A Hybrid Tour-Based Model for Energy Analysis of Multi-Modal Intra-City Freight: A Case Study of Autonomous Electric Vehicles

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MOTIVATION

- Modeling freight movement data and route choice information is crucial to planning and reducing energy use for freight transportation
- The effect that new technologies have on the existing freight network and freight movement is unknown
- There is lack of an efficient energy analysis tool for freight movement considering adoption of emerging transportation technologies and multi-modal shifts

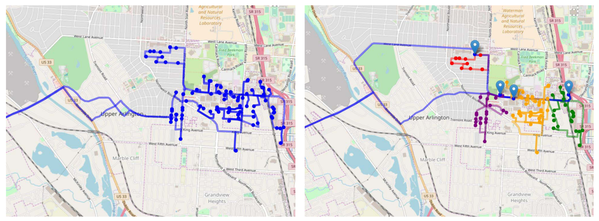
OBJECTIVE

Propose a hybrid tour-based model to evaluate the energy impact of multi-modal intra-city freight movement for future scenarios

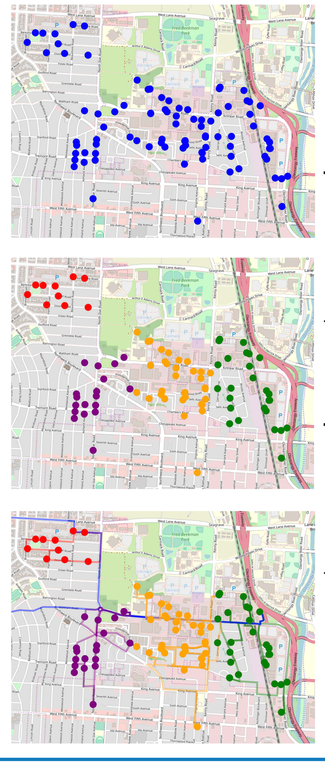
SCENARIOS

Baseline: Single modal package delivery using a conventional diesel-fueled delivery truck

Autonomous electric vehicle (AEV): The packages are dropped off at a number of distribution centers by conventional trucks and then delivered to final destinations using smaller AEVs



HYBRID ROUTE OPTIMIZATION MODEL



TRAVELING SALESMAN PROBLEM

$$\min \sum_{i=1}^{n} \sum_{j\neq i, j=1}^{n} c_{ij} x_{ij}$$

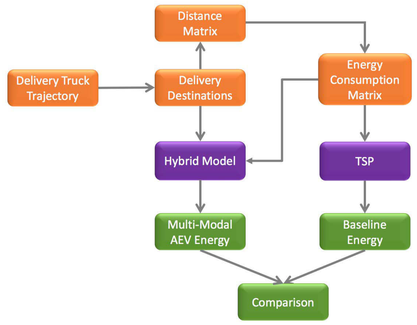
$$s.t.\ \ x_{ij} \in \{0,1\} \qquad i,j = 1,\dots,n$$

$$\sum_{i=1, i\neq j}^{n} x_{ij} = 1 \qquad j = 1,\dots,n$$

$$\sum_{j=1, j\neq i}^{n} x_{ji} = 1 \qquad i = 1,\dots,n$$

$$\sum_{i,j\in S, i\neq j}^{n} x_{ji} \leq |S| - 1 \qquad \forall S \subset V, S \neq 0$$

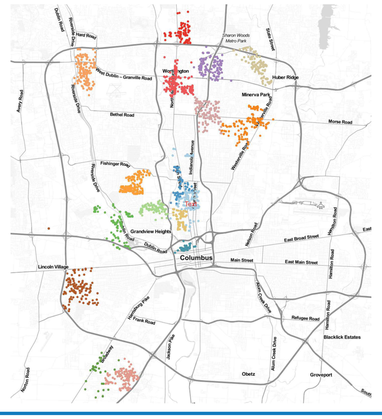
COLUMBUS CASE STUDY LOGIC



DELIVERY TRUCK DATA

- Second-by-second GPS data from 18 delivery trucks for a full day's delivery on 7/18/2017
- On average, each truck delivers to 111 locations
- Features
  - Time and date
  - Longitude and latitude
  - Coolant temperature
  - Engine speed

DELIVERY DESTINATIONS



PERFORMANCE METRICS

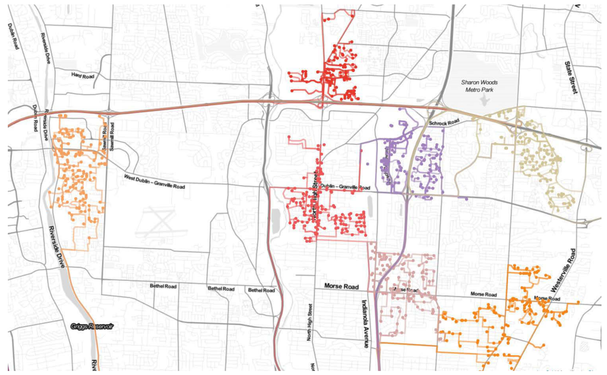
Total energy consumption—the total energy consumed, in gallons of gasoline, for delivering all packages to their destinations during a one-day analysis

Total delivery time—the total time for all vehicles to finish delivering all packages and to travel back to departure origins during a one-day analysis

- Includes both vehicle travel time and vehicle stopping time for package delivery
- Estimated from the trajectory data, the average vehicle stopping time for a package delivery is 130.9 seconds (the unit is vehicle * hour)

Total vehicle miles traveled (VMT)—the total miles traveled by all vehicles during the process of delivering all packages to their destinations

OPTIMIZED ROUTE FOR BASELINE SCENARIO



OPTIMIZED ROUTE FOR AEV SCENARIO

COMPARISON

Electric vehicle delivery capacity: 50

Average stop time: 130.9 seconds

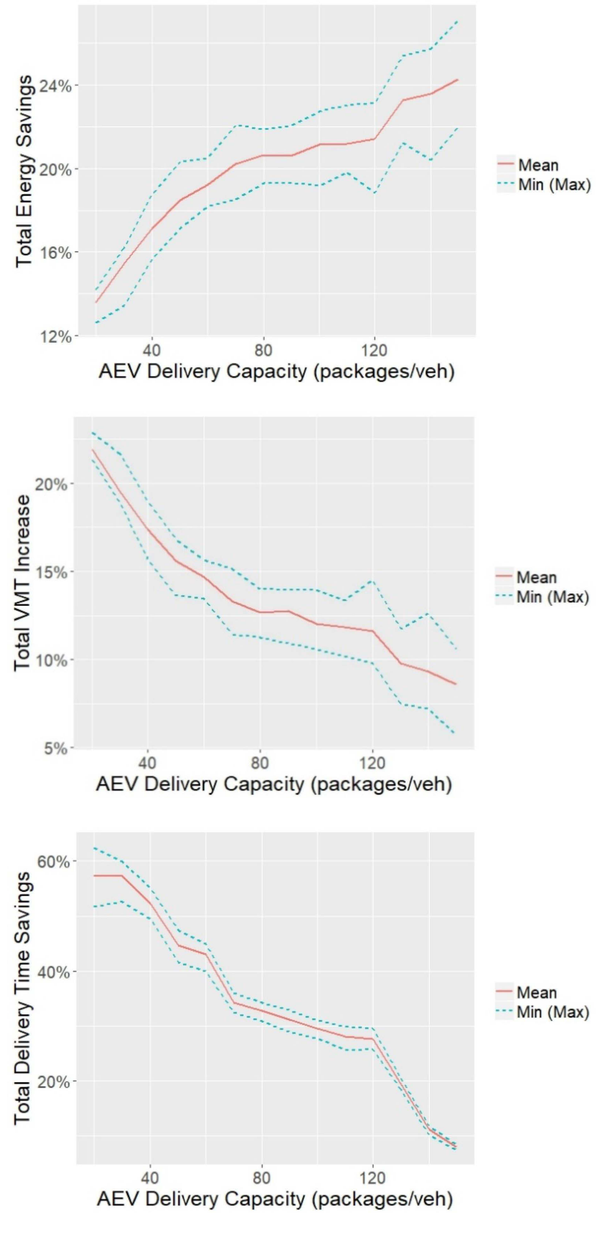
	Baseline	AEV	Savings
VMT (mile)	739.2	849.3	+14.9%
Total Travel Time (vehicle x hour)	4.5	2.5	-44.9%
Total Energy (gallons)	85.3	68.8	-19.4%

SENSITIVITY ANALYSIS

- The average delivery capacity of a AEV was set at 20 to 150 packages/vehicle
- The hybrid route optimization model was run for 20 different random seeds for each capacity value
- Sub-depot locations were randomly chosen in the cluster area for each run

SENSITIVITY ANALYSIS RESULTS

- Energy savings: 13.6%–24.3%
- Delivery time savings: 8.0%–57.3%
- VMT increase: 8.6%–21.9%



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