Heavy Duty Trucks: The Challenge of Getting to Zero

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Outline

- Motivation
- Research approach
- Simulation results
- Scenario analysis
- Case studies
- Conclusions

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The challenge: Increasing freight demand

- Continued globalization of manufacturing, trade
- Rapid increase in e-commerce
  - Affects supply chains, distribution networks
  - Fragments freight shipments
- Trucks account for a growing share of pollution

How can we reduce truck emissions to achieve health and GHG reduction goals?

Research questions

1. What is the market for zero-emission heavy duty trucks in 2020, 2025, and 2030?
2. What is the impact of using zero emission trucks on fleet operations, costs, and GHG emissions?
3. What markets could be efficiently served by zero emission trucks, given current and expected performance attributes?

California provides opportunity for study

- GHG reduction targets, regulations
  - Ambitious targets for decarbonization
  - Regulations promote experimentation
- Demonstrations provide operational data
  - California is pioneer in demonstrating zero and near-zero truck performance
  - Battery electric, various types of hybrid electric in test operations

We use operational data as a starting point, conduct analysis for 2020, 2025, 2030

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Research approach

- Consider the drayage market
  - Shorter trips more feasible for trucks with limited range
- Consider two alternatives relative to conventional diesel
  - Battery electric (BETs) – the only type of ZEHDT available in the market
  - Natural gas hybrid electric (HETs)
- Develop simulation model based on operational data
  - Estimate number of trucks required to perform same set of pickup/deliveries
- Use model results to compare costs, emissions reductions of diesel, BET, HET scenarios
- Supplement model results with case studies

Simulation

- Optimize routing and scheduling for fleet operations for given shares of EV trucks in the fleet, taking into account range and charging time
- Based on drayage operations data: 2010 - 2012 port data
- Simulations for 2020, 2025, 2030
- HETs have same performance as diesels

How many trucks are needed to perform all pickups and deliveries when we add BETs to the fleet?

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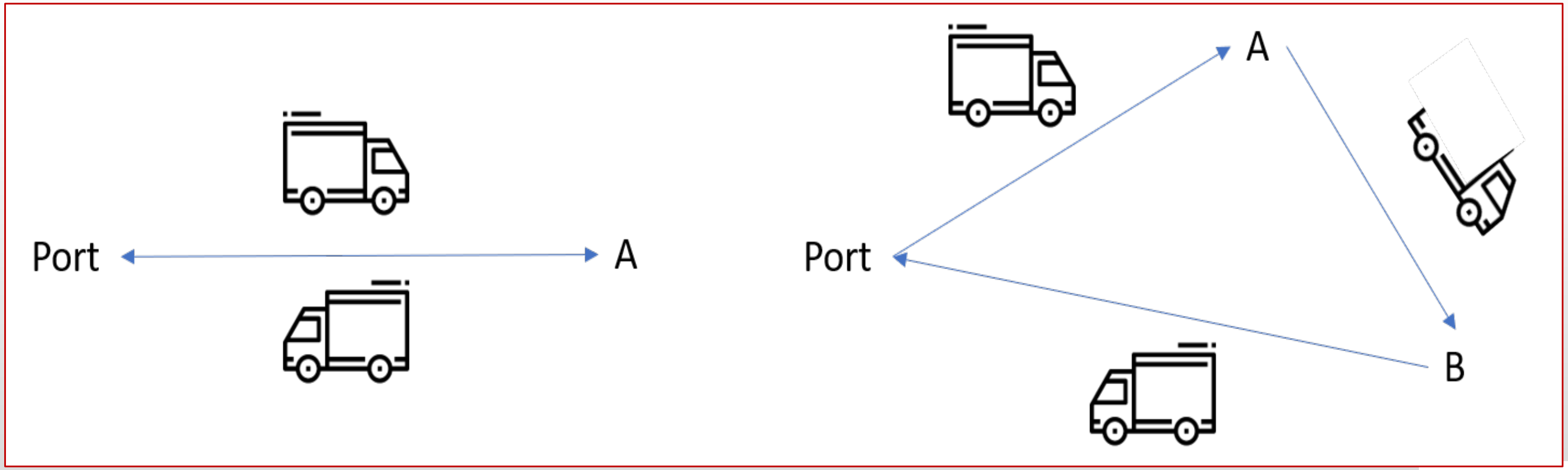
Simulation problem

A drayage operation with two types of tours:
1) load in/load out; 2) load out/empty trip/load in



Assumptions

1. All trucks start from the port and return to the port.
2. Demand = number of containers, and only exist between the port and other locations. Containers are either fully loaded or empty.
3. Trucks operate in 3 different states, carrying no container, carrying an empty container, and carrying a fully loaded container.
4. Different power consumption rates for each different operating state, (e.g. different mpg for diesel and different battery consumption rates for BET)
5. All BETs are battery powered, charging stations are at the port.
6. No refueling detours for any truck
7. Trucks operate 8 hours/day

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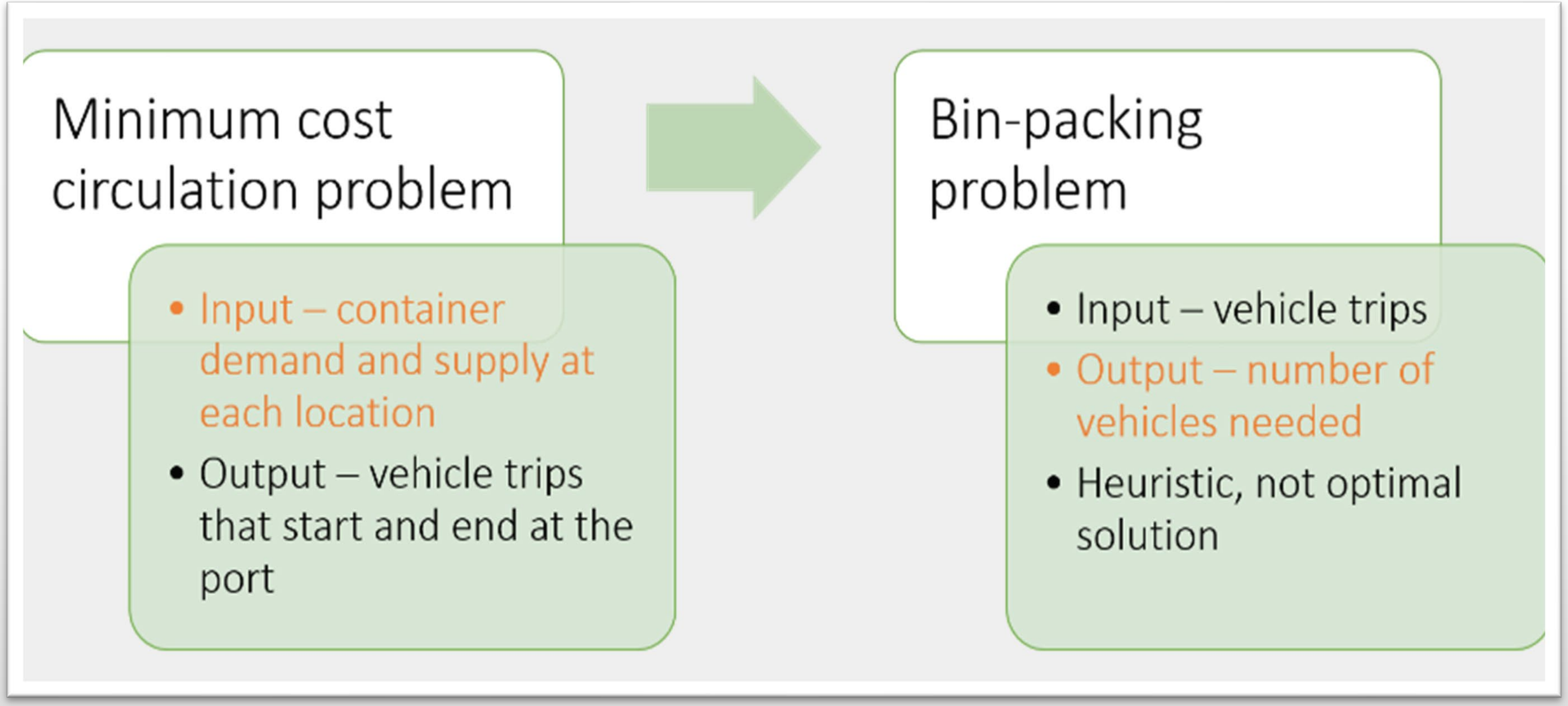
Two stage simulation approach

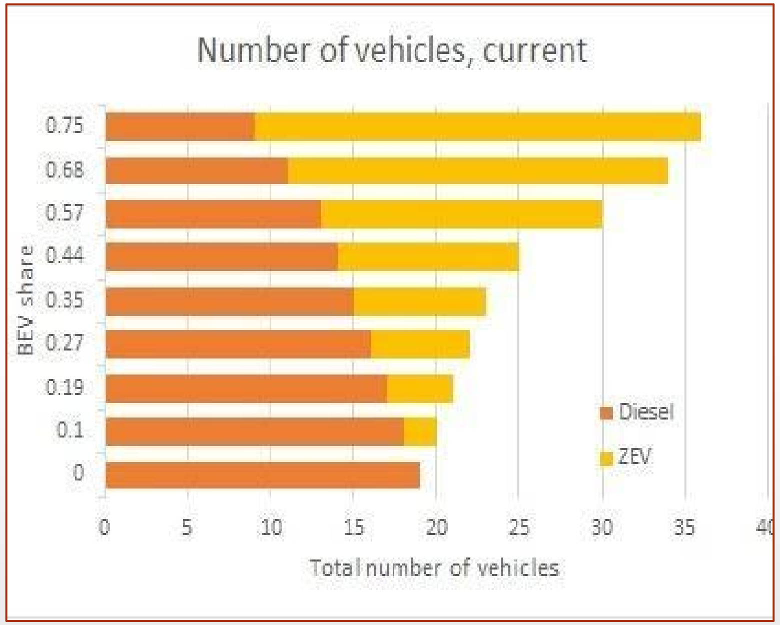


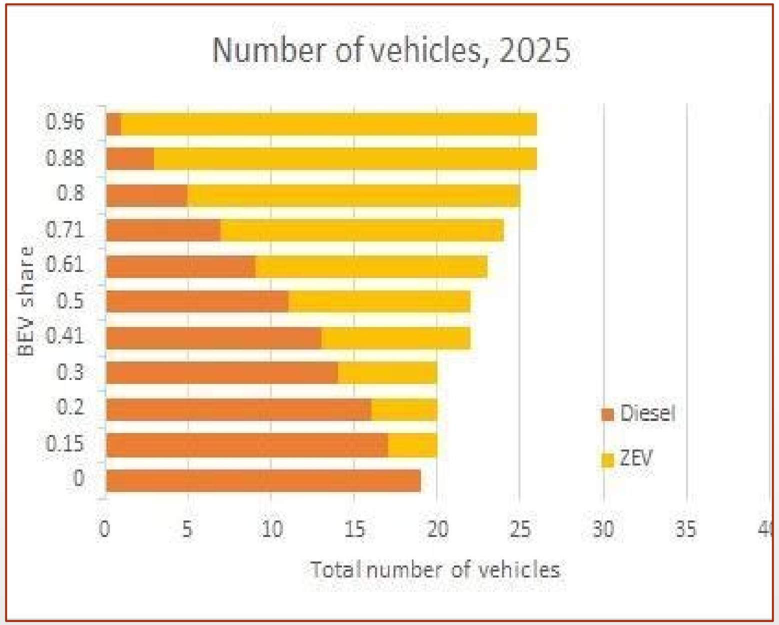
1. Minimize total VMT subject to serving all demand
2. Minimize the total fleet subject to performing all trips generated in stage 1

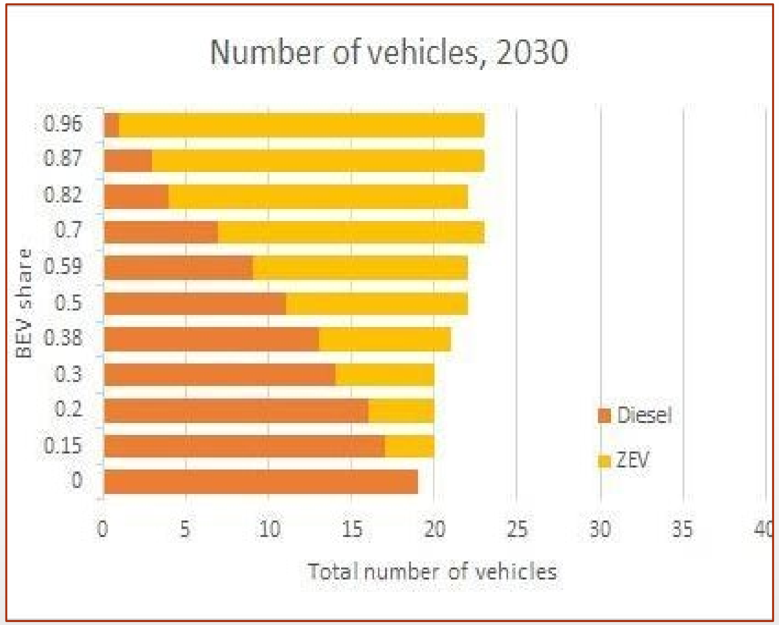
Selected simulation parameters

Common to all trucks	
Speed: 20 mph for trips < or = 5 miles; 45 mph otherwise Daily operation: one 8-hr shift per truck	
Diesel	BET
Range (miles)	Loaded/empty/no container
>300 mi all years	Year 2020: 60/85/100 Year 2025: 156/250/328 Year 2030: 204/323/433
Refueling time	
15 min	3 hours for 0-80%; + 2hours for 80-100%
Battery capacity (kwh)	
N/A	Year 2020: 240 Year 2025: 525 Year 2030: 650

Results 1: Number of vehicles required







2020:
Max possible BET share is 75%
Vehicle fleet size = 36

2025:
Max possible BET share is 96%
Vehicle fleet size = 26

2030:
Max possible BET share is 96%
Vehicle fleet size = 23

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Comparing costs and emissions reductions

- Four fleet scenarios
  - All diesel (baseline)
  - All HETs
  - Midpoint BET
  - Maximum BET
- Three target years
  - 2020
  - 2025
  - 2030
- Three criteria pollutants
  - PM 2.5
  - NOX
  - CO2
- Costs
  - Capital costs, annualized
  - Operating and maintenance costs
  - Driver costs
  - *Fueling infrastructure costs not included*

Annualized costs for comparisons

Capital costs	All diesel	All HET	Midpoint BET	Maximum BET
2020	$ 358,891	$ 437,437	$ 789,135	$ 1,457,874
2025	$ 377,017	$ 421,838	$ 506,682	$ 675,318
2030	$ 392,426	$ 436,221	$ 502,304	$ 570,874
Vehicle operating costs	All diesel	All hybrid	Midpoint BET	Maximum BET
2020	$1,456,182	$1,070,401	$1,310,931	$1,123,265
2025	$1,317,293	$976,931	$1,094,283	$786,000
2030	$1,207,064	$901,620	$1,004,675	$741,824
Driver operating costs	All diesel	All hybrid	Midpoint BET	Maximum BET
2020	$ 1,026,000	$ 1,026,000	$1,350,000	$1,944,000
2025	$ 1,026,000	$ 1,026,000	$1,188,000	$1,404,000
2030	$ 1,026,000	$ 1,026,000	$1,188,000	$1,242,000
Total annualized costs	All diesel	All hybrid	Midpoint BET	Maximum BET
2020	$2,482,182	$2,096,401	$2,660,931	$3,067,265
2025	$2,343,293	$2,002,931	$2,282,283	$2,190,000
2030	$2,233,004	$1,927,620	$2,192,675	$1,983,824

Results 2: Emissions savings, relative to diesel

Net emissions savings	All HET	Midpoint BET	Max BET
$PM_{2.5}$ (g)			
2020	2350	3525	8075
2025	1175	3150	7525
2030	1175	3275	7525
NO_X (kg)			
2020	2725	675	1550
2025	1225	600	1425
2030	1225	625	1425
CO_2 (kg)			
2020	1311500	687750	1576500
2025	1160500	1019750	2429500
2030	1040500	880500	2024000

Max BET gives greatest reduction in emissions

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Results 3: Cost (savings) per unit of emissions removed

cost per emissions reduced	All HET	Midpoint BET	Max BET
$PM_{2.5}$ (per gram)			
2020	$ (130.74)	$ 172.76	$ 208.55
2025	$ (251.52)	$ 21.79	$ 19.27
2030	$ (222.68)	$ 21.22	$ (9.41)
NO_X (per kg)			
2020	$ (112.75)	$ 902.21	$ 1,086.49
2025	$ (241.26)	$ 114.42	$ 101.76
2030	$ (213.59)	$ 111.18	$ (49.68)
CO_2 (per kg)			
2020	$ (0.23)	$ 0.89	$ 1.07
2025	$ (0.25)	$ 0.07	$ 0.06
2030	$ (0.25)	$ 0.08	$ (0.03)

All hybrid generates emissions savings at negative costs

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Findings on simulations

- Differences between 2020 and 2025 due to using actual data for 2020
- Trade-offs between costs and emissions reduction
  - Max BET achieves the greatest emission reduction
  - Max BET emissions reductions grow over time as battery technology improves and number of vehicles goes down
  - Midpoint BET is never the best option; combines diesel emissions with high capital costs of BET
  - HETs produce both emissions reductions and cost savings due to lower capital and driver costs
- Taking operational constraints into account affects results
  - Many studies assume a one-to-one substitution for BETs
  - Range and charging time adds to costs by requiring larger total number of vehicles
- BETs become more cost-effective in 2030

Caveats

- Caveats
  - Simulation of simple trips; actual operations more complex
  - No consideration of gross vehicle weight limits
  - Assumed one 8 hour shift/day
  - No consideration of charging infrastructure costs
  - No consideration of additional space required for extra vehicles

All of these factors would add to BET costs

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Case studies

Estimate share of the daily pickups and deliveries that could be made using BETs, accounting for performance, weight restrictions

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Participant firm characteristics

Firm 1	Firm 2
Drayage and direct delivery, chemicals, liquids, dray bulk	Drayage and direct store delivery, natural foods
All trucks owned	All trucks leased
Employee drivers + owner operators	All employee drivers
Trucks operate 1 shift per day	Trucks operate near 24 hours per day

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Definitions and assumptions

- ***Trip***: origin-destination pair without stops; same weight
- ***Tour***: combination of trips starting & ending at a firm location in one day; may include multiple trips
- ***Daily route***: all tours conducted by a single truck in a 24 hr. period
- Distance categories (in miles): short < 40, medium 40-80, long 80-120, extra long > 120
- Electricity consumption based on tractor trailer weight (full or empty)
- Charging at the home yard

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Tours and daily distance by distance category

Firm 1				
Single tour	< 40 mi	40 – 80 mi	80 – 120 mi	>120 mi
Month 1	54%	15%	8%	23%
Month 2	59%	14%	6%	21%
Daily distance	<40 mi	40 – 80 mi	80 -120 mi	>120 mi
Month 1	4%	22%	18%	56%
Month 2	13%	27%	13%	47%
Firm 2				
	<40 mi	40 - 80 mi	80 – 120 mi	>120 mi
Single tour	20%	44%	17%	19%
Daily distance	10%	12%	12%	66%

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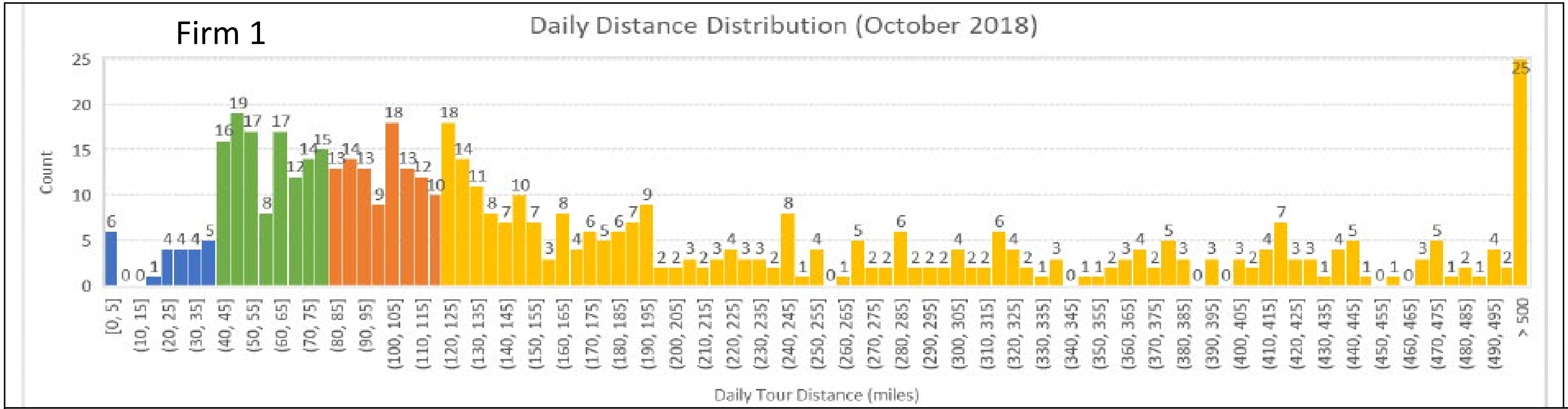
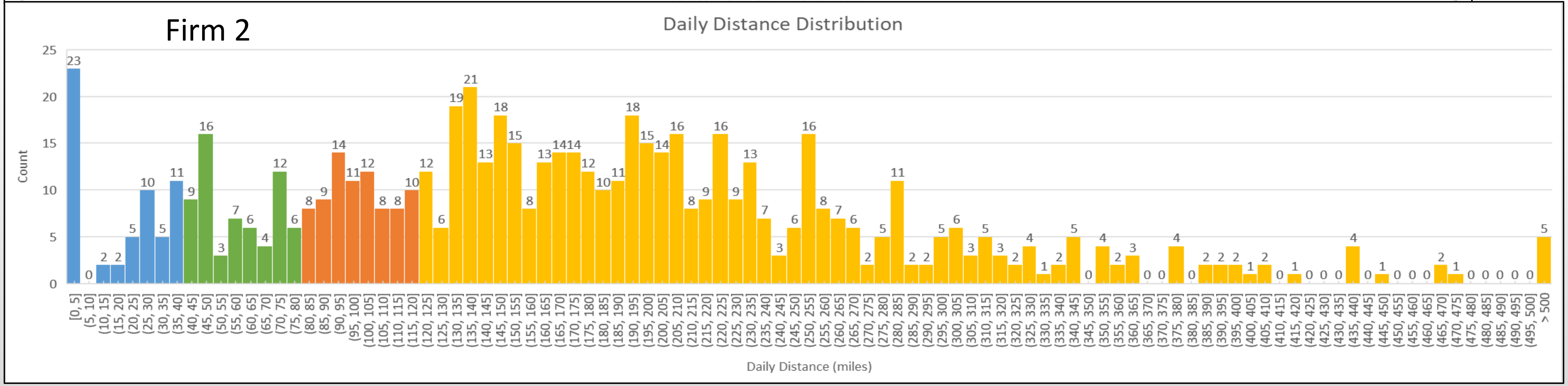
Daily distance distributions





Results

Share of truck days that can be served with BETs, with and without weight limits

Firm 1		2020	2025	2030
Battery Capacity (kwh)		240	525	650
Average % of truck days	Without Weight Limits	30%	61%	82%
	With Weight Limits	18%	43%	58%
Firm 2				
% of truck days that can be operated by ZEVs	Without weight limits	8%	38%	64%
	With weight limits	2%	12%	22%

Findings from case studies

- Diversity, complexity of short-haul market
- Likely near-term penetration in the range of 10-15% due to intensive use of fleet vehicles
- Many institutional and operational barriers
  - Owner operators
  - Charging infrastructure and costs

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Conclusions

- Market for BEVs heavily influenced by range, weight and operating practices
- Transition to BETs in 2020s likely to be more costly than anticipated
- Transition depends on progress of battery technology, charging infrastructure, grid capacity
  - Tesla promise would be break through
  - If battery technology improves as expected, large portion of market could potentially be served
- Transition depends on subsidies
  - Need for offsets to up front vehicle costs, stranded assets, charging facilities, restructuring of freight operations

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Thank you

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