Optimizing Inter-Hospital Patient Transfer (IHT) Routing

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Executive Summary

46.8% fuel cost reduction over real-world baseline

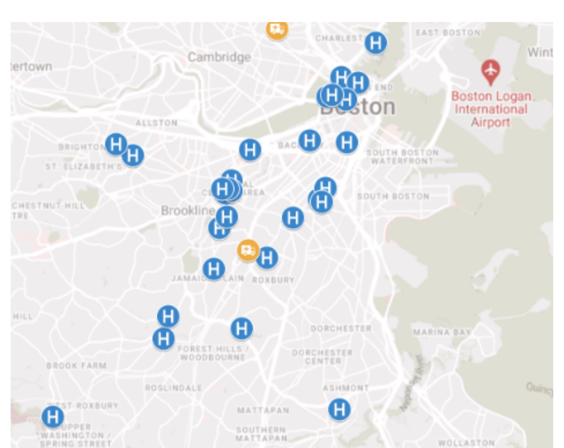
Go Electric! More Distance; Less Cost

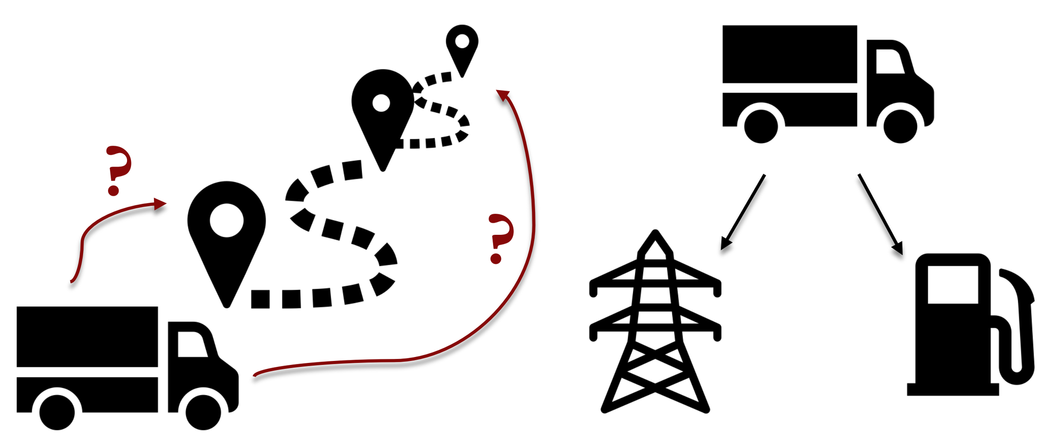
⊕ Realistic ⊕ Interpretable ⊕ Robust

Problem Statement

Fictional patient transport company based in Boston

- **Given:** Pre-determined demand of patient transfers
- **Goal:** Optimize multi-ambulance routing and vehicle type to minimize direct costs to the company





- Fuel & electricity costs (EV) ∝ distance traveled
- Driver wages ∝ travel time
- Maintenance costs ∝ # ambulances deployed

Motivation

1.3M inter-hospital transfers/year (**3.5%** of net admissions)

Specialized care hospital dependent

Cost reduction → Investment to improve healthcare infrastructure

↓5 mins in ambulance response time → **Pell JP et. al. Effect of reducing ambulance response times….* → **2x Survival Rate** for cardiac arrests not witnessed*

Data

Extracted Data

- Coordinates of hospitals
- # Staffed beds
- $/mi for Fuel (ICE) & EV

Processed Data

- Distance & Time (TravelTime API)

Intelligently Synthesized Data

- Patient transfer demand ∝ staffed beds
- Vehicle maintenance cost & driver wages

Mixed Integer Formulation

Multi-Objective

$$\min_{x,y,u} \quad \sum_{k\in K} f_k * y^k + \sum_{i\in V}\sum_{j\in V}\sum_{k\in K} c^k * d_{ij} * x_{ij}^k + w * \sum_{i\in V}\sum_{j\in V}\sum_{k\in K} (t_{ij}+t_b) * x_{ij}^k$$

Flow Constraints

$$\sum_{j\in V}\sum_{k\in K} x_{ij}^k = 1 \qquad \forall\, i\in P \quad (2)$$

$$\sum_{k\in K} x_{i(i+|P|)}^k = 1 \qquad \forall\, i\in P \quad (3)$$

$$\sum_{i\in V} x_{ij}^k - \sum_{i\in V} x_{ji}^k = 1 \qquad \forall\, j\in V, k\in K \quad (4)$$

Bounds & Linking Constraints

$$\sum_{i\in V}\sum_{j\in V} x_{ij}^k * (t_{ij}+t_b) \le t_{max} \qquad \forall\, k\in K \quad (5)$$

$$\sum_{i\in V}\sum_{j\in V} x_{ij}^k \le d_{elec} \qquad \forall\, k\in E \quad (6)$$

$$x_{ij}^k = 0 \qquad \forall\, i\in D,\ j\in D,\ k\in K \quad (7)$$

$$x_{ij}^k \le y^k * depot_i^k \qquad \forall\, i\in D,\ j\in V\ k\in K \quad (8)$$

Sequence Constraints

$$u_i^k = 1 \qquad \forall\, i\in D,\ k\in K \quad (9)$$

$$u_i^k - u_j^k + 1 \le (|V|-1) * (1 - x_{ij}^k) \qquad \forall\, i\in P\cup H,\ j\in P\cup H,\ k\in K \quad (10)$$

$$2 \le u_i^k \le |V| \qquad \forall\, i\in P\cup H,\ k\in K \quad (11)$$

Decision Variables

$$x_{ij}^k = \begin{cases} 1 & \text{if ambulance } k \text{ transfers patient from node } i \text{ to node } j \\ 0 & \text{otherwise} \end{cases}$$

$$y^k = \begin{cases} 1 & \text{if ambulance } k \text{ is used for patient transfers} \\ 0 & \text{otherwise} \end{cases}$$

$$u_i^k = \text{sequence of traversing node } i \text{ by ambulance } k$$

Key Features

- ✓ Multi-Depot
- ✓ Gas Ambulances vs EVs
- ✓ Sequenced Outputs

Key Additions

- ✓ Driver travel constrained by 8hrs
- ✓ EV ambulances travel less than 60mi in one charge

Flavor of Robustness

Scenario 1	Scenario 2	Scenario 3	Scenario 4
t (Actual)	$t \pm 5\%$	$t \pm 10\%$	$t \pm 50\%$

Added traffic scenarios; uniformly averaged for robust route

Results & Impact

Formulation	Metric			
	Fuel Costs	Wage Costs	Fixed Costs	Overall
Baseline (USD)	27.29	**166.97**	9.60	203.85
Optimized (USD)	**14.52**	170.40	**6.10**	**191.02**
Percent Improvement (%)	46.78	-2.06	36.46	6.29

→ Baseline based on current standard practice

→ Ambulances at central "regions" + real-time dispatch

Geographical Visualizations

Optimal routes available on interactive webpage for interpreting model output

Scope of Improvement

→ Scaling up the problem with duality techniques

→ Quantify emission reduction with minimization of Total distance traveled & Utilization of EV

→ Allowing ambulances to start and end at different depots, incorporating notion of depot capacity

→ Adding time windows based on patient availability

→ Priority variable for emergency or special needs