OFF-HOURS DELIVERY: SIMULATED SYSTEMWIDE RESULTS FOR THE CHICAGO REGION

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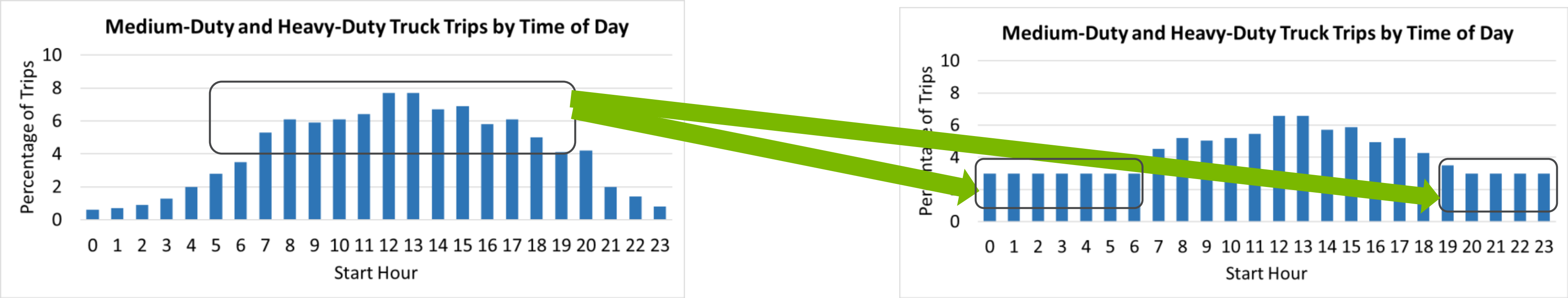
Off-Hours Delivery (OHD): Definition and Motivation



OHD Concept: shift delivery times from daytime to overnight *(7 PM-6 AM in this study)*

Motivation: Alleviate congestion, fleet energy and delivery cost (lower travel time of drivers)

Problems:

- Businesses may not have overnight staff to accept OHD
- Noise and emissions from internal combustion (IC) engines -> municipalities often constrain OHD for quality-of-life reasons

Opportunity: Battery electric vehicles (BEV) are quiet and zero-emission (plus trusted vendor programs and/or high-tech secure entry devices are becoming available) -> overcome the problem

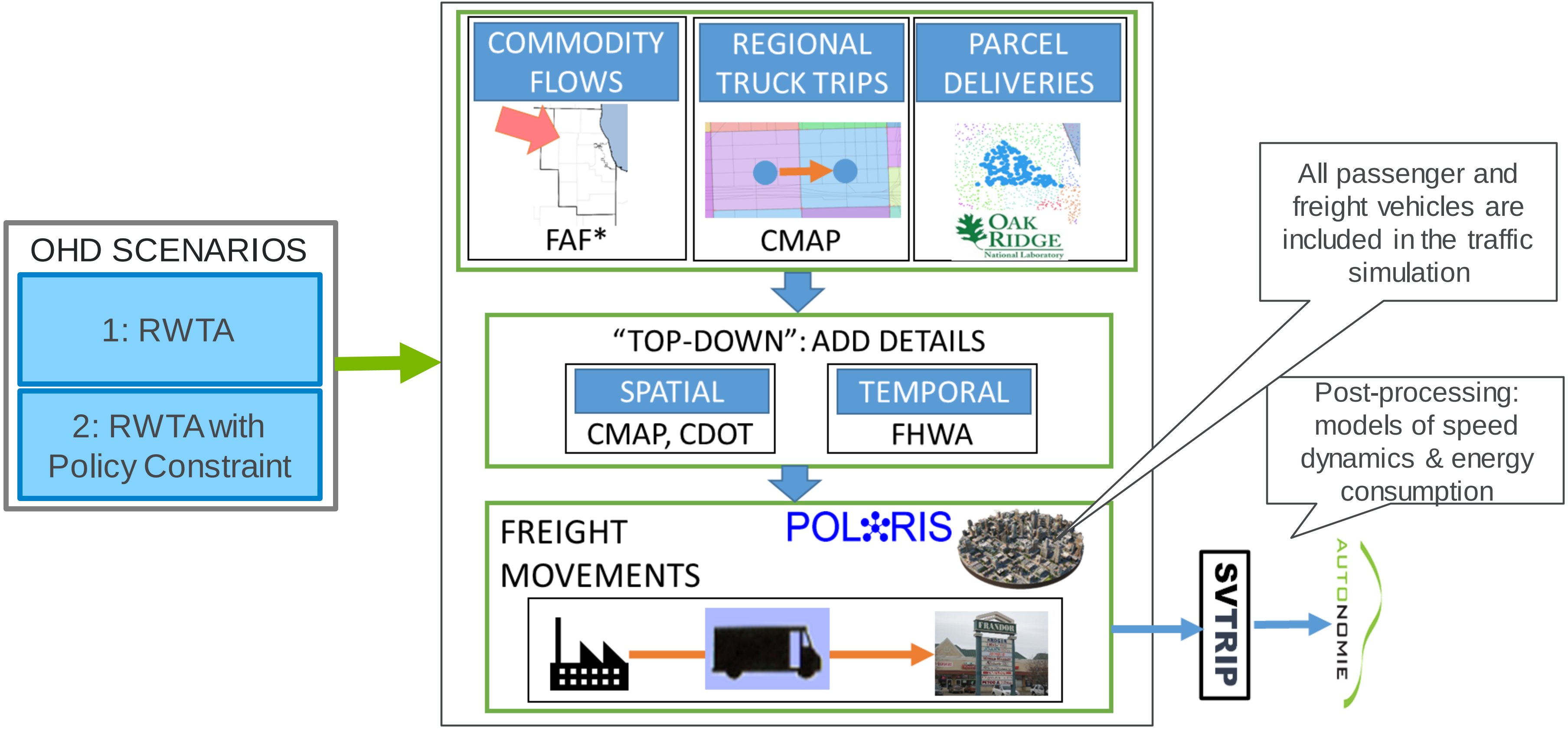
OHD has been studied in deployments at different metropolitan regions

- **In the Literature:**
  - Holguín-Veras et al. (2010) performed a pilot study in New York City with four participating firms
  - Holguín-Veras et al. (2013) performed a survey in New York Manhattan area for willingness to accept off-hour delivery
  - Holguín-Veras et al. (2016) collected GPS data in the following locations for 2-4 weeks for each regular hour delivery (6 AM to 7 PM) and off-hour delivery (7 PM to 6 AM) that primarily on chain grocery stores, printing businesses, dairy product producer, etc.
  - Mommens et al. (2018) collected GPS data that focuses only Supermarkets in Brussel, Flemish, Walloon regions in Belgium.
- **Gap:** <u>The comprehensive, regional impacts on congestion and energy have not been analyzed using a regional, systems simulation approach.</u>

Study Overview

- **Objective:** Quantify the regional energy and mobility impacts of off-hours delivery using the SMART 1.0 “top-down” model, and evaluating the effects of both (1) ***receiver willingness-to-accept (RWTA)*** off-hours deliveries, and (2) local policies that affect OHD.
- **Scope:** Business-to-business, or B2B, deliveries only (i.e., we do not study e-commerce deliveries to households) in the Chicago metropolitan region.
- **Scenarios:**
  1. Effect of OHD on vehicle miles traveled (VMT) and energy consumption based only on RWTA
  2. Effect of OHD on VMT and energy consumption based on both RWTA and local municipality policies

Platform for OHD Scenarios Analysis: Argonne's "Top-Down" Freight Model in POLARIS



*Freight Analysis Framework (FAF)

Data

- **POLARIS' Top-Down Freight Model with Medium-Duty Truck (MDT) and Heavy-Duty Truck (HDT) trips:** This study uses truck trips from Argonne's "Top-Down" freight model, with truck trips based on MDT and HDT truck trip tables from the Chicago Metropolitan Agency for Planning (CMAP) (more information in US Department of Energy (2020)).
- **POLARIS locations with land use:** The following land uses are available in the POLARIS model (number of POLARIS locations):
  - Residential (361K), major shopping (1K), mix (46K), business (11K), culture (1K), hotel (674), medical (1K), education (7K), civic (14K), industry (11K), manufacturing (1K), distribution (1K), intermodal (155), recreation (10K)
- **US Census Zip Code Business Patterns (ZBP):** Number of establishments by employment size and 6-digit NAICS codes that are located in each zip code.
  - NAICS codes in POLARIS locations are unknown. ZBP data can be used to assign a NAICS code on locations which can be identified based on their zip code. Subsequently, NAICS codes and employee sizes can be assigned using top-down model.
- **CMAP Municipality Survey:** CMAP conducted a survey of municipal plans, programs, and operations throughout the Northeastern Illinois area in 2014. The survey data are used to identify various OHD restrictions (or lack thereof) throughout the region.

Approach to Development of Scenario Inputs

Locations

Identify Potential OHD Locations

Commercial locations in POLARIS are identified using their land use information.

Infer NAICS Code

Location's NAICS code are assigned using Census data.

Estimate OHD Willingness

For each location (receiver), willingness to accept OHD is estimated using a behavioral model.

Set Municipality OHD Policy

For each location (receiver), any OHD restrictions (based on municipality policies) are identified.

Trips

Input Trips from the Top-Down Argonne Freight Model

The POLARIS top-down trips originally come from CMAP's regional MDT and HDT trip tables.

Select Trips for OHD Shift (→2 scenarios)

Two subsets of MD/HD trips are selected for OHD based on (1) receiver's willingness to accept OHD, and (2) willingness plus municipality policies.

Update Trip Start-time

Selected trips' start times are updated by randomly drawing from a uniform distribution between 7:00 PM and 6:00 AM.

Assign NAICS and Employment to Each POLARIS Location

ID	Zip Code	NAICS 3 Digits	Land Use	Employee Size
1	60604	323	Business	n5
2	60604	423	Business	n5_9
3	60604	423	Business	n10_19
4	60604	423	Business	n5
5	60604	424	Manufacturing	n5
6	60604	424	Manufacturing	n20_49
7	60604	424	Business	n5
8	60604	445	Mix	n5
9	60604	711	Major Shopping	n10_19
. . .	. . .	. . .	. . .	. . .

For each zip code:

- Do a spatial join to select POLARIS locations within the zip code boundaries
- Select the corresponding ZBP information
- Randomly distribute ZBP information (3-digit NAICS code and employment) to POLARIS locations

- Based on industries with higher receiver willingness to accept OHD, we focus on the following POLARIS land uses, which are associated with industries with higher receiver willingness:
  - Businesses (11,601); Hotels (674); Major Shopping (1,194); Manufacturing (1,254); Mix (46,423)
  - There are total of 61,146 locations that can be identify as a OHD candidate in the POLARIS.

Receiver's Willingness To Accept (RWTA) OHD

Based on (1) a behavioral model from the literature (led by Rensselaer Polytechnic Institute), (2) example deployments from other areas, and (3) the research team's judgment, the following NAICS codes are identified as **candidates for OHD** (3-digit NAICS codes were used in the willingness-to-accept behavioral model):

- Manufacturing (NAICS 31-33)
- Wholesale trade (NAICS 42)
- Retail trade (NAICS 44-45)
- Hospitals (NAICS 62)
- Arts, entertainment, and recreation (NAICS 71)
- Accommodations and food services (NAICS 72)
- Other services (NAICS 81)

Model	Model 1	
Independent variables	**Parameter**	**t-stat**
Constant	0.61	(2.78)
Number of deliveries	-0.07	(-9.17)
Incentives		
One time incentive in $1000 (OTI)	0.18	(6.95)
Carrier discount in percent (CDR*100)	3.00	(6.81)
Business Support (BS)	0.55	(3.82)
Public Recognition (PR)	0.34	(2.24)
Trusted Vendor (TV)		
NAICS		
Clothing stores, binary variable	-2.73	(-4.57)
Performing arts, binary variable	-1.96	(-5.69)
Interaction terms: OTI and NAICS		
OTI for food and beverage stores	0.12	(2.56)
OTI for apparel manufacture stores	0.23	(1.72)

Excerpt From p. 74, "Integrative Freight Demand Management in the New York City Metropolitan Area: Implementation Phase (2013)

Final Selection: Industry Codes of Receivers That Are Willing to Accept OHD

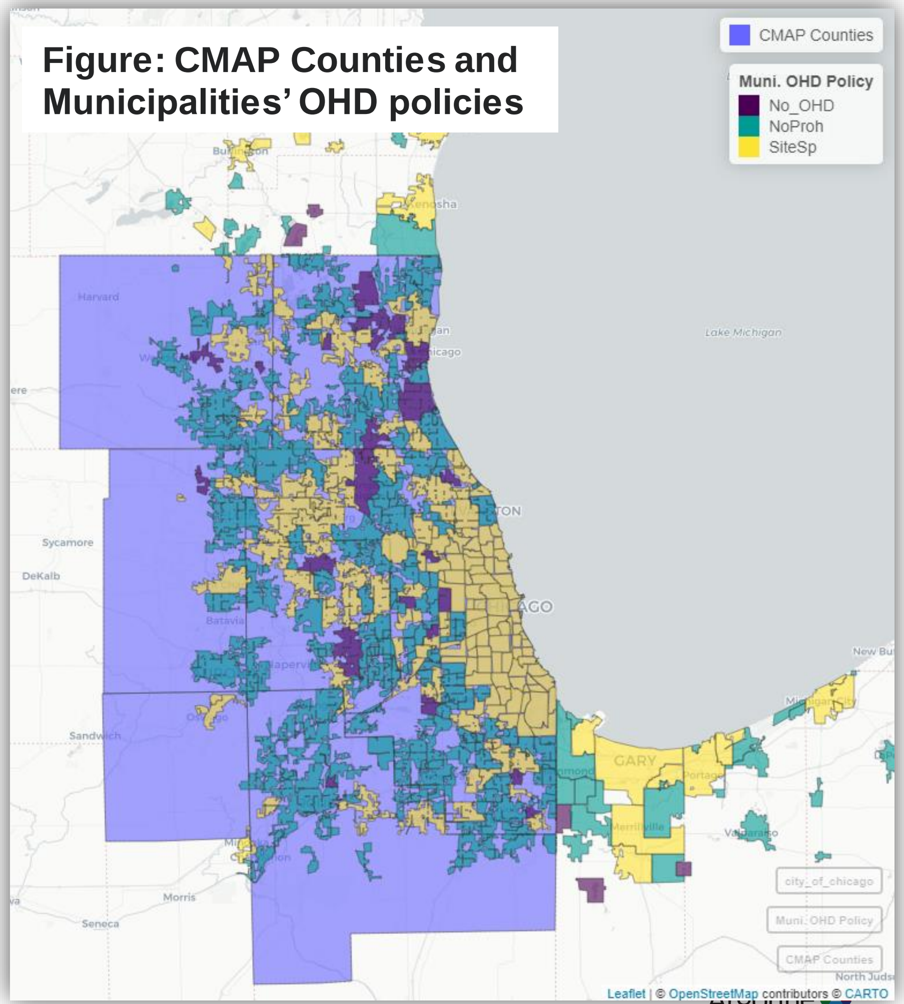
NAICS	Description
311	Food Manufacturing
312	Beverage and Tobacco Product Manufacturing
314	Textile Product Mills
315	Apparel Manufacturing
321	Wood Product Manufacturing
322	Paper Manufacturing
323	Printing and Related Support Activities
324	Petroleum and Coal Products Manufacturing
325	Chemical Manufacturing
326	Plastics and Rubber Products Manufacturing
327	Nonmetallic Mineral Product Manufacturing
331	Primary Metal Manufacturing
332	Fabricated Metal Product Manufacturing
333	Machinery Manufacturing
334	Computer and Electronic Product Manufacturing
335	Electrical Equipment, Appliance, and Component Manufacturing
336	Transportation Equipment Manufacturing
337	Furniture and Related Product Manufacturing
339	Miscellaneous Manufacturing

NAICS	Description
423	Merchant Wholesalers, Durable Goods
424	Merchant Wholesalers, Nondurable Goods
425	Wholesale Electronic Markets and Agents and Brokers
441	Motor Vehicle and Parts Dealers
442	Furniture and Home Furnishings Stores
443	Electronics and Appliance Stores
444	Building Material and Garden Equipment and Supplies Dealers
445	Food and Beverage Stores
446	Health and Personal Care Stores
447	Gasoline Stations
448	Clothing and Clothing Accessories Stores
451	Sporting Goods, Hobby, Musical Instrument, and Book Stores
452	General Merchandise Stores
453	Miscellaneous Store Retailers
622	Hospitals
711	Performing Arts, Spectator Sports, and Related Industries
713	Amusement, Gambling, and Recreation Industries
721	Accommodation
722	Food Services and Drinking Places
812	Personal and Laundry Services
813	Religious, Grantmaking, Civic, Professional, and Similar Organizations

CMAP Municipality Survey

- CMAP conducted a survey of plans, programs, and operations among municipalities of Northeastern Illinois in 2014. 370 municipality participated in the survey. The survey contains a question regarding OHD regulations. Three policies are identified based on this question:
    - No_OHD → OHD is not permitted
    - NoProh → OHD is permitted
    - SiteSp → OHD is permitted only in some areas or sites
- As the map shows, OHD policy data are missing for some municipalities. Monte Carlo draws from a probability mass function, formed by the available data, are used to assign an OHD policy where it is missing.

Figure: CMAP Counties and Municipalities' OHD policies

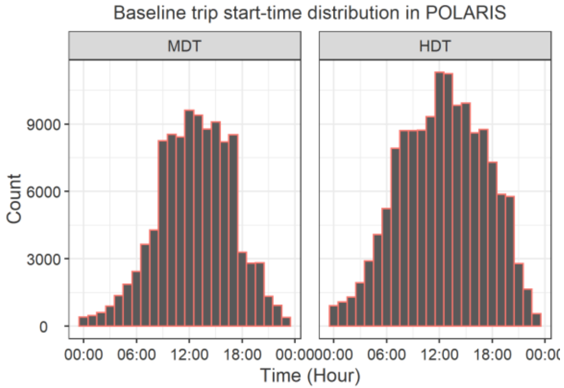


Result: Scenario Inputs

Distributions of Trip Start Times for MDT/HDT Trips

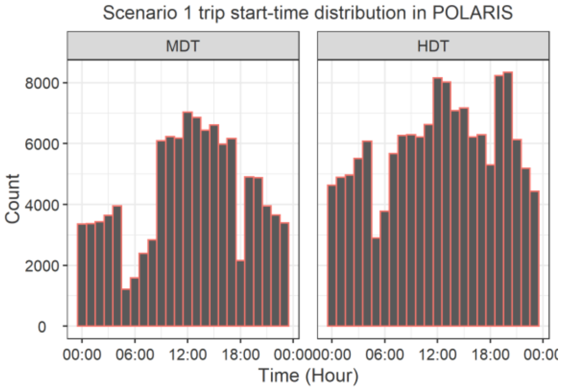
Note: this spike occurs because new OHD trips are added to existing overnight trips.

Baseline



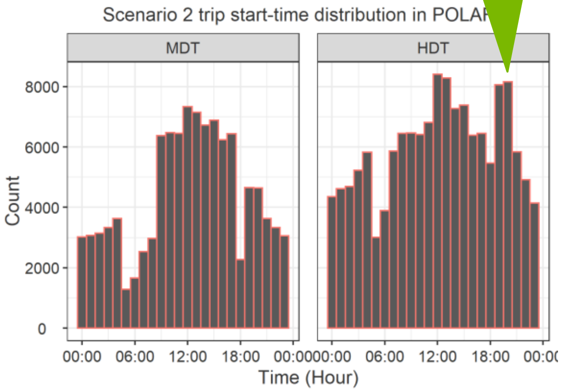
Start times are distributed throughout the day according to the Federal Highway Administration (FHWA) Traffic Data Computation Method: Pocket Guide (2018; Publ. No. FHWA-PL-18-027).

Scenario 1



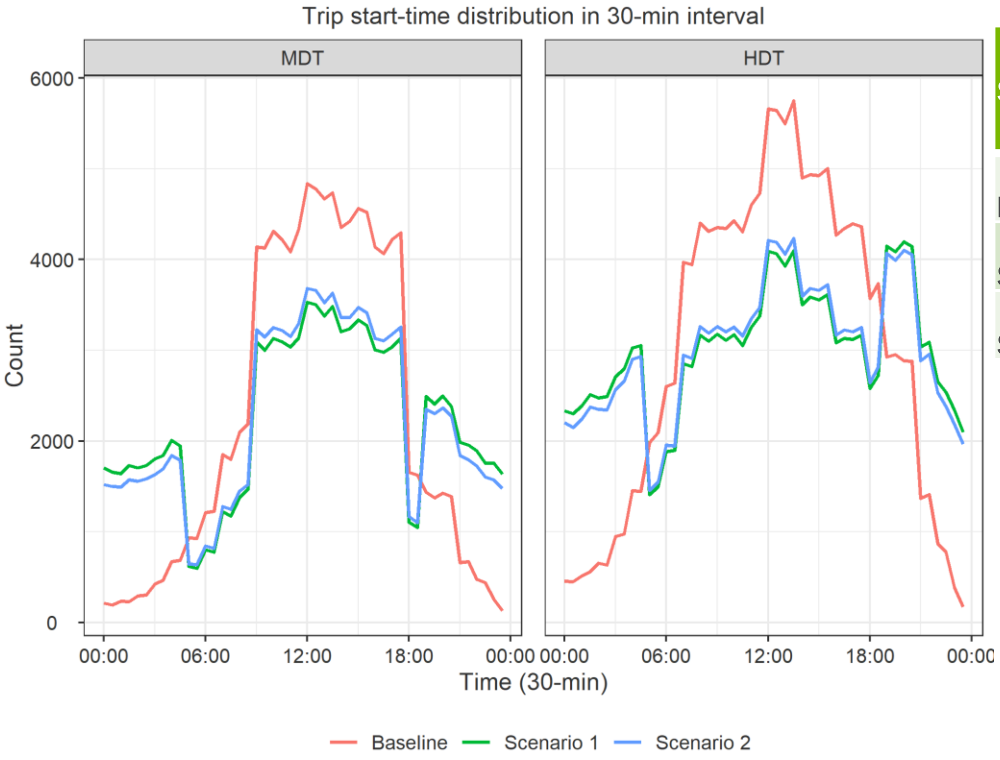
In scenario 1, candidate MDT/HDT OHD trips (based on RWTA) are selected and their start times are shifted from daytime to a random overnight time.

Scenario 2



In scenario 2, candidate MDT/HDT OHD trips (based on RWTA) are examined; if the trip's destination permits OHD, or (for destinations in "SiteSp" areas) there is no residence in a 50 meter radius, the trip is shifted to a random overnight time.

In Scenario 1 (2), 6% (5%) of MDT/HDT Trips Shift to Overnight.



Total number of trips by time of day per scenario

Scenario	00:00 AM - 05:30 AM		06:00 AM - 6:30 PM		7:00 PM - 11:59 PM	
	MDT	HDT	MDT	HDT	MDT	HDT
Baseline	14,852	32,352	377,308	478,820	33,016	66,488
Scenario 1	71,448	104,516	271,052	344,016	82,676	129,128
Scenario 2	65,080	99,064	283,212	354,304	76,884	124,292

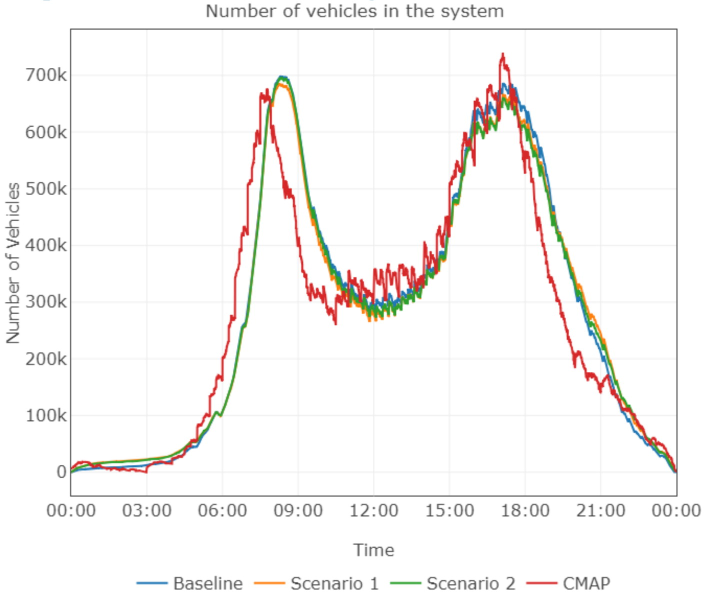
No. of trips shifted from baseline to scenarios

	MDT		HDT		Total Trip by Scenario
	AM	PM	AM	PM	
Scenario 1	56,596	49,660	72,164	62,640	241,060
Scenario 2	50,228	43,868	66,712	57,804	218,612
Scn1 - Scn2	6,368	5,792	5,452	4,836	22,448
%∆ from Scn2	12.68%	13.20%	8.17%	8.37%	10.27%

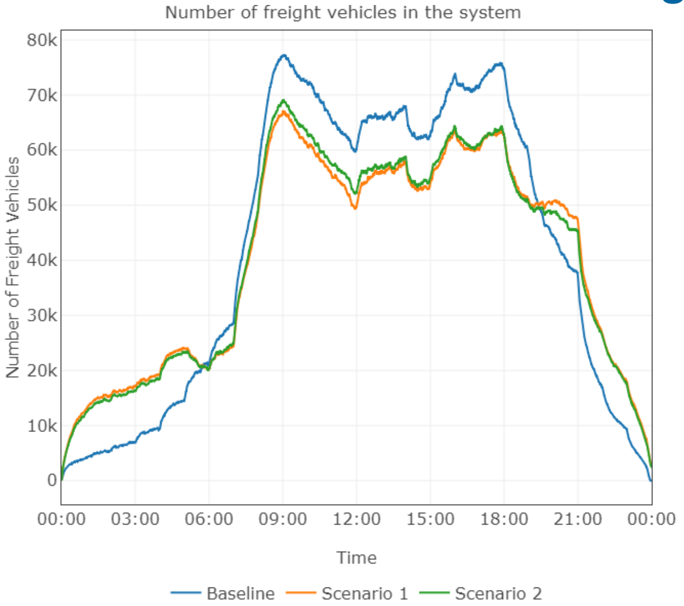
AM → 12:00 AM to 6:00 AM
PM → 7:00 PM to 12:00 AM

Validation

The Top-Down model was validated in SMART 1.0; so, just need to check the in-network curves to ensure they match, as the assignment process has been updated recently. We also check the in-network curves for freight only.



The vehicles-in-network curves overlap well with the household travel survey data (CMAP).



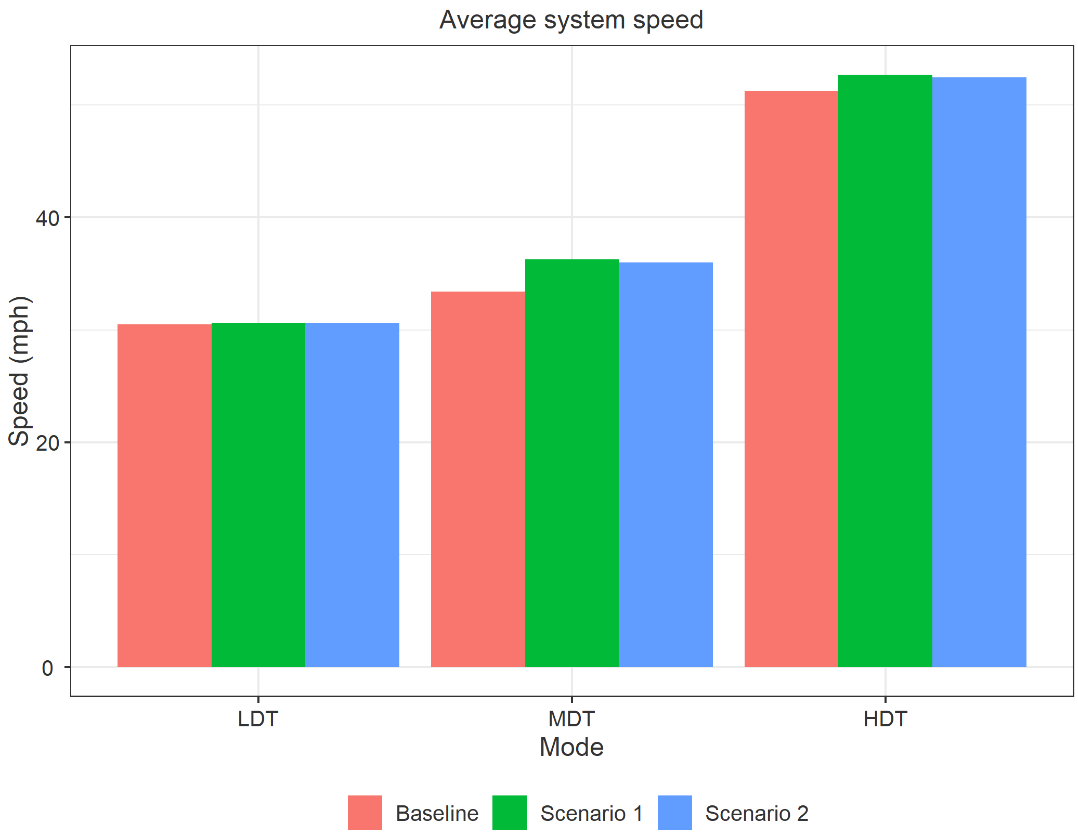
This plot shows total number of freight related vehicles in the system. As expected, many trucks have shifted to overnight hours for Scenarios 1 and 2.

Results: Average System Speed

System speed computed as $v = \frac{total\ miles\ traveled}{total\ hours\ traveled}$ for each mode.

As seen in the system speed plot in scenario 1&2, MDT/HDT speeds increased compared to the baseline due to traveling at less congested times. For LDT, there is a very slight gain in speed since there are less MDT/HDT trucks traveling during the day.

More detail on the next slide...



Results: VMT, Speed and Energy

Mode	Scenario	Values			%Diff (vs. Baseline)		
		VMT	Speed* (mph)	Fuel (kg)	VMT	Speed (mph)	Fuel (kg)
MDT	Baseline	2,667,914	33.42	870,808			
	Scen. 1	2,612,143	36.28	857,313	-2.09%	8.56%	-3.19%
	Scen. 2	2,620,381	35.97	882,699	-1.78%	7.62%	-2.40%
HDT	Baseline	20,960,043	51.24	10,515,073			
	Scen. 1	20,313,124	52.67	10,470,413	-3.09%	2.79%	-3.78%
	Scen. 2	20,356,307	52.47	10,391,911	-2.88%	2.39%	-3.58%

LDT also experienced a modest improvement in systemwide speeds (0.4%) in each scenario.

*System speed computed as $v = \frac{total\ miles\ traveled}{total\ hours\ traveled}$ by each mode

Discussion – 1

- VMT reductions:
  - MDT VMT decreased by 1.8-2.1%, indicating that MDTs were able to take shorter paths when traveling overnight (compared to daytime travel)
  - Similarly, HDT VMT decreased by 2.9-3.1%
    - Since HDT trips are longer on average than MDT trips, it seems that they are able to find even better (shorter) paths than MDT when switching to overnight
- Speed increases:
  - MDT average speed increased from 33.4 to about 36 mph (7.6-8.6%), reflecting the shift of some MDT trips to nighttime travel in an uncongested network
  - HDT speed increased from 51.2 mph by about 1.5 mph (2.4-2.8%), which is not as high as the MDT increase because HDT trips, being longer-distance, already utilize a fair amount of high-speed roads (interstates, etc.)

Discussion – 2

- Fuel savings:
  - OHD results in fuel savings due to two factors:
    - Reductions in VMT, which on its own creates fuel savings (all else equal)
    - Increases in speed, particularly starting from a lower level (e.g., 30 mph), given that vehicles tend to operate most efficiently around 40-50 mph
  - MDT fuel consumption decreased by 2.4-3.2%, which reflects the reduction in MDT VMT (1.8-2.1%) and the average MDT speed increase
  - HDT fuel consumption decreased by 3.6-3.8%, which reflects the reduction in VMT (2.4-2.8%), and the average HDT speed increase
    - Presumably, speeds are improved most on lower-speed links (e.g., arterials), which is why we see improved fuel savings beyond what VMT alone would cause
- Policy effects: by relaxing policies that restrict OHD, improved results for VMT, speeds and fuel savings are obtained

Limitations and Extensions

- Behavior model and local policies do not reflect new technologies such as BEV, high-tech locks to allow entry to trusted delivery drivers
- Round-the-clock operations:
  - Fleets can achieve savings by better utilization of their vehicles
  - Autonomous vehicles (AV) could make it easier for shippers and carriers to provide OHD
- Our traffic fundamental diagrams currently do not account for vehicle mix (e.g., percentage of cars vs. trucks on a link), but given the impact of MDT/HDT on traffic, it is likely that we are underestimating the overall traffic impact of OHD

-> Improved data, models, and input from businesses, local municipalities on "what-if" scenarios can improve the estimation of these impacts (e.g., maybe overnight delivery with BEVs would be allowed where it is not now)

-> Improving our traffic flow models to account for the different impacts of cars and trucks can improve the accuracy of estimation

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