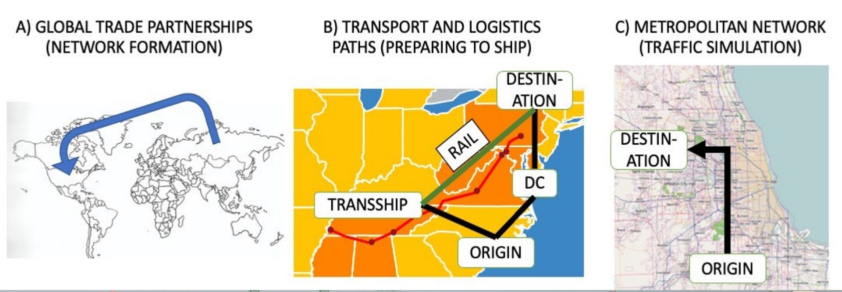
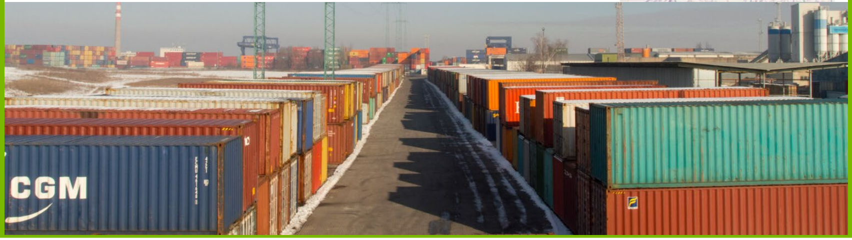
Transportation Research Board Annual Meeting (Paper 23-02960)
Committee Meeting, Freight Transportation Planning and Logistics (AT015)
Tuesday, January 10, 2023

INTRODUCING CRISTAL: A MODEL OF **C**OLLABO**R**ATIVE, **I**NFORMED, **S**TRATEGIC **T**RADE **A**GENTS WITH **L**OGISTICS





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Contributors

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and

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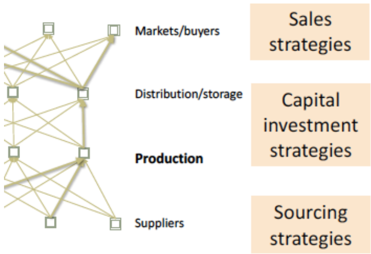
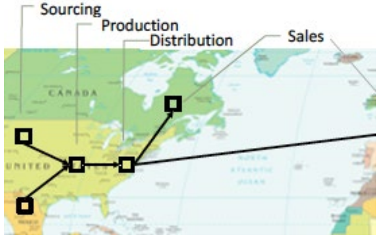
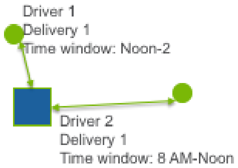
Moshe Ben-Akiva provided feedback on an earlier version of this work.

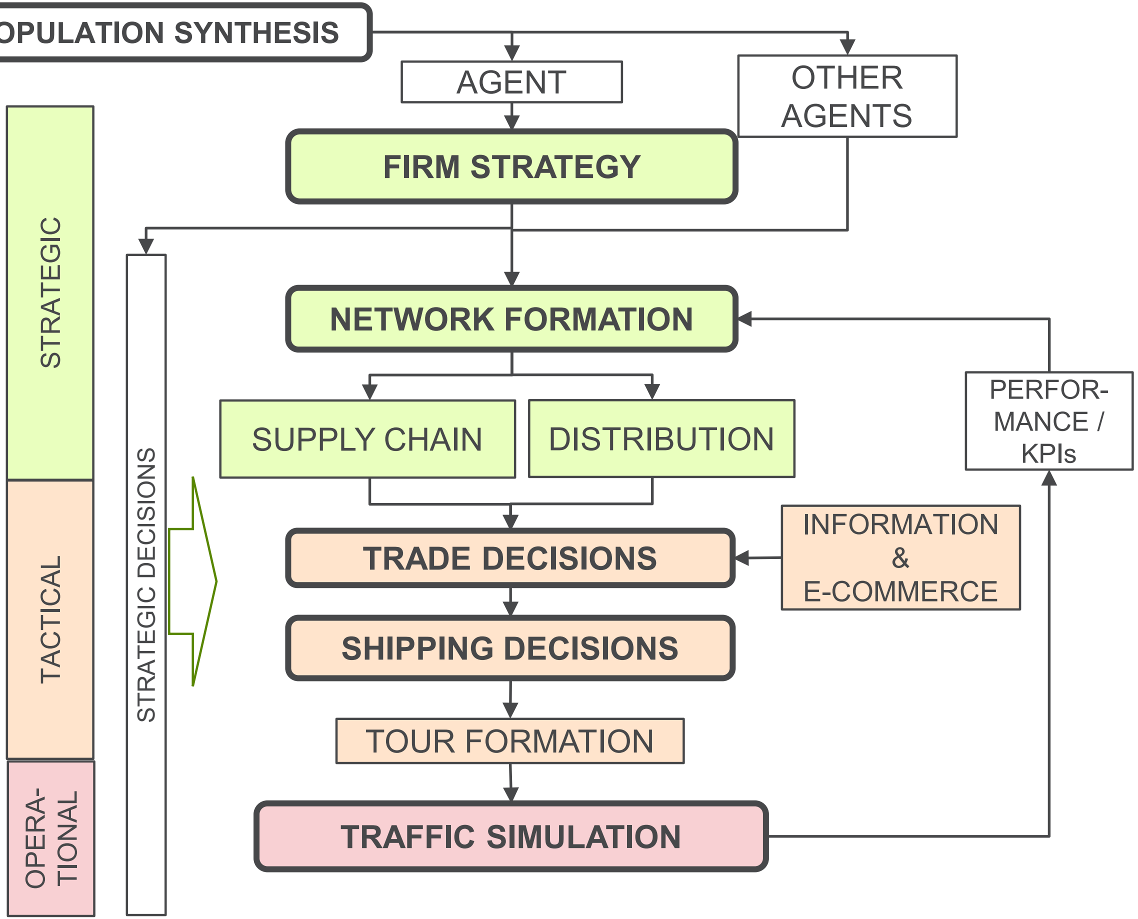
CRISTAL

Collaborative
Informed
Strategic
Trade
Agents
with
Logistics



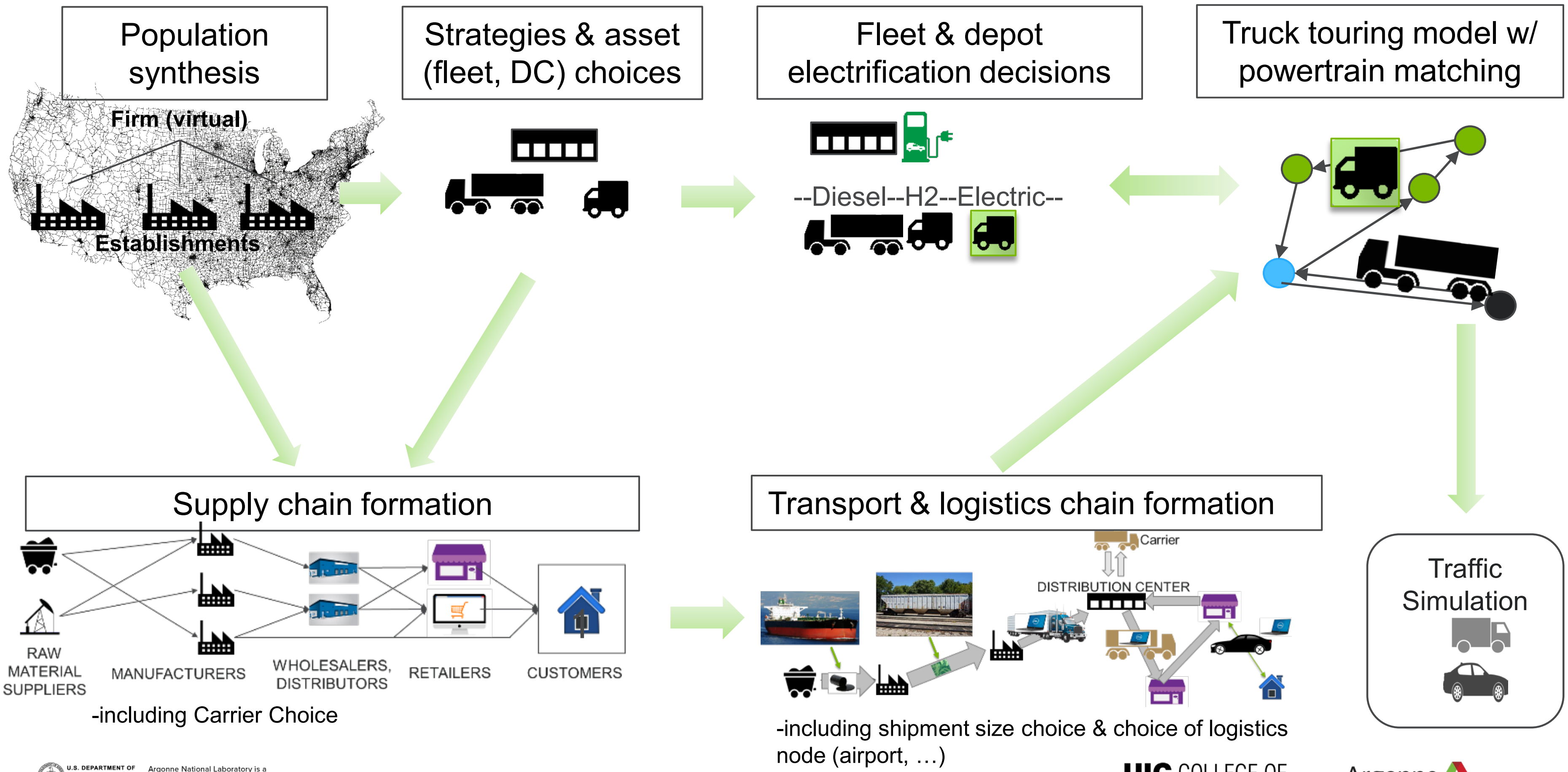




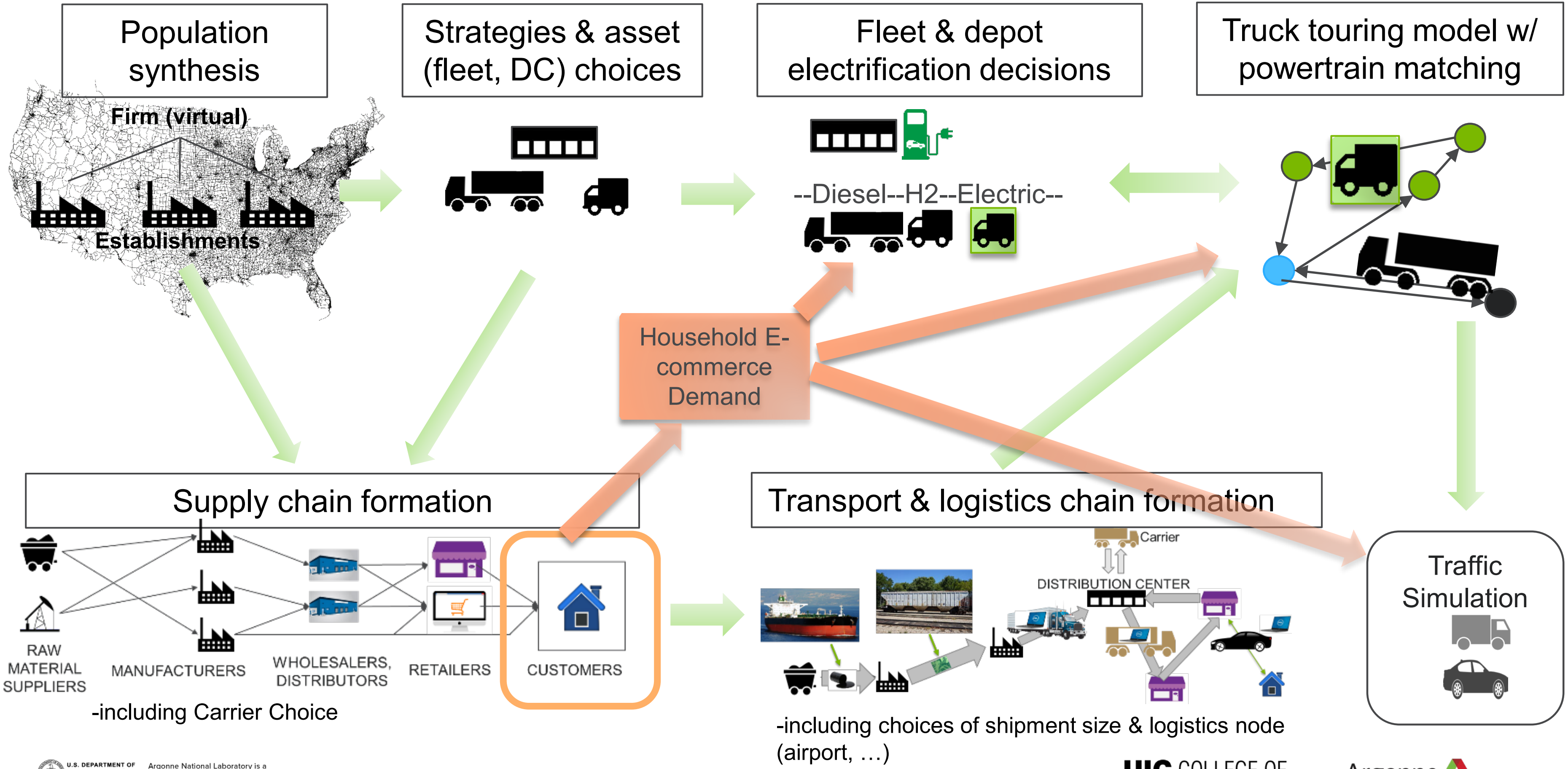


*Stinson and Mohammadian (2022). Introducing CRISTAL: A model of collaborative, informed, strategic trade agents with logistics, Transportation Research Interdisciplinary Perspectives Volume 13, https://www.sciencedirect.com/science/article/pii/S2590198222000033

IMPLEMENTATION: MODEL COMPONENTS



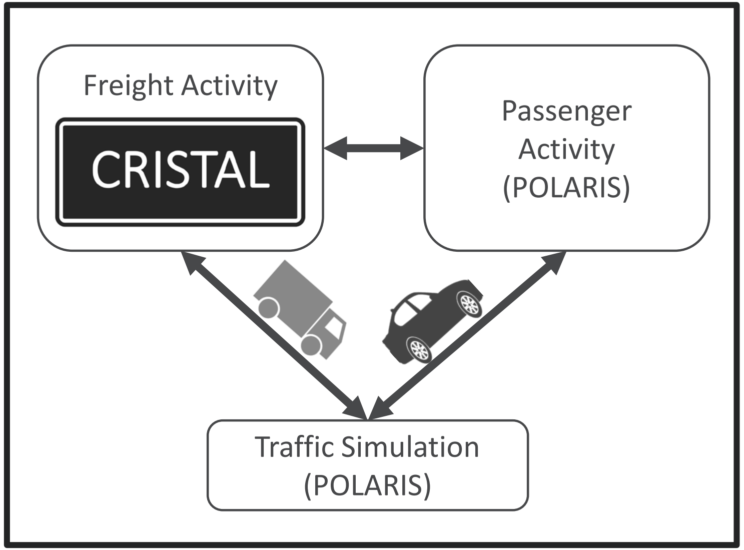
IMPLEMENTATION: MODEL COMPONENTS



IMPLEMENTATION OPTIONS

1. Stand-alone tool
2. Integrate with traffic assignment process
3. Integrate with passenger model for freight-passenger interactions (e.g., MatSim, regional MPO model, …)

Object-oriented (in C++) implement-ation for US Dept. of Energy SMART Mobility Workflow analysis:



DATA

Business and properties
-US Census County & Zip Code Patterns (CBP, ZBP) and Statistics on US Businesses (SUSB)
-Proprietary sources - Dun & Bradstreet, Yahoo Finance, Bloomberg, CoStar (real estate) …

Fleets: Vehicle Inventory and Use Survey (VIUS) & proprietary source, Argonne Machine Learning for Energy Consumption tool

Freight flows
-BTS and Census Commodity Flow Survey (CFS)
-BTS Freight Analysis Frameworks (FAF)
-US Census Input/Output relationship

Geospatial, grade & elevation:
-OpenStreetMaps
-USDOT transportation network shapefiles
-HERE, US Geological Survey

GPS: ATRI, INRIX, private fleets

Other: Highway Performance Monitoring System (HPMS), household e-commerce demand (WholeTraveler, ASU, GrubHub, …)

DATA-DRIVEN MODEL COMPONENTS

- Population characteristics
- Behavioral econometric models of freight agent decisions
- Optimization algorithms, heuristics to model operations
- Behavioral models of household e-commerce demand
- Multimodal network attributes
- Vehicle characteristics (e.g., energy consumption and emissions)
- Model calibration/validation

Novel Features and Applications

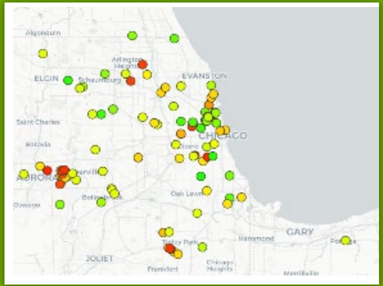
MODELING BOTH FIRMS AND THEIR MEMBER ESTABLISHMENTS IMPROVES FREIGHT AGENT REPRESENTATION

NEW MODEL TO SYNTHESIZE FIRMS AND ESTABLISHMENTS

Establishments in the North American Industry Classification System (NAICS) 31, 32, 44, 48, 72

SITE SELECTION

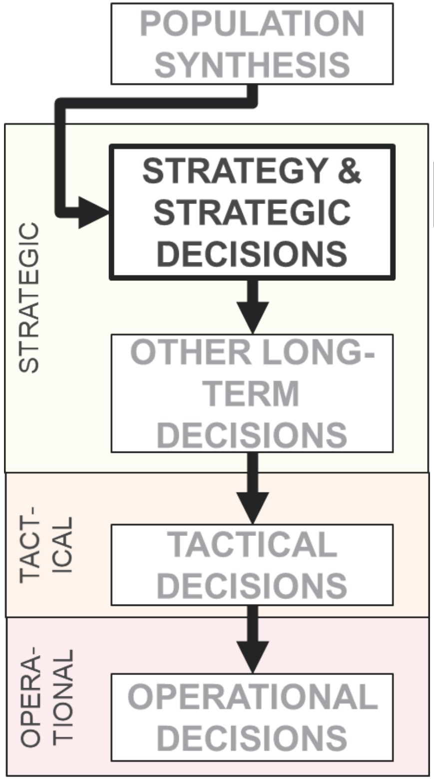
Business locations in region



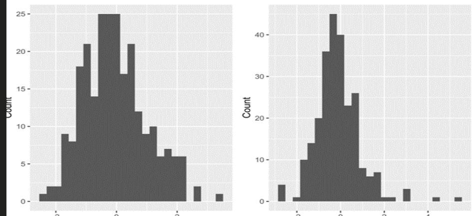
The new detailed firm population allows us to study:

- ***Baseline and future*** business population
- ***Fleet, DC and electrification/hydrogen powertrain decisions*** by firms
- ***Shipment & truck movements*** that pass through the DC belonging to the firm

MODELS OF STRATEGY AND STRATEGIC ALIGNMENT IMPROVE BEHAVIORAL ASPECTS



STRATEGIES



Customer Service Focus

Logistics Sophistication Focus

STRATEGIC ASSET DECISIONS

Fleet size and mix

Number of Medium-Duty Trucks

Number of Heavy-Duty Trucks

Distribution Center (DC) preferences:

Total Area (Square Feet, SF)

Mean Area

Variance in Area

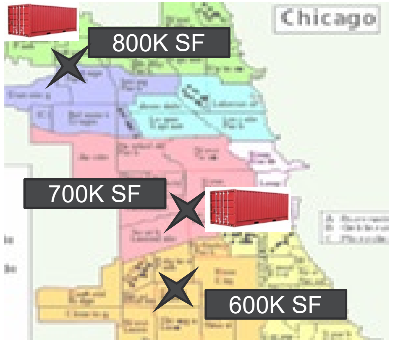
Proximity to Water Port

Proximity to Intermodal Yard

Align downstream decisions

Example: Create DC Location Choice Set using Strategy Model.

Preferred **DC Area:** 650+/-150 SF & Preferred **Miles to Intermodal (IMX) Truck-Rail Yard**: <15 mi.



IMX truck-rail yard

Candidate location

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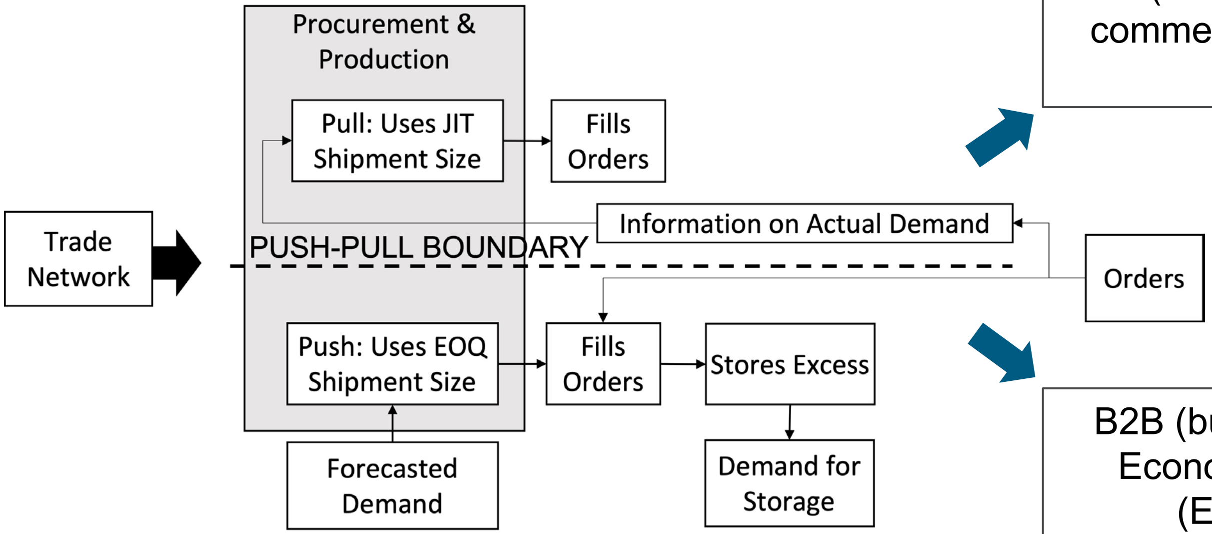
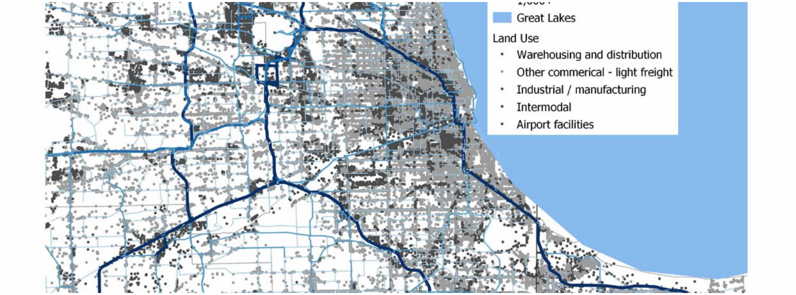
INFORMATION HAS IMPACTS ON ORDER SIZE (& FREQUENCY) AND DEMAND FOR WAREHOUSING



B2C (business-to-consumer) E-commerce: Just-in-time (JIT) order sizes

B2B (business-to-business): Economic Order Quantity (EOQ) order sizes

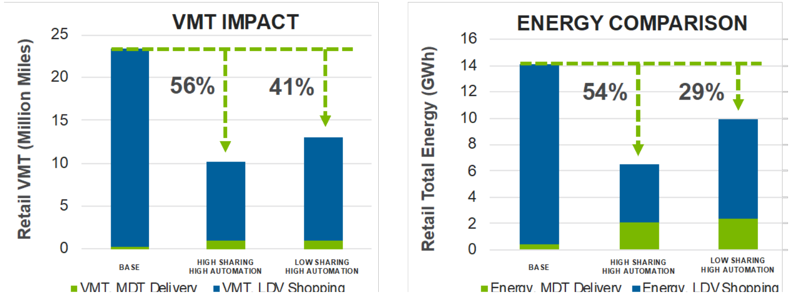
APPLICATIONS



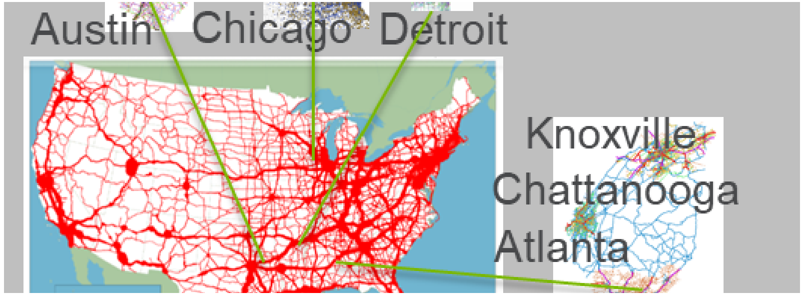
Simulated truck traffic in Chicago region.

Medium & heavy duty truck trips	1.03 million	↑ 26%
Avg. stops per tour	8.13	↑ 26%

Scenario with 35% increase in freight demand.*



E-commerce effects of more parcel delivery and less household shopping.



CRISTAL is being used for further analysis in DOE SMART 2.0 and SuperTruck 3 studies.

*Completed by Abdelrahman Ismael, Olcay Sahin, Hyun Seop Uhm.

Recent Publications & Presentations

CRISTAL

Stinson and Mohammadian (2022). Introducing CRISTAL: A model of collaborative, informed, strategic trade agents with logistics, Transportation Research Interdisciplinary Perspectives Volume 13 https://www.sciencedirect.com/science/article/pii/S2590198222000033

1. Stinson, M., A. Mohammadian (2022). Strategic alignment in agent-based models. Presented at the International Association of Travel Behavior Research, December 11-15, 2022, Santiago, Chile.
2. (Best Paper Award) Monique Stinson, Joshua Auld and Abolfazl Mohammadian (2020). A large-scale, agent-based simulation of metropolitan freight movements with passenger and freight market interactions. 9th International Workshop on Agent-based Mobility, Traffic and Transportation Models, Methodologies and Applications (ABMTRANS-20), Warsaw, Poland.
3. Stinson, M., A. Enam, A. Moore, J. Auld (2020)—Citywide Impacts of E-Commerce: Does Parcel Delivery Travel Outweigh Household Shopping Travel Reductions?:
   - Paper: https://dl.acm.org/doi/10.1145/3357492.3358633
   - Alternative Fuels Institute webinar (2021)
   - Chicago Metropolitan Agency for Planning Freight Advisory Committee (2020)
   - Transportation Research Board Annual Meeting Workshop on First/Last-Mile (2020)
   - FHWA's Freight Model Improvement Program (FMIP) webinar (2019)
   - Association for Computing Machinery - Smart Cities Conference (2019)
   - METRANS International Urban Freight (I-NUF) Conference (2019)
4. Stinson, M.A., J. Auld and A. Mohammadian (2020). Light Duty Vehicle Choice Models Examining Alternative Fuel Technology Preferences among Commercial Fleet Owners. Transportation Research Procedia, Volume 46.
5. Cokyasar, T., A. Subramanyam, J. Larson, M. Stinson, O. Sahin (2022). Time-Constrained Capacitated Vehicle Routing Problem in Urban E-Commerce Delivery, TRR.
6. Subramanyam, A., T. Cokyasar, J. Larson, M. Stinson (2022). Joint Routing of Conventional and Range-Extended Electric Vehicles in a Large Metropolitan Network. Transportation Research Part C.
7. Moawad, A., Z. Li, I. Pancorbo, K. Gurumurthy, V. Freyermuth, E. Islam, R. Vijayagopal, M. Stinson, A. Rousseau. A Real-Time Energy and Cost Efficient Vehicle Route Assignment Neural Recommender System. arXiv:2110.10887 [cs.LG].
8. Stinson, M., and A. Mohammadian. Modeling Firm Transportation Strategy using Big Text Data. Proceedings of the IEEE Forum on Integrated and Sustainable Transportation Systems, 2020, in Delft, The Netherlands, doi: 10.1109/FISTS46898.2020.9264878.

TRB Annual Meeting 2023

Standing Committee on Air Quality and Greenhouse Gas Mitigation (AMS10)

IMPACTS OF FREIGHT FLEET ELECTRIFICATION IN THE ATLANTA – CHATTANOOGA REGION

Based on the Best Paper Award presentation by:

Natalia Zuniga (nzuniga@anl.gov), Vincent Freyermuth, **Monique Stinson**, Olcay Sahin

Work conducted at Argonne National Laboratory

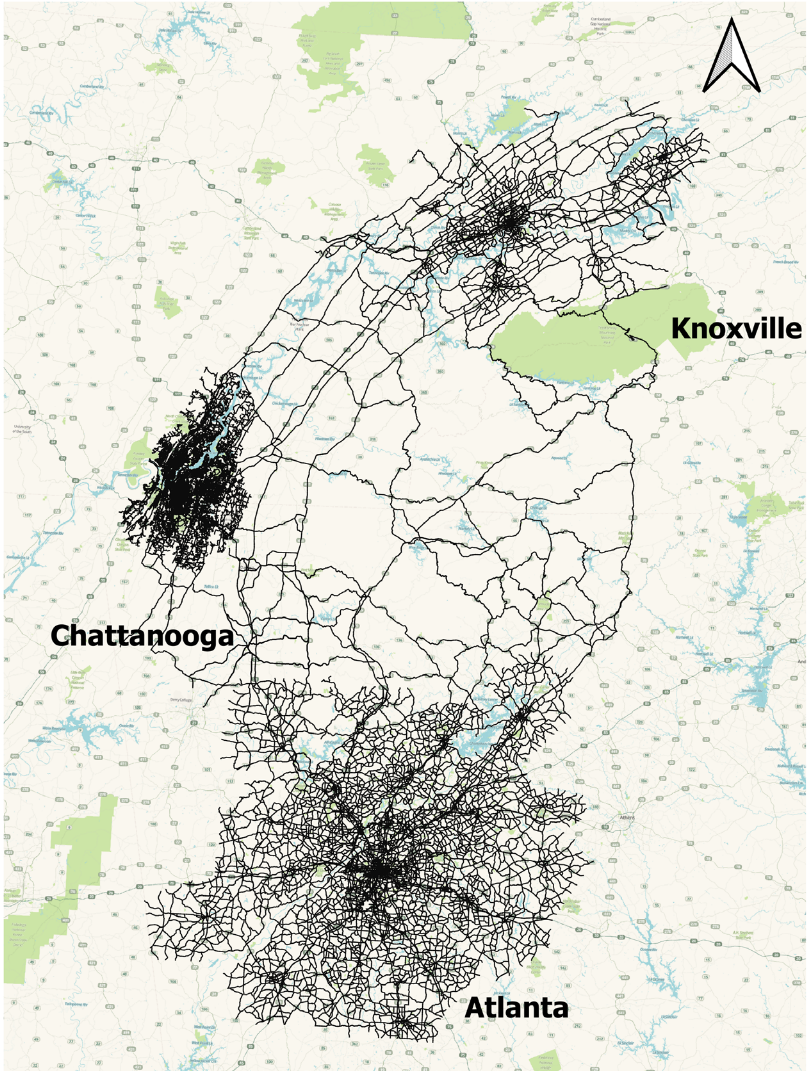
January 11th, 2023

INTRODUCTION

- The transportation sector is one of the **largest contributors** to US greenhouse gas (GHG) emissions.
- A significant part of these emissions come from **freight-related trips**.
  - In 2019, MD and HD vehicles accounted for **24% of the transportation sector** GHG emissions (EIA, 2022) and were responsible for **7% of the total GHG** emissions in the nation (EPA, 2021), despite accounting for only **9% of the total VMT**.
- With truck freight transportation operations expecting an approximate **growth of 30%** between 2019 and 2040 and **50%** between 2019 and 2050 (FHWA, 2022), measures should be taken to **reduce the environmental impact of MD and HD vehicles** in the sector.

STUDY REGION

Atlanta-Chattanooga-Knoxville:
- 6.7 million residents
- 7,820 traffic analysis zones (TAZs)
- Network:
  ~85,700 links (71,425 nodes)



SCENARIO DEFINITION

- ST (short term)–2025 to 2035
- MT–2035 to 2045
- LT–2045 to 2050

- ❑ **Low technology**: evolution of technology assuming limited investment in R&D or BAU.
- ❑ **High technology:** significant investment has led to major technology improvements, meeting the USDOE Vehicle Technology Office targets.

Vehicle Technology Assumptions

Scenarios	Baseline			Short-term						Medium-term						Long-term					
				Low			High			Low			High			Low			High		
Vehicles	LD	MD	HD	LD	MD	HD	LD	MD	HD	LD	MD	HD	LD	MD	HD	LD	MD	HD	LD	MD	HD
Powertrain Distribution																					
ICE	98%	100%	100%	82%	89%	100%	58%	72%	87%	62%	68%	100%	33%	45%	76%	40%	39%	97%	2%	26%	52%
ISG	2%	0%	0%	10%	7%	0%	18%	18%	12%	20%	18%	0%	14%	28%	15%	30%	23%	3%	8%	27%	25%
HEV	0%	0%	0%	4%	4%	0%	13%	7%	0%	10%	7%	0%	18%	15%	0%	8%	24%	0%	21%	22%	0%
PHEV	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	7%	0%	0%	0%	0%	0%	13%	0%	0%
BEV	0%	0%	0%	4%	1%	0%	11%	4%	1%	9%	7%	0%	29%	12%	6%	23%	15%	0%	57%	26%	7%
FCV	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	0%	0%	0%	0%	0%	16%
Automation Distribution																					
L0	100%	100%	100%	95%	94%	100%	80%	88%	93%	85%	85%	100%	50%	65%	69%	57%	69%	98%	10%	43%	34%
L3	0%	0%	0%	5%	6%	0%	20%	13%	7%	15%	15%	0%	45%	30%	29%	41%	31%	2%	72%	50%	57%
L5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	6%	2%	2%	0%	0%	18%	8%	9%
Vintage Distribution																					
0-5 years	31%	31%	30%	32%	33%	30%	32%	33%	30%	32%	33%	30%	32%	33%	31%	33%	33%	30%	31%	31%	33%
6-10 years	34%	33%	30%	34%	32%	30%	33%	33%	30%	33%	34%	30%	33%	33%	31%	33%	32%	30%	34%	34%	33%
10+ years	34%	37%	40%	34%	35%	40%	35%	35%	40%	35%	34%	40%	35%	35%	38%	34%	35%	40%	34%	35%	34%

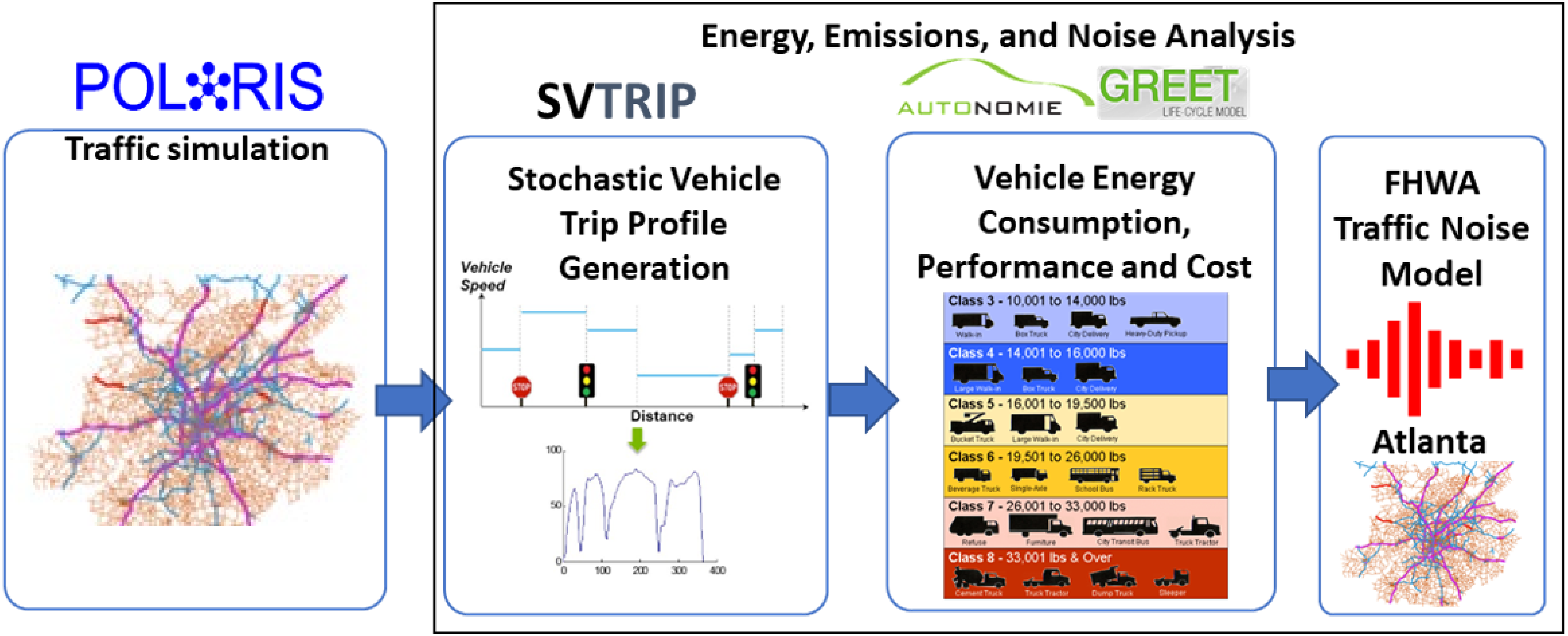
Vehicles: LD = light duty, MD = medium duty, HD = heavy duty.

Automation: L0 = level 0 (no automation), L3 = level 3 (conditional automation), L5 = level 5 (full automation).

Powertrains: ICE = internal combustion engine, ISG = integrated starter generator, HEV = power-split hybrid electric vehicles, PHEV = plug-in hybrids electric vehicles, BEV = battery electric vehicles, FCV = fuel cell vehicles.

APPROACH

TOOLS

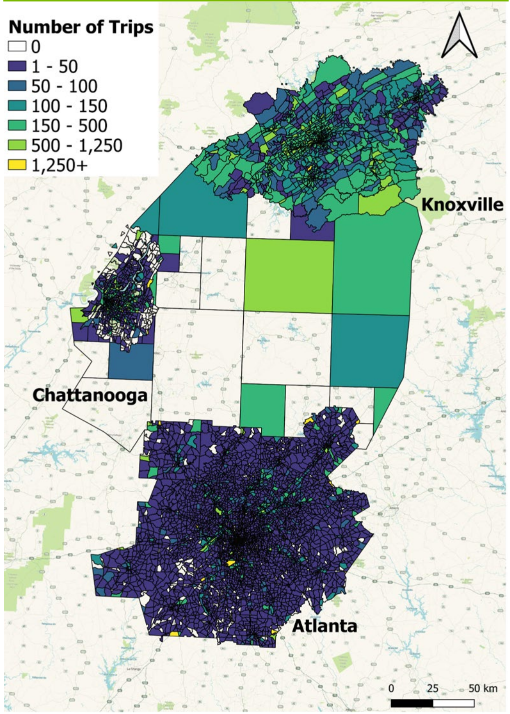


*The dynamic traffic simulation also includes all light-duty trips.

More information: https://vms.es.anl.gov/tools

FREIGHT DEMAND

HD VEHICLES



Source: Trips from the Atlanta Regional Commission (ARC) Activity-Based Model

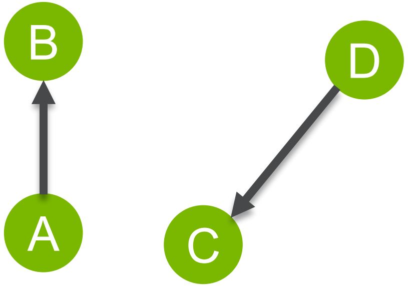
Daily trips

- MD: 520,000
- HD: 418,000

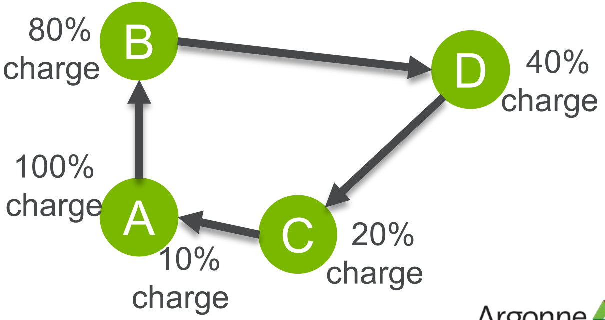
Assumptions

- All HD are freight
- 60% of MD are freight

Example "trips"

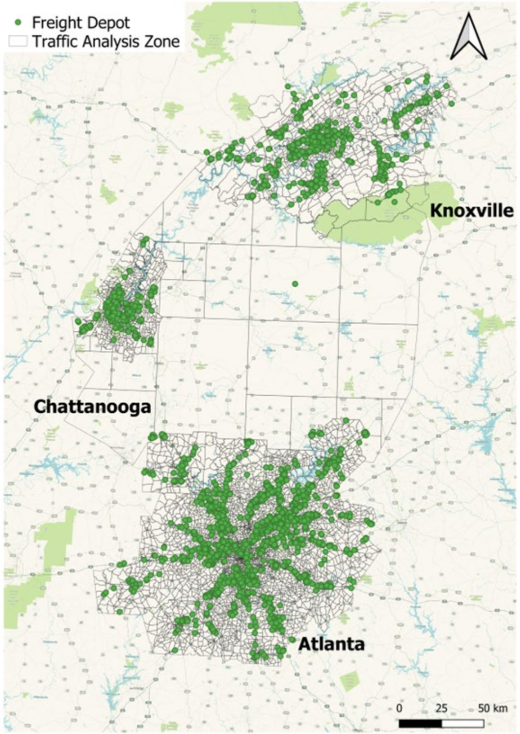


Problem:
To estimation drain on battery, we need TOURS:



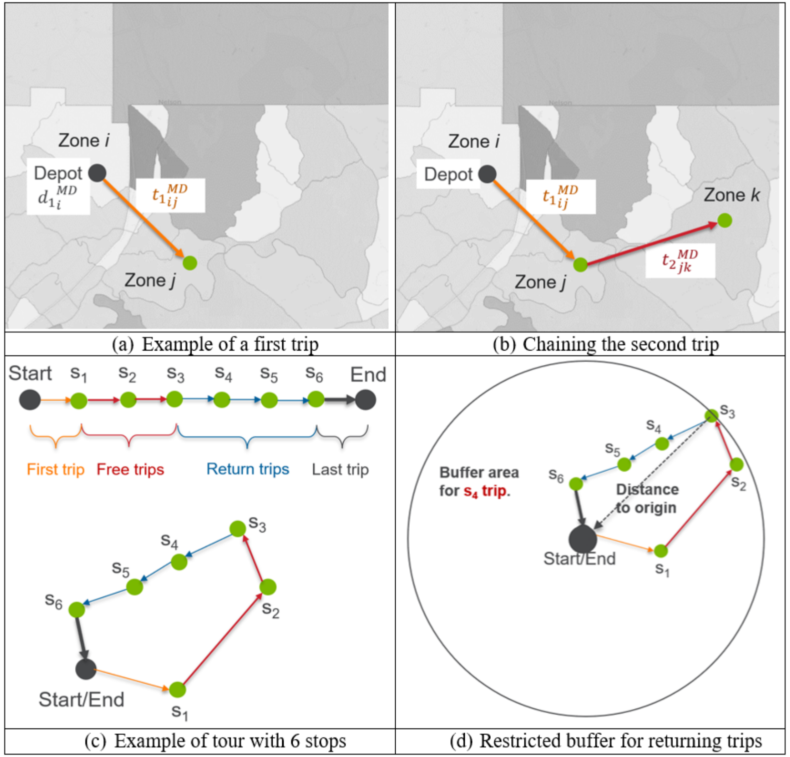
ASSUMPTIONS

- **Depots** are estimated using the approximate number of businesses in the region and were distributed across zones with more than 1% of industrial use.
- **Fleet by depot**: 32% of the trucks are in fleets of 15 or less, and 68% of trucks are in fleets of 15 or more (BTS).
- **Tour length**: Avg. daily VMT by MD (HD) trucks is ~48 miles (~96 miles) for operations within 200 miles (Source: 2002 VIUS)
- **Number of stops**: obtained stochastically based on a combination of daily VMT and approximate trip length.

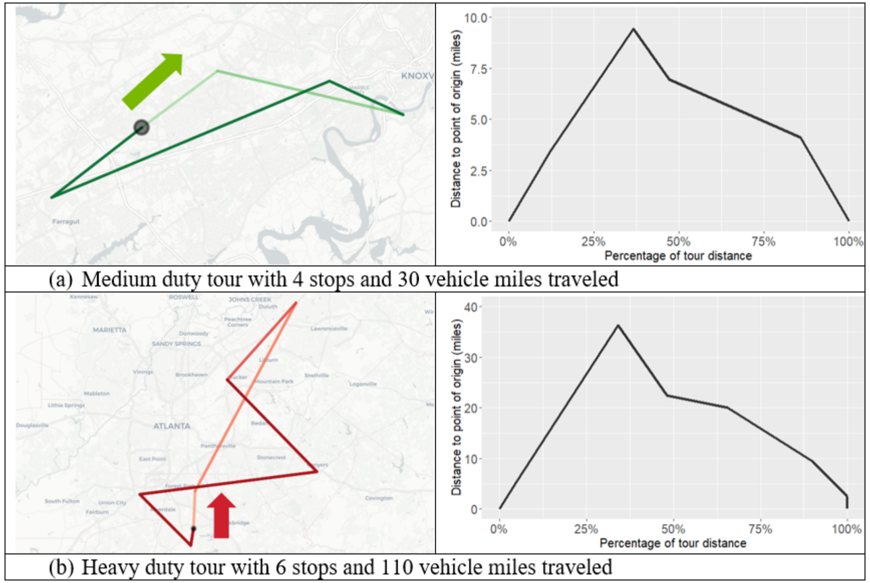


Location of freight depots

OUR NEW TOUR ALGORITHM GENERATES REALISTIC LOCAL TOURS FOR TRUCK ELECTRIFICATION ANALYSIS



Tour chaining process



Example freight tours

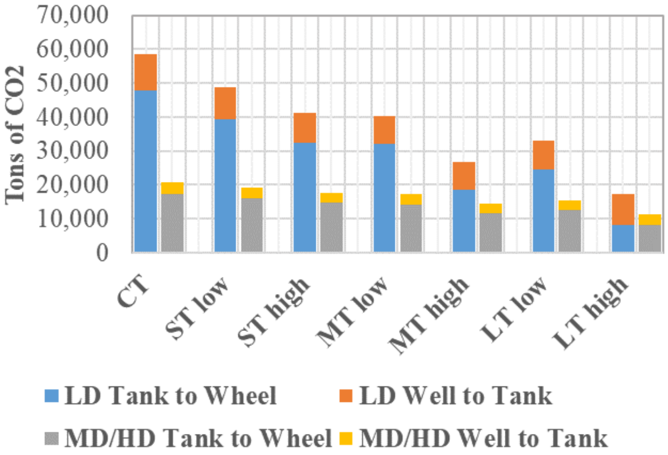
Nice validation feature:
The trip “legs” match ARC’s input trip data!

SCENARIO ANALYSIS: ELECTRIFICATION IMPACTS

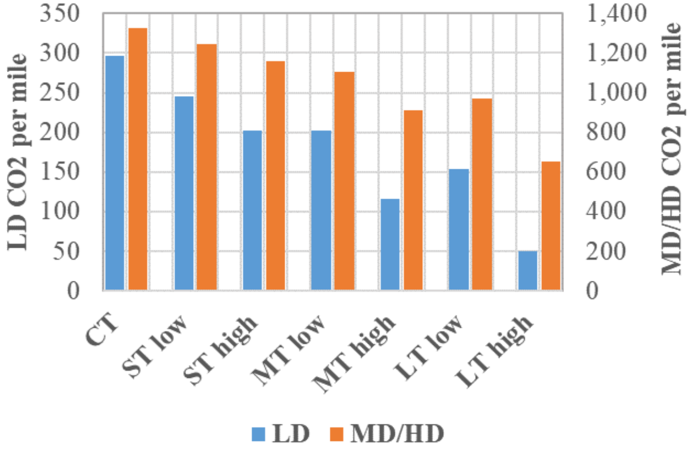
EMISSIONS ANALYSIS

- CO_2 emissions decrease:
  - As fleets electrify over time (CT -> ST -> MD -> LT) and
  - As vehicle technology improves (example: differences between “low” and “high” technology scenarios in the long term)
- Emission reductions are due mainly to driving (tank-to-wheel), esp. by BEV
  - Emissions from gas/diesel production (well-to-tank) ~steady
- Greatest reductions by LD fleet, but truck fleet reductions are significant as well
- Long-term High-Technology scenario (relative to base case):
  - LD emissions decrease by a factor of 6
  - MD/HD emissions decrease by factor of 2

(a) CO2 emissions by vehicle type



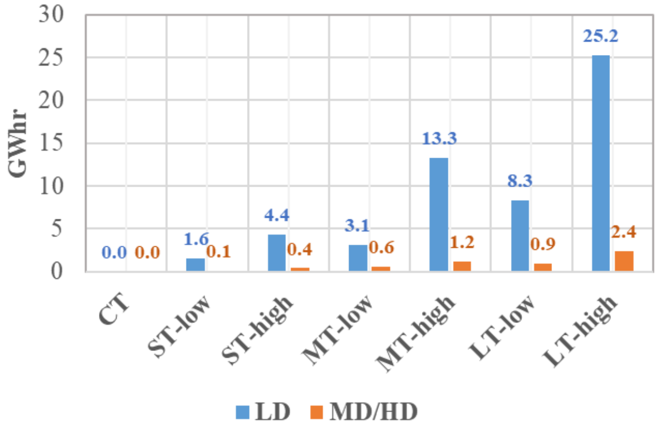
(b) CO2 emissions per mile



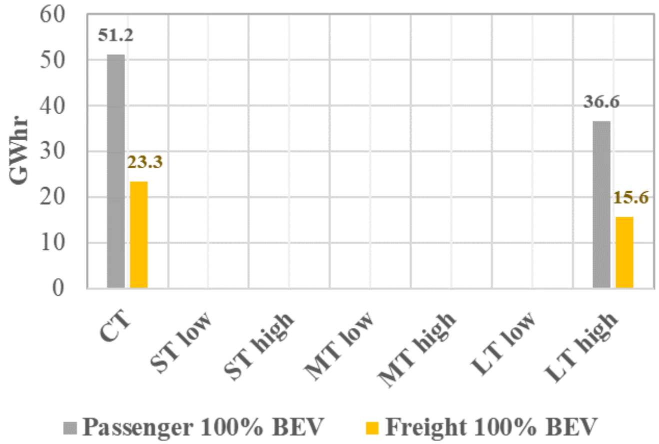
ELECTRICITY DEMAND

- LD demand > MD/HD demand
  - LD fleet is larger
  - LD electrification adoption assumed to be higher
- LT-high scenario
  - 25.2 GWhr required for LD
  - 2.4 GWhr (~10%) for trucks
  - MT-High demand is about 50% of LT-High
- Vehicle technology is an important factor in effective decarbonization efforts
  - (b) shows 30% less electricity demand in LT-High vs. baseline @ 100% BEV adoption

(a) Demand across scenarios



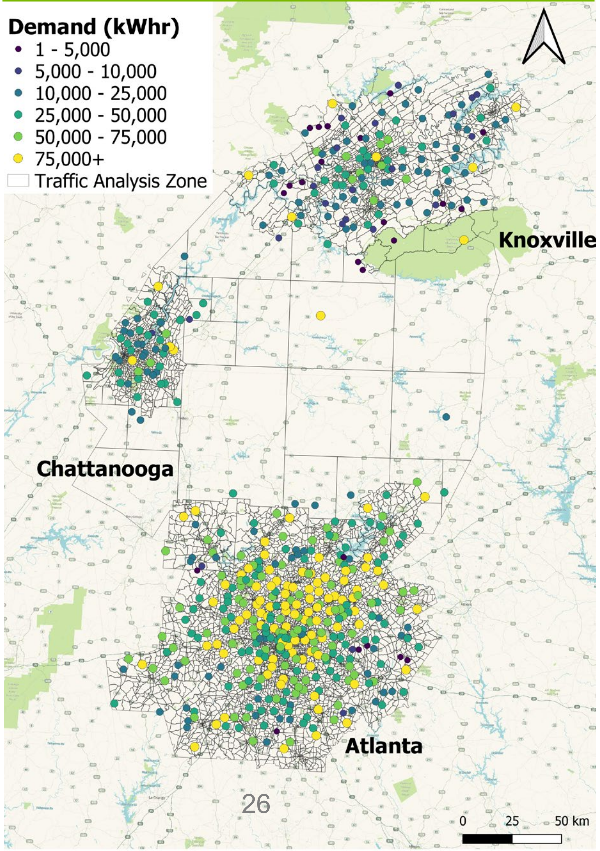
(b) Demand for extreme cases



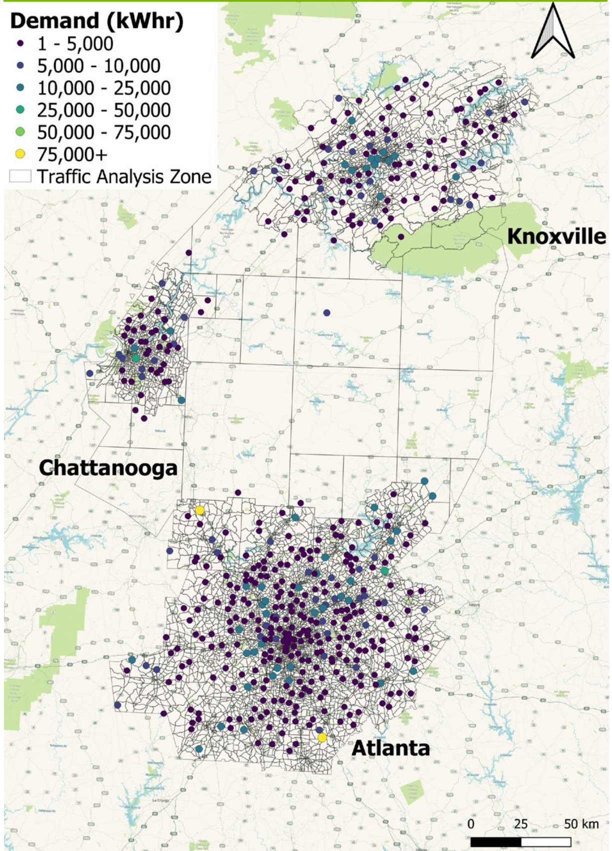
ELECTRIC GRID IMPACT

- Assumptions
  - LD vehicles charge at trip origin
  - Trucks charge at depot
- High grid impacts for LDs where trip intensity is high
  - Grid demand increases by ~50% at many locations
- MD/HD grid impacts esp. in industrial corridors
- Ongoing work regarding power plant requirements

LD VEHICLES



MD/HD VEHICLES



SUMMARY & CONCLUSIONS

SUMMARY

- LD vehicles have much more electricity demand
  - Larger LD fleets (compared to MD/HD) & assumed higher adoption rates
  - Trucks consume ~10% vehicle electricity demand
- Vehicle technology improvements are critical for reducing electricity demand
  - Electricity demand is ~30% less in the "high technology" scenario
- Grid improvements are required
  - Demand at many nodes will grow by 45+% relative to base year
- Truck fleet electrification alone would not significantly affect the grid, but when combined with passenger vehicle electrification, would cause issues
- Grid improvements are required on a long-term basis

CONCLUSIONS*

- Public agencies and other stakeholders face ongoing questions about freight transportation
  - Impacts on the economy, sustainability, equity…
  - Changes in freight as supply chains reorganize
  - Effects of major system factors (COVID, Panama Canal, …)
- Many public agencies are facing questions about the impacts of new powertrains (electric, hydrogen fuel cell):
  - How will new powertrains affect emissions, energy consumption, equity…?
  - Where should charging stations be located?
  - What are the impacts on the grid?
  - Is there a role for public-private partnerships?
- Awareness of current and emerging stakeholder questions will help agencies provide better data and tools to users

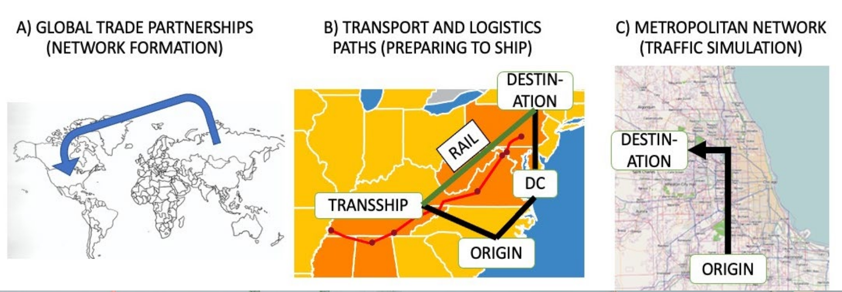
*personal opinion of M. Stinson

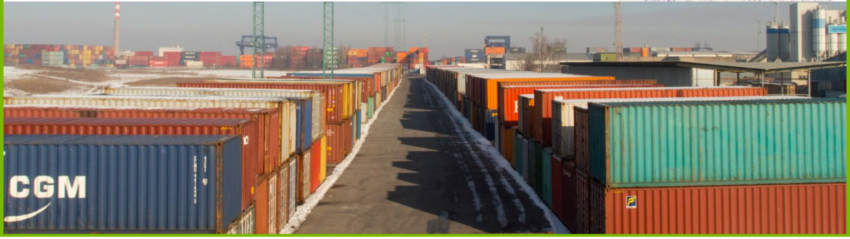
ACKNOWLEDGEMENT

CRISTAL: The work described was sponsored by the U.S. Department of Energy (DOE) Vehicle Technologies Office (VTO) under the Systems and Modeling for Accelerated Research in Transportation (SMART) Mobility Laboratory Consortium, an initiative of the Energy Efficient Mobility Systems (EEMS) Program. The following DOE Office of Energy Efficiency and Renewable Energy (EERE) managers played important roles in establishing the project concept, advancing implementation, and providing ongoing guidance: Erin Boyd (Office of Energy Policy and Systems Analysis, U.S. Department of Energy). The submitted manuscript has been created by UChicago Argonne, LLC, Operator of Argonne National Laboratory (Argonne). Argonne, a U.S. Department of Energy Office of Science laboratory, is operated under Contract No. DE- AC02-06CH11357. The U.S. Government retains for itself, and others acting on its behalf, a paid-up nonexclusive, irrevocable worldwide license in said article to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the Government.

FREIGHT ELECTRIFICATION: The authors would like to acknowledge the financial support provided for this work by Raphael Isaac (Office of Vehicle Technologies, U.S. Department of Energy). The submitted manuscript has been created by the UChicago Argonne, LLC, Operator of Argonne National Laboratory (Argonne). Argonne, a U.S. Department of Energy Office of Science laboratory, is operated under Contract No. DE-AC02-06CH11357. The U.S. Government retains for itself, and others acting on its behalf, a paid-up nonexclusive, irrevocable worldwide license in said article to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the Government. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

THANK YOU!





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