OPTIMAL FACILITY LOCATION AND SERVICE AREAS FOR THE DISTRIBUTION OF CRITICAL RELIEF IN POST-DISASTER ENVIRONMENTS

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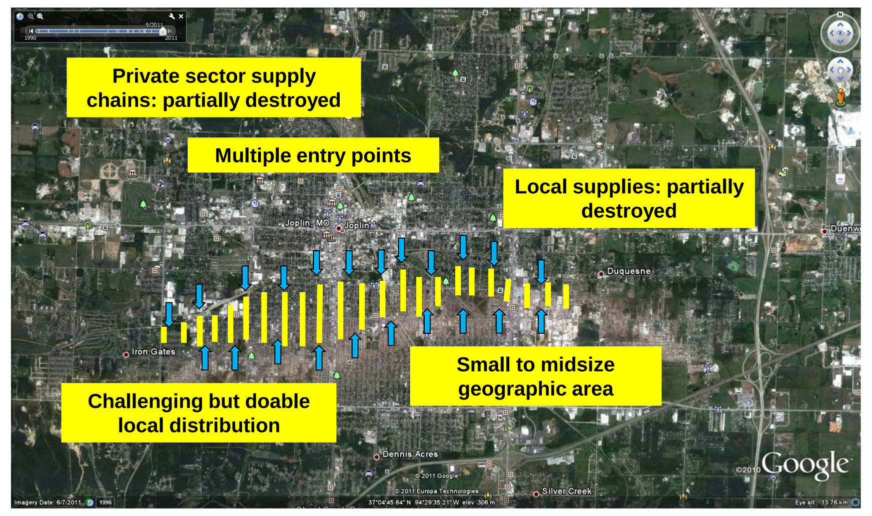
MOTIVATION

- Natural disasters affect millions of people every year, and trillions of dollars in damage
- Due to climate change, disasters are becoming more catastrophic
- Catastrophic events pose unique challenges to the humanitarian sector:
  - Delivering aid to the locals
  - Planning and prepositioning relief is many times financially prohibited

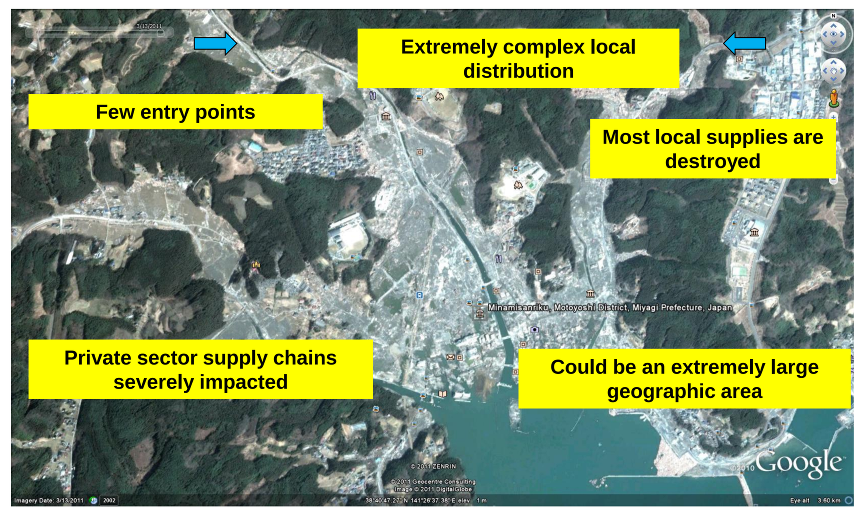
This research aims to contribute to the Disaster Response Logistics (DRL) field efforts through the location and planning of Points of Distribution (PODs) to deliver relief supplies.

LESSONS FROM FIELD WORK

Lesson: Disasters are Catastrophes are not the same



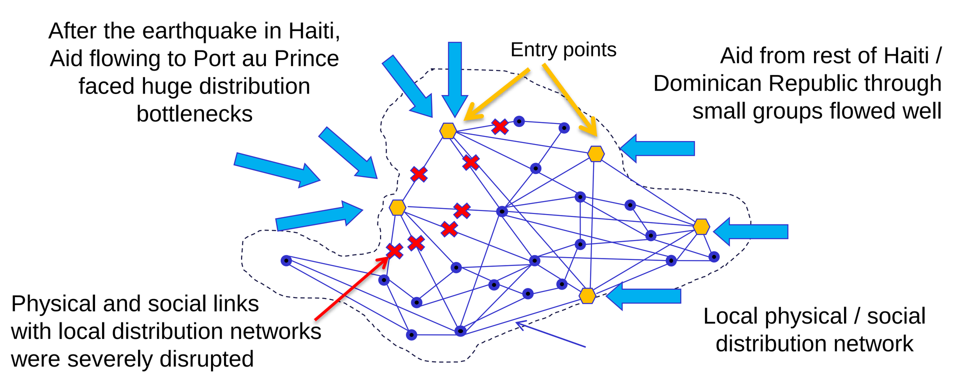
Disaster: Joplin Tornado



Catastrophe: Japan Tsunami

Lesson: Challenge of Local Distribution

Distribution of supplies at the local level requires large amounts of resources.




A similar crisis unfolded in Puerto Rico after Hurricane María

Lesson: Commercial Logistics is different from DRL


▲ People line up to get into a Walmart store in San Juan. Photograph: Joe Raedle/Getty Images

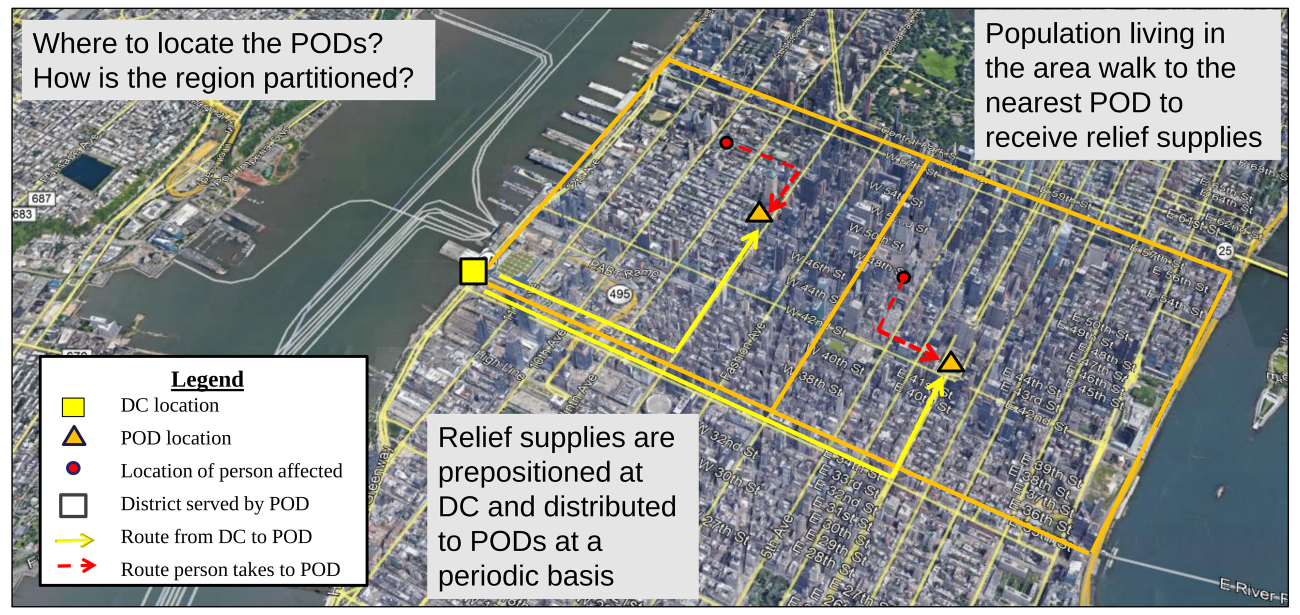
After Hurricane Maria struck Puerto Rico in 2017, vital supplies were stuck in ports and warehouses, leading to crisis among the population in need

Characteristic	Commercial Logistics	Disaster Response Logistics
Objective	Min Logistics Costs	Min Social Costs (add deprivation costs)
Flow of cargo	Self-contained	Material convergence
Demand	Known with some certainty	Unknown/dynamic
Decision making structure	Controlled by a few decision makers	Non-structured, thousands of DMs
Periodicity	Repetitive	One in a lifetime
Supporting systems	Stable and functional	Severely impacted

DISCRETE-CONTINUOUS MODEL

Assumptions:

- Demand is continuously distributed in the region
- Location of supplier warehouse is fixed and has a fixed capacity
- PODs may be located anywhere in the region
- Relief supplies are sent from the warehouse to the PODs using vehicles of similar characteristics
- A generic commodity type is considered
- Manhattan distances are assumed
- Typical shapes are considered for the regions and districts



Objective: Minimize Total Social Costs

Social Costs = Logistical Costs + Deprivation Costs

$$\Phi = \sum_{i,j}\left[c^F(x_{ij}^p, y_{ij}^p) + c^H \frac{f_{ij} q_{ij}}{2} + 2c^T \tau^D (x_{ij}^p, y_{ij}^p) f_{ij} veh_{ij} + \int_{b(x_i)} \int_{b(y_j)} \rho(x,y) \gamma_g(\theta_g, \delta(x,y,x_{ij}^p, y_{ij}^p)) dydx \right]$$

- Deprivation costs $\gamma_g(\theta_g, \delta)$ depend on deprivation times, δ, which include:
  - The time to walk to the POD
  - The time they have to wait for the relief

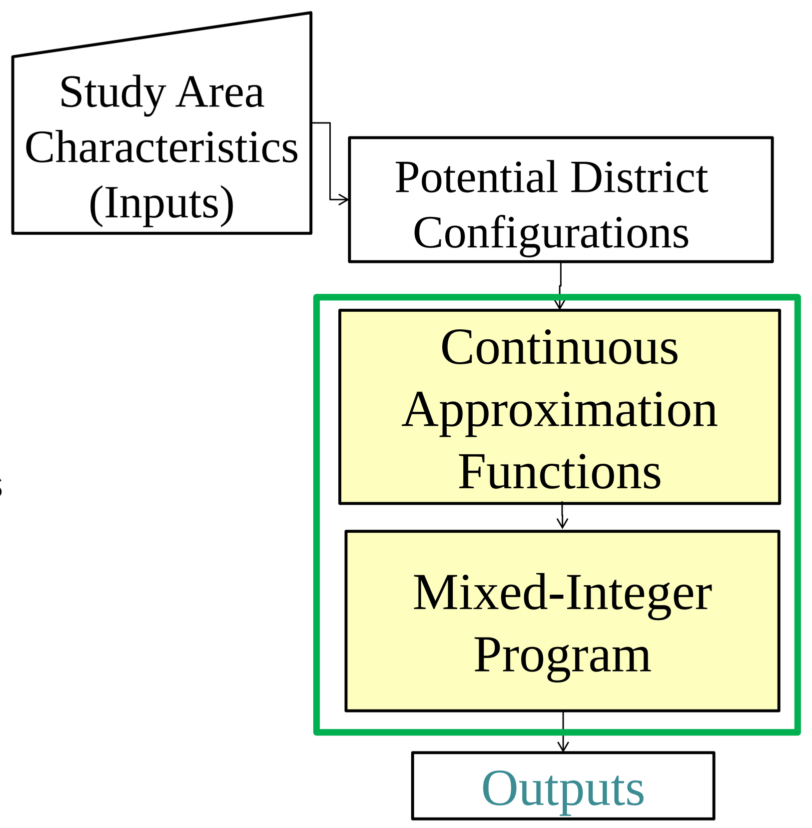
Deprivation costs are defined as *"the economic value of the human suffering caused by a lack of access to a good or service"* (Holguín-Veras et al. 2013)

Discrete-Continuous Model:

Minimize $\Phi = \Omega + \Gamma$

Subject to:

Constraint	Description
$b^L(x_i) \le x_{ij}^p \le b^U(x_i) \quad \forall i,j$ $b^L(y_j) \le y_{ij}^p \le b^U(y_j) \quad \forall i,j$	Boundary conditions of the district
$\tau_{ij}^W = \tau_{ij}^{VEH} + \tau^{SA} q_{ij} \quad \forall i,j$	Waiting times
$t_{ij} \ge \tau^{DC} + \tau^{SA} + 2\tau_{ij}^{VEH} \quad \forall i,j$	Time between deliveries
$p_{ij}^s = \rho A_{ij} \quad \forall i,j$	Population served
$q_{ij} = t_{ij} \eta p_{ij}^s \quad \forall i,j$	Shipment size
$q_{ij} \le Q^V veh_{ij} \quad \forall i,j$	Transportation capacity
$\sum_j \sum_i q_{ij} f_{ij} T \le Q^{TOT}$	Supply capacity

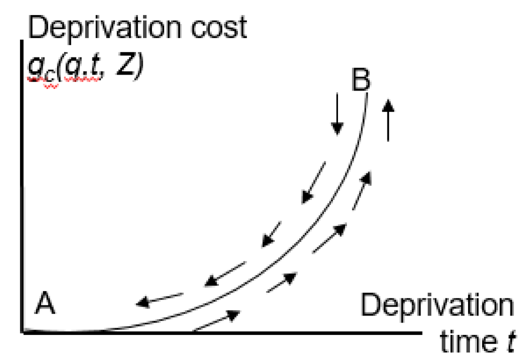


RESULTS

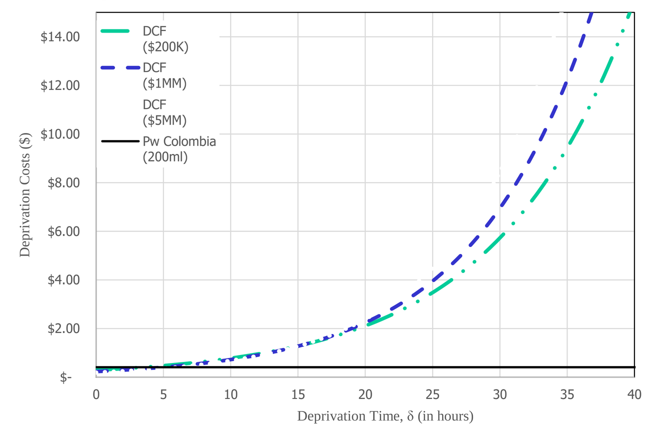
Empirical Estimates for Water Deprivation

Deprivation cost functions:

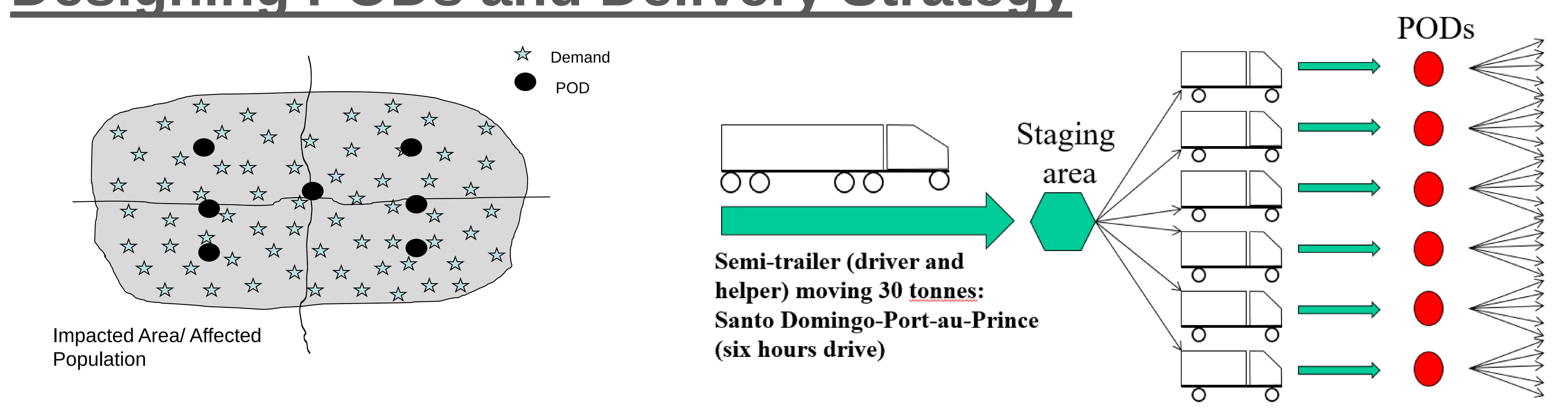
- Monotonic
- Non-linear
- Convex
- Non-additive demands
- Possibly Hysteretic



Deprivation Cost Function for Water

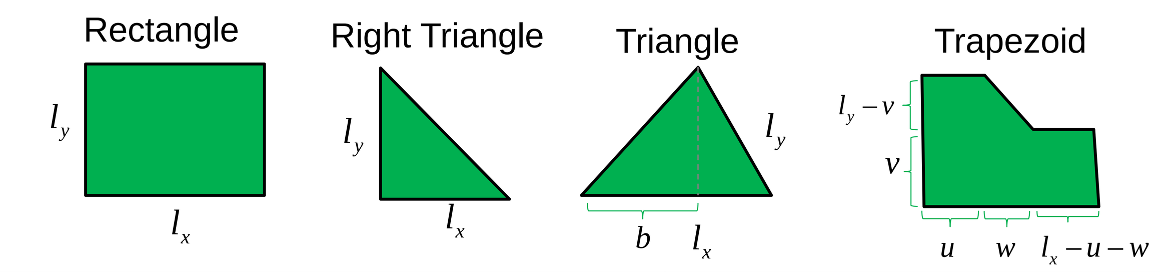


Designing PODs and Delivery Strategy



Continuous Approximation Functions

Assuming demand is uniformly distributed, we generate the following CA functions for typical districting shapes:



	Rectangle	Trapezoid
Linear Deprivation Cost	$\Gamma = \rho\left(b^L + m^L\tau^W\right) l_x l_y + \frac{\rho m^L}{s^{wp}}\left[l_x y^{o2} + l_y x^{o2} - l_x l_y x^o - l_x l_y y^o + l_x^2 \frac{l_y}{2} + l_y^2 \frac{l_x}{2}\right]$	$\Gamma = \rho\left(b^L + m^L\tau^W\right)\left(l_y u + wv + \frac{w^2}{2}\right) + \frac{\rho m^L}{s^{wp}}\left[\frac{l_y^2 u}{2} + \frac{l_y u^2}{2} + uvw + \frac{v^2 w}{2} + \frac{w^2 u}{2} + vw^2 + \frac{w^3}{3} - l_y u x^o - vwx^o - \frac{w^2 x^o}{2} + l_y x^{o2} - l_y u y^o - vwy^o - \frac{w^2 y^o}{2} + uy^{o2} + wy^{o2}\right]$
Exponential Deprivation Cost	$\Gamma = \frac{\rho\alpha e^{\beta\tau^w}}{\left(\beta/s^{wp}\right)^2}\left[e^{(\beta/s^{wp})(l_x + l_y - x^o - y^o)} + e^{(\beta/s^{wp})(l_x - x^o + y^o)} + e^{(\beta/s^{wp})(l_y + x^o - y^o)} + e^{(\beta/s^{wp})(x^o + y^o)} - 2e^{(\beta/s^{wp})(l_x - x^o)} - 2e^{(\beta/s^{wp})(l_y - y^o)} - 2e^{(\beta/s^{wp})x^o} - 2e^{(\beta/s^{wp})y^o} + 4\right]$	$\Gamma = \frac{\rho\alpha e^{\beta\tau^w}}{\left(\beta/s^{wp}\right)^2}\left[e^{(\beta/s^{wp})(x^o + y^o)} + e^{(\beta/s^{wp})(l_y + x^o - y^o)} + e^{(\beta/s^{wp})(u + w - x^o + y^o)} + e^{(\beta/s^{wp})(l_y + u - x^o - y^o)} + \frac{\beta}{s^{wp}} e^{(\beta/s^{wp})(u + w + v - x^o + y^o)} - 2e^{(\beta/s^{wp})(u + w - x^o)} - 2e^{(\beta/s^{wp})(l_y - y^o)} - 2e^{(\beta/s^{wp})x^o} - 2e^{(\beta/s^{wp})y^o} + 4\right]$

Illustration: Locating PODs using rectangular districts

Assume the location of one POD in a rectangular shaped region

Insights obtained from the optimal solutions:

- PODs will be located at the center and will move closer to the DC at a magnitude of the ratio of unit cost of delivery and deprivation costs per distance travelled.
- Districts will be equal if the frequency of deliveries remain equal.
- Waiting times get larger at districts that are farther away, and as the shipment size increases.
- The larger the waiting times with respect to the next district, the smaller the size of the district.