TRAFFIC IMPLICATIONS OF DEPLOYING CONNECTED, AUTONOMOUS DRAYAGE TRUCKS

A Simulation Analysis of the I-710 Corridor in Southern California

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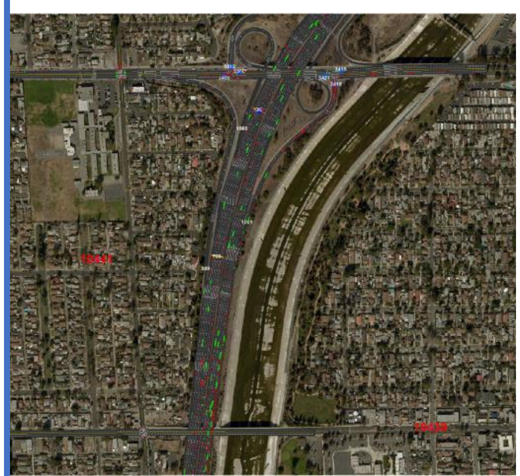
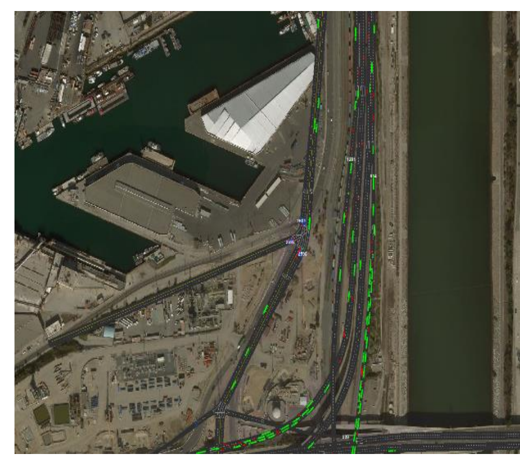




Outline

1. Background
2. Data and Methods
3. Findings
4. Conclusions and limitations

1. Background

- Zero-emissions autonomous trucks are on the horizon
  - Tesla Semi (Battery electric; range: 300 or 500 km)
  - Nikola One (Hydrogen electric; range >500 km)
- Trucks could be autonomous (TuSimple) and/or connected (Peloton)
- Hope: safer, cleaner, more efficient
- **What are the traffic implications of connected, autonomous trucks for traffic and transportation infrastructure in a busy freight corridor?**

1. Background

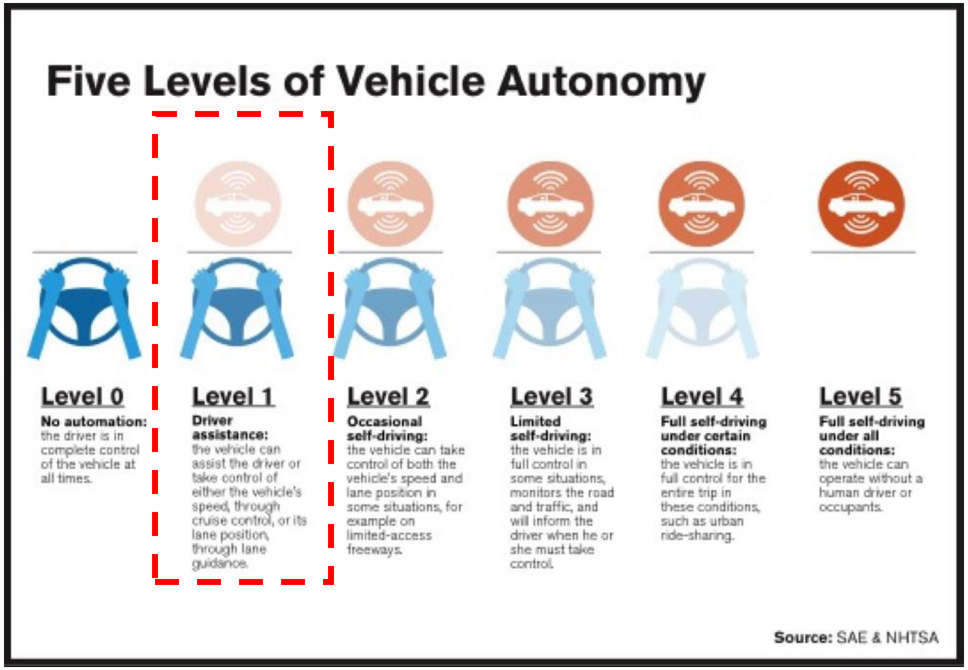
Research choices

- We are interested in **gauging potential traffic implications of deploying connected, automated trucks**. Efficiency gains come from platooning (and smoother driving)
- Platooning should increase road capacity, enhance safety, and save energy (reduced drag)
- **Potential gains will depend on traffic demand, driver behavior, and the infrastructure**
- To understand potential traffic complexities resulting from platooning, we chose **vehicular microsimulation** applied to an area where trucks make up a large percentage of traffic.

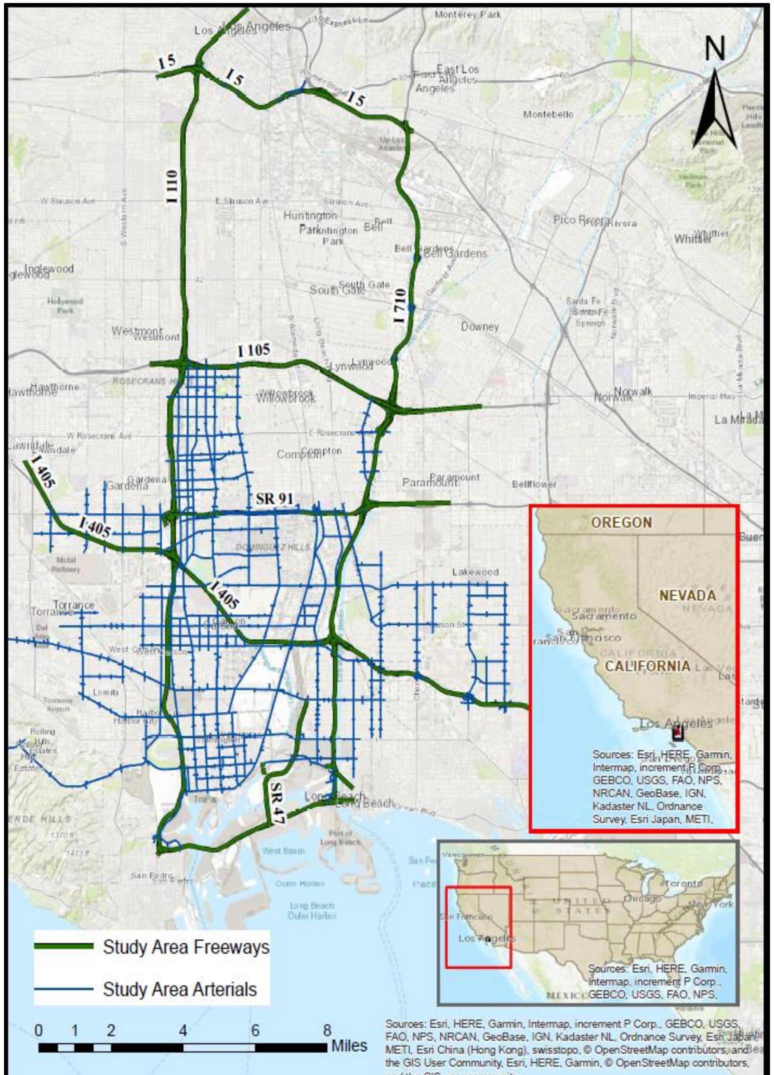
1. Background

Key feature here: connected trucks;
Level of automation: 1 “hands on”

[a driver is in control of steering, but acceleration is automated. Modeled with the constant time gap model]



1. Background: Study Area



- Study area: from the San Pedro Bay Port (Ports of Long Beach and Los Angeles in Southern California) to downtown Los Angeles. Includes freeways and arterials
- Our network includes 314 miles of freeways and 281 miles of arterials.
- Key freeway: I-710

1. Background: I-710

I-710

- Most direct route between the SPBP complex and major railyards (Vernon and East LA)
- Connects with both the I-10 and the SR-60 freeway, which carry trucks to railyards and warehouses in the Inland Empire
- In 2012, the northbound % of trucks on the I-710 varied from 13.9% by the SPBP to 7.8% by the I-5 (13,735 truck AADT out of 177,000 vehicle AADT).
- By comparison, I-110: % of northbound trucks = 5.7% by the SPBP and 0.76% by the I-5.

1. Background: I-710

- **I-710: one of the earliest freeways in Southern CA**. It goes back to the "Great Free-Harbor Fight" of the 1890s when LA incorporated a stretch of land to link the city to the ports.
- The construction of the I-710 started after WWII by Long Beach to connect the ports with local industry; commuter traffic was a lesser concern.
- Freeway construction displaced close to 11,000 residents. It concluded in 1965 but awkwardly, its northern extremity ended in a residential neighborhood.
- During the mid-1960s, Caltrans began planning the connection of the northern end of the I-710. Plans to extend, widen, or double-deck parts of the I-710 created an almost constant source of controversies (e.g., 4.9-mile, $3.2-billion tunnel to connect the I-710 with the I-210 Freeway).

1. Background: I-710

- Following NEPA & CEQA in the 1970s, legal challenges by cities and environmental organizations seeking more rigorous environmental reviews of I-710 projects.
- Work on the I-710 (restarted in 1982 after Gov. Brown signed a bill bypassing municipal governments) was stopped again by lawsuits for EJ reasons.
- In 2012, the LA County Metropolitan Transportation Authority released the I-710 Corridor Project Draft Environmental Impact Report/Statement for public review. Following public opposition to this EIR/S, Caltrans released a Recirculated Draft EIR (June 2017). It includes:
  - **Alternative 7** (preferred by EJ org.): create a ZE/NZE freight corridor.
  - **Alternative 5C** (LA Metro): add one general purpose lane in each direction, deploy ZE/NZE trucks, & install electric charging and hydrogen stations.

1. Background: Our Purpose

We analyze variations of these alternatives to answer two questions:

1. What are potential changes in traffic performance associated with the deployment of connected, autonomous (level 1) drayage trucks?

2. To what extent would the introduction of connected, self-driving vehicle reduce the need for new infrastructure on the I-710?

2. Data and Methods

- Road network originally developed by *Bhagat (2014)*
- Freeway and arterial layouts come from the California Department of Transportation (Caltrans).
- Basic freeway characteristics (e.g., number of lanes and speed limits) and the location of healthy detectors were extracted from Caltrans’ freeway Performance Measurement System (PeMS)
- Freeway ramp metering: we assume that freeway ramp meters release up to one vehicle per lane every 2 s.

2. Data and Methods

- Our origin-destination (OD) demand data come the Southern California Association of Government (SCAG).
- We performed a **sub-area analysis** using TransCAD to redistribute O-D trips from SCAG's network to our network
- O-D demands were modified to match traffic volumes in 15 min intervals using the **dynamic traffic assignment** algorithm of Choi et al. (2009). Matching either with observed counts from PeMS, or [on arterials] with artificial counts generated based on distributing AADT.
- Our model has **354 loop detectors** (147 on freeway mainlines, 86 on ramps, and 121 artificial detectors on arterials).
- Following FHWA recommendations, we relied on the GEH statistic to assess how close our simulated traffic counts are from observed data in 15-minute intervals over 24 hours.

2. Data and Methods

- 2005 and 2012 [base year for forecasts]] comparison:
  - *Annual Average Daily Traffic (AADT) data shows a 2% decrease*
  - *fleet distribution for Los Angeles County using EMFAC (the California Air Resources Board emission model*) – 0.01% - 6% difference

- OD demand adjusted using Matlab to create a class of connected, autonomous port-trucks for the scenarios presented below

2. Data and Methods – Truck platooning

- To model connected trucks, we relied on Cooperative Adaptive Cruise Control (CACC), which provides longitudinal control of vehicle motions *(Shladover, Station, & Lu, 2015).*

- The headway ***h*** between two trucks is assumed to be between 0.3 &1 s *(Janssen et al., 2015).* Darbha, Konduri, & Pagilla *(*2017): ***h***$\in$[0.5 s, 1 s].

- In practice h depends on distance needed to stop as leader stops (breaking technology/state, and truck weight)

2. Data and Methods – Constant time gap model

Constant time gap model (TransModeler 5.0):

$$A_i(t) = -\frac{1}{h}(V_i(t) - V_{i-1}(t) + \lambda\delta_i)$$

where the spacing error is estimated by:

$$\delta_i(t) = D_{i,i-1}(t) + hV_i(t) + D_{i,i-1}{}^{desired}$$

- $A_i(t)$: acceleration rate of vehicle *i* at time *t*;
- ***h***: desired following headway (s);
- $V_i(t)$: speed of vehicle i at time *t*;
- δ_i: spacing error for vehicle i requiring correction to achieve the desired headway *h*;
- $D_{i,i\text{-}1}(t)$: distance between vehicle *i* and the front of vehicle *i*-1 at time *t*;
- $D_{i,i\text{-}1}{}^{desired}$: desired distance between vehicle *i* and the front of vehicle *i*-1 at 0 speed; and
- λ is the control gain.

2. Data and Methods – Neighboring lane model

For conventional vehicles, some default TM car-following parameters did not adequately replicate traffic characteristics in our study area. E.g.: platoons of trucks were observed driving under congested conditions when adjacent lanes were free.

- we calibrated the Neighboring Lane Model, which applies a multinomial logit model to compute the utility of switching to adjacent lanes. Primary model variable = perceived gain in speed i (Caliper, 2018). Default value (0.05); upper bound = 3.0.
- We focused on the number of trips that could not be completed due to missed turns and adjusted the best perceived speed gain to 0.25.

2. Data and Methods – Scenarios

- Recirculated Draft Environmental Impact Report (RDEIR) – Caltrans, 2017
  - Forecasts a growth in annual twenty-foot equivalent units (TEUs)

Year	Cargo growth (million TEUs)
2012	14.1
2035	41.1

  - Assume 35% moved by rail
  - This leaves 26.7 million TEUs to move by 2035, a ~90% increase compared to 2012
  - Following SCAG, we assumed zero increase in demand for other vehicle classes (sharing, transit, more efficiency compensate)

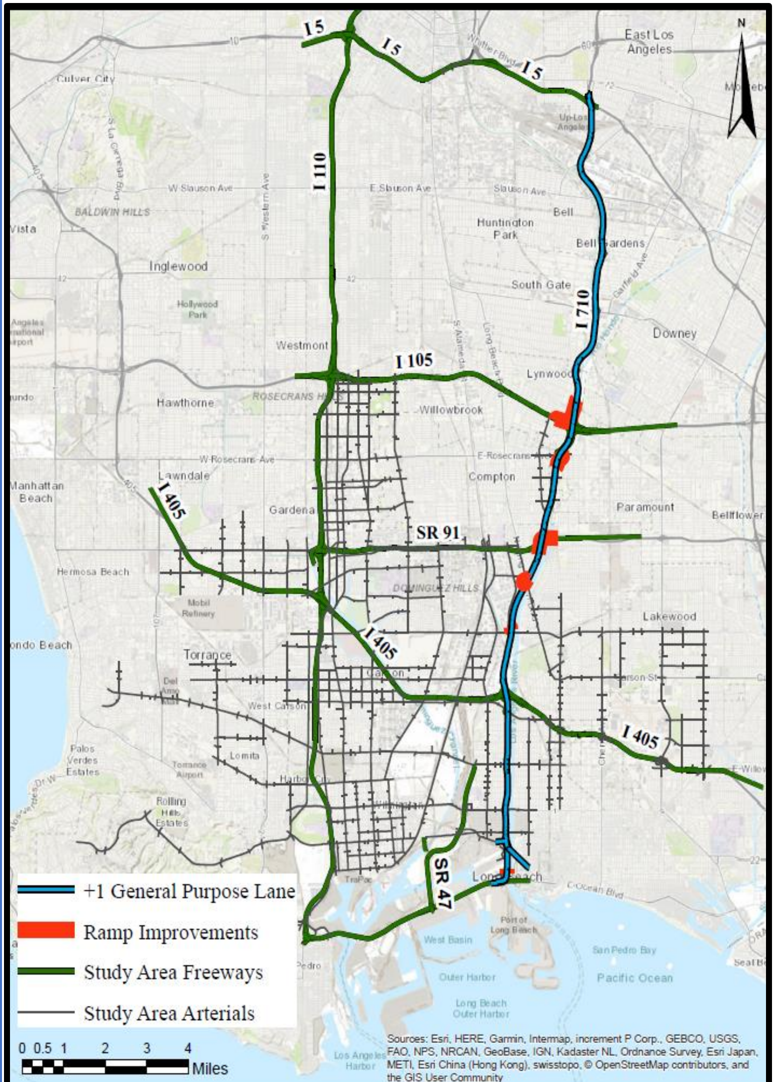
2. Data and Methods – Scenarios

Scenarios for simulation analysis:

Scenario	90% increase over 2012 in Port HDT demand (2035 forecast)	Penetration rate of connected, level-1 Port HDT	Penetration rate of connected, level-1 (all classes)	6 ramp improvements along the I-710	Additional lane in each direction along the I-710
1	- -	0%	0%	- -	- -
2A	✓	0%	0%	- -	- -
2B	✓	100%	0%	- -	- -
3A	✓	0%	0%	✓	- -
3B	✓	100%	0%	✓	- -
3C	✓	100%	100%	✓	--
4A	✓	0%	0%	✓	✓
4B	✓	100%	0%	✓	✓

2: current infrastructure; 3: ramp improvements; 4: 3 + additional general-purpose lane between E Ocean Blvd and I-5

2. Data and Methods – Scenarios



Network Edits (3A-4B)

Facility Type	Location	Improvement	Length
On Ramp	I-710 NB (Port Area)	Added Lane	0.07 miles
Off Ramp	I-710 NB (Rosecrans Ave)	Added Lane	0.28 miles
Freeway to Freeway Connector	I-710 SB to I-105 WB	Added Lane	0.51 miles
On Ramp	I-710 SB (S Susan Rd)	Added Lane	0.08 miles
Freeway to Freeway Connector	SR91 WB to I-710 SB	Added Lane	0.56 miles
Off Ramp	I-710 SB (N Long Beach Blvd)	Added Lane	0.13 miles
		Total	**1.60 miles**

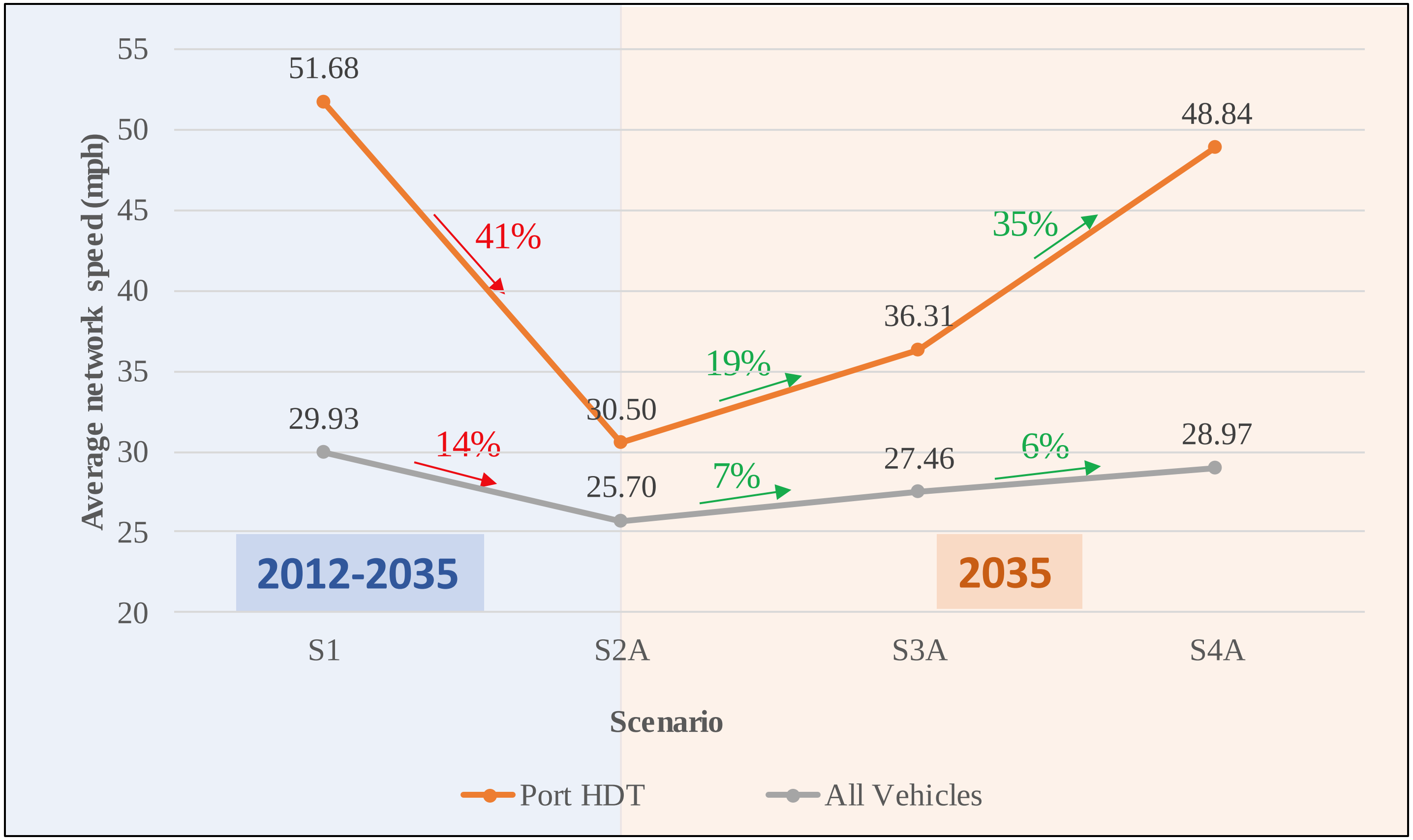
3. Findings

- Network Traffic Performance – Baseline traffic (2012) and no infrastructure improvement **– 24-hour simulation**

Vehicle Class	Vehicle Count	VMT	VHT	Average Vehicle Speed (mph)
LDV	3,532,108	18,910,953	646,896	29.23
LDT	50,565	320,321	7,233	44.28
MDT	42,226	231,834	6,635	34.94
HDT	51,268	320,416	8,872	36.11
Port HDT	56,681	609,354	11,791	51.68

3. Findings: Average network speeds

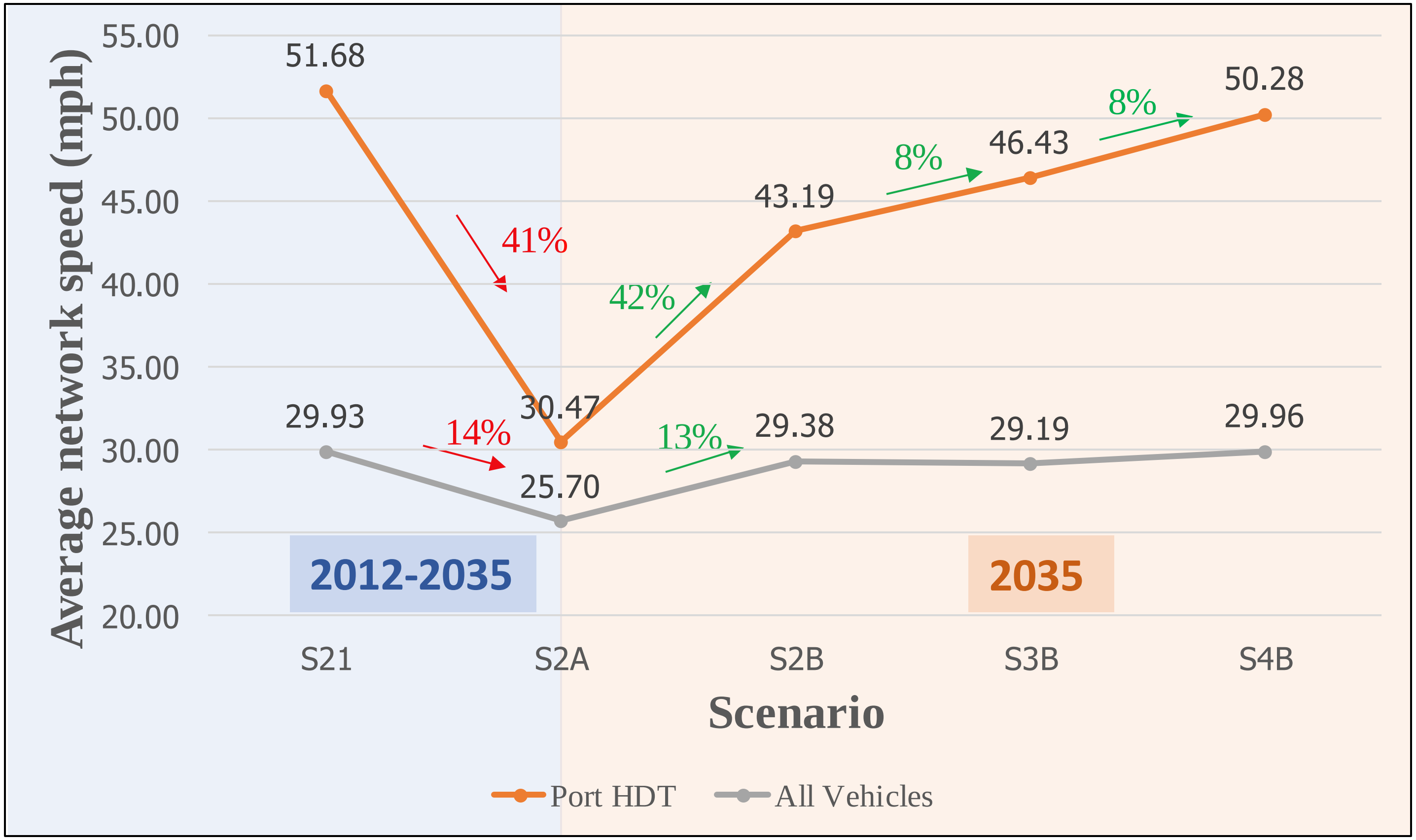
Scenarios without connected, autonomous trucks



In this case, adding a lane to the I-710 is worth considering (S4A best)

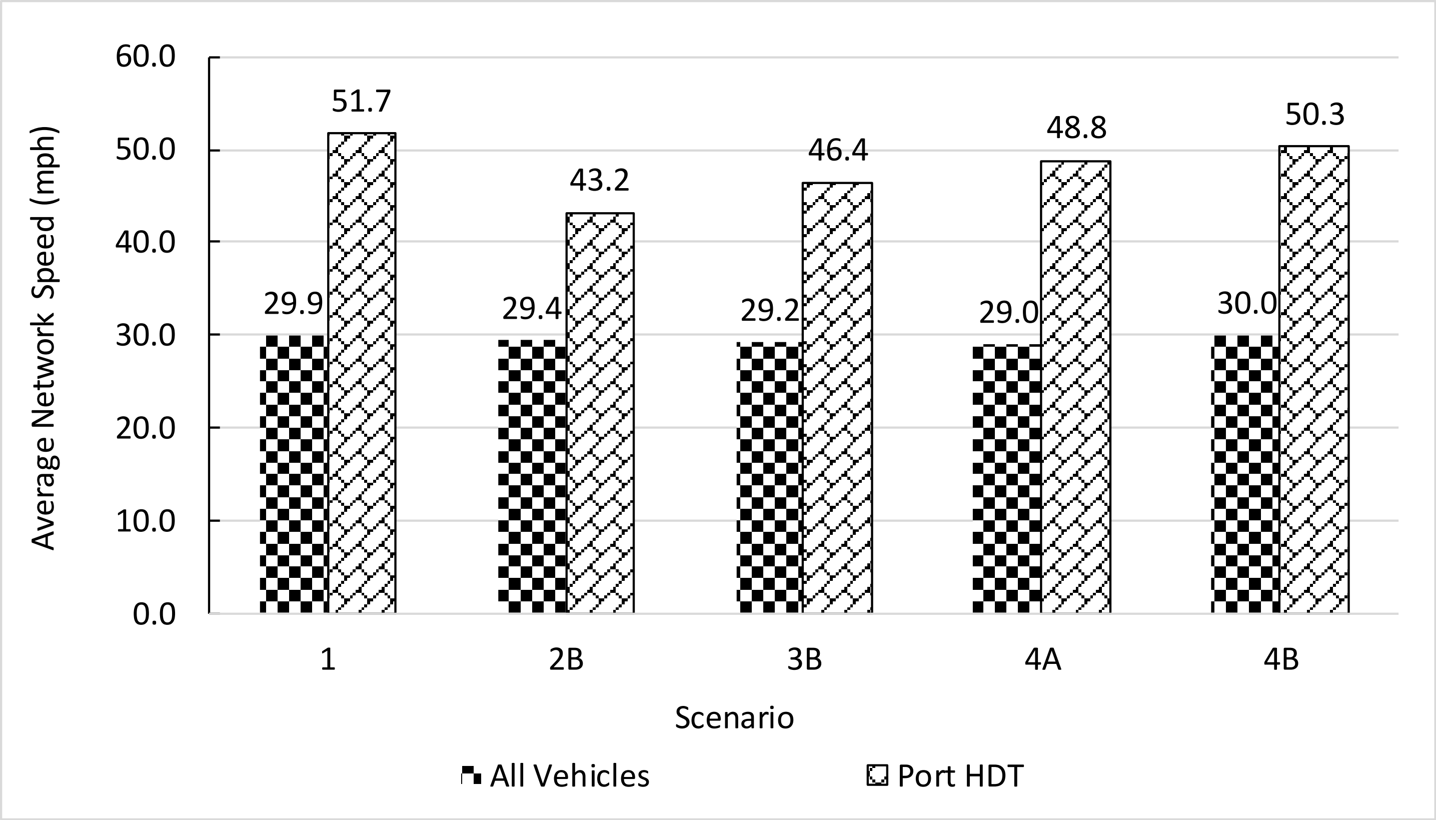
3. Findings: Average network speeds

Scenarios with connected, autonomous trucks



3. Findings: Average network speeds

Scenarios with connected, autonomous trucks (h=0.5 s)

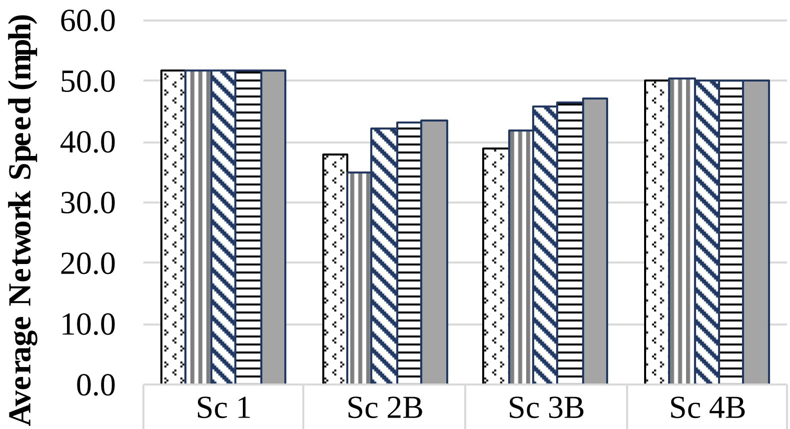


Adding a lane to the I-710 may not be desirable (small gain); 3B is best?

3. Findings: Impact of headway

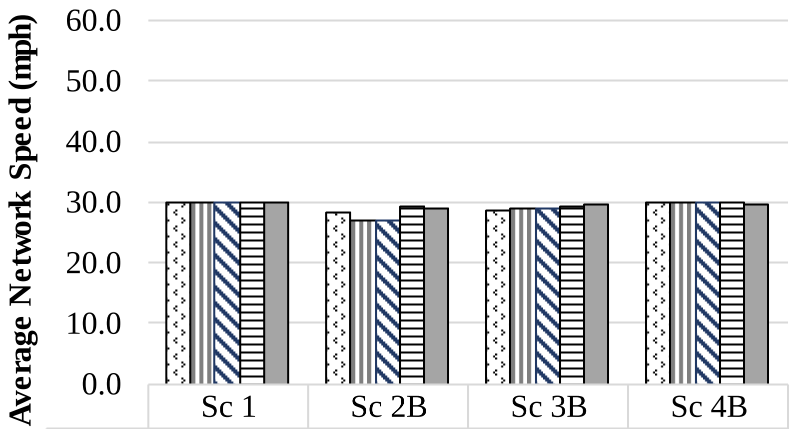
Impact of headway on network speeds – Port trucks & All Vehicles

Average Network Speed of Connected, Autonomous Port Trucks



	Sc 1	Sc 2B	Sc 3B	Sc 4B
1.0 s	51.7	37.8	39.0	50.3
0.8 s	51.7	35.0	42.0	50.5
0.6 s	51.7	42.1	45.7	50.3
0.5 s	51.7	43.2	46.4	50.3
0.3 s	51.7	43.7	47.2	50.1

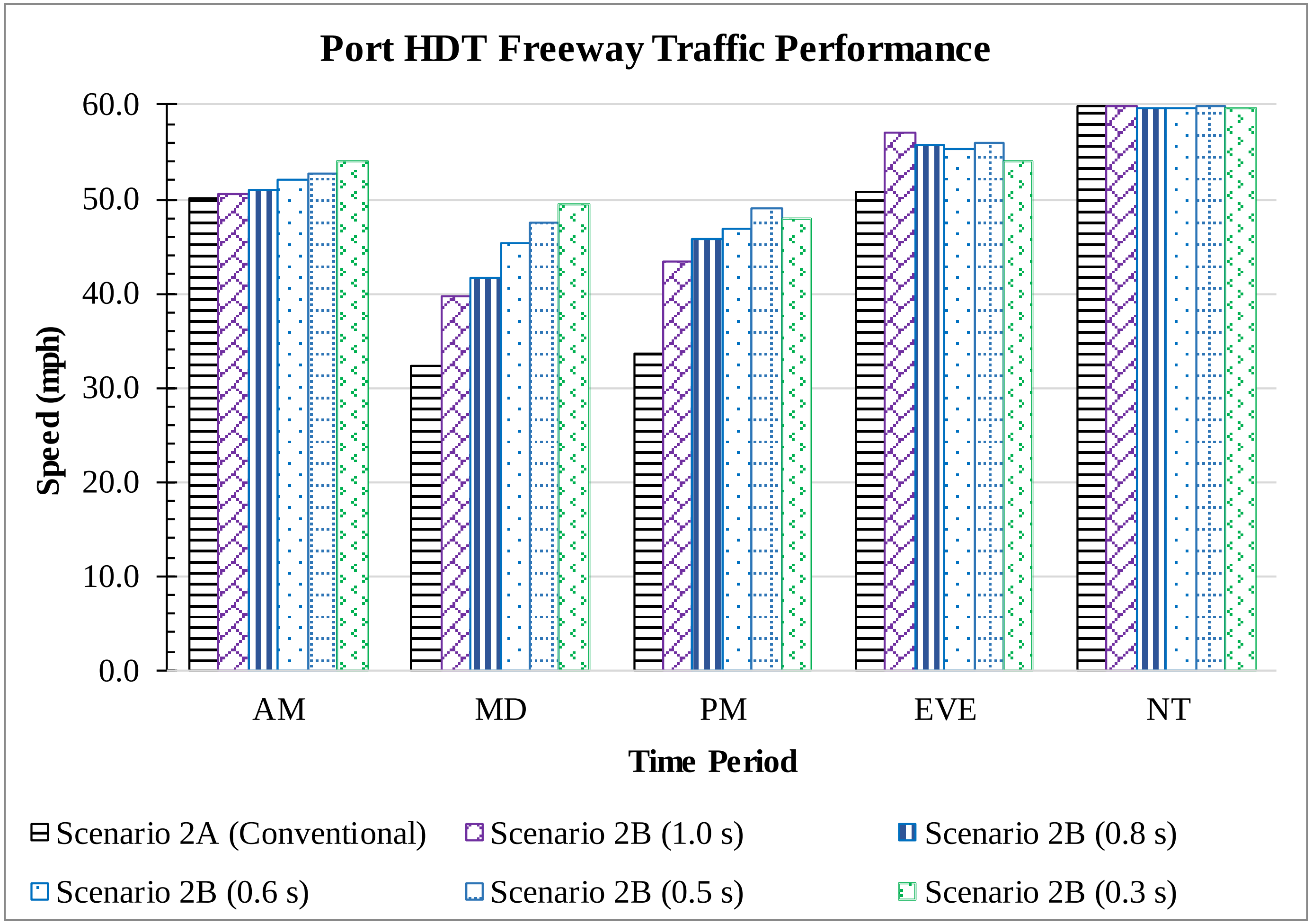
Average Network Speed for All Vehicles



	Sc 1	Sc 2B	Sc 3B	Sc 4B
1.0 s	29.9	28.4	28.8	29.8
0.8 s	29.9	26.8	29.0	29.8
0.6 s	29.9	26.8	29.0	29.8
0.5 s	29.9	29.4	29.2	30.0
0.3 s	29.9	29.0	29.7	29.5

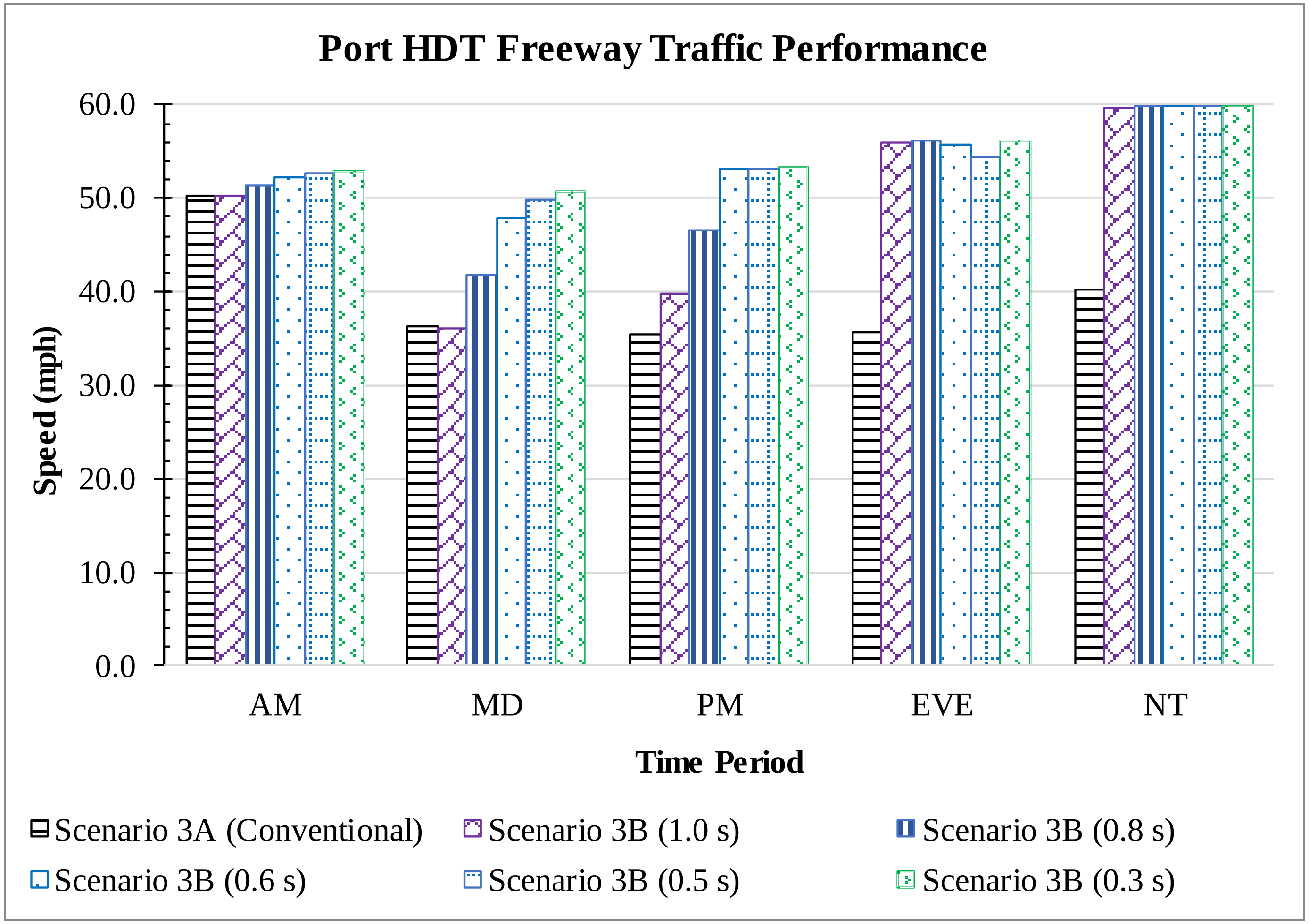
3. Findings: Conventional vs. Connected

Freeway speeds of conventional vs. connected port trucks Scenario 2 (no infrastructure improvements)



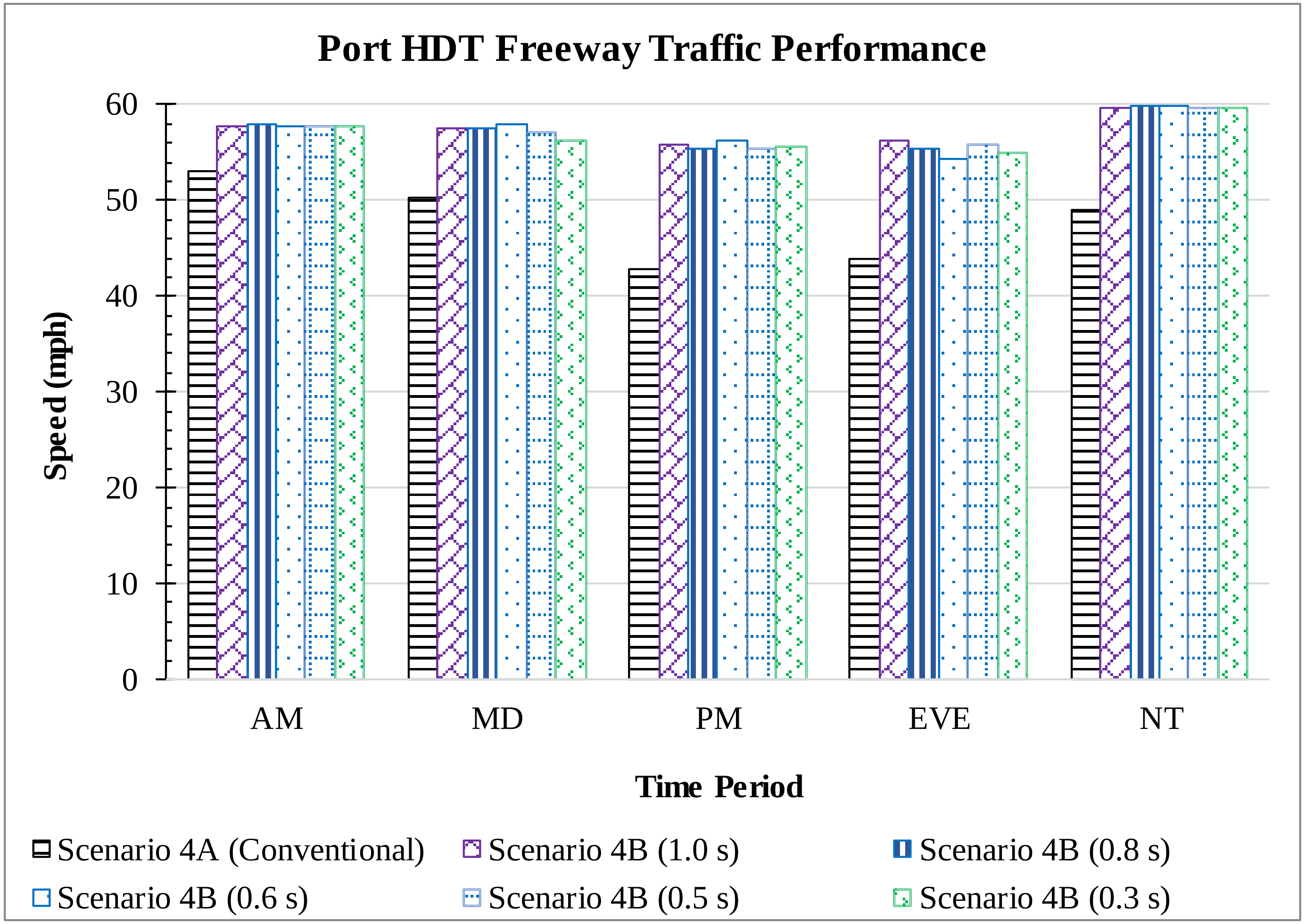
3. Findings: Conventional vs. Connected

Freeway speeds of conventional vs. connected port trucks
Scenario 3 (ramp improvements)



3. Findings: Conventional vs. Connected

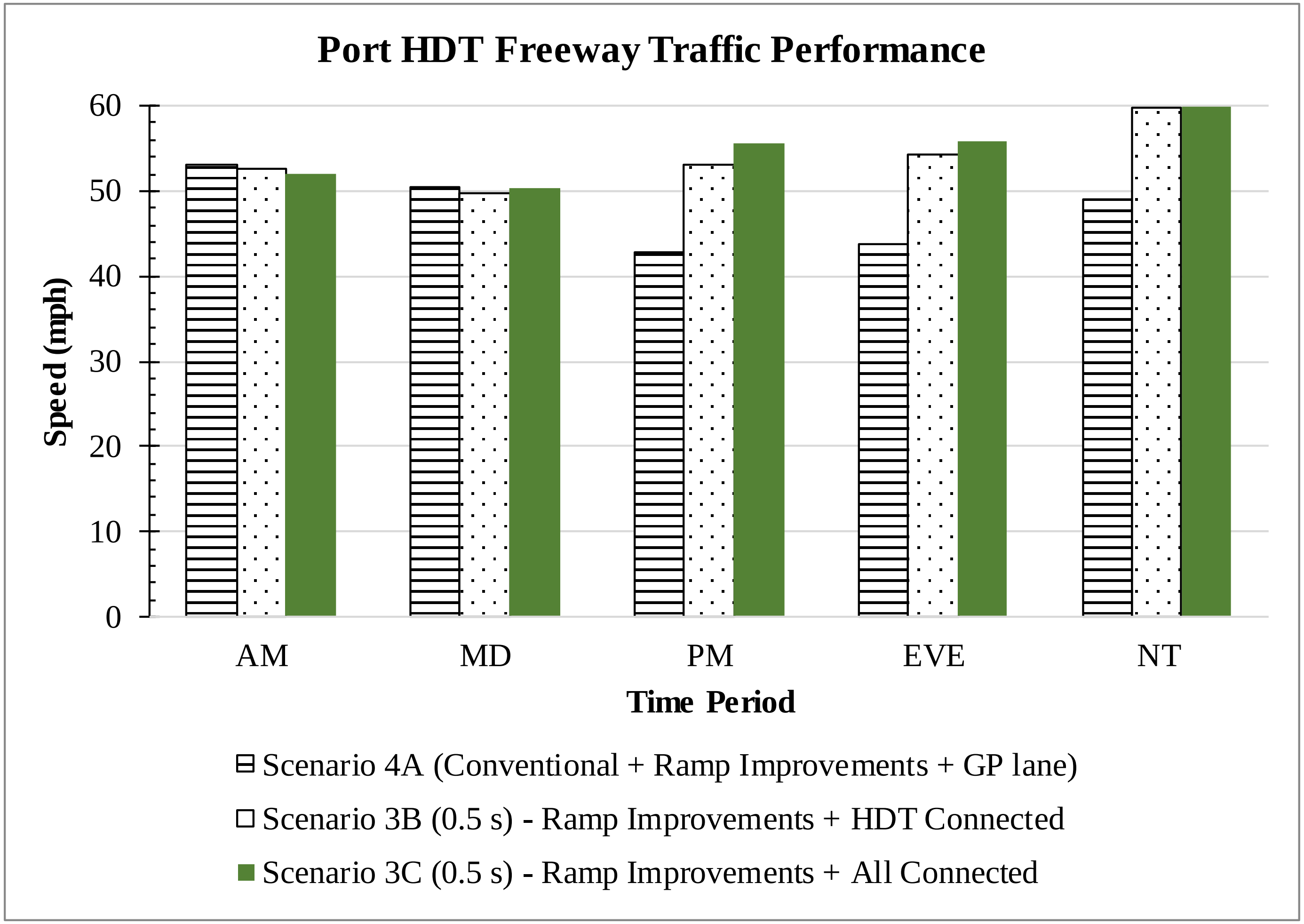
Freeway speeds of conventional vs. connected port trucks Scenario 4 (ramp improvements + extra lane)



3. Findings: All Vehicles are Connected

What if all vehicles were level-1 connected?

- **Adding a lane to the I-710 is not desirable; 3B-C are best**



3. Findings: Vehicle behavior

Lane restrictions under California Vehicle Code (CVC) sections *22406*, *21655*, and *21654*

- Lane restrictions result in the formation of long platoons. Note: Peloton is planning platoons of size 2…
- With long platoons, LDVs are sometimes unable to change lanes or access off-ramps…

4. Conclusions - Recap

1. **Connected truck technology is a substitute for additional capacity**. Here, traffic improvements associated with the deployment of connected, autonomous trucks is roughly equivalent to an additional lane
2. As expected, the constant headway parameter *h* is critical.
3. Reducing *h* does not always improve performance if long platoons are allowed
4. Lane restrictions for trucks may need to be redefined for corridors where autonomous trucks are in operation

4. Conclusions - Limitations

1. **Results are only as good as the realism of underlying models** (car following model, lane changing model…)

2. Interactions between conventional vehicles and connected trucks? **Complex**

3. Our simulations are accident free – it is not clear what the net impact of connected trucks would be in a mixed fleet

4. Our simulations did not limit the size of a truck "convoy" (with Peloton, it will initially be limited to 2)

4. Conclusions – Future work

1. Quantify avoided pollution from zero-emission port trucks, and
2. Environmental Justice implications using CalEnviroScreen

Any other suggestions?

Thank you!

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