Hydrogen Demand and Refueling Infrastructure Planning for Medium- and Heavy-Duty Fuel Cell Vehicles in California

Guozhen Li and Joan Ogden

Institute of Transportation Studies, UC Davis
We built a model to understand infrastructure planning questions for M/D/HD FCVs:

- Refueling Station Location & Size
- Truck Route Network
- Long-haul FCVs
- Refueling Station Location & Size
- H2 Demand
- Location
- Population
- Local FCVs

To understand infrastructure planning questions for M/D/HD FCVs
Two Markets

- Local
  - Package delivery trucks
  - Drayage trucks
  - Transit buses
- Long-haul
  - HD tractors
  - Package delivery trucks

Photo credit to: Toyota
Photo credit to: Nikola Motor
Photo credit to: UPS
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Local FCVs

- Fleets
- Population
- Hub (location)
- Refueling Stations
- Size
- Location
- H2 Demand

Local FCVs
Local FCVs: How Many & Where

**FCV population target**
- California targets 100,000 zero-emission freight vehicles by 2030
- We assume 40,000 local FCVs by 2030

**FCV fleets & hubs**
- Ports, airports, package delivery centers, bus yards, industrial parks (266 hubs)

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Local FCVs: H2 Demand
Local FCVs: Refueling Stations

Station selection criteria:

- Minimize total number of stations
- Ensure all demand points are within 10 minutes driving time to station
- Sizes between 500~20K kgH2/day

Total required stations: 132

Legend:
- Blue markers represent hydrogen stations
- Gray lines indicate roadways
Long-Haul FCVs

• Refueling Network
  • Refueling station locations
  • Refueling station size estimates

• Truck Route Network
  • Simplify California's truck route
  • Identify key trips

UCDAVIS
Network nodes include:
- Highway intersections
- Existing truck service facilities
- Freight loading/unloading points
- E.g. ports, airports

Simplified Truck Route Network

Actual Truck Routes

Long-Haul FCVs Network
Long-Haul FCVs: Trips

- We choose 380 trips between California's major metropolitan areas.
- Every trip takes the shortest path on our simplified truck route network.
- We want all trips to be refuelable.

San Diego

Downtown LA

Downtown

San Francisco
Long-Haul FCVs: Optimal Station Locations

Assume limited FCV range of 150 miles.

Refuel all 380 trips (on any trip, an FCV is ensured to have a place to refuel before tank runs empty).

model as an integer programming problem

\[ \text{subject to} \]

\[ \text{minimize} \]

\[ \text{subject to} \]

\[ A = \text{set of all nodes that can provide fuel for a vehicle with range } R \text{ to travel to node } i \text{ on trip } t \]

\[ R = \text{range of FCVs} \]

\[ G_i = \text{set of all nodes on trip } t \]

\[ T = \text{set of all trips} \]

\[ x_i = \begin{cases} 1 & \text{if node } i \text{ is chosen as a refueling station location} \\ 0 & \text{otherwise} \end{cases} \]

\[ x^f \text{ and } x^t \text{ are decision variables, } x^f = 1 \text{ when node } i \text{ is chosen as a refueling station location. } \]

\[ N = \text{total number of nodes/candidate sites} \]
Long-Haul FCVs: Refueling Locations

- 14 refueling locations can cover the whole network
- Big city stations + connector stations in rural areas
Next Steps

• Integrate local and long-haul networks
• Include station cost in optimization
• Sensitivity analysis
Acknowledgements

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Supporting Slides
Two Markets

Local FCVs

• Small geographic area
• Return to hub

Central refueling at hubs

Long-haul FCVs

• Large geographic area

A state-wide refueling network

Vehicle operations

Infrastructure
For each analysis year (2018-2030), we assign the statewide new FCV population across the 200+ fleets. Old vehicles die out following a survival curve. Priorities are given to:

- „Seed“ fleets in their „seed years“
- Fleets already operating FCVs
- Fleets near other FCV fleets
- „Seed“ fleets in their „seed years“

Local FCVs: How Many & Where
Local FCVs: New Population
Local FCVs: Vehicle Population

H2 Demand

Average Daily Vehicle Population

150 miles/day/truck

Buses: 13.9

Average MPkgH2 (efficiency)

Daily H2 Demand (kgH2/day)

Package delivery: 20

Drayage: 15

*: The fuel efficiency numbers are obtained from Dr. Andrew Burke's FCV simulation with the ADVISOR software.
We collected a dataset of 266 potential FCV fleets/hubs:

- Ports (9)
- Airports (12)
- Package delivery centers (134)
- Bus yards (42)
- Industrial parks (69)

For now we assume only 1 fleet at each hub (multiple fleets sharing a hub is also supported).
Local FCVs: Statewide Target

- State plan targets 100K zero-emission freight vehicles by 2030
- We assume ½ of these ZEVs are FCVs, that is 50K
- We assume 80% of these FCVs are locally operated
- That leads to the target of 40K local FCVs by 2030

Local FCVs: Statewide Target
Every year each fleet is assigned a score based on the following:

- If it is its "seed" year of that fleet: 10 pt
- If it already has FCVs: 8 pt
- If it shares a hub location with another FCV fleet(s): 5 pt
- If it is close to another FCV hub: 5-0.25*driving time to closest FCV hub in minutes (negative values are set to 0)
- If it is the "seed" year of that fleet: 10 pt

Final score is the highest of the above items.

A high-score fleet takes however many FCVs of their desired type as they want, and the next high-score fleet comes in to do the same, until all available new FCV quota runs out.

Local FCVs: New Vehicle Assignment
Local FCVs: Vehicle Survival Curve

- We adopt the survival curve from CA VISION database.
Local FCVs: Station Size Histograms
Long-Haul FCVs: The Route Network

• We hand-picked important points on CA's truck route network to be our network nodes

• Intersections of major highways

• Ports and airports

• Existing truck service facilities

• The arcs represent actual roadway links between points

• Arc length are driving distance measured with Google Maps API

75 nodes, 86 arcs
Long-Haul FCVs: The Long-Haul Trips

- Trips are between CA's major metropolitan areas:
  - Los Angeles area
  - San Diego area
  - Fresno area
  - San Francisco area
  - Sacramento area
  - Redding/Red Bluff area

- 380 trips
- 20 nodes are OD nodes
- All trips take shortest distance path between OD nodes

Long-Haul FCVs: The Long-Haul Trips
Long-Haul FCVs: Station Placement Algorithm

• Objective: minimize number of refueling stations

Constraint: all 380 trips must be refuelable

Formation: binary integer programming

\[ \begin{align*}
F = & \text{set of all nodes that can provide fuel for a vehicle with range } R \text{ to travel to node } l \text{ on trip } t \\
R = & \text{range of FCVs (maximum distance an FCV can travel after a full refuel)} \\
Q = & \text{set of all nodes on trip } t \\
T = & \text{set of all trips} \\
\end{align*} \]

and \( x_l^T = 0 \) when otherwise;

\[ x_l^T \in \{0,1\} \text{ are decision variables, } x_l^T = 1 \text{ when node } l \text{ is chosen as a refueling station location,} \]

\[ N = \text{total number of nodes/candidate sites} \]

where

\[ \sum_{l \in T} x_l^T = \text{total number of refueling stations} \]

subject to

\[ \sum_{l \in T} x_l^T = \text{objective: minimize} \]

subject to

\[ \sum_{l \in T} x_l^T = \text{objective: minimize} \]
Long-Haul FCVs: Station Placement Algorithm

How to make sure all trips are refuelable?

- Make sure all node all trips can be reached without running out of fuel
- Each node on each trip leads to a linear constraint

To ensure node 6 can be reached:

\[ x_6 + x_4 + x_9 \geq 1 \]
Our Model Is Highly Customizable

- FCV range limits
- FCV trips: ODs, paths
- Long-haul route network x candidate station sites
- Station coverage criteria (e.g., 5', 10', 15 minutes)
- FCVs' hydrogen VMT and fuel efficiencies
- FCVs' fleets and hubs: A hub can be shared by multiple fleets.
- FCV population growth assumptions

You can customize
Our model is only as good as its input data.

We are looking for good data on:

- MD/HD fleet/operator info: location, fleet size, operation routes, etc.
- FCV specs: fuel efficiency, range, refueling speed, etc.
- Freight traffic data: ODs, routing, payload, refueling behavior
- H2 station costs (as alternative optimization targets)

We are looking for good data on...
Thank you!

Author Info
Guozhen Li
ligz@ucdavis.edu

PhD Candidate, Transportation Technology and Policy
Master's Student, Computer Science
University of California, Davis

Research/Work Interests:
- Geospatial analysis
- Optimization
- Data analytics / data science / data visualization
- Transportation & alternative fuels