Powering What's Next in Freight Transportation

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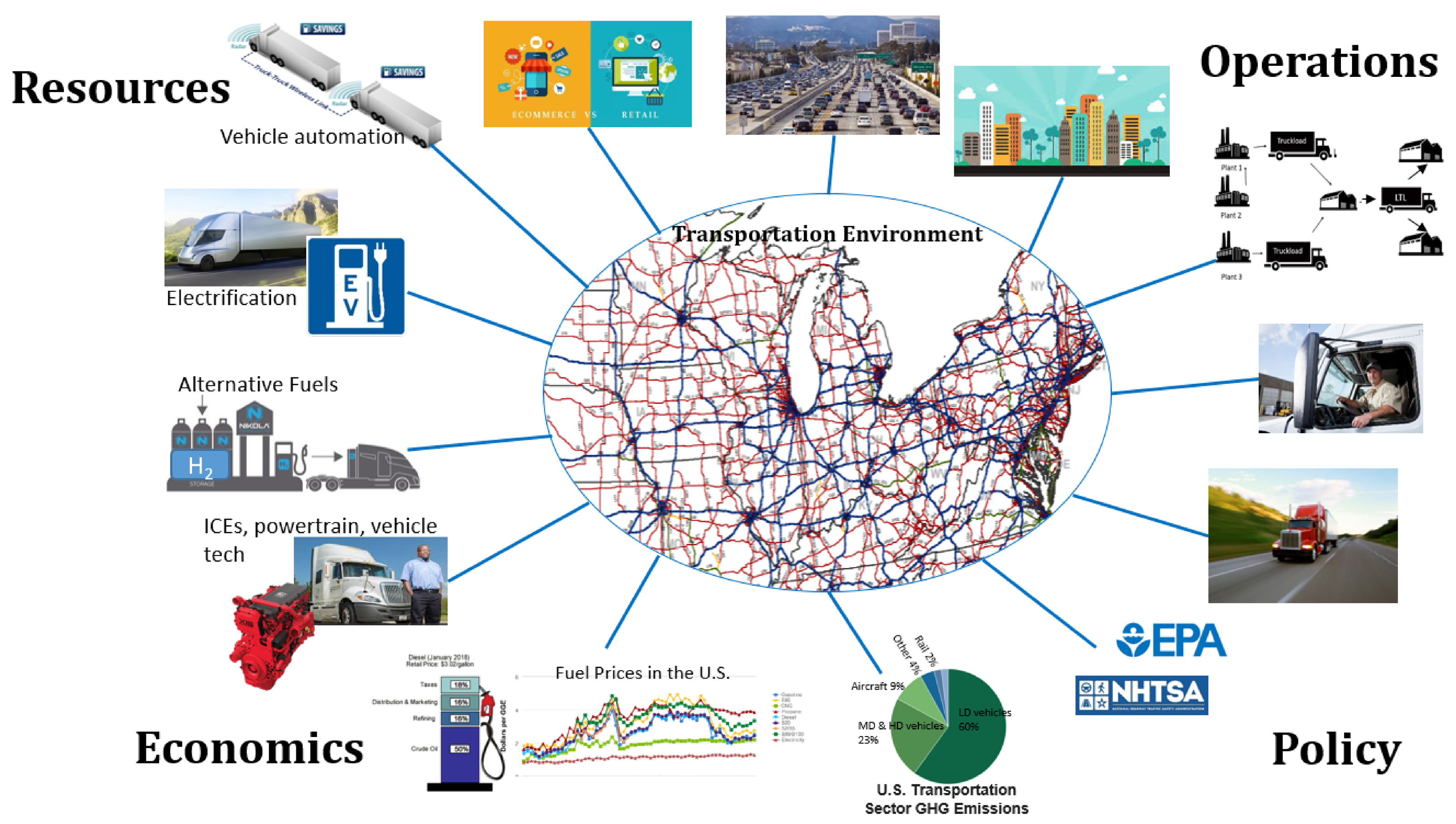
Sponsor: Cummins, Inc.

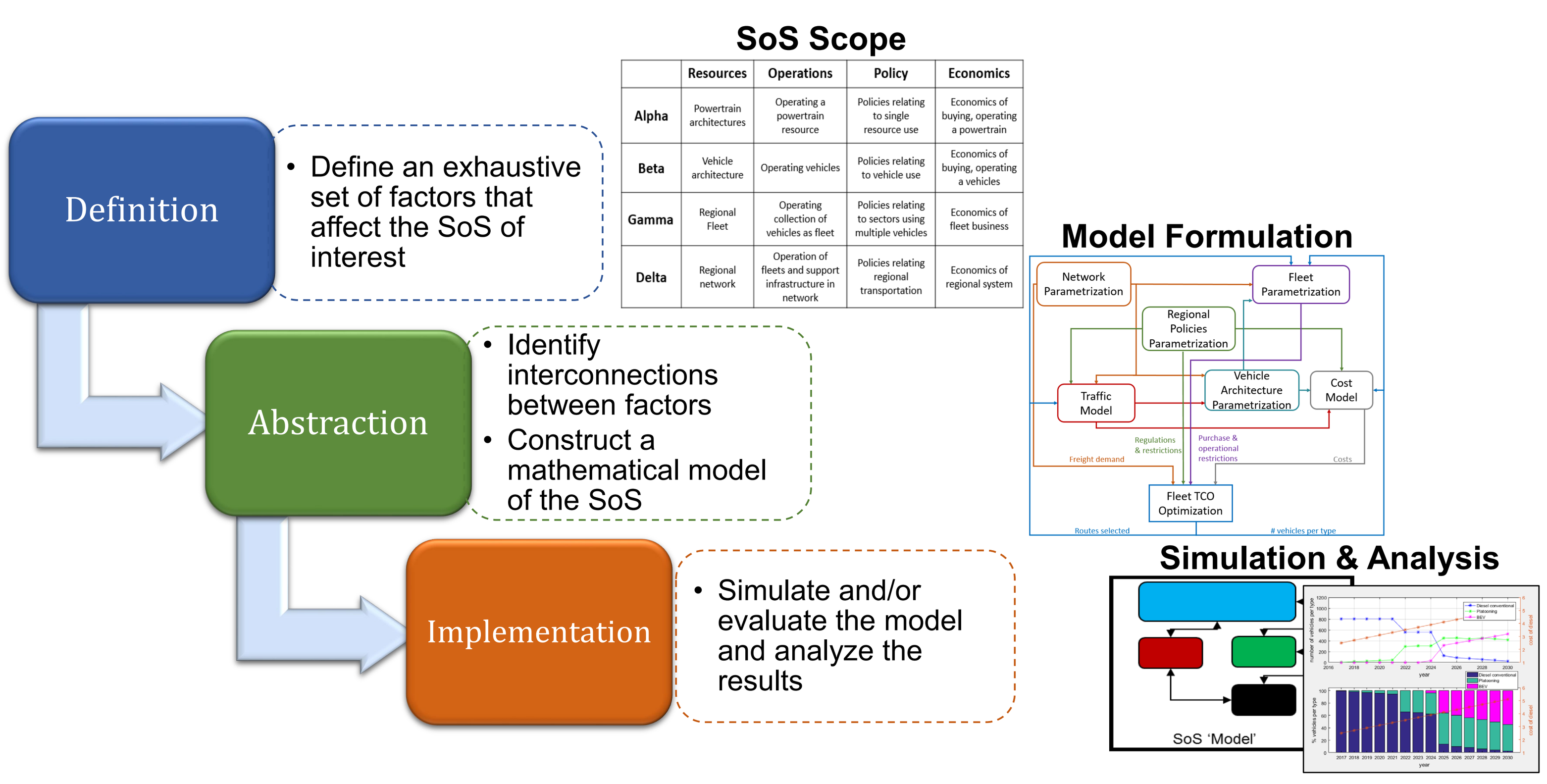
Problem Statement

Develop a simulation framework to enable manufacturers and policymakers to incentivize adoption of **low and zero emission powertrains and vehicle autonomy for Class 8 vehicles**



Approach and/or Methodology

Use the System-of-Systems (SoS) engineering methodology to model the Freight Transportation System (FTS)



The future technology composition of the FTS is modeled as a function of purchasing and operations decisions made by independent fleets operating in a U.S. line-haul network

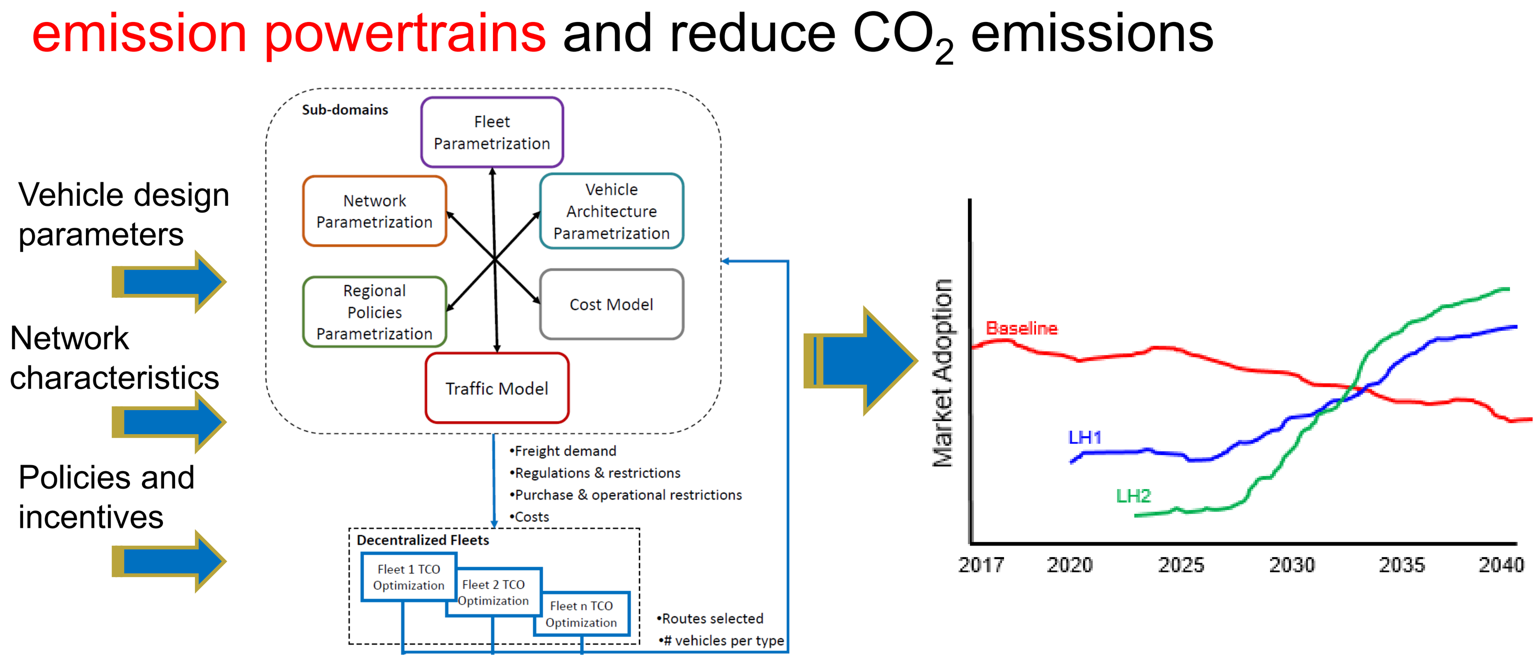
- The FTS SoS is represented by parametrized, time-varying components
- A **Total Cost of Ownership (TCO)** optimization model, formulated as a mixed-integer linear program, represents fleet adoption and vehicle utilization behaviors
- Fleets adopt certain technologies and optimize vehicle allocation on the network to minimize TCO
- TCO is a function of purchasing and operational costs:
  - Technology upcharge costs
  - Fuel consumption
  - Driver costs
  - Maintenance and reliability
  - Availability of fueling/charging stations
  - On-road charging tolls

$$TCO = \gamma \sum_{q} \sum_{(i,j)\in A} x_{q,ij}\left[d_{ij}\left(\xi_{q,ij}C_{e,q} + C_{driver} + C_{M,q}\right) + B_q T_{d,q} C_{delay,c}\right]$$

$$+\gamma\Phi_{BS}\left(x_{q,n}S_f - \sum_{(i,j)\in A} x_{q,ij}d_{ij}\xi_{q,ij}C_{e,q}\right) + \gamma\Phi_{CR}T_{CR}\sum_{(i,j)\in G} x_{q,ij}$$

$$+\sum_{q} x_{q,new}C_{p,q} - \sum_{q} x_{q,r}C_{r,q} + x_{q,new}\left(\Phi_{CR}U_{CR} - B_{cap}C_{kWh}\Phi_{BS}\right)$$

- The FTS SoS Model is used to determine vehicle and policy design parameters that increase adoption of low and zero emission powertrains and reduce CO_2 emissions



Results

Vehicle architectures introduced to the network for adoption:

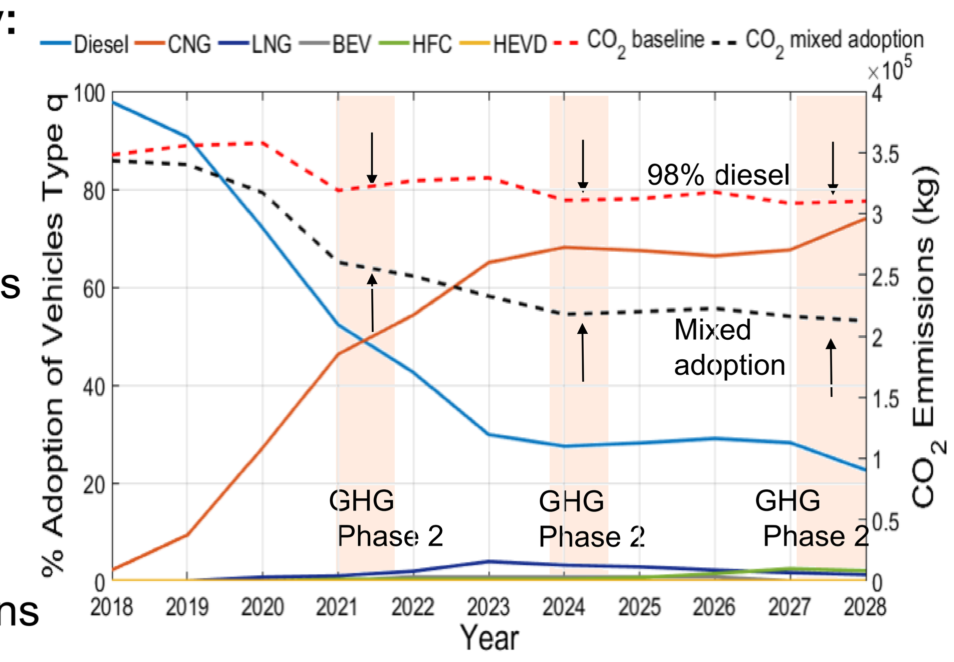
- Diesel, CNG, LNG, hybrid electric diesel (HEVD), battery electric (BEV), and hydrogen fuel cell (HFC)

Vehicle Type	Vehicle Cost ($)	Eff. (mi/EN) (@55 mph)	Range (mi)	Capacity (ton)	Maint. Cost ($/mi)	Reliability (% trips/year)	Emissions[g] (kg CO_2/EN) Well-to-tank	Tank-to-wheel
Diesel	145,000	6	1000	25	0.15	1	9.45	10.16
CNG	172,000	5.1	600	23	0.165	2	2.23	7.11
LNG	190,000	5.25	1000	23	0.165	2	2.56	7.73
HEVD	175,000	6.3	1100	24	0.158	5	9.45	10.16
BEV	210,000	0.39	300	23	0.175	5	0.63	0
HFC	250,000	11	450	24	0.175	5	17.6	0

Projecting multi-fleet adoption over a small regional network

Adoption trends are influenced by:

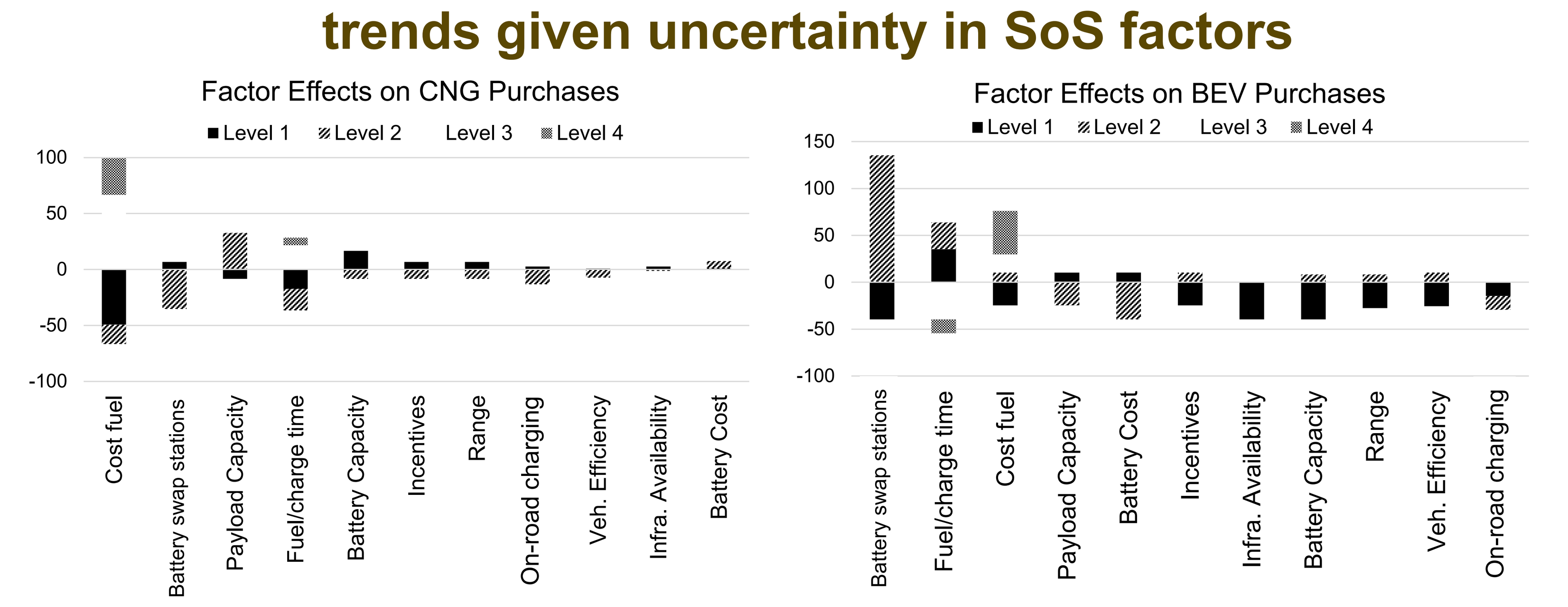
- Fleet characteristics
- Cost of energy
- Fuel tax incentives
- GHG Phase 2 standards
- Available fueling, charging stations
- Charging and fueling times



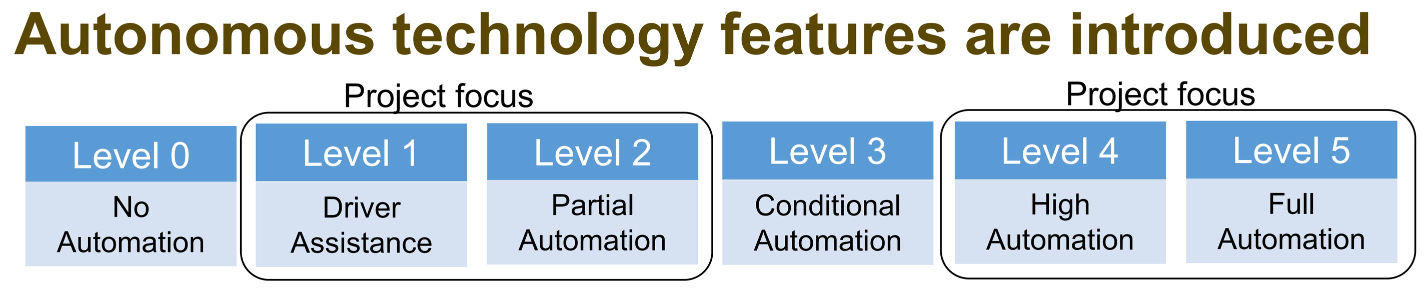
Results demonstrate:

- Rapid reduction in CO_2 in 2021, 2024, 2027 due to fuel efficiency impacts of GHG Phase 2
- Reduction of 30% in CO_2 emissions in 2028 given 80% CNG adoption

Sensitivity analysis to understand variation in adoption trends given uncertainty in SoS factors

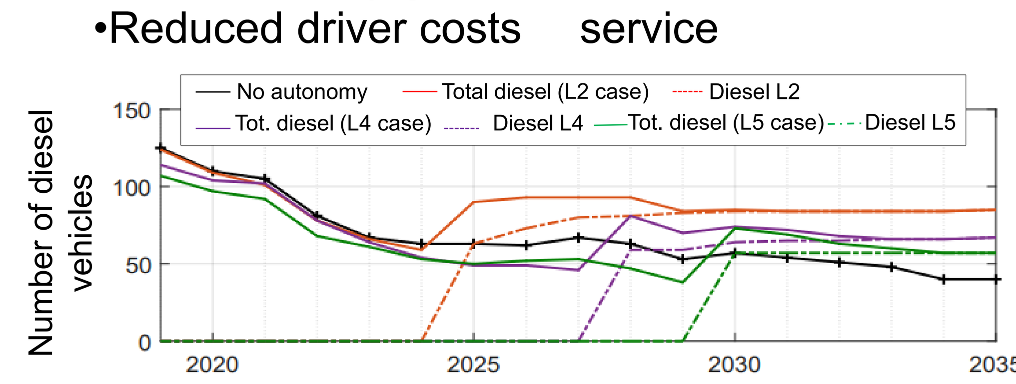


Autonomous technology features are introduced

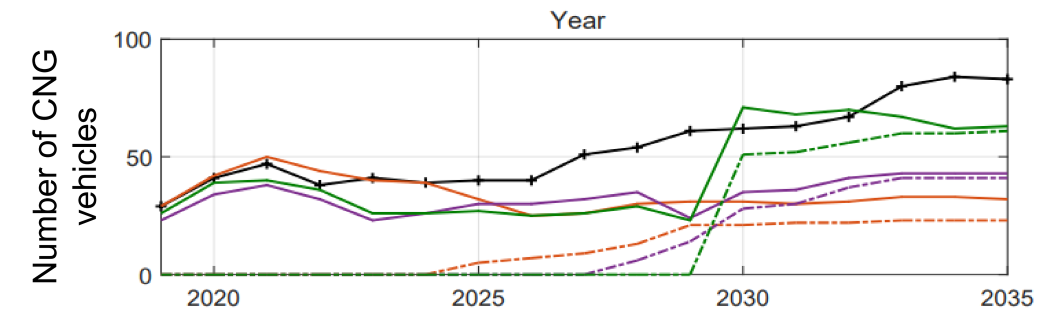


Adoption of powertrains and vehicle automation is projected given:

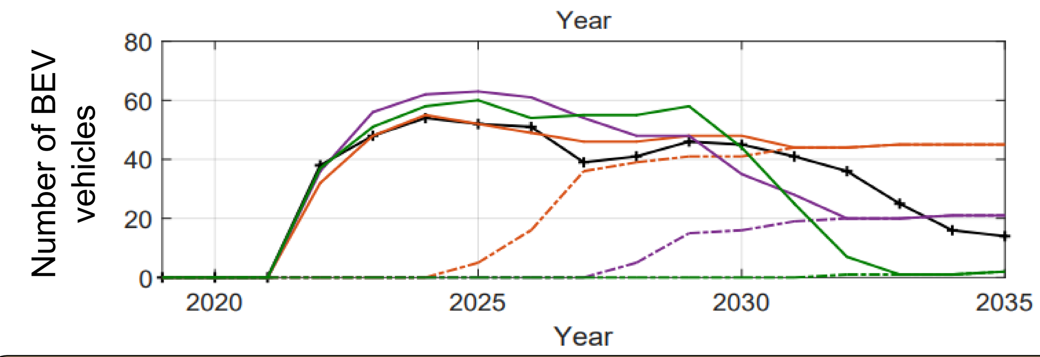
- Upcharge costs
- Fuel efficiency gains
- Reduced driver costs
- Vehicle reliability
- Extension of hours of service
- Allocation of platooning vehicles on routes



Vehicle autonomy increases diesel adoption



Vehicle autonomy decreases CNG adoption



L2 autonomy increases BEV adoption

Select Publications

1) A. Guerrero de la Peña, N. Davendralingam, A. Raz, G. Shaver, D. DeLaurentis, V. Sujan, and N. Jain, "Projecting Line-Haul Truck Technology Adoption: How Heterogeneity Among Fleets Impacts System-Wide Adoption." *Transportation Research Part E: Logistics and Transportation Review*, vol. 124, pp. 108-127, April 2019

2) A. Guerrero de la Peña, N. Davendralingam, A. Raz, G. Shaver, D. DeLaurentis, V. Sujan, and N. Jain, "Modeling the Combined Effect of Powertrain Options and Autonomous Technology on Vehicle Adoption and Utilization by Line-haul Fleets." *Proceedings of the 2019 IEEE Intelligent Transportation Systems Conference*, Auckland, New Zealand, October 27-30, 2019.

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