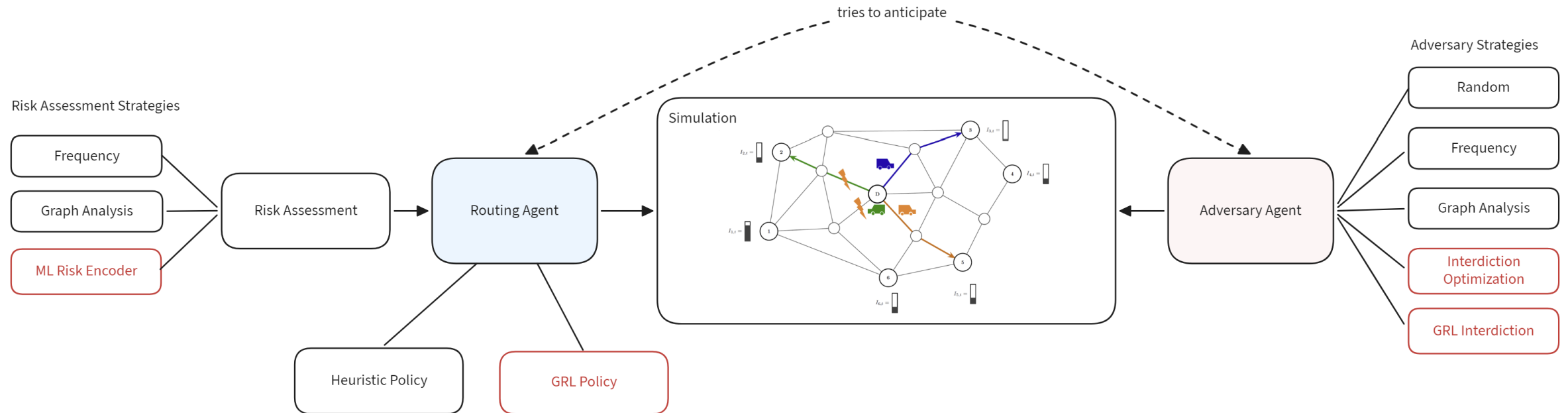
Objective: minimize cumulative shortage

$$\min \sum_{t=0}^T \sum_{i=1}^N [-I_i(t)]_+$$

Routing Agent and Adversary Agent

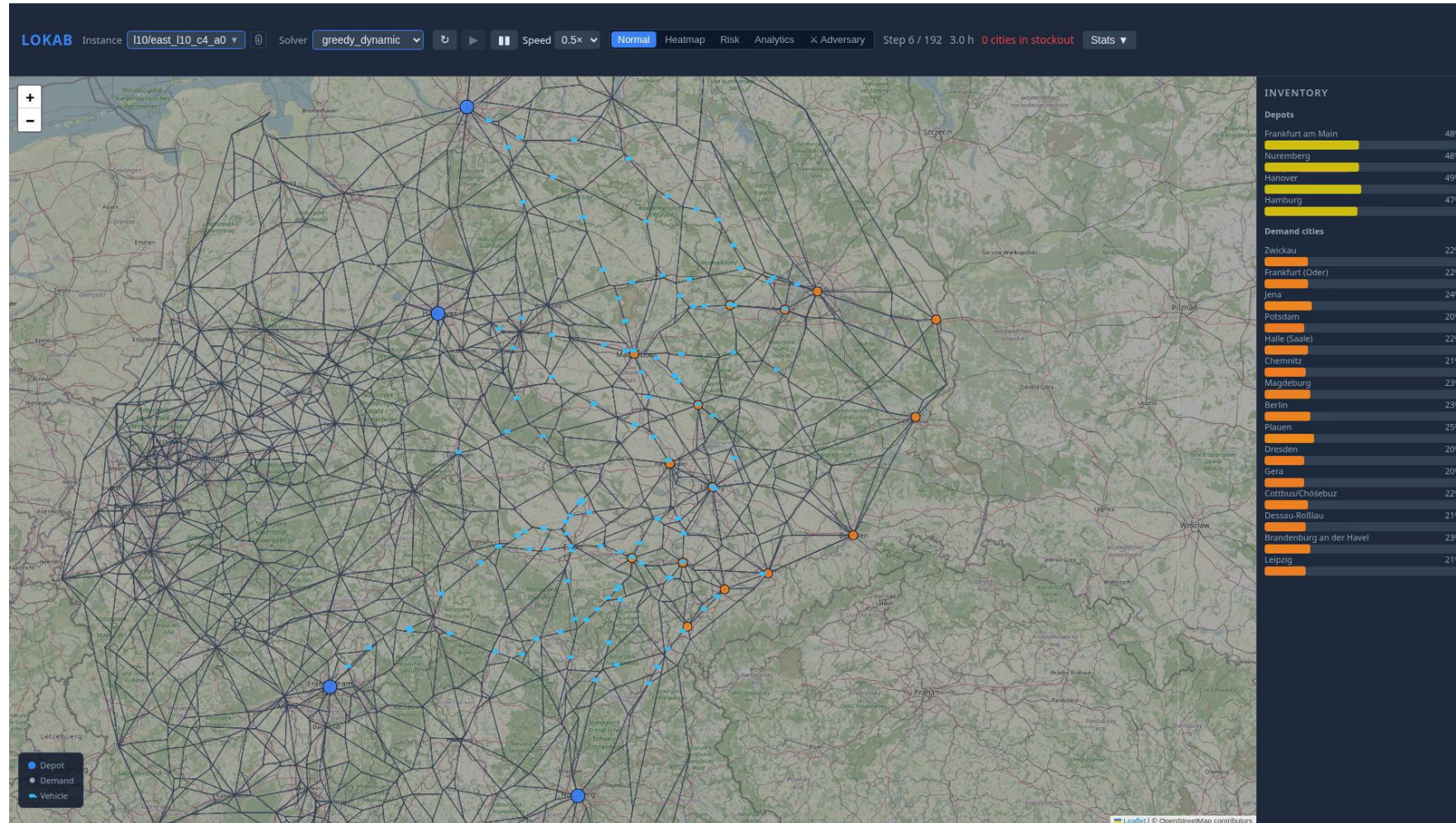


Agent Strategies



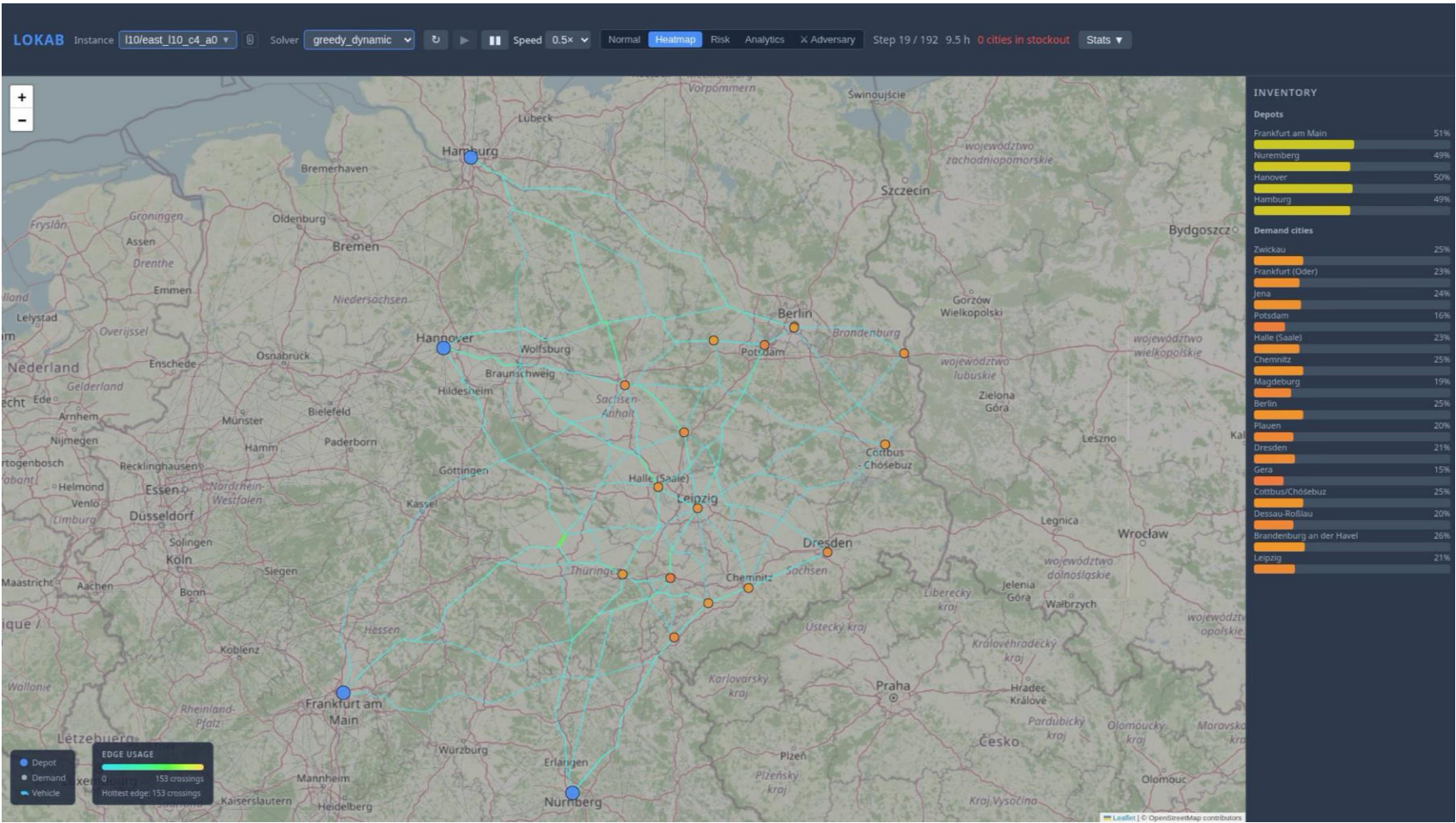
Outlook: Risk Assessment

Transport Flow without Disruptions



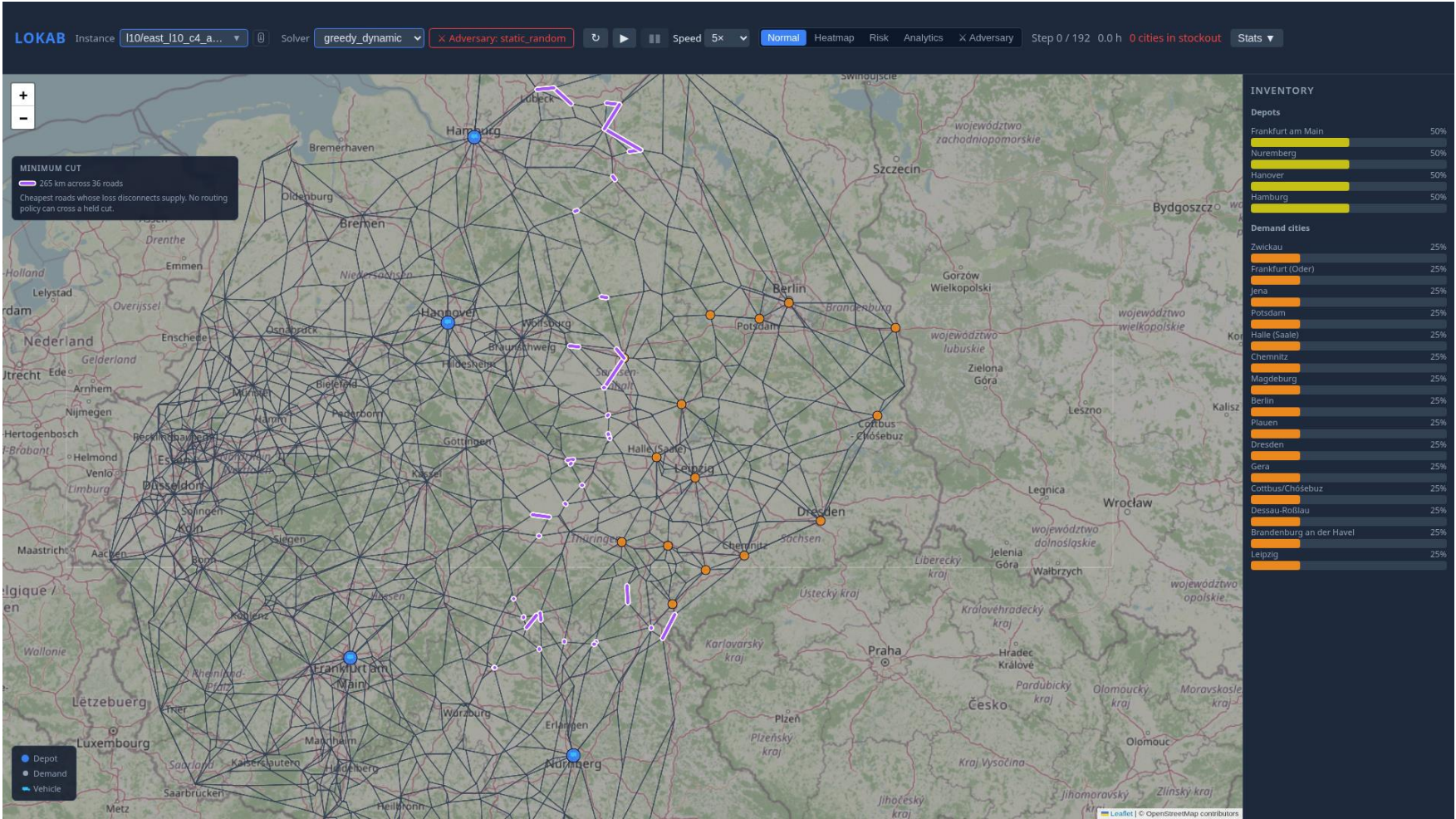
Outlook: Risk Assessment

Important Corridors Heatmap



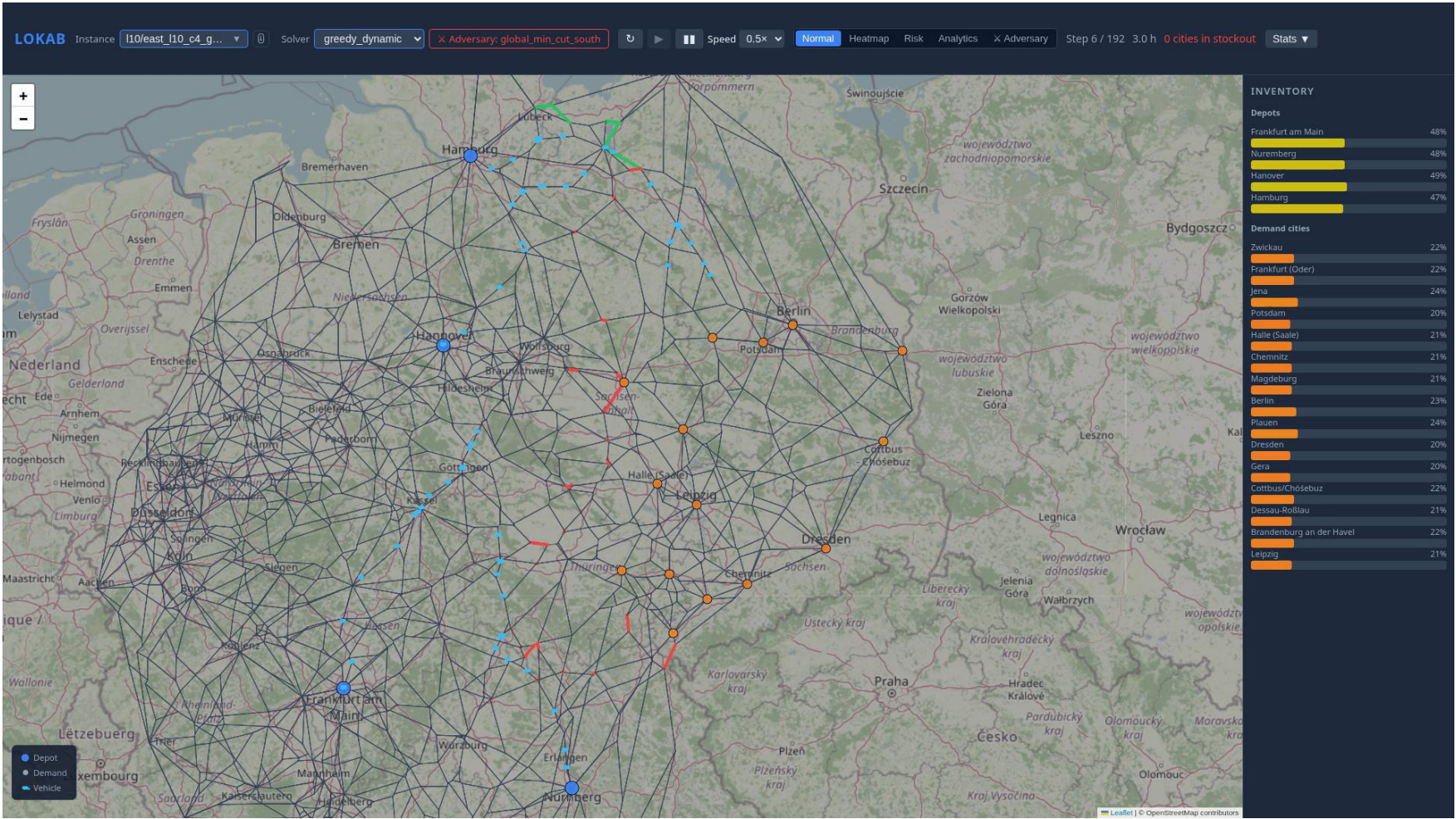
Outlook: Risk Assessment

Min-Cut Disruption



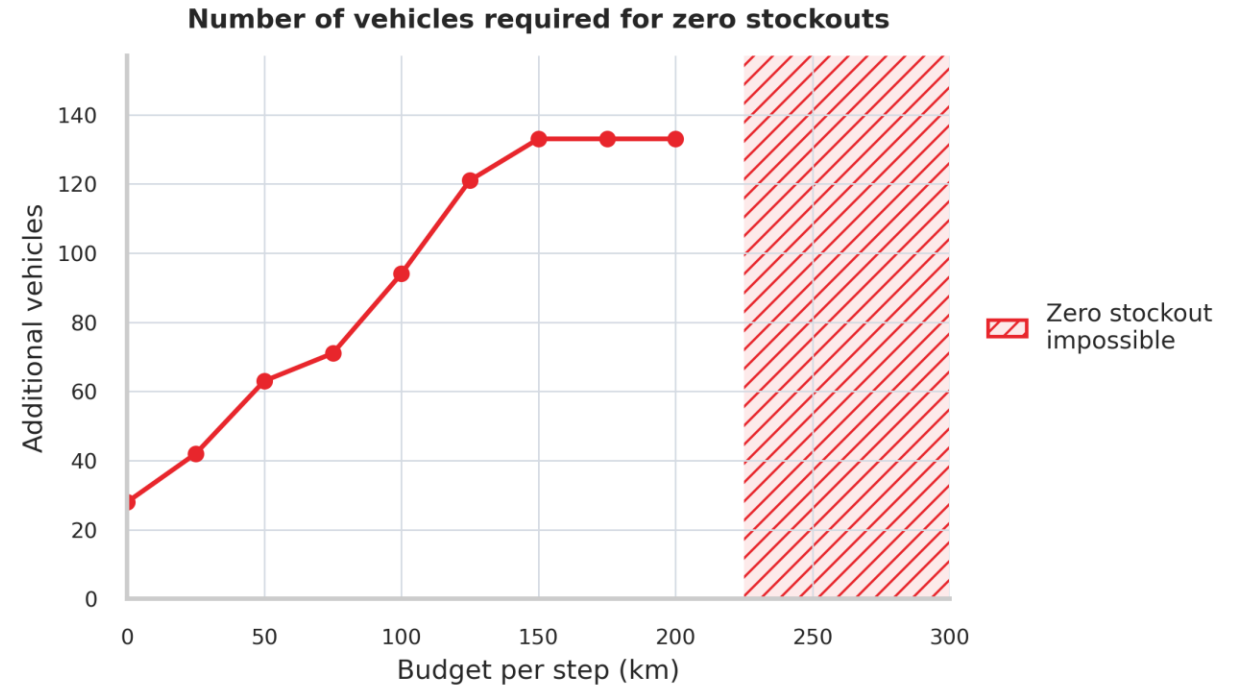
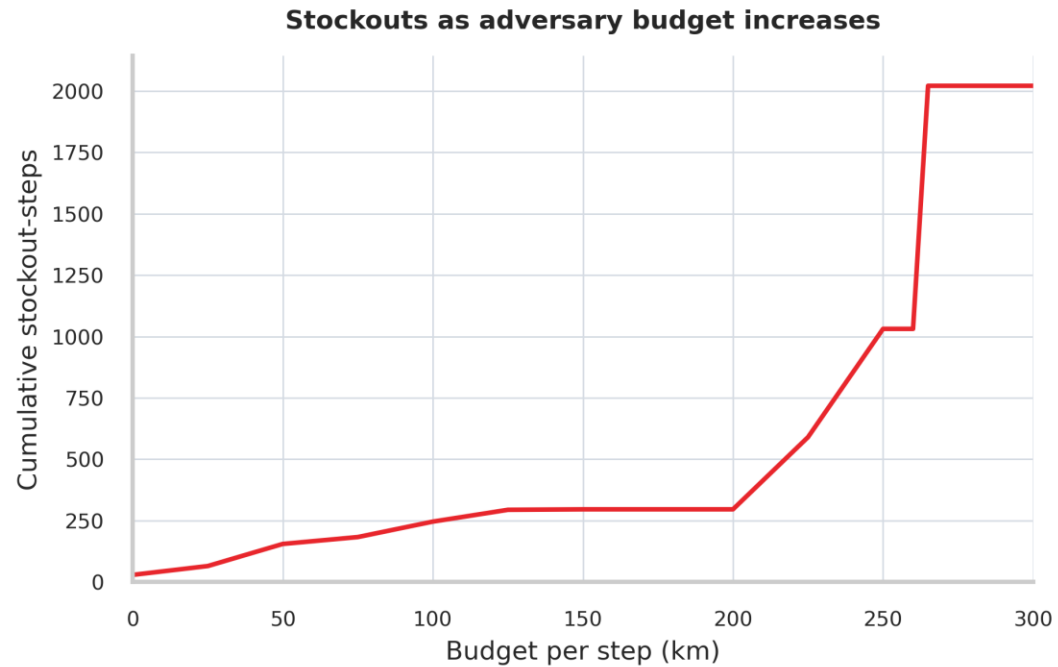
Outlook: Risk Assessment

Transport Flow with active Min-Cut Adversary



Outlook: Risk Assessment

Transport Flow with active Min-Cut Adversary



Summary & Outlook

- A learned GRL policy can often match or outperform other methods specifically designed for the problem.
- This advantage is especially important in C2 environments and problems where requirements change, and dynamic and adverse situations are the norm.
- Future Work:
 - Further improving GRL methodology (Multi-Agent approaches, Centralized vs Decentralized, Adversary Prediction).
 - Scaling GRL to larger and more diverse graphs.
 - Exploiting analogies between civilian and military planning problems as well as risk assessments.

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