Strategic Network Design for Hyperconnected Mobile Supply Chains

Julien MAURICE[1,2], Simon Soonhong KWON[1,2], Pr. Benoit MONTREUIL[1,2,3]

1. *Physical Internet Center, Supply Chain & Logistics Institute, Georgia Institute of Technology, Atlanta, GA, USA*
2. *H. Milton Stewart School of Industrial and Systems Engineering, Georgia Institute of Technology, Atlanta, GA, USA*
3. *Coca-Cola Material Handling & Distribution Chair, Georgia Institute of Technology, Atlanta, GA, USA*

IPIC 2024

10th International Physical Internet Conference
May 28-30, 2024
Savannah, GA USA

Georgia Tech
Physical Internet Center
Supply Chain & Logistics Institute

Agenda

I.
Introduction

II.
Hyperconnected Mobile Supply Chains

III.
Case study

IV.
Conclusion

Motivation

From Conventional Construction to Distributed Construction

Conventional Construction

- On site production
- Exposed to hazard, thief, disruptions

Distributed Construction

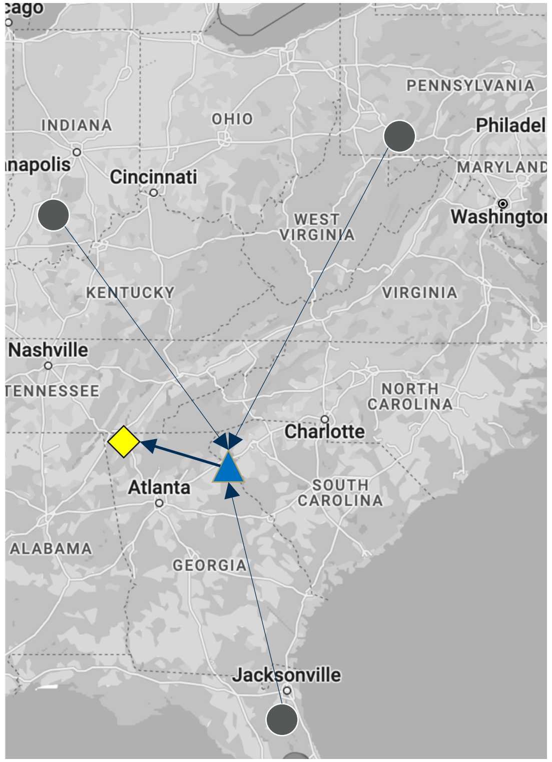
- In Factory Production
- Controlled Environment
- Near to Demand Production

Motivation

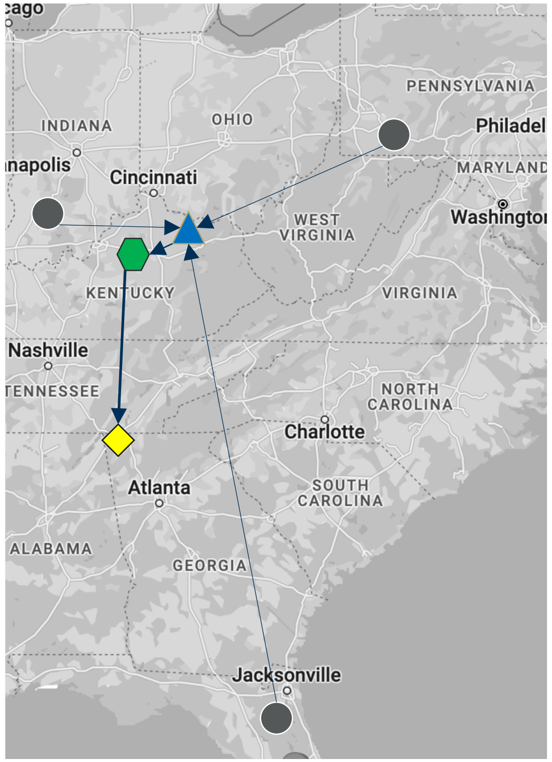
From Conventional Construction to Distributed Construction

On site Construction

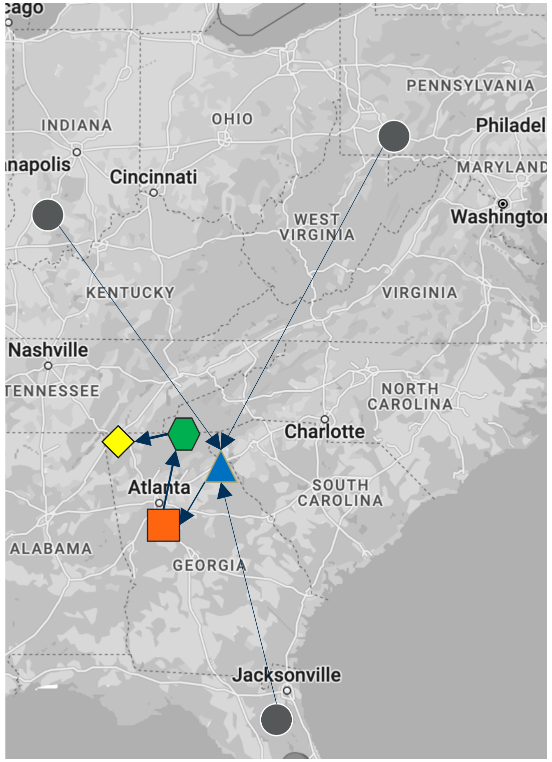
1. Conventional



2. Traditional Modular



3. Distributed Modular



Near to Demand Factory Production

● *Manufacturers* ▲ *Distributor(s)* ■ *Consolidation Center* ⬢ *Assembly Center* ◆ *Erection Site*

Leveraging the concept of containerized production…

An example in the chemical industry : the F3 factory project

Example in operation

Example in transport

- **Footprint (up to 50%)**
- **Capital expenditure (40%)**
- **Operating expenditure (up to 20%)**
- **Energy consumption (up to 30%)**
- **Number of equipment needed (60%+)**
- **Time to market for new products**

- **Production yield and capacity (20%+)**

Kessler S., 2015, Modularized production and logistics in process industry, 2nd IPIC, Paris, France

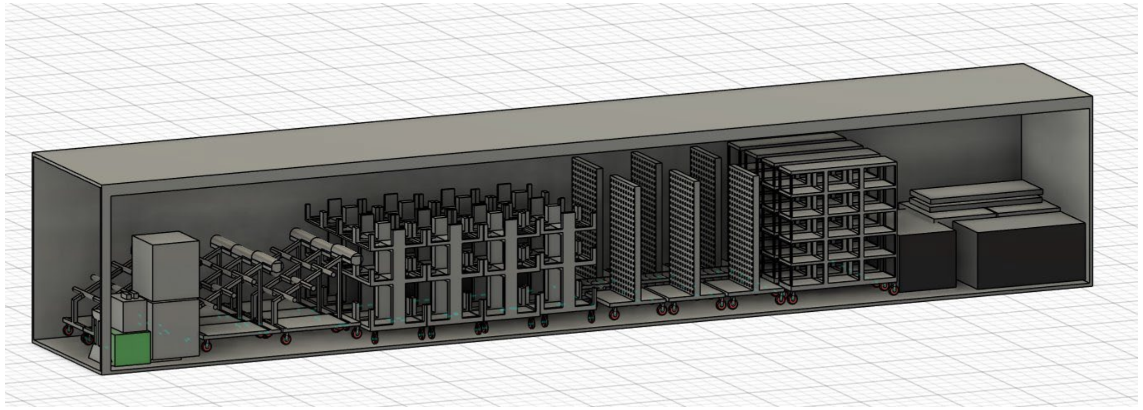
… and Fractal Cell…

Concept of Fractal Layout (Montreuil, 1999):

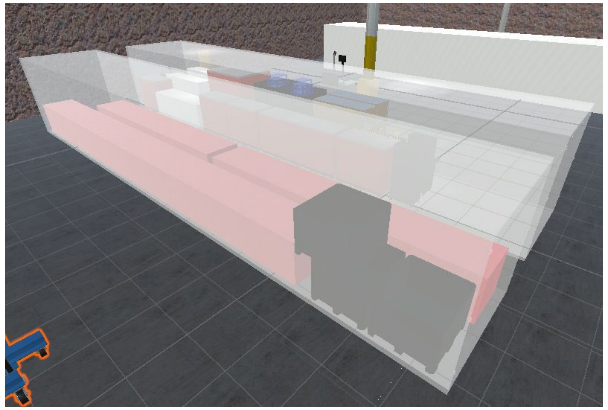
- *“Allocates the total number of workstations for most processes equally across several fractal cells”*
- *“Exploits the advantages and contains the pitfalls of both the Assembly Line and Job Shop organizations”*

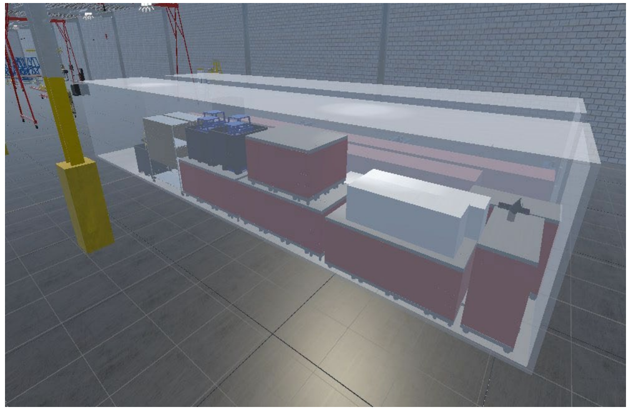
Idea : Pack fractal cells to allow an agile capacity deployment

Consolidation Center equipment Packing (1 cell)



Assembly Center equipment Packing (1 cell)





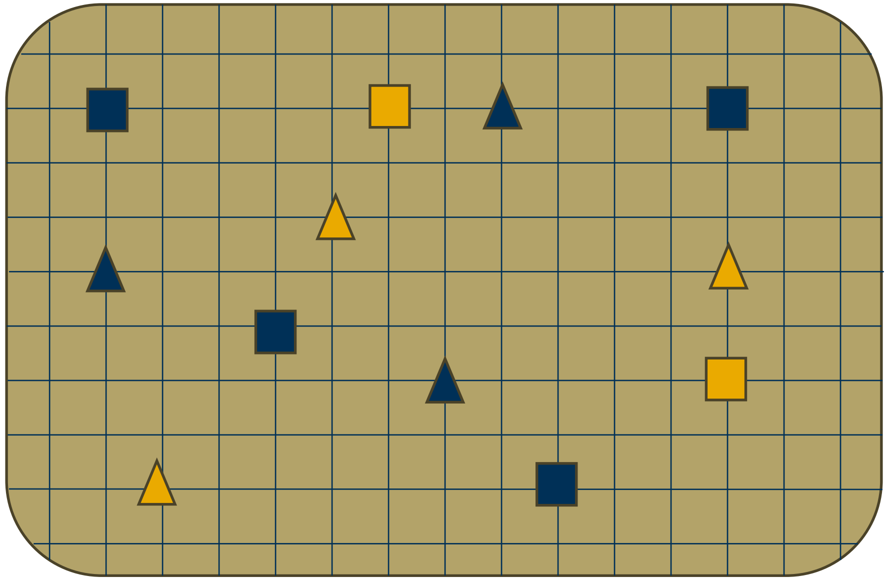
B. Montreuil (1999) Fractal layout organization for job shop environments, International Journal of Production Research, 37:3, 501-521, DOI: 10.1080/002075499191643

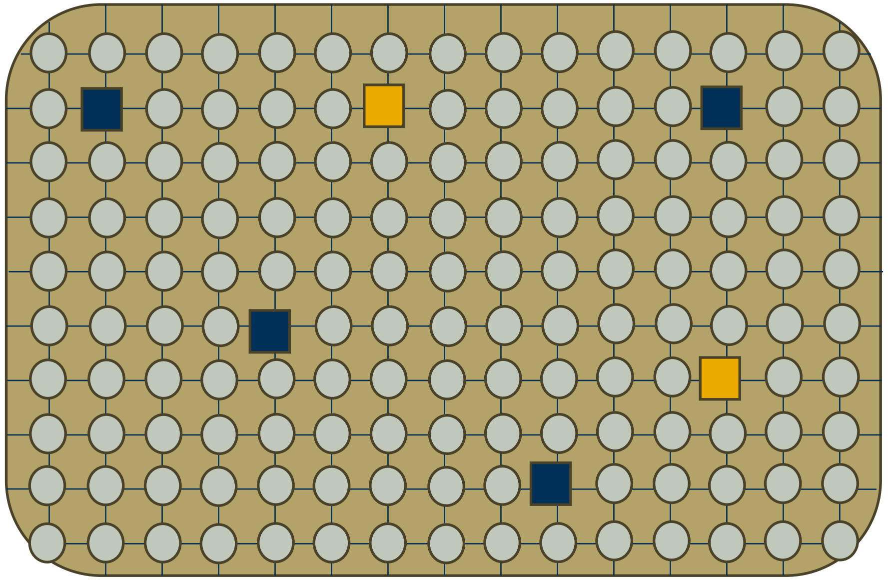
… in an open network

Montreuil et al.(2013) defined openness in a network as:

- “accessibility, willingness and availability of actors and networks to deal with any actor or network”

Example of an open network of Distribution Centers (DC)





Facilities dedicated Company A

Facilities dedicated Company B

DC dedicated Company A

DC dedicated Company B

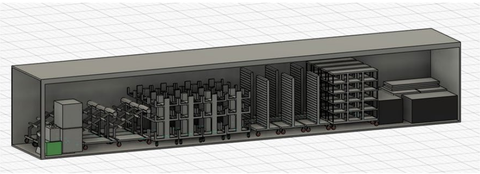
DC shared by companies A and B

Montreuil, B., Meller, R.D., Ballot, E. (2013). Physical Internet Foundations. In: Borangiu, T., Thomas, A., Trentesaux, D. (eds) Service Orientation in Holonic and Multi Agent Manufacturing and Robotics. Studies in Computational Intelligence, vol 472. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-35852-4_10

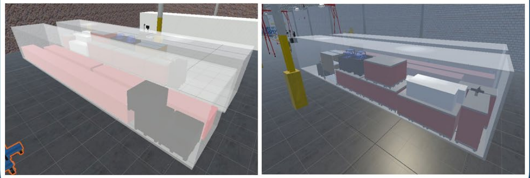
Leveraging concepts of containerized production…

… and Fractal Cell…

Consolidation Center equipment Packing
(TH = 2mods/day)

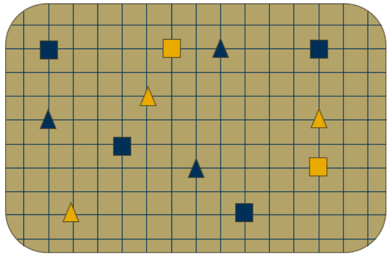


Production Center equipment Packing
(TH = 2mods/day)

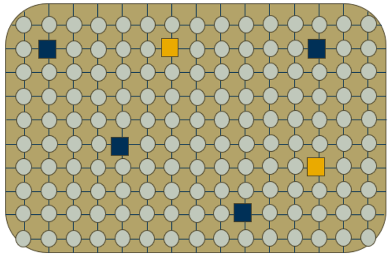


… in an open network

Example of an open network of Distribution Centers (DC)



Facilities dedicated Company A — Facilities dedicated Company B — DC dedicated Company A — DC dedicated Company B



DC shared by companies A and B

➡ ***How to design a network at the strategic level for multi-tier supply chains leveraging containerized production in an open network ?***

Related Literature

Dynamic Facility location

Jena SD, Cordeau J-F, Gendron B. , 2015, **Dynamic facility location with generalized modular capacities,** Transportation Science ;49: 484–99. https://doi.org/10.1287/trsc.2014.0575

- Not considering different types of production

Mobile Supply Chains

Shahmoradi-Moghadam H., Schönberger J., 2021, Joint optimization of production and routing master planning in mobile supply chains, Operations Research Perspectives 8 https://doi.org/10.1016/j.orp.2021.100187

- Manufacturing Site are homogenous
- Assumed homogenous Mobile factory fleet
- Mobile Factory are used in addition of fixed production facility of a customer

Hyperconnected Mobile Production

Marcotte and Montreuil, 2016, Introducing the Concept of Hyperconnected Mobile Production, 14th IMHRC Proceedings (Karlsruhe, Germany – 2016)

- Lacks a formularized decision-making process for users of such systems
- Only considered the production level and distribution level, not the fulfillment level

Fergani et al, 2020, Optimization of hyperconnected mobile modular production toward environmental and economic sustainability, Environmental Science and Pollution Research 27

- Bi-objective (Costs + GHGs emissions)
- The network of facilities is assumed to be known
- No-interaction between production modules

Hyperconnected Mobile Supply Chains

The evolution of Supply Chains

Conventional Construction → ***Distributed Construction***

Atomistic

- Solo operations

Integrated

- End-to-End SC
- Mixed of dedicated & centralized DCs/Factories
- Different SC for each stakeholder

Collaborative

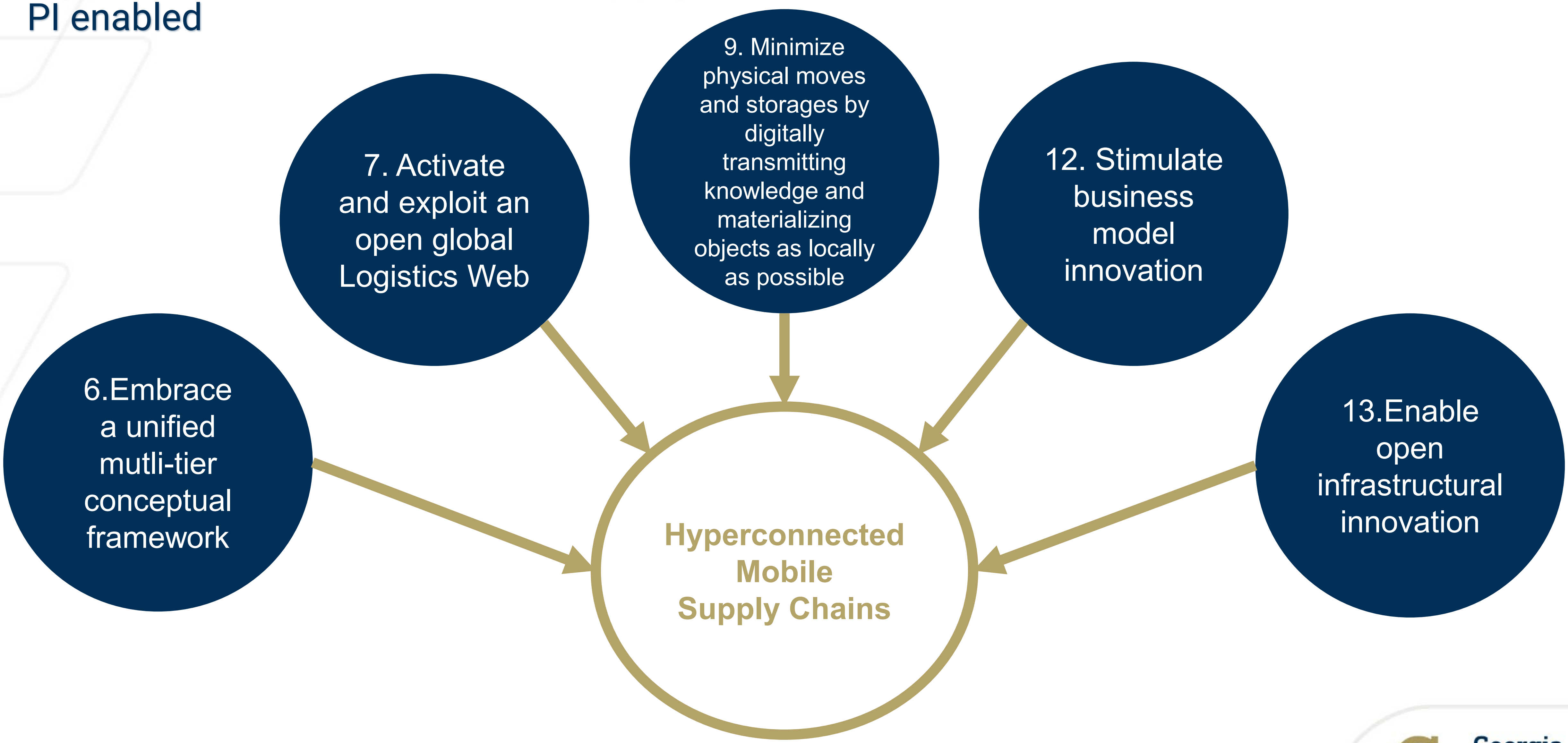
- Horizontal & Vertical Collaboration
- Eco. of scales
- Alliances

Hyperconnected

- PI enabled
- Open assets sharing & Flow consolidation / Co-operations
- No Alliances needed

Hyperconnected Mobile Supply Chains

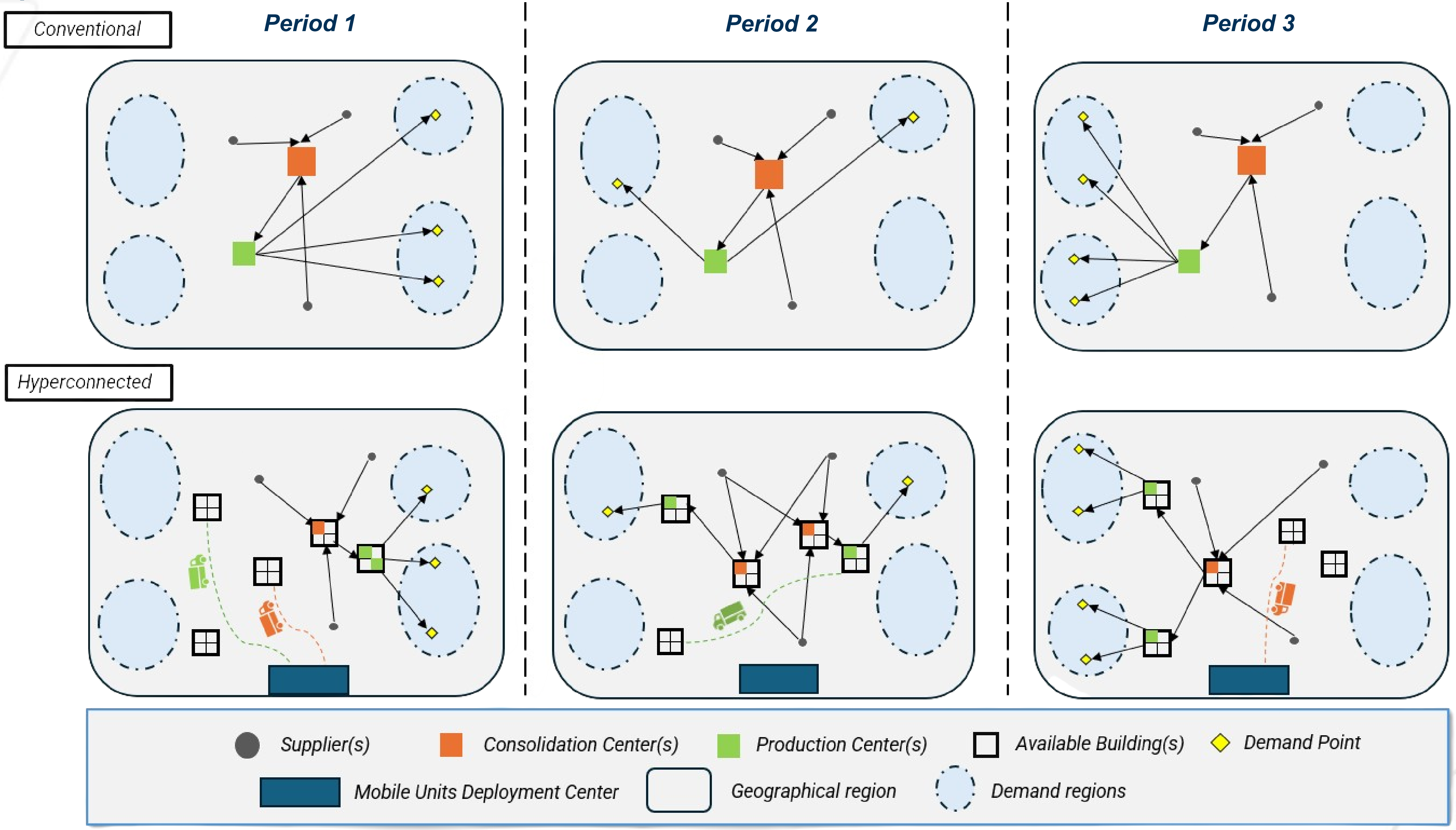
PI enabled



Montreuil, B. Toward a Physical Internet: meeting the global logistics sustainability grand challenge. *Logist. Res.* **3**, 71–87 (2011). https://doi.org/10.1007/s12159-011-0045-x

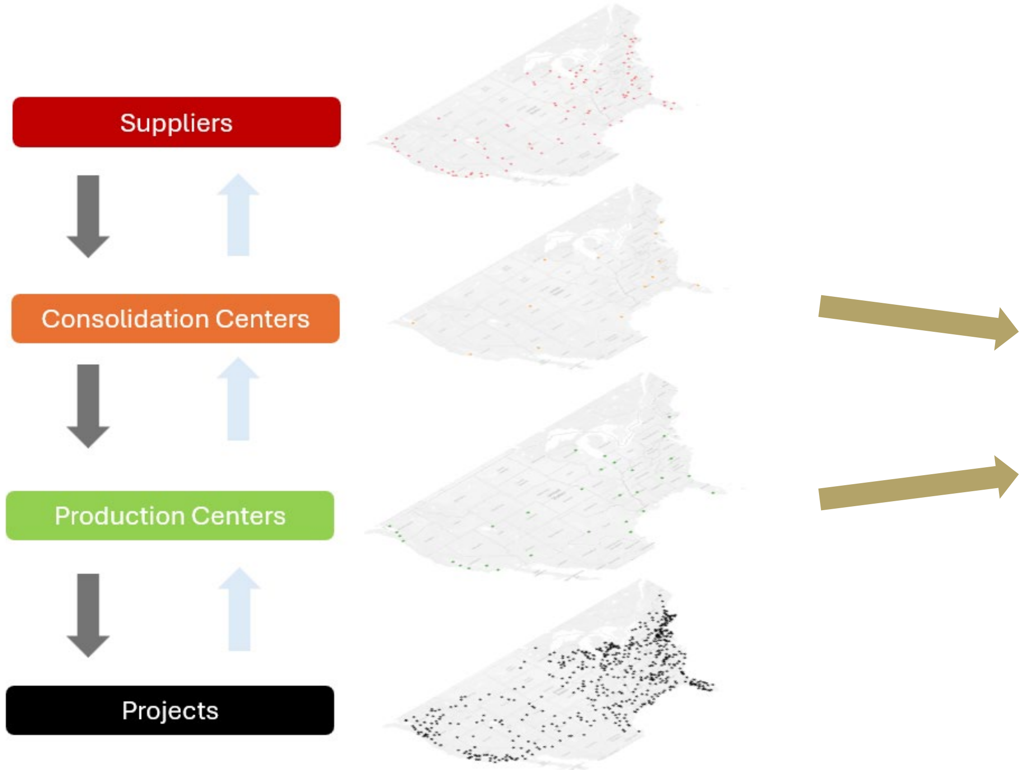
Hyperconnected Mobile Supply Chains

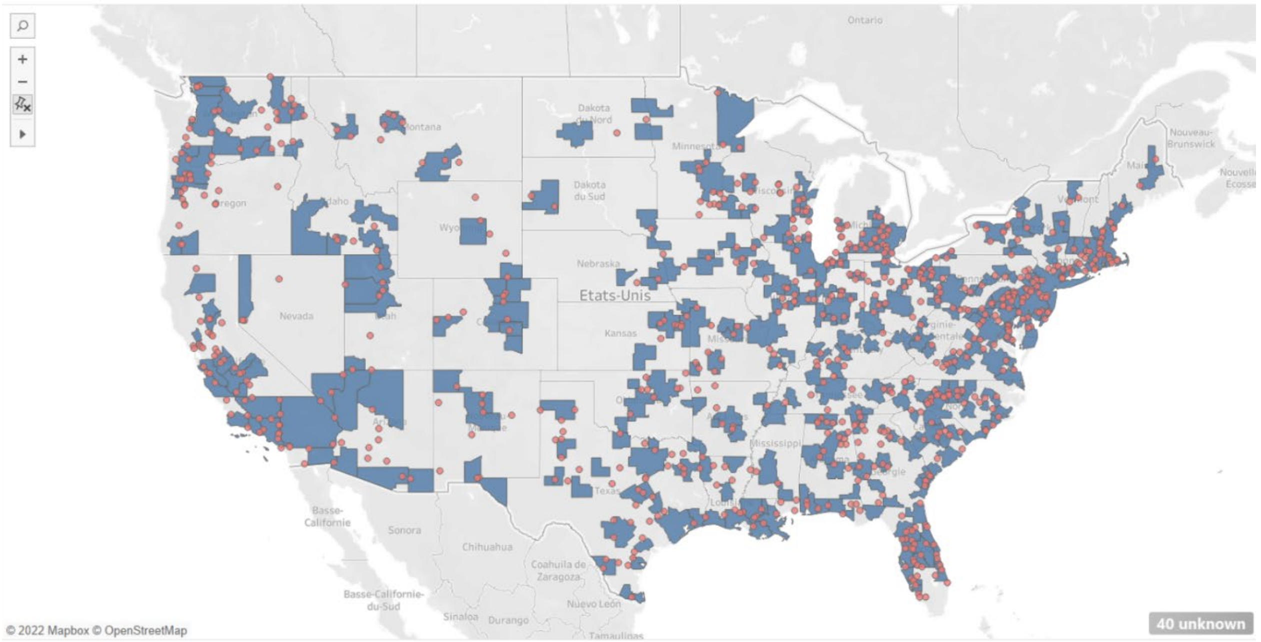
Concept



Problem statement

Given a pool of candidate facilities,
determine for each period the number, size and capacity of facilities to open





: Candidate facilities (743 locations)

: MSA

Hyperconnected Mobile Supply Chains
Model Objectives and Decisions

Objectives of the network:

- Minimize total cost of the network (operating + opening + transportation)

Assumptions:

- Modular capacity by increment of 2
- Deterministic demand

Hyperconnected Mobile Supply Chains
Model Objectives and Decisions

Objectives of the network:

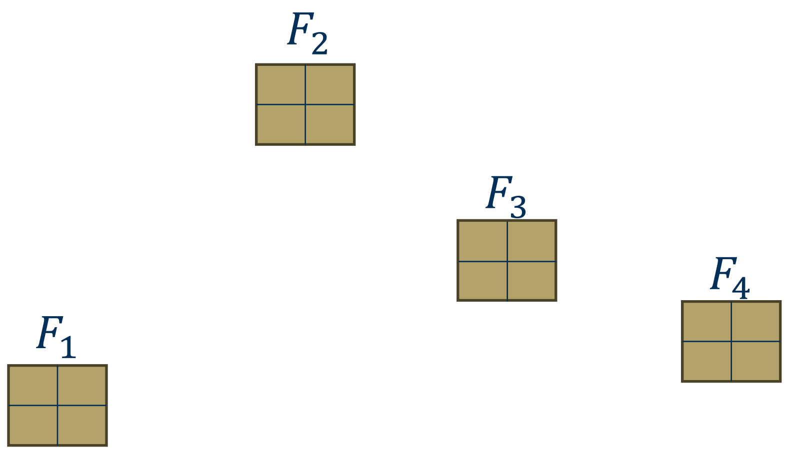
- Minimize total cost of the network (operating + opening + transportation)

Assumptions:

- Modular capacity by increment of 2
- Deterministic demand

Given :

- Set of facilities F



Hyperconnected Mobile Supply Chains
Model Objectives and Decisions

Objectives of the network:

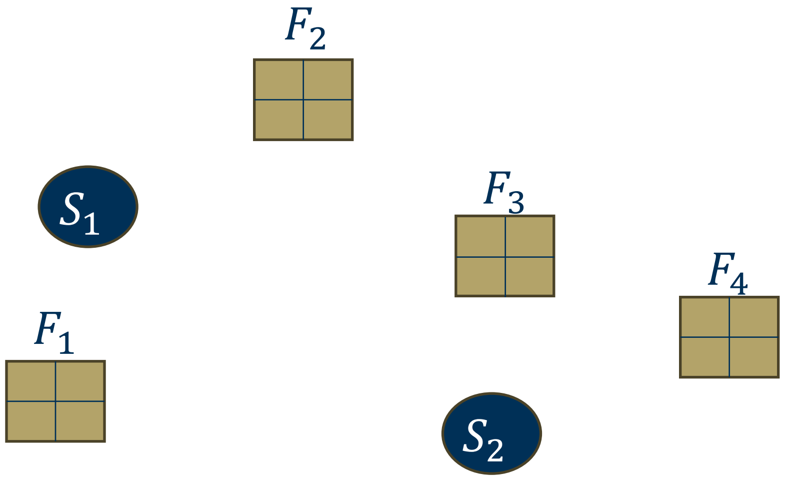
- Minimize total cost of the network (operating + opening + transportation)

Assumptions:

- Modular capacity by increment of 2
- Deterministic demand

Given :

- Set of facilities F
- Set of suppliers S



Hyperconnected Mobile Supply Chains
Model Objectives and Decisions

Objectives of the network:

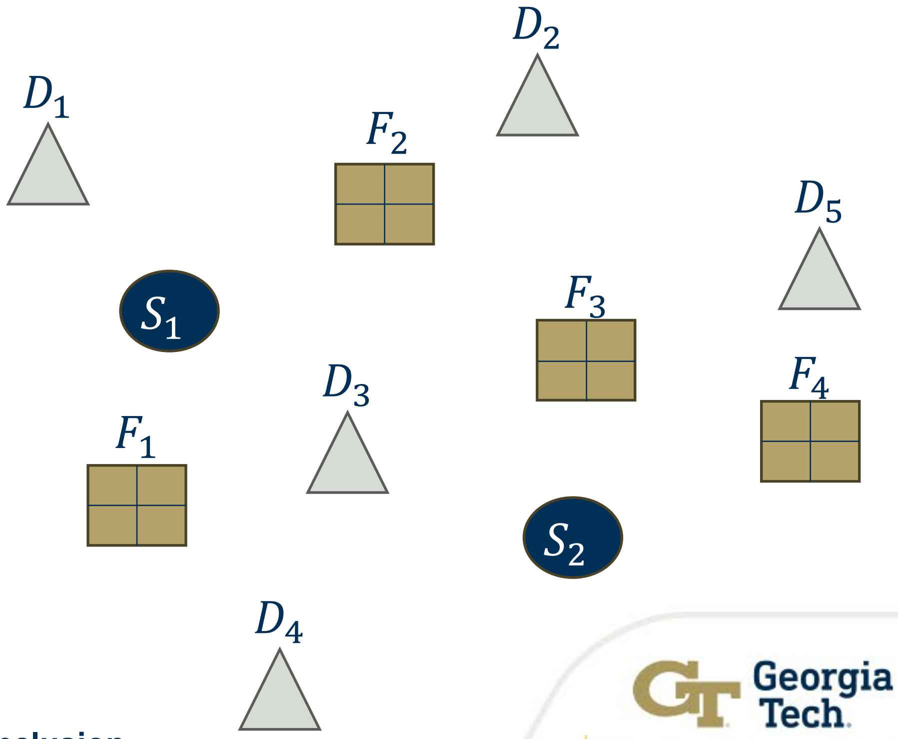
- Minimize total cost of the network (operating + opening + transportation)

Assumptions:

- Modular capacity by increment of 2
- Deterministic demand

Given :

- Set of facilities F
- Set of suppliers S
- Set of demand points D at period t



Hyperconnected Mobile Supply Chains
Model Objectives and Decisions

Objectives of the network:

- Minimize total cost of the network (operating + opening + transportation)

Assumptions:

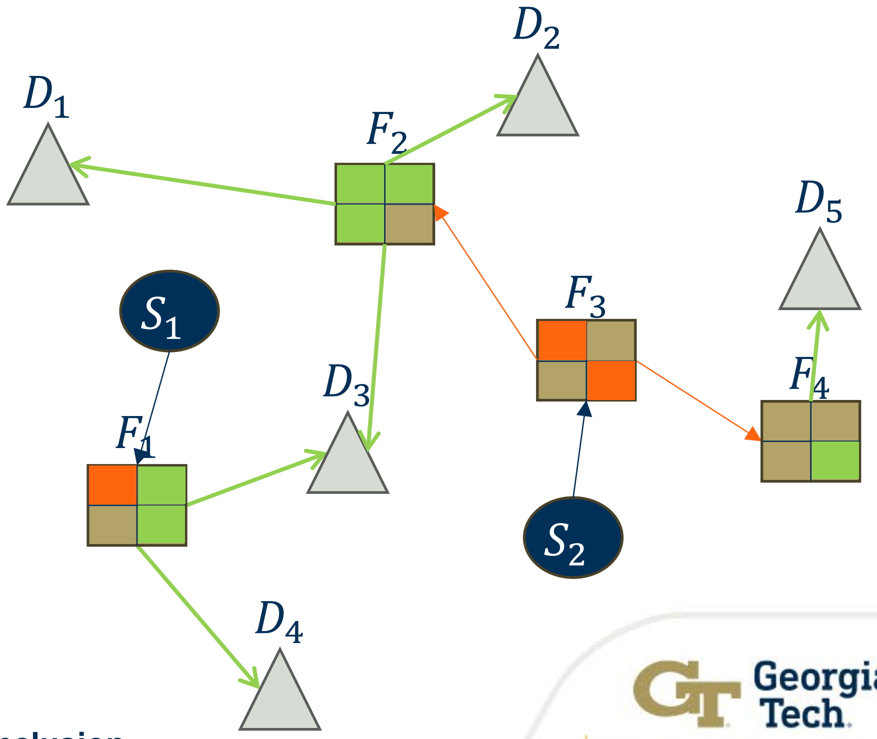
- Modular capacity by increment of 2
- Deterministic demand

Given :

- Set of facilities F
- Set of suppliers S
- Set of demand points D at period t

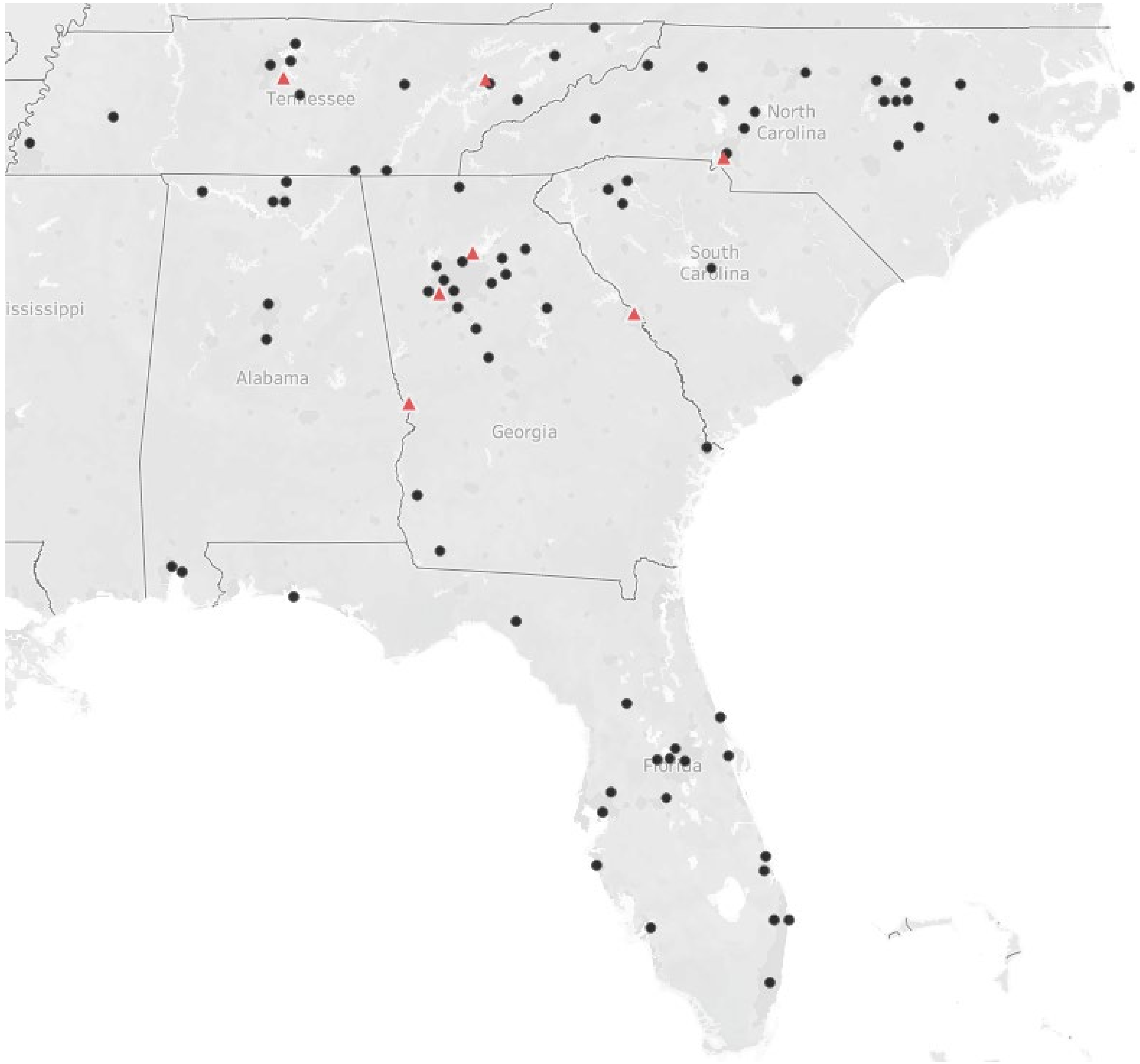
Determine :

- Capacity allocated to a facility for production of Tier 1 and Tier 2
- Volume between facility with Tier 2 production and Tier 1 production
- Volume between facility with Tier 1 production and Market Demand
- Volume between Tier 2 facilities and Suppliers



Case study
Context

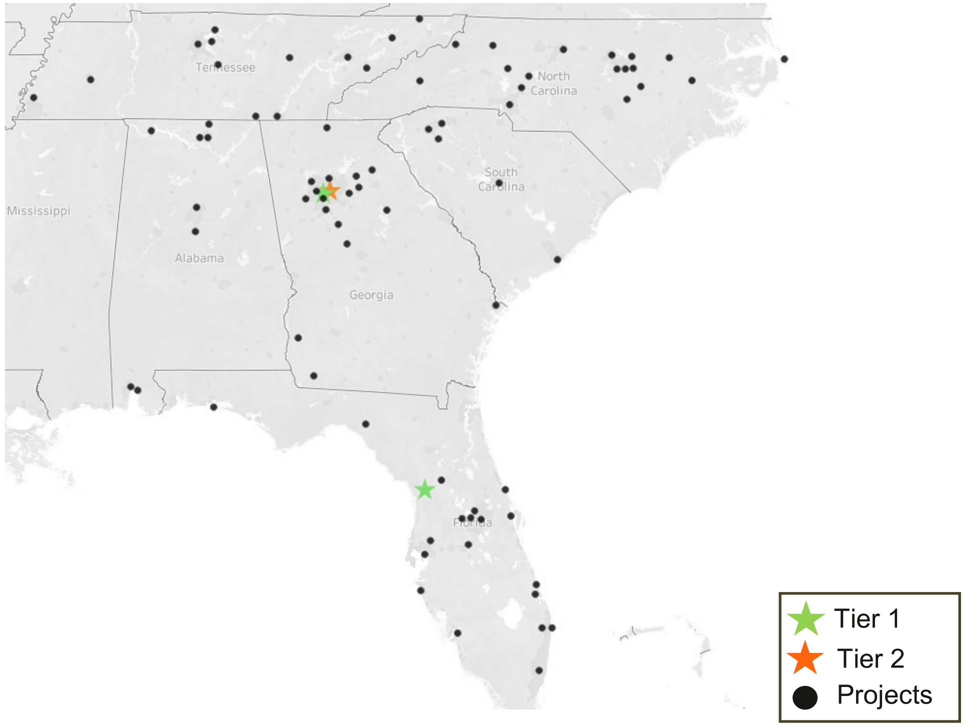
- Focus on Southeast
- 120 demand points corresponding to new hotels
- 7 suppliers
- Time granularity of a month, total of 12 periods



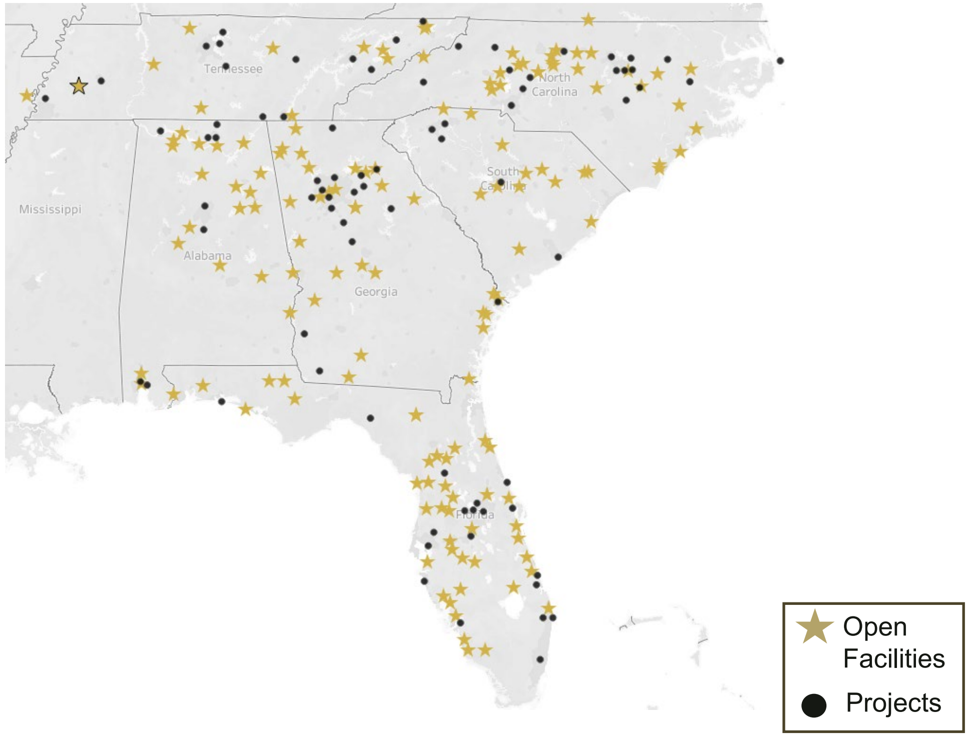
Set of 120 demand points (black) and 7 suppliers (red)

Case study
Context

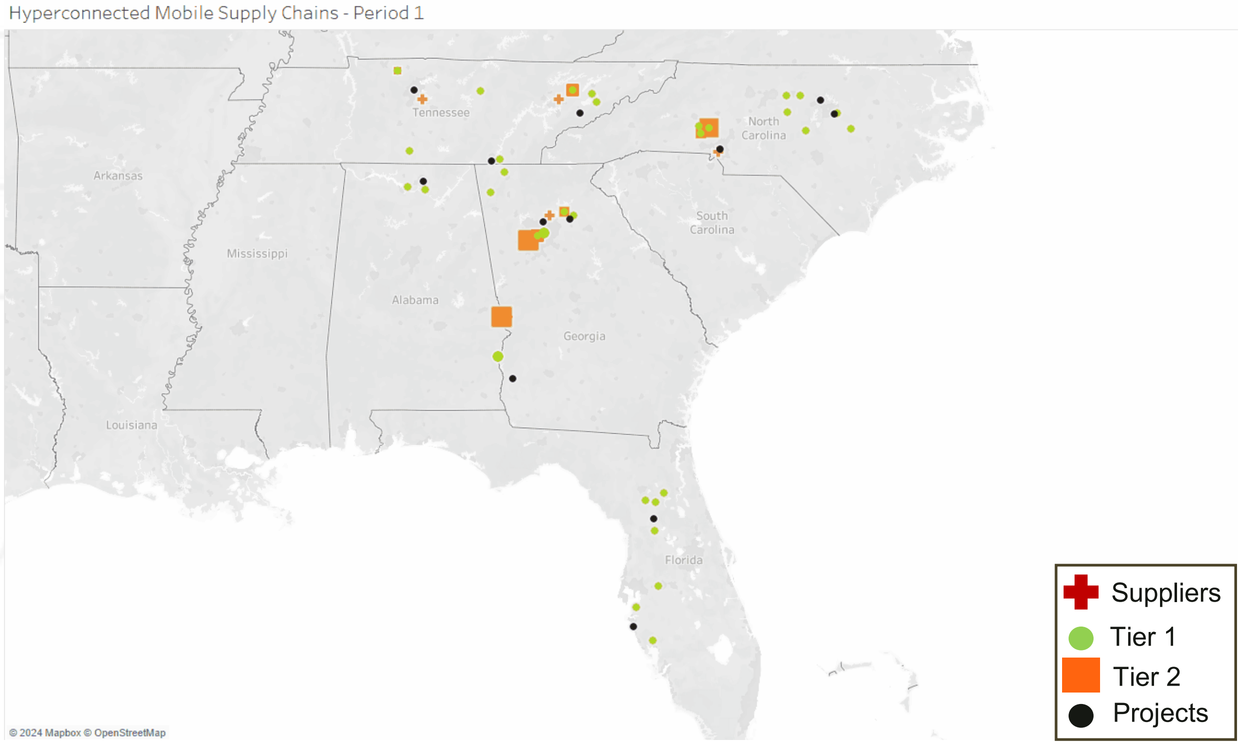
Baseline



Hyperconnected Mobile Supply Chains



Case study
Results



Result of Hyperconnected Mobile Supply Chains network evolution

	Scenario		Improvement
	Base	HMSC	
Avg. Distance Travelled Tier 1 (miles)	172	51.2	70.2%
Avg. Distance Travelled Tier 2 (miles)	244.8	155.6	36.4%
Avg. Distance Travelled Suppliers (miles)	47.8	19.2	59.9%
Average Deployed Capacity Tier 1 (unit/day)	27	2,3	91.2%
Average Deployed Capacity Tier 2 (unit/day)	21	6.5	69%
Total Cost	$ 866,665,832	$ 237,617,100	72%

HMSC outperformed baseline scenario thanks to more flexibility, agility, and smaller sized facilities

Conclusion

Hyperconnected Mobile Supply Chains:

- **Substantial reduction in distanced traveled**
- **Substantial reduction in facilities' size**

Future work:

- ***Multi-objective formulation considering GHG's emissions and societal objective***
- ***Improve GHG's emissions modeling***
- ***Consider stochasticity in the demand***
- ***Run experiments with large scale instances***

Thanks !

julien.maurice@gatech.edu
skwon82@gatech.edu
benoit.montreuil@isye.gatech.edu