IPIC 2024

Hyperconnected Transportation Planning: Advancing a Multimodal Relay Ecosystem

Jingze Li, Sahrish Shaikh, Dr. Valerie M. Thomas, Dr. Benoit Montreuil

Physical Internet Center
School of Industrial and Systems Engineering
Georgia Institute of Technology

Georgia Tech
Physical Internet Center
Supply Chain & Logistics Institute

Sustainability Challenges and Opportunities in Regional Overland Transportation

The current way of regional overland transportation is unsustainable, which predominantly relies on a fragmented connection of rail and truck services

(Diesel) Truck

Trucks move roughly 72.6% of the nation's freight by weight.

- 15.6 cents per ton-mile
- 154.1 tons of GHG emissions per million ton-miles
- Long-haul truck driver shortage

Rail

- 5.1 cents per ton-mile
- 21.2 tons of GHG emissions per million ton-miles
- Fixed locations and schedules

Cleaner Truck Technology

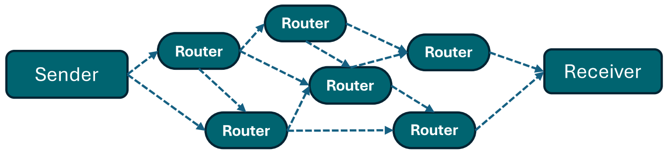
Daimler Mercedes-Benz GenH2 Truck

Tesla Electric Semi Truck – Semi

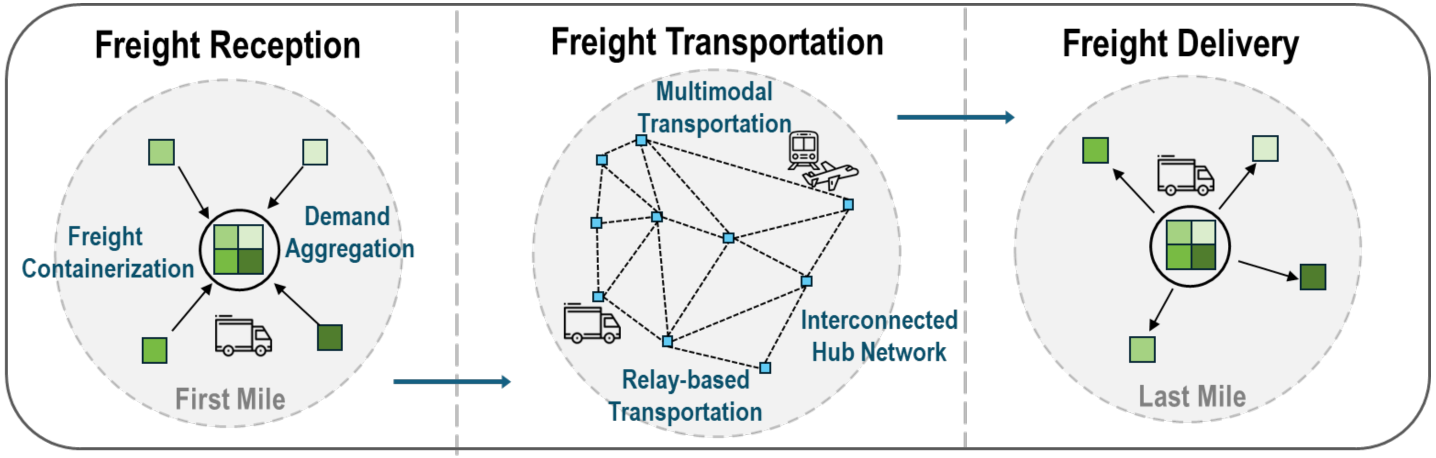
Georgia Tech
Physical Internet Center
Supply Chain & Logistics Institute

Paradigm Shift towards Hyperconnected Transportation

To address unsustainable issues in regional overland transportation,
this research proposes a shift from fragmented connection of truck and rail transport to a multimodal relay ecosystem, called Hyperconnected Transportation.



Hyperconnected Transmission in the Digital Internet



Hyperconnected Transportation in the Physical Internet

Applicable scenarios:
- A multimodal logistics corporation
- A hyperconnected transportation planning platform

Literature Review

- **Physical Internet, Synchro-Modality, Hyperconnected Logistics**
  - Montreuil, B. (2011); Pan, S., Ballot, E., Huang, G. Q., & Montreuil, B. (2017);
    Pan, S., Ballot, E., Huang, G. Q., & Montreuil, B. (2017);
    Ambra, T., Caris, A., & Macharis, C. (2019); Ambra,T.,Caris,A.,& Macharis,C.(2019).

- **Decision Making and Performance Assessment Related to Hyperconnected Transportation**
  - ➢ **Network Design Problem**
    - Kulkarni, O., Cohen, Y. M., Dahan, M., & Montreuil, B. (2021); Grover, N., Shaikh, S. J., Faugère, L., & Montreuil, B. (2023)

Our research focuses on developing optimization-based decision support for hyperconnected transportation planning and performing simulations of real cases to evaluate the multi-dimensional performances.

Relation to Previous Publications

Hyperconnected Transportation Strategies

Previous research explores replacing long-haul end-to-end truckers with short-haul relay truckers to improve timeliness, efficiency, and allow drivers to return home daily.

This follow-up research explores adding multimodal transportation to achieve zero-emission targets while ensuring timeliness, efficiency, and daily return for truck drivers.

Performance Summary

Truck-only End-to-end vs. Relay Transport

54% ↑ truckers back home daily
11% ↑ delivery velocity
3% ↓ transportation cost
3% ↑ CO_2 emission

54% ↑ truckers back home daily
11% ↑ delivery velocity increase
3% ↓ transportation cost
6% ↓ CO_2 emission

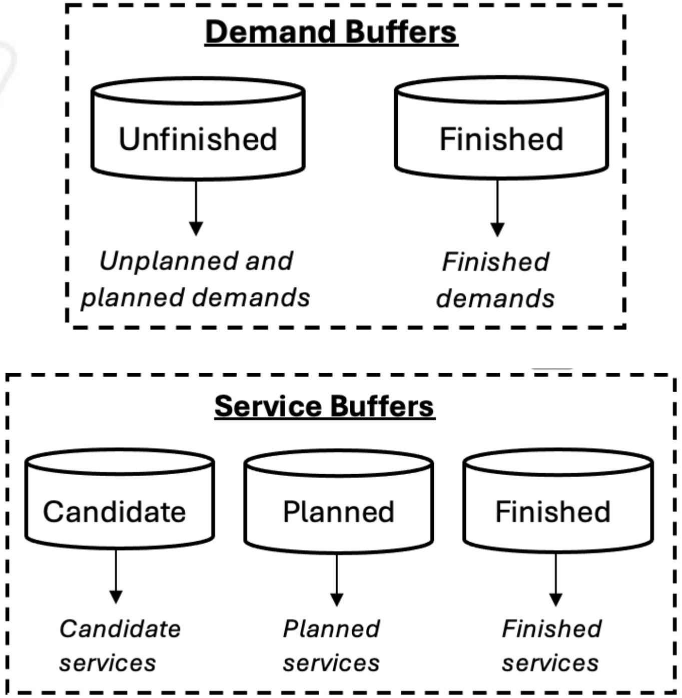
Truck-only vs. Multimodal Relay Transport

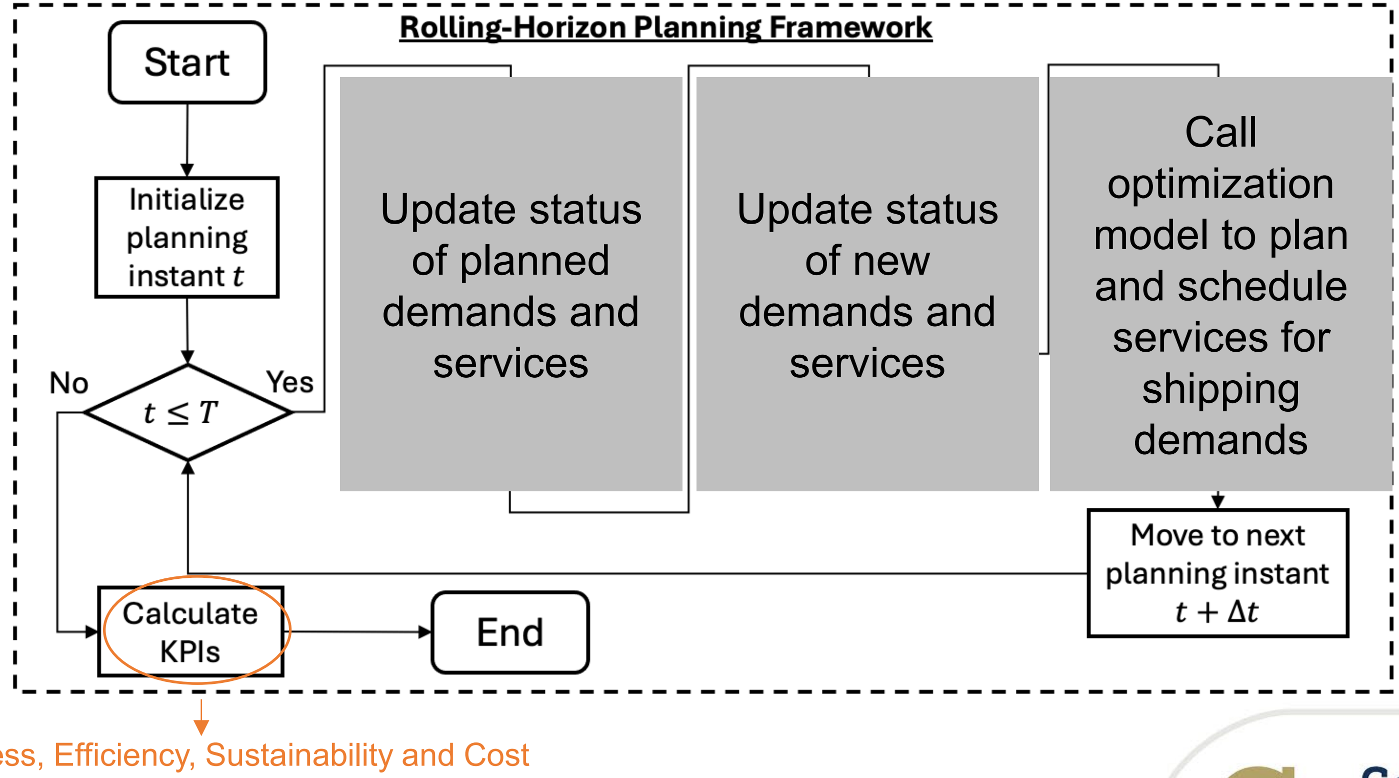
14.2% ↓ average trucker driving time
16.7% ↓ transportation cost
60% ↓ CO_2 emission

Georgia Tech Physical Internet Center
Supply Chain & Logistics Institute

Rolling-Horizon Hyperconnected Transportation Planning Framework

We developed a Rolling-Horizon Hyperconnected Transportation Planning Framework that dynamically plans freight deliveries based on the status of both new and scheduled shipping demands and multimodal services.





Multimodal Service Network Design Optimization

We built a Multimodal Service Network Design Optimization model to plan and schedule multimodal services for shipping demands, aimed at minimizing lateness, reducing costs, and cutting emissions.

Decisions

- How to move demands via multimodal services
- How to hold demands at hubs
- How to schedule multimodal services
- $L_k \in \mathbb{R}^{\geq 0}$: delivery lateness of shipping demand k, $\forall k \in \mathcal{K}$

- Scenario 1 : End-to-end truck-only services
- Scenario 2 : Truck-only relay services
- Scenario 3 : Multimodal relay services

min Total Lateness Penalty + Total Transportation Cost + Total Emission Penalty

$s.t.$

To guarantee network flow balance and demand satisfaction

To ensure enough service capacities to transport demands

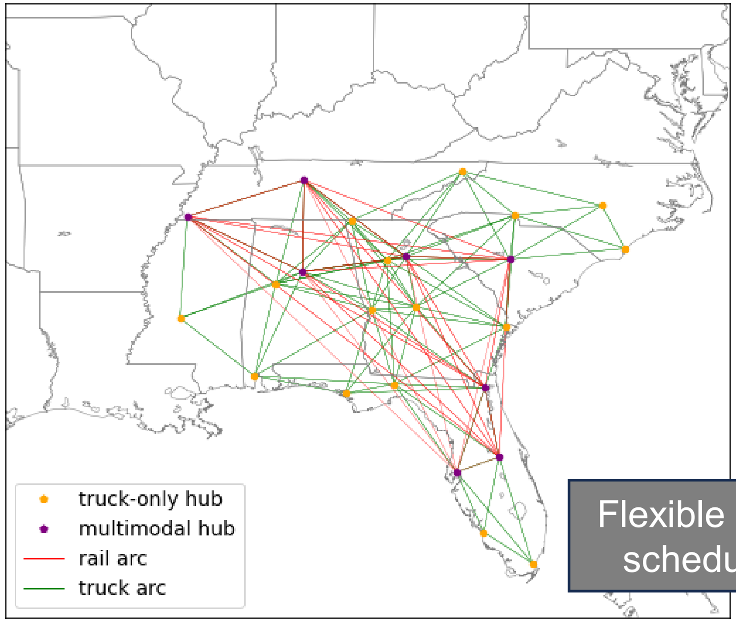
To calculate the delivery lateness of shipping demands

Georgia Tech Physical Internet Center
Supply Chain & Logistics Institute

A Case Study on Multi-OEM Vehicle Delivery

We performed a case study in the Southeastern US automotive delivery sector, which involves multiple OEMs and encompasses imports, exports, and domestic movements by truck in 2021.

Hyperconnected Hub Network

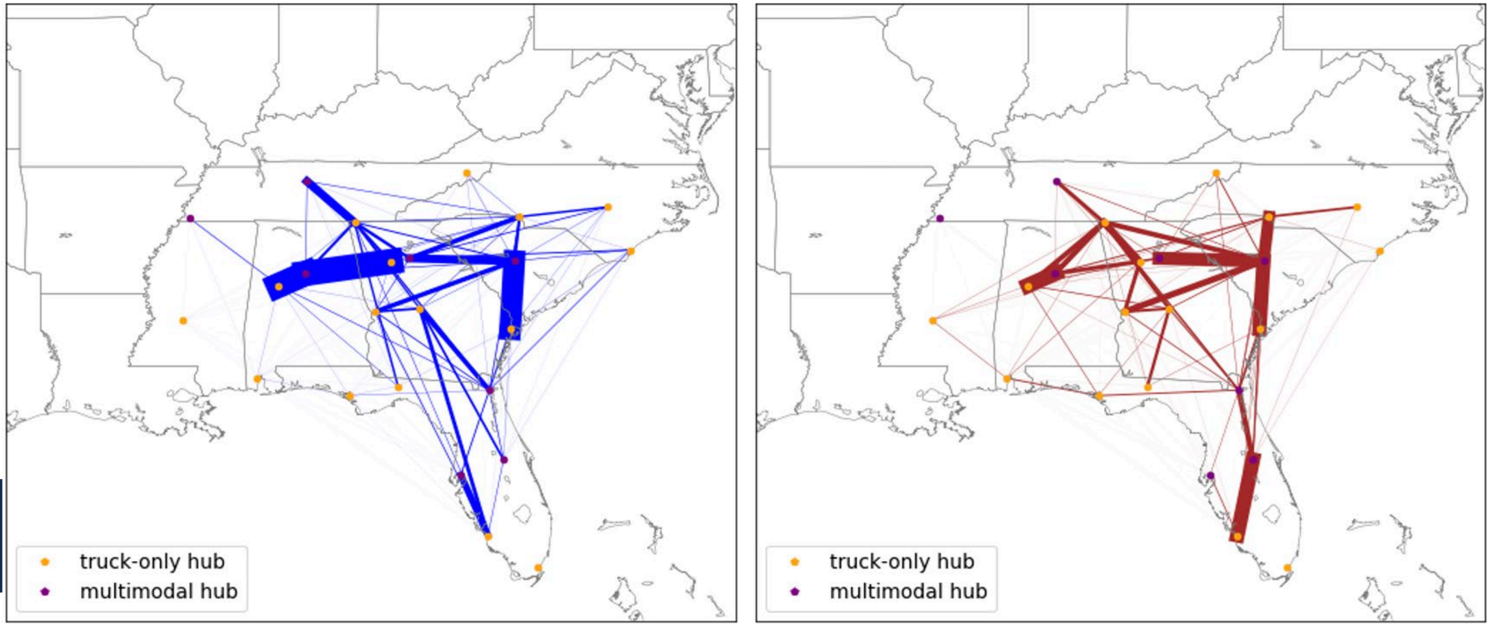


Flexible truck schedules

- 16 truck-only hubs, 8 multimodal hubs
- 168 relay truck arcs according to traffic regulations
- 49 rail arcs managed by CSX Corporation

Fixed rail schedules

Inter-Hub Shipping Demands Towards the East (Left) vs. West (Right)



- By setting market share as 5%, we have approximately 1,157 cars daily and 32,396 cars in total for a testing horizon of 28 days.

Case Study Setup

Service Mode	Rail Services	Truck Services		
Average Speed (MPH)	50	60		
Fleet Type	Tri-level auto-rack railcars (Capacity: 15 vehicles)	8-car hauler trucks (Capacity: 8 vehicles)		
Fuel Type	Diesel	Diesel	Electricity	Hydrogen
Cost Rate* (Per Fleet Unit Per Mile)	$0.67	$2.00	$2.25	$2.42
CO_2 Emission Rate (Per Ton Mile)	0.021	0.12	0.07	0.06

**The cost rates are estimated based on fleet depreciation, labor cost, and fuel cost*

We assess the benefits of rail mode and cleaner truck technology in the context of hyperconnected transportation through,

- experiment 1: diesel truck only vs. rail + diesel truck
- experiment 2: diesel truck only vs. rail + electric truck vs. rail + hydrogen trucks

Georgia Tech
Physical Internet Center
Supply Chain & Logistics Institute

Impacts of Multimodality on Hyperconnected Transportation

	Mode	Diesel Trucks	Rail + Diesel Trucks
Timeliness	Avg late percentage per demand unit (%)	0.36	1.73 ↑
	Avg Late hours per demand unit	0.01	0.26 ↑
	Avg lateness penalty per demand unit ($)	0.42	10.44 ↑
Efficiency	Avg rail transportation hours per short haul demand unit	-	1.07
	Avg truck transportation hours per short haul demand unit	3.71	2.98
	Avg rail transportation hours per long haul demand unit	-	5.39
	Avg truck transportation hours per long haul demand unit	9.05	6.02
	Avg travel hours per truck driver	6.85	6.26 ↓
	Avg empty travel percentage per truck driver (%)	9.19	10.32 ↑
Sustainability	Average CO_2 emission per demand unit per mile (kg)	0.26	0.19 ↓
	Average emission penalty per demand unit per mile ($)	0.010	0.008 ↓
Cost	Average transportation cost per demand unit per mile ($)	2.34	1.86 ↓
	Average overall cost per demand unit per mile ($)	2.36	1.90 ↓

1.4% ↓ on-time rate due to fixed rail schedules

8.6% ↓ average trucker driving time

12.3% ↑ empty miles due to sparse rail terminals

20% ↓ CO_2 emission

19.5% ↓ overall cost

Impacts of Cleaner Truck Technology on Hyperconnected Transportation

	Mode	Rail + Diesel Trucks	Rail + EV Trucks	Rail + Hydrogen Trucks
Timeliness	Average late percentage per demand unit (%)	7.11	10.75 ↑	14.02 ↑
	Average Late hours per demand unit	0.37	0.60 ↑	0.81 ↑
	Average lateness penalty per demand unit ($)	14.6	23.9 ↑	32.23 ↑
Efficiency	Average rail transportation hours per short haul demand unit	1.08	1.22	1.73
	Average truck transportation hours per short haul demand unit	2.99	2.91	2.67
	Average rail transportation hours per long haul demand unit	5.48	6.47	6.77
	Average truck transportation hours per long haul demand unit	5.36	5.06	4.83
	Average travel time per truck driver	6.27	6.22 ↓	5.88 ↓
	Average empty travel percentage per truck driver (%)	9.85	11.32 ↑	11.98 ↑
Sustainability	Average CO_2 emission per demand unit per mile (kg)	0.19	0.11 ↓	0.09 ↓
	Average emission penalty per demand unit per mile ($)	0.008	0.005 ↓	0.004 ↓
Cost	Average transportation cost per demand unit per mile ($)	1.81	1.94 ↑	1.95 ↑
	Average overall cost per demand unit per mile ($)	1.87	2.02 ↑	2.05 ↑

Higher transportation cost using cleaner truck technology pushes the model to delay demands for consolidation and plan more rail usage

Cleaner truck scenarios reduce more CO_2 emission with sacrifice of transportation cost given current technology

IPIC 2024

Impacts of Cleaner Truck Technology on Hyperconnected Transportation

	Mode	Diesel Trucks	Rail + EV Trucks	Rail + Hydrogen Trucks
Timeliness	Average late percentage per demand unit (%)	0.36	10.75 ↑	14.02 ↑
	Average Late hours per demand unit	0.01	0.60 ↑	0.81 ↑
	Average lateness penalty per demand unit ($)	0.42	23.9 ↑	32.23 ↑
Efficiency	Average rail transportation hours per short haul demand unit	-	1.22	1.73
	Average truck transportation hours per short haul demand unit	3.71	2.91	2.67
	Average rail transportation hours per long haul demand unit	-	6.47	6.77
	Average truck transportation hours per long haul demand unit	9.05	5.06	4.83
	Average travel time per truck driver	6.85	6.22	5.88
	Average empty travel percentage per truck driver (%)	9.19	11.32 ↑	11.98 ↑
Sustainability	Average CO_2 emission per demand unit per mile (kg)	0.26	0.11 ↓	0.09 ↓
	Average emission penalty per demand unit per mile ($)	0.010	0.005 ↓	0.004 ↓
Cost	Average transportation cost per demand unit per mile ($)	2.34	1.94 ↓	1.95 ↓
	Average overall cost per demand unit per mile ($)	2.36	2.02 ↓	2.05 ↓

10.5% / 13.7% ↓ on-time rate due to fixed rail schedules

23.1% / 30.3% ↑ empty miles due to sparse rail terminals

50% / 60% ↓ CO_2 emission

17% ↓ overall cost

Georgia Tech
Physical Internet Center
Supply Chain & Logistics Institute

Conclusion Future work

Conclusions

- Rail mode contributes to cost savings and emission reductions, which can be further enhanced with more flexible schedules and denser network.
- Cleaner truck fuel types can reduce more emissions than rail mode, but these gains may be constrained by high costs given current technology.
- A combination of both rail and cleaner truck technology gains both in emission reductions and cost savings compared to diesel-truck-only scenario

Future works

- To develop more efficient algorithms for accelerating optimization model, such as a dynamic discretization discovery algorithm, is essential for handling larger test cases or higher market shares.
- To add end-to-end transportation scenarios to experiment section for comparing the benefits of multimodality and cleaner truck technology in the hyperconnected transportation.
- To consider multiple commodities with varying inter-modal transshipment cost

Thank you!

Questions:

jonyli@gatech.edu
sahrish.shaikh@gatech.edu
valerie.thomas@isye.gatech.edu
benoit.montreuil@isye.gatech.edu