ZEV Routing and Fleet Size Minimization for Drayage Operations

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OUTLINE

❖ Background & Motivation
❖ Problem Description
❖ Models & Algorithms
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BACKGROUND & MOTIVATION

Total U.S. Greenhouse Gas Emissions by Economic Sector in 2017

- Transportation: 29%
- Electricity: 28%
- Commercial & Residential: 22%
- Agriculture: 9%
- Industry: 12%

Data from Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017
BACKGROUND & MOTIVATION

Total U.S. Greenhouse Gas Emissions by Economic Sector in 2017

- Electricity: 28%
- Agriculture: 9%
- Commercial & Residential: 12%
- Transportation: 29%
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Zero Emission Vehicles In Drayage Operations

APPLICABLE?
PROBLEM DESCRIPTION

Types of Trips Allowed in Our Drayage Operations
PROBLEM DESCRIPTION

• For each trip, all trucks must start from the port and then return to the port.

• Demands are in the form of the number of containers and they only exist between the port and the other locations. The containers are either fully loaded or empty.

• All trucks operate under three different states: carrying no container, carrying an empty container or carrying a fully loaded container.

• Trucks have different power consumption rates for each different operating states. Diesel - miles per gallon (mpg) values | ZEV - battery consumption rates

• All ZEVs are battery powered and the charging stations are installed within the port.

• There are no refueling detours for any truck because fueling stations are pervasive for diesel trucks and ZEVs charge at the port.
MODELS & ALGORITHMS

Minimize Total Miles Travelled
Minimize Fleet Size to Satisfy the Demand

Minimum cost circulation problem
- Input – container demand and supply at each location
- Output – vehicle trips that start and end at the port

Bin-packing problem
- Input – vehicle trips
- Output – number of vehicles needed
- Heuristic, not optimal solution
MODELS & ALGORITHMS

- **Minimum Cost Circulation Problem**
  - Formulate into a linear programming problem
  - Feed into standard LP solver to solve it optimally

- **Bin-packing Problem**
  - Adapt a subset sum algorithm
  - A heuristic algorithm with fast speed and good solution quality

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**Algorithm 1 Subset sum algorithm**

1: $U \leftarrow N$
2: $k \leftarrow 1$
3: while $U \neq \emptyset$ do
4: \[ T_k \leftarrow \arg \max_{P \subseteq U} \left\{ \sum_{i \in P} d_i : \sum_{i \in P} d_j \leq k_P \right\} \]
5: \[ U \leftarrow U \setminus T_k \]
6: $k \leftarrow k + 1$
7: end while
8: return $T_1, T_2, \ldots, T_{k-1}$

DATA DESCRIPTION

- POLA & POLB Survey Data 2010-2012
- Contains origin and destination pairs for container demands
- 10 representative days are selected to generate average daily demand
- 135 empty containers | 176 loaded containers | 94 locations
### NUMERICAL RESULTS

#### Diesel Truck
- Estimated refueling time – 0.25 h
- Tank capacity – 226 gallons
- MPG under different states – 8 | 7 | 5 mpg

#### Speed
- Short distance average speed – 20 miles/h
- Long distance average speed – 45 miles/h
- Long distance criteria – > 5 miles of radius

#### ZEV Truck
- Charging time – 3 hrs for 0-80% and 2 hrs for 80-100%
- Charging pattern – 0-20% is left unused
- Battery capacity, Battery consumption rate and Vehicle range under the different states – next slide

#### Others
- Truck daily operation time limit – 8 hrs
- Truck refueling detours – None
- Distance increase factor – 1.25
# NUMERICAL RESULTS

<table>
<thead>
<tr>
<th>Year</th>
<th>Consumption Rate with Fully Loaded Container (kwh/mile)</th>
<th>Consumption Rate with Empty Container (kwh/mile)</th>
<th>Consumption Rate with No Container (kwh/mile)</th>
<th>Battery Capacity (kwh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td>4</td>
<td>2.82</td>
<td>2.4</td>
<td>240</td>
</tr>
<tr>
<td>2025</td>
<td>3.37</td>
<td>2.1</td>
<td>1.6</td>
<td>525</td>
</tr>
<tr>
<td>2030</td>
<td>3.18</td>
<td>2.01</td>
<td>1.5</td>
<td>650</td>
</tr>
</tbody>
</table>

Battery Information for different years

<table>
<thead>
<tr>
<th>Year</th>
<th>Fully Loaded Container (mile)</th>
<th>Empty Container (mile)</th>
<th>No Container (mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td>60</td>
<td>85</td>
<td>100</td>
</tr>
<tr>
<td>2025</td>
<td>156</td>
<td>250</td>
<td>328</td>
</tr>
<tr>
<td>2030</td>
<td>204</td>
<td>323</td>
<td>433</td>
</tr>
</tbody>
</table>

ZEV ranges for different years
NUMERICAL RESULTS

Distances and Fleet Size under Different ZEV Ratios – Present Year
NUMERICAL RESULTS

Distances and Fleet Size under Different ZEV Ratios – Year 2025
NUMERICAL RESULTS

Distances and Fleet Size under Different ZEV Ratios – Year 2030
NUMERICAL RESULTS – Emissions

<table>
<thead>
<tr>
<th>Vehicle Technology</th>
<th>Criteria Pollutant Emissions</th>
<th>CO2 Emissions</th>
<th>CO2-TOU (g/mile)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>PM$_{2.5}$ (g/mile)</td>
<td>NO$_x$ (g/mile)</td>
<td>(g/mile)</td>
</tr>
<tr>
<td>Diesel Present</td>
<td>0.01</td>
<td>1.91</td>
<td>3143.2</td>
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<tr>
<td>Diesel 2025</td>
<td>0.005</td>
<td>0.96</td>
<td>2781.6</td>
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<tr>
<td>Diesel 2030</td>
<td>0.005</td>
<td>0.96</td>
<td>2494.6</td>
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<tr>
<td>ZEV Present</td>
<td>0</td>
<td>0</td>
<td>992.0</td>
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<tr>
<td>ZEV 2025</td>
<td>0</td>
<td>0</td>
<td>932.0</td>
</tr>
<tr>
<td>ZEV 2030</td>
<td>0</td>
<td>0</td>
<td>871.0</td>
</tr>
</tbody>
</table>

Emission Rates for Diesel Trucks and ZEVs
NUMERICAL RESULTS – Emissions

Estimated Emissions for Diesel Trucks and ZEVs – Present Year

Reduction 6954 kg
NUMERICAL RESULTS – Emissions

Estimated Emissions for Diesel Trucks and ZEVs – Year 2025

Reduction 10782 kg
NUMERICAL RESULTS – Emissions

Estimated Emissions for Diesel Trucks and ZEVs – Year 2030

Reduction 9053 kg
CONCLUSIONS

- With today’s battery technology and assuming charging only occurs at the depot, the driving range is not sufficient to cover all the demand and there is still a need to maintain a diesel fleet.

- With more efficient battery technology projected for Years 2025 and 2030, the performance of the ZEVs significantly improves: average number of trips for the ZEVs increases, the charging time reduces significantly.

- Replacing diesel trucks with ZEVs in drayage operations can eliminate PM2.5 and NOx emissions by diesel trucks. The reduction in CO2 is quite significant.
THANKS

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