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Impact of Modular Containerization on Parcel Logistics Network

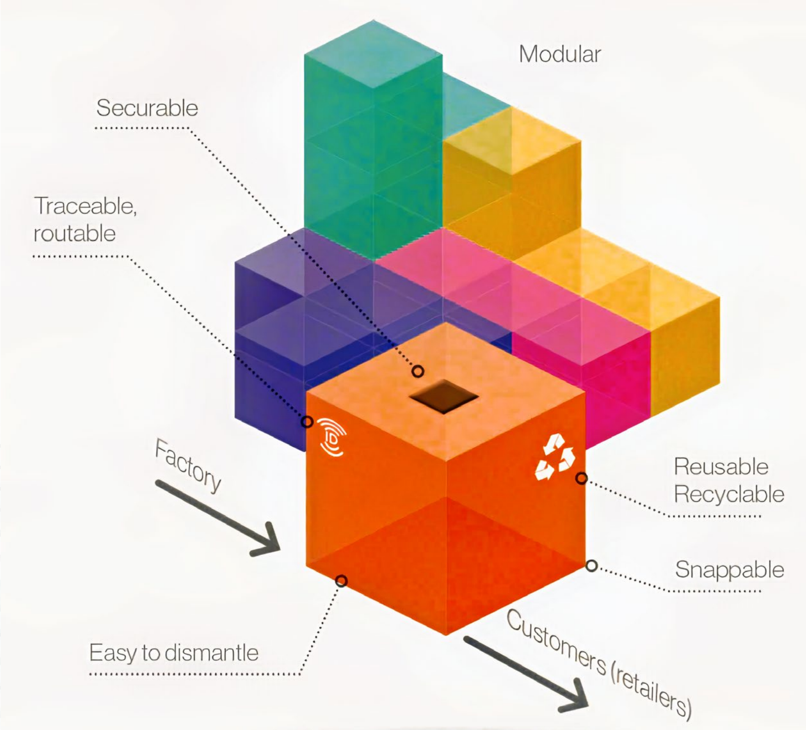
Sahrish Jaleel Shaikh, Nayeon Kim, Mumen Rababah, Benoit Montreuil, Jeffrey S. Smith

Physical Internet Center

AUBURN UNIVERSITY

Corresponding author: sahrish.shaikh@gatech.edu

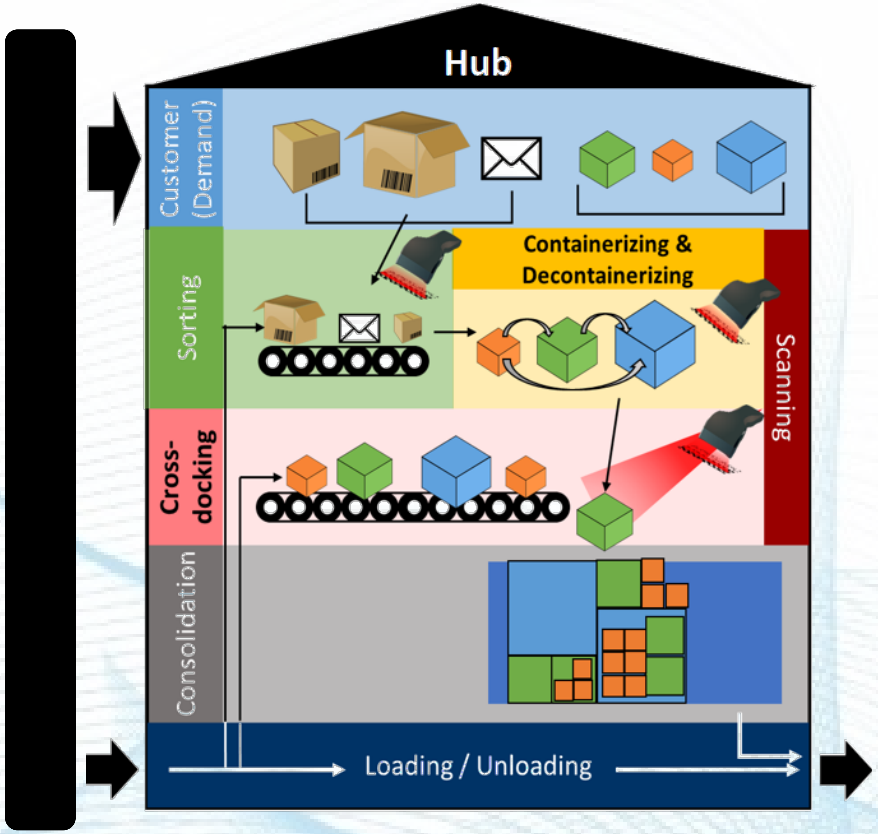
Redefining Parcels: Embracing the π

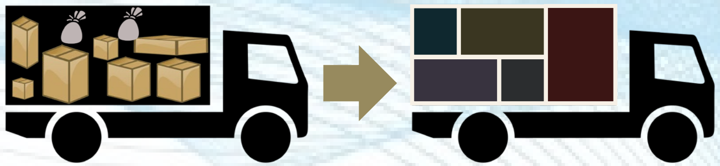


*We assess the **feasibility of using modular containers** for enhanced parcel operations in the **East Coast Region** of the USA. We design and employ **simulation-based scenario designs and assessments** to analyze impact on transportation cost, efficiency, space utilization, and environmental footprint.*

pitney bowes https://www.parcelandpostaltechnologyinternational.com/news/parcels/pandemic-sees-us-parcel-volumes-grow-by-nearly-40-in-2020.html

Unleashing Modular Potential





Simplified Management

Modular containers - easy to handle, store and transport, reducing handling efforts

Superior Reliability

Robust & reliable structure, enhancing truck fill rate by easing stacking constraints

Automation-Friendly

Optimized for automation - supporting efficient (un)loading and container crossdocking

Streamlined Operations

Facilitates dynamic consolidation & deconsolidation across the logistics network

Intelligent Tracking

Smart, efficient tracking through innovative technologies like RFID on containers

Plotting the Path: Containerization Journey

Demand Generation

Create and predict parcel demand using statistical distributions or historical data

System Design

Develop base network and mesh network structures for parcel management.

Design KPIs to evaluate the performance

Simulation Platform

Implement a discrete-event agent-based simulation in AnyLogic

Scenario Modeling

Identify critical features of the containerization

Develop a set of containerization scenarios based on the critical features

Output Analysis

Calculate KPIs from simulation outputs

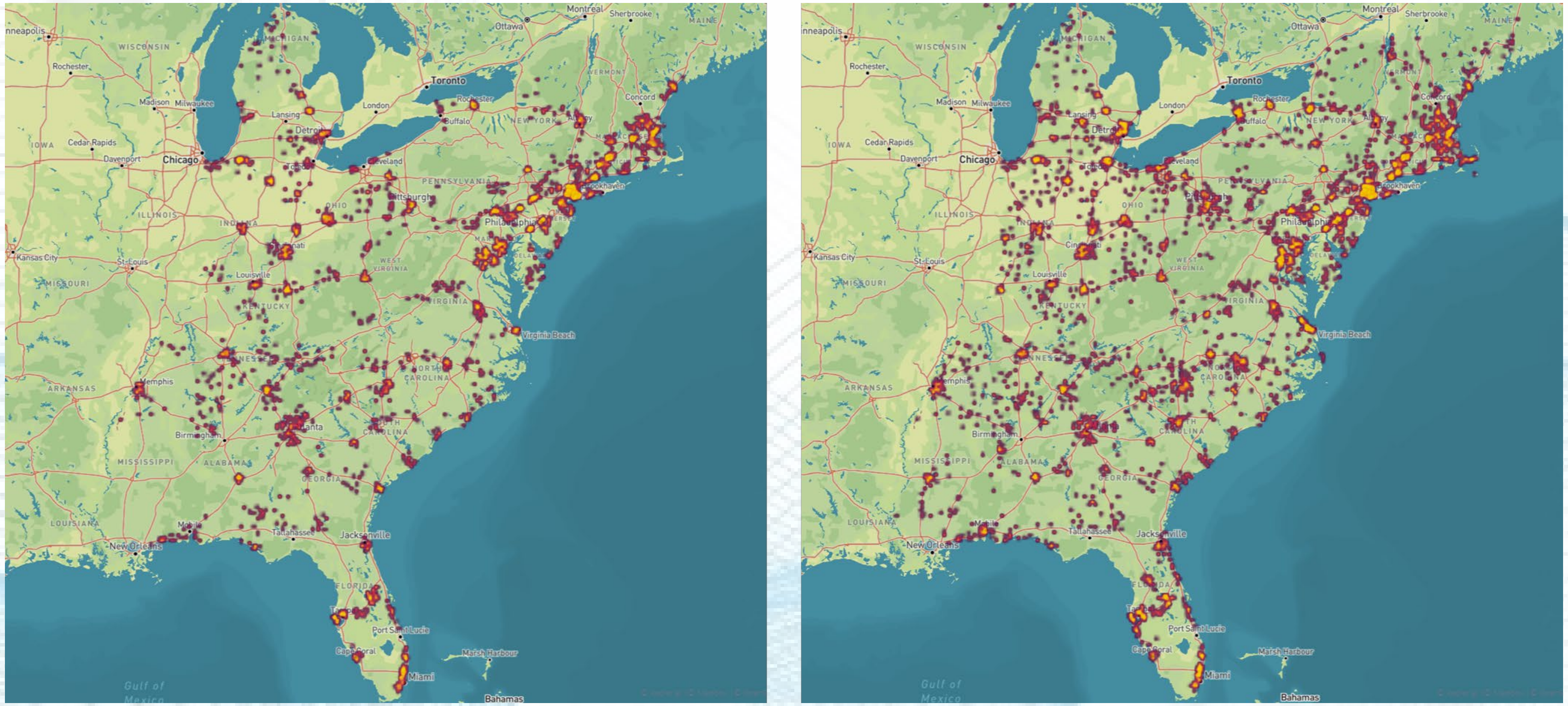
Draw insights from output analysis

Traversing East Coast Demand

- Simulating demand for East Coast USA region
- Over 19 million parcels generated over 10 days
- Using statistical distributions or historical data

Parcel Type	Weight(lb)	Volume (cubic inches)
Small	< 10	< 450
Regular	≤ 75	< 10,000
Irregular	> 75	-

Parcel Types and their Weight-Volume Relationships



Geospatial heatmap representation of parcels generated over 10 days period (Left: Origins, Right: Destinations)

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Network Design : Node Network

- Analyzed demographic data, major cities, highway intersections, and historical flow trends
- Six spatial cluster planes and corresponding hub resource tiers
- Local hubs (tier-2), Gateway hubs (tier-3), and Regional hubs (tier-4)
- Identified potential hub locations for efficient service and reliable parcel delivery

Showcasing the spatial distribution of local hubs (left), gateway hubs (center), and regional hubs (right)

Network Design : Establishing Connectivity

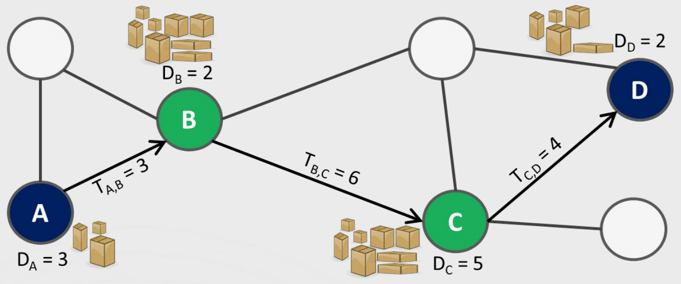
- Horizontal and vertical networks within a multi-tier structure
- Mesh networks within each tier and hyperlinks connecting horizontal networks
- Open or dedicated networks based on usage and accessibility

Showcasing the typical horizontal inter-hub flows of local hubs (left), gateway hubs (center), and regional hubs (right)

Operational Symphony : Key Protocols

1. **Parcel Routing Strategies**

- *Efficient routing of parcels through network*
- *Base network vs. hyperconnected tiered mesh networks*
- *Adherence to service level requirements*



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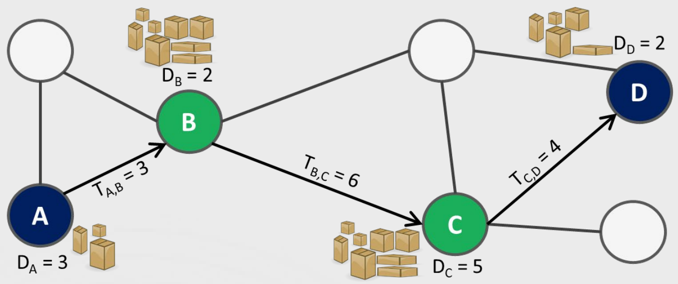
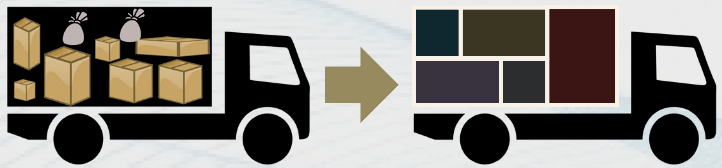


2. **Parcel Consolidation**

- *Utilization of bags and containers*
- *Maximizing load efficiency*
- *Reducing overall transportation costs*



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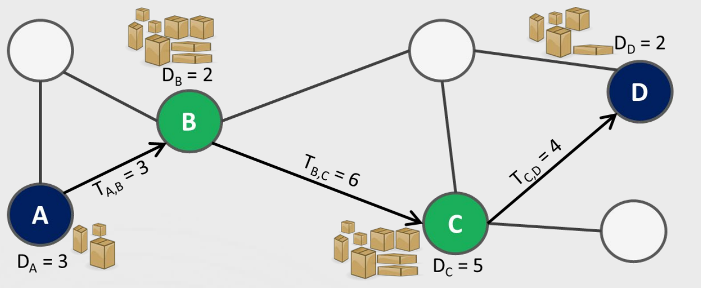

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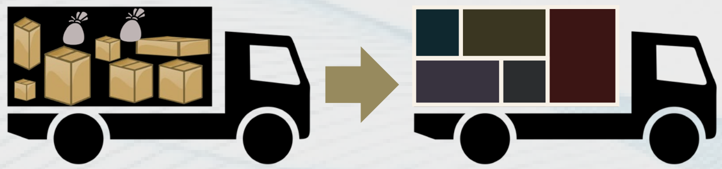
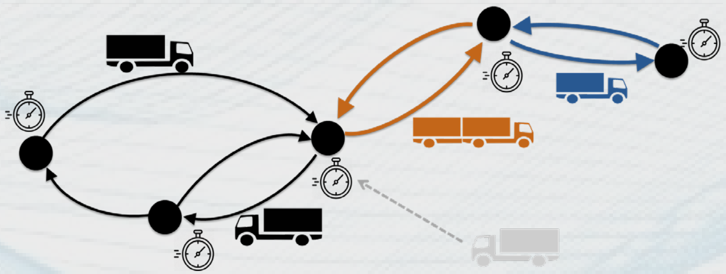


3. **On-Demand Trucking**

- *Flexible transportation solutions*
- *Addressing fluctuations in parcel volume*
- *Streamlining the supply chain and reducing idle time*



Navigating Efficiently: Parcel Routing

Base Network Routing

- *Algorithm: Shortest path algorithm for parcel routing*
- *Direct shipments for service level requirements not met through planned routes*

Algorithm 1

procedure ParcelRoute(O, D, S) ▷ Origin, Destination, Service Level
  $H_O \leftarrow$ nearest hub to O, $H_D \leftarrow$ nearest hub to D, $S' \leftarrow (S -$ time to hubs$)$
  for each $O'D'S'$ combination **do**
    Generate k feasible paths considering S' constraints
    Select a path that maximizes consolidation
  end for
  if package cannot be delivered within S following the selected path **then**
    send parcel directly to D
  else
    send parcel via determined route, traversing hubs until it reaches H_D and finally D
  end if
end procedure

Navigating Efficiently: Parcel Routing

Mesh Network Routing

- *Algorithm: Efficient routing through suitable combination of hubs*
- *Ensuring efficient delivery and meeting service requirements*

Algorithm 2

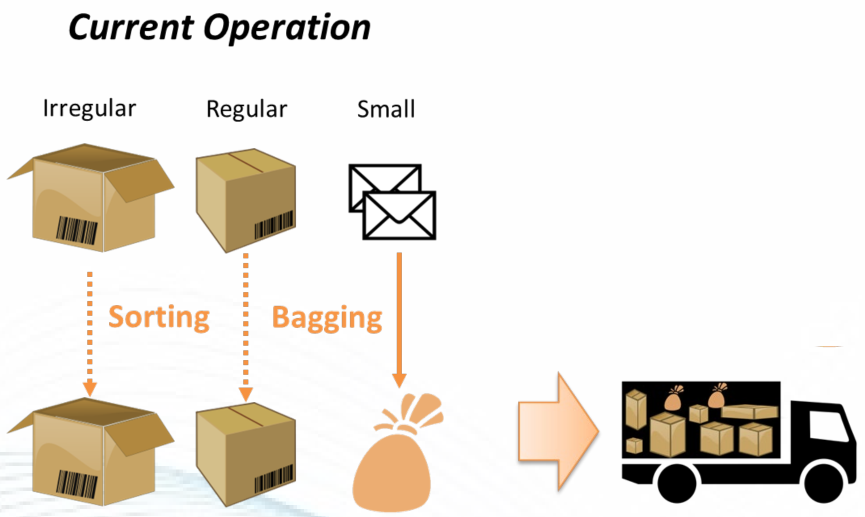
procedure OPTIMALPARCELROUTE(O, D) ▷ Origin, Destination
  if direct path between O and D **then** ▷ Direct path
    send parcel directly to D
  end if
  $LH_O, LH_D \leftarrow$ nearest local hub to O and D ▷ Local Hubs
  if direct path between LH_O and D **then**
    send parcel via LH_O to D
  else if direct path between LH_O and LH_D **then**
    send parcel via LH_O, LH_D, and then to D
  end if
  $GH_O, GH_D \leftarrow$ nearest gateway hub to LH_O and LH_D ▷ Gateway Hubs
  if direct path between GH_O and LH_D **then**
    send parcel via LH_O, GH_O, LH_D, and then to D
  else if direct path between GH_O and GH_D **then**
    send parcel via LH_O, GH_O, GH_D, LH_D, and then to D
  end if
  $RH_O, RH_D \leftarrow$ nearest regional hub to GH_O and GH_D ▷ Regional Hubs
  if direct path between RH_O and GH_D **then**
    send parcel via LH_O, GH_O, RH_O, GH_D, LH_D, and then to D
  end if
  find shortest path from RH_O to RH_D using feasible regional hub connections
  send parcel via determined route, passing through regional hubs until it reaches RH_D, then send it to GH_D, LH_D, and finally to D
end procedure

Tiered hub system:
Local hubs (Tier 2)
Gateway hubs (Tier 3)
Regional hubs (Tier 4)

Optimizing Efficiency: Parcel Consolidation

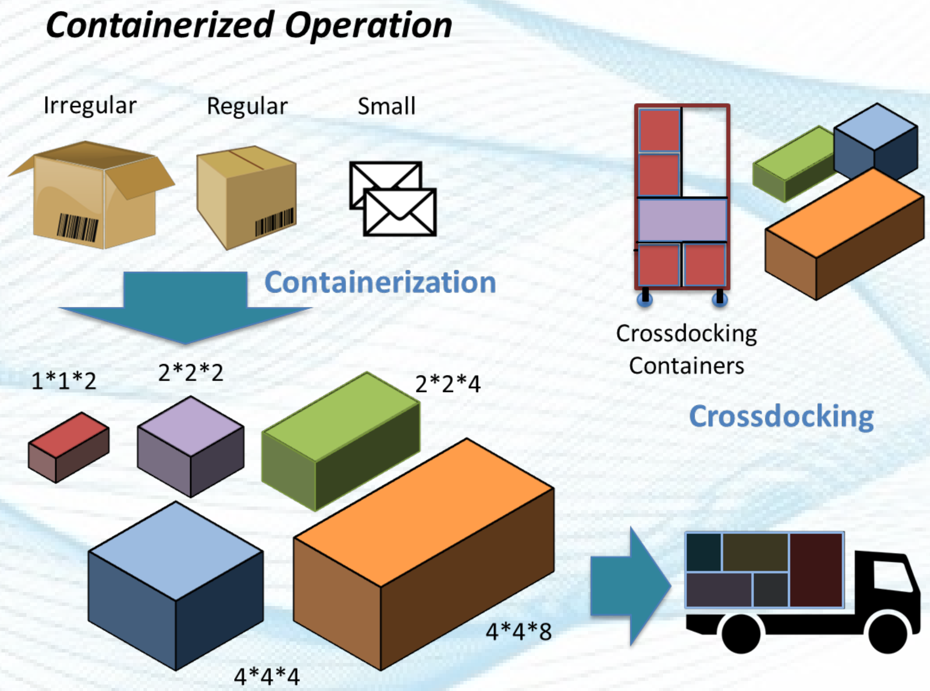
Bag Consolidation

- Two-stage process
- Stage 1: Combine small packages with the same origin, destination, and service level
- Stage 2: Further consolidation at initial hub if fill rate < 50%

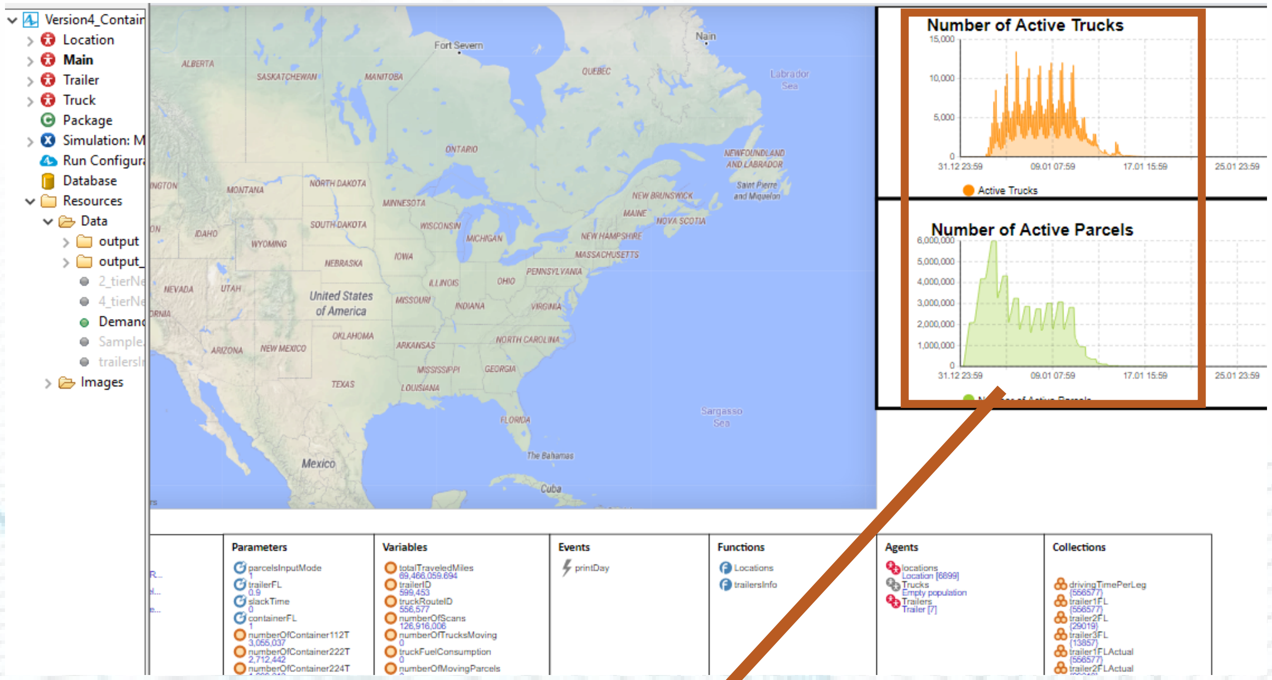


Mesh Network Consolidation

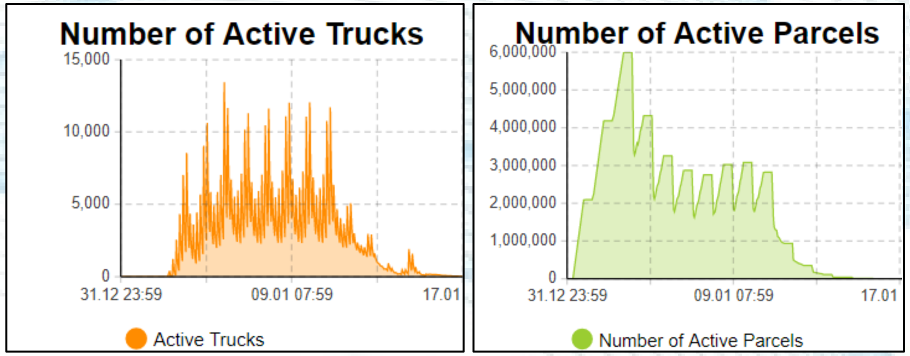
- Utilize π-containers in various sizes
- Elevate packages through tiered hubs based on service level and destination
- Container consolidation occurs at Tier-2 and Tier-3 hubs



Simulation Platform - Specifications

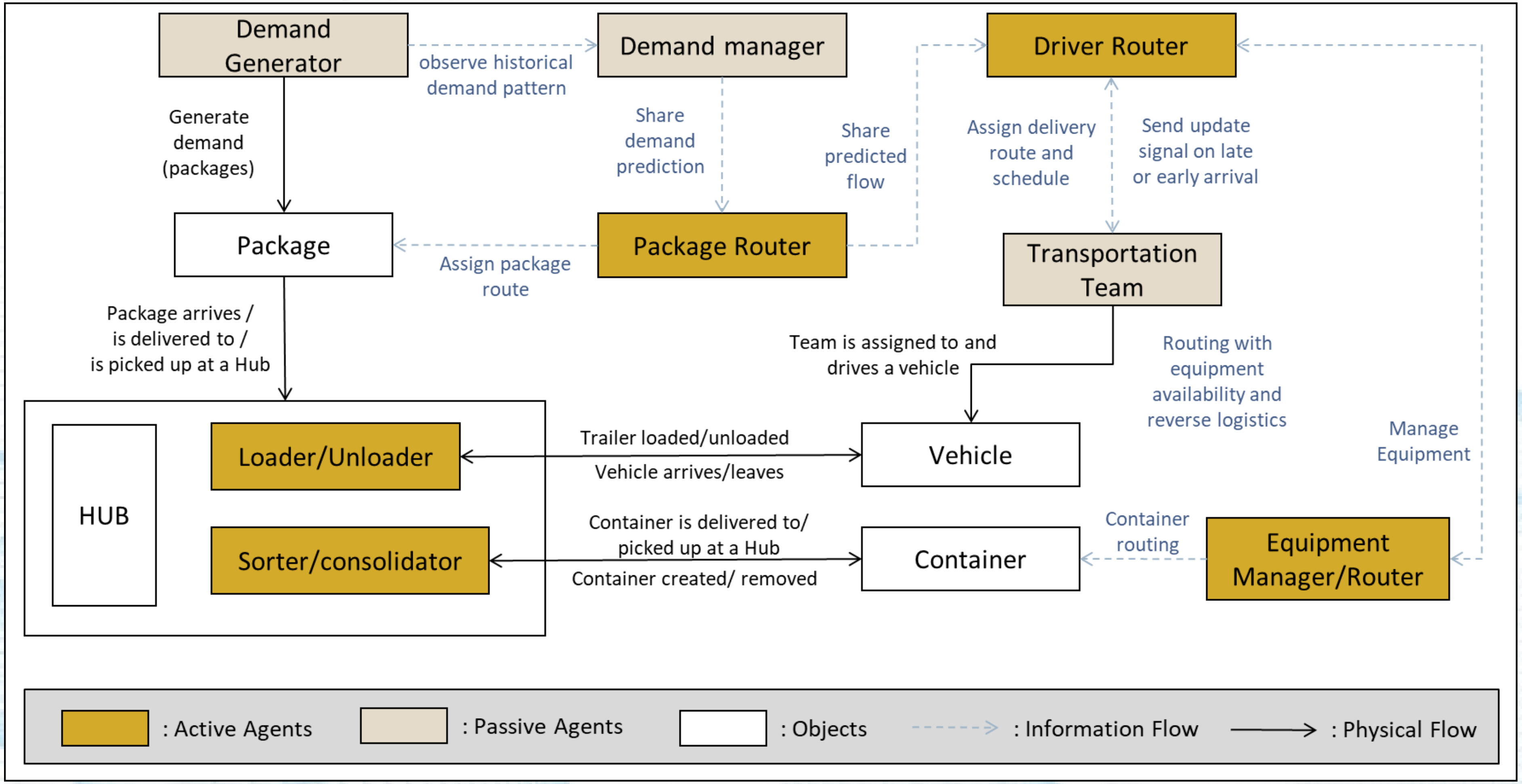


Monitoring during simulation



- Software: AnyLogic®
- Scale
  - ~139M parcels over 10+ days
  - ~10,000 SLICs
- Dynamically manages and tracks all trucks, trailers, parcels, and containers
- Allows monitoring global stats as simulation runs
- Enables testing various scenarios by modifying parameters or input data

Discrete-Event Agent-Based Simulation



Simulation Model of Containerized Parcel Logistic Network

Experimentation

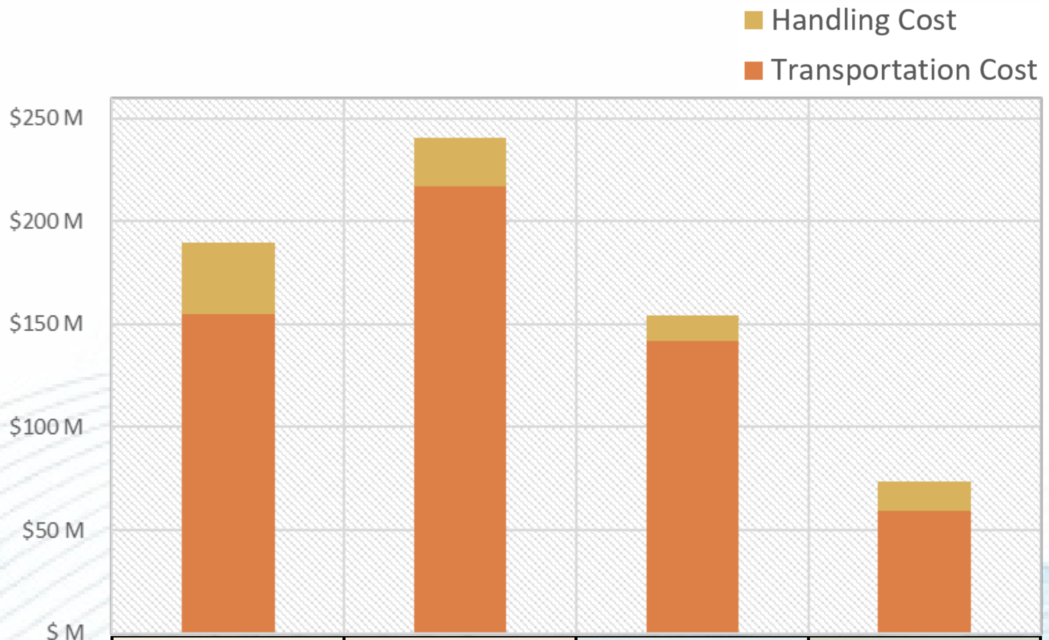
- Generated over 19 million parcels spanning ten days
- East Coast USA region
- Base network with 713 hubs
- Transition to mesh network with hub structure:
  - 457 local hubs
  - 217 gateway hubs
  - 39 regional hubs

Network/ Transportation	Containerization		
	No containers (NC)	Single Large Container (SLC)	Various Size Containers (VC)
Base Network	Scenario 1 (BN-NC)	Scenario 2 (BN-SLC)	Scenario 3 (BN-VC)
Tiered Mesh Network			Scenario 4 (MN-VC)

Driving Efficiency

Reducing Operational Costs

- Operational costs reduced by **61%** with **mesh network (MN)** and **various sizes of containers (VC)**
- Handling cost reduced by using containers; saving is larger under base network **(BN)** as parcel and vehicle routes focused on **efficiency** whereas those in **(MN)** focused on **service** utilizing crossdocking and on-demand transportation
- Mesh network can reduce transportation cost significantly



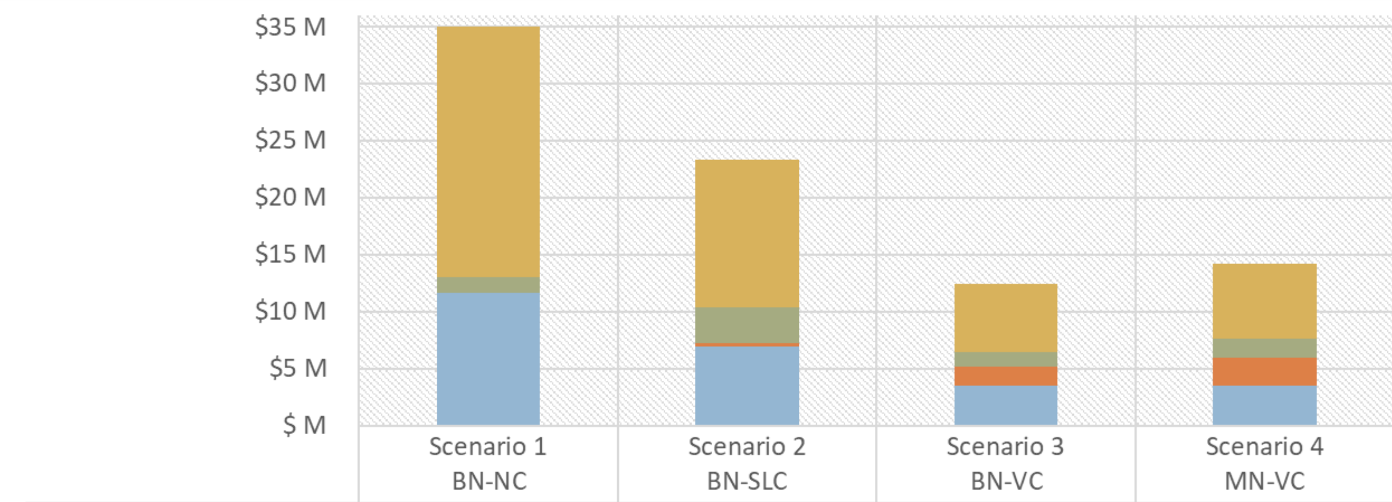
	Scenario 1 BN-NC	Scenario 2 BN-SLC	Scenario 3 BN-VC	Scenario 4 MN-VC
Total Operations Cost	$ 190 M	$ 241 M	$ 154 M	$ 74 M
Savings		$ -51	$ 36 M	$ 116 M
% Savings		27%	19%	61%
Transportation Cost	$ 155 M	$ 217 M	$ 142 M	$ 60 M
Savings		$ 62 M	$ 13 M	$ 95 M
% Savings		40%	9%	51%
Handling Cost	$ 35 M	$ 23 M	$ 12 M	$ 14 M
Savings		$ 12 M	$ 23 M	$ 21 M
% Savings		33%	65%	60%

Efficient Handling Strategies

Minimizing Handling Costs

- Total handling cost savings are maximized (up to **65%**) with container operation in **base network** (Scenario 3)
- **Mesh network** operation reduces the handling cost by **~60%**, accounting for the new transportation and routing scheme (Scenario 4), which induces more **modular container operations** that can be **standardized and automated**

Component-wise handling cost for each scenario



	Scenario 1 BN-NC	Scenario 2 BN-SLC	Scenario 3 BN-VC	Scenario 4 MN-VC
Loading/Unloading	$22 M	$13 M	$6 M	$7 M
Bagging/Containerizing	$1 M	$3 M	$1 M	$2 M
Crossdocking (Containers)		$252 K	$2 M	$2 M
Sorting (Parcels,bags)	$12 M	$7 M	$3 M	$3 M

Cost Structure

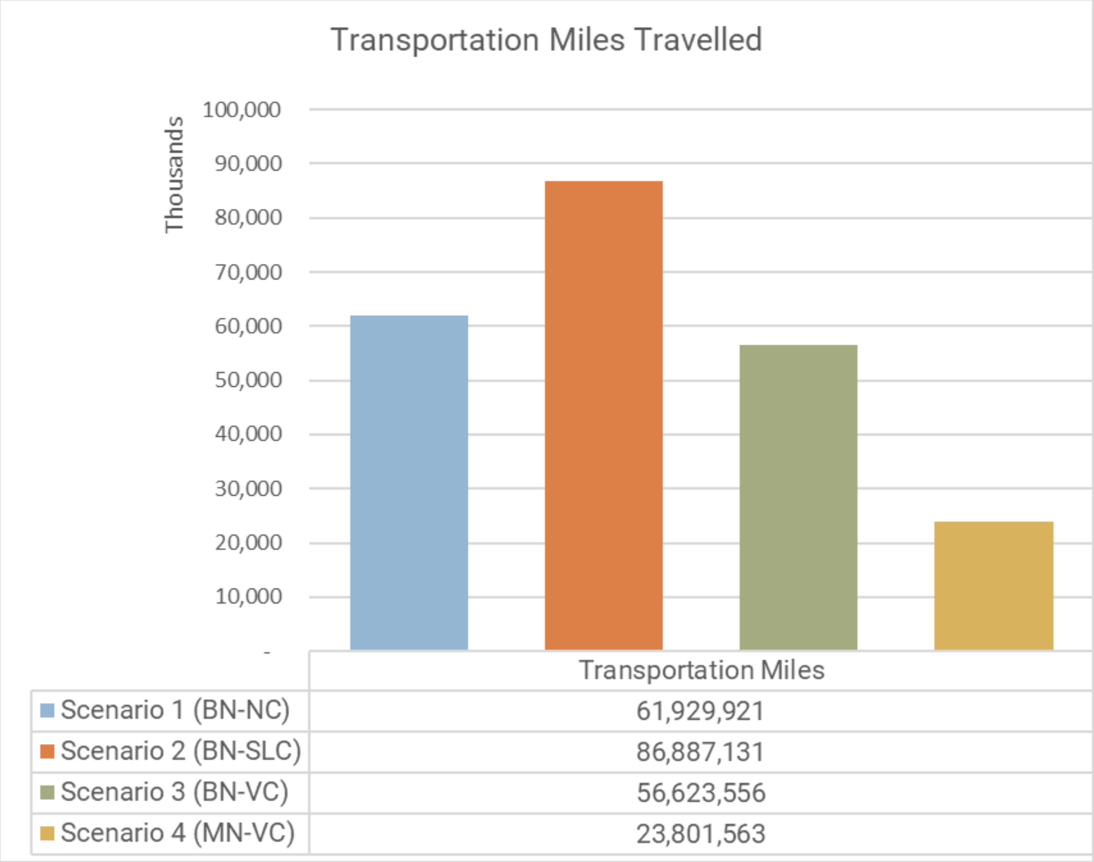
$ per unit handling	Unloading	Emptying	Sorting	Filling	Crossdocking	Loading
Parcel - Irregular	0.55		0.55			0.55
Parcel - Regular,Small	0.15		0.15			0.15
Bag	0.16	0.16	0.16	0.16		0.16
Large Container	1.61	0.24		0.24	0.15	1.61
Small Container	0.27	0.04		0.04	0.10	0.27

The cost structure used in the study was based on previous research conducted for an international parcel delivery company.

Cost-Effective Transport

Reducing Transportation Cost

- Significant reduction in transportation costs
- BN-NC: Transportation costs → $155 m
- MN-VC: Transportation costs **decreased to $60 m**
  - **Reduction in number of trips** required to transport parcels
  - Total trips(MN-VC)
    - 174,618 (**19% lower** than scenarios 1-3)
  - Higher fill rates and 3-trailer trucks
  - Mesh network's **efficient use of container space**

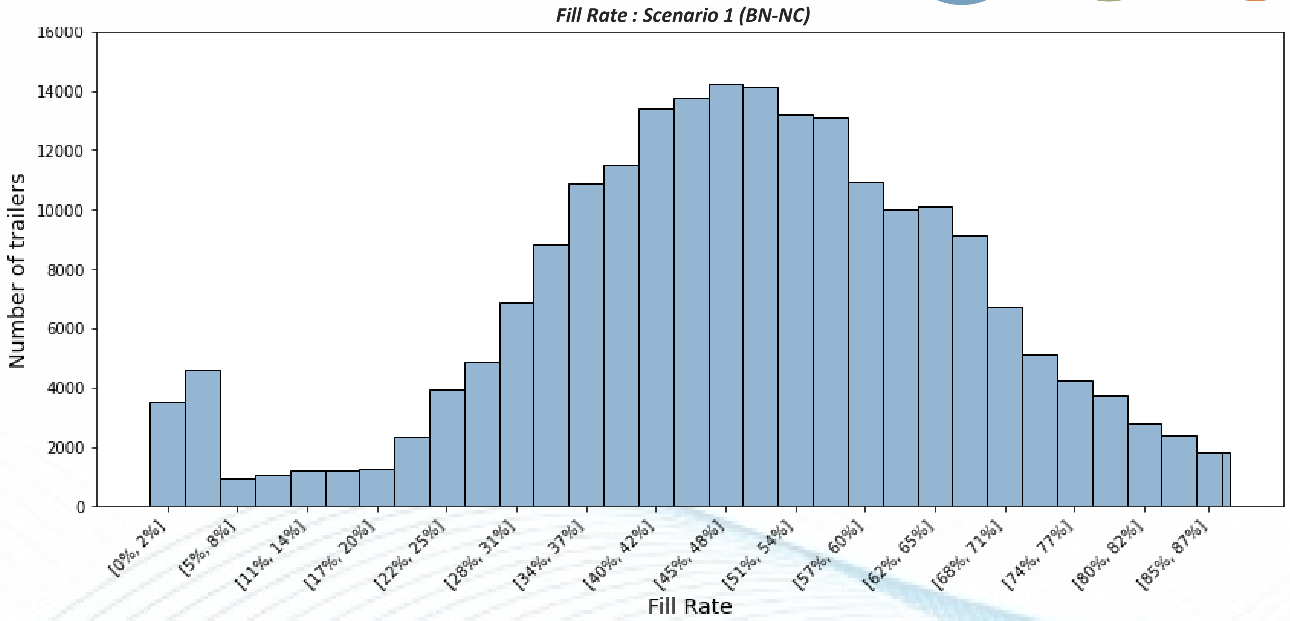


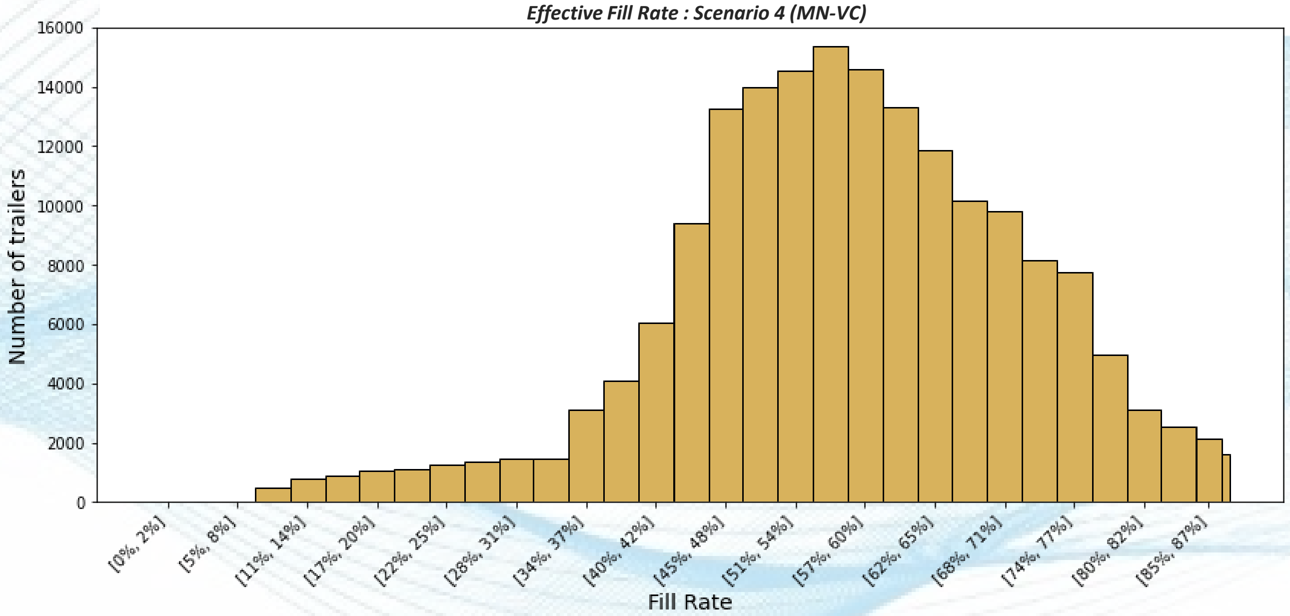
Efficient Load Utilization

Boosting Truck Fill Rates

- **Effective fill rate** = Parcel volume / Trailer volume
- Indicates utilization of trailer space
- Significant increase in **three-trailer truck utilization** in MN
- 3-trailer trucks depict higher consolidation legs and have a **higher fill rate** as compared to 1-trailer trucks which may be running on low volume legs

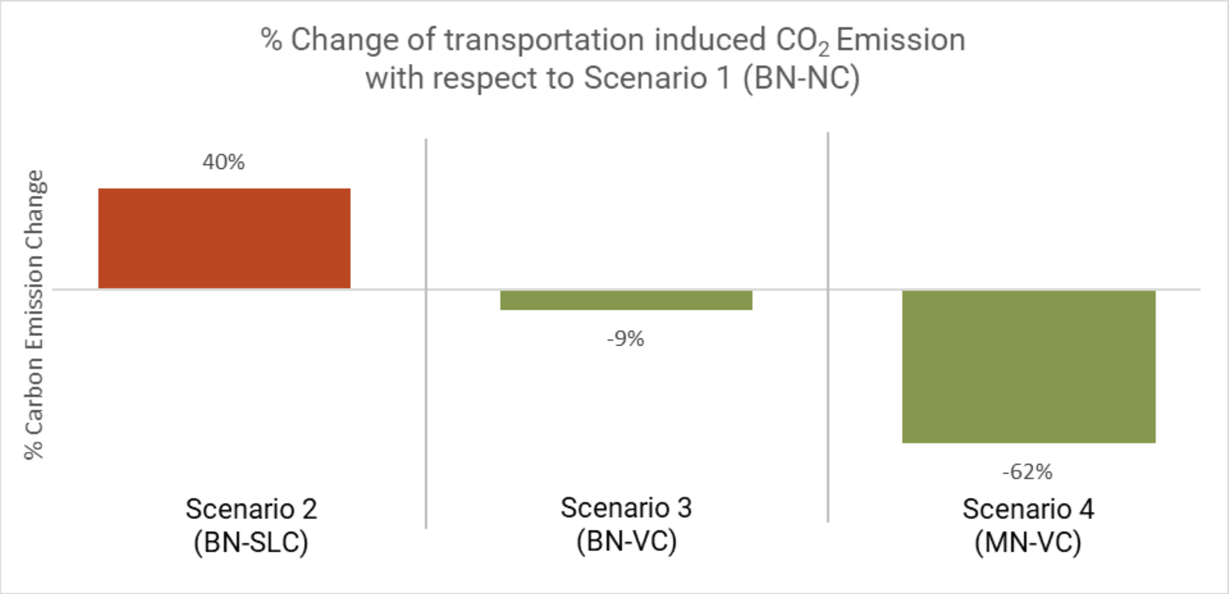
	Scenario 1 BN-NC	Scenario 2 BN-SLC	Scenario 3 BN-VC	Scenario 4 MN-VC
Number of trips	213,100	215,457	214,940	174,618

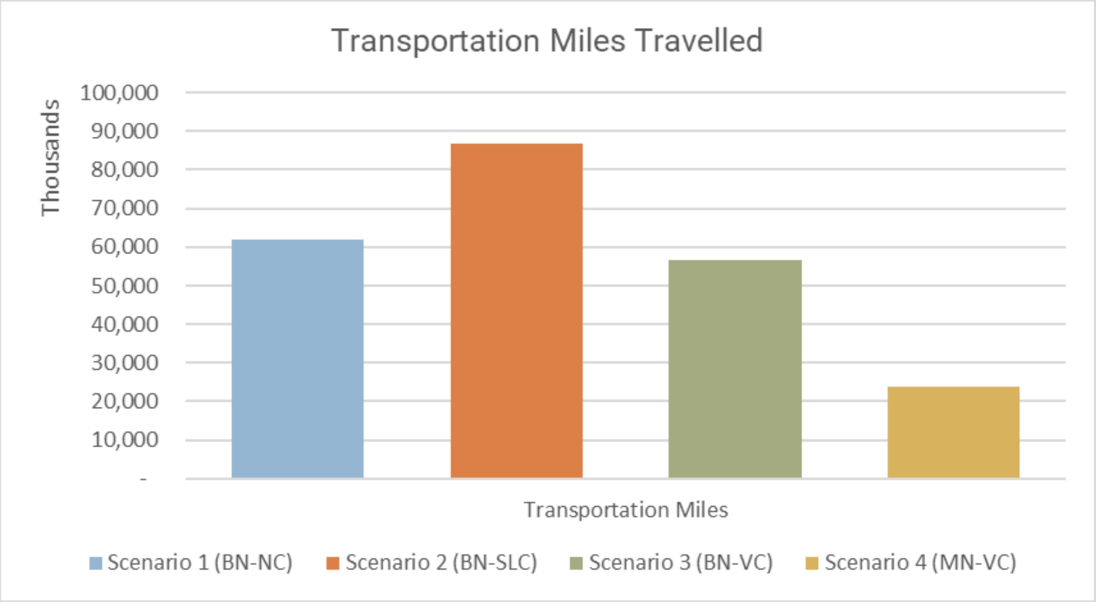




Sustainable Operations

Reducing Environmental Footprint



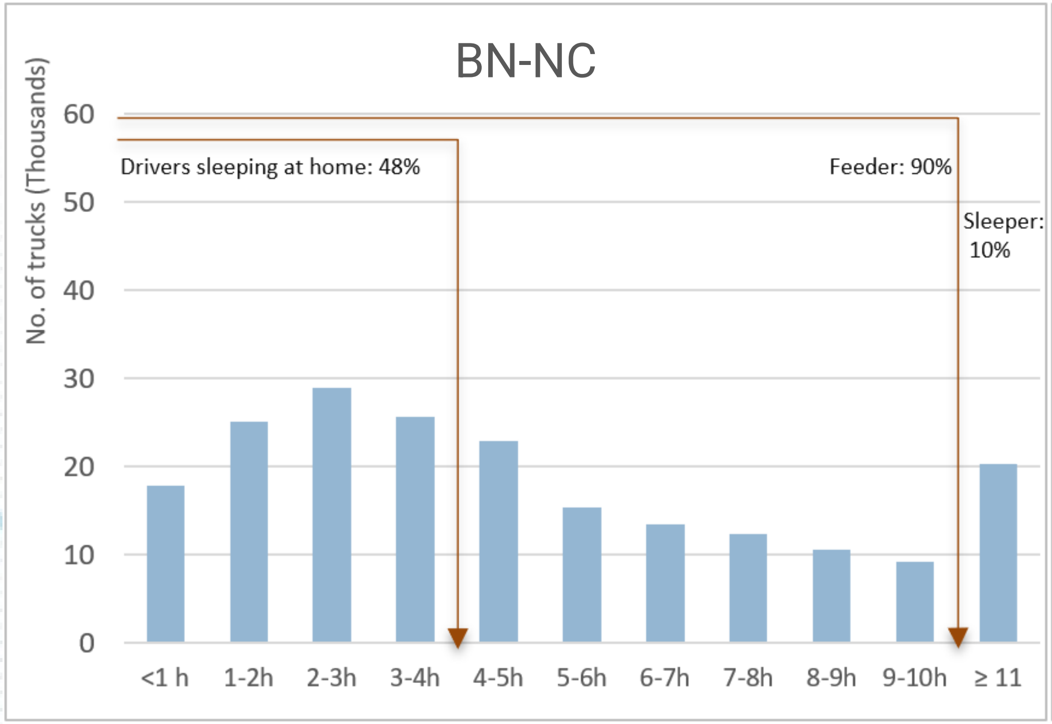


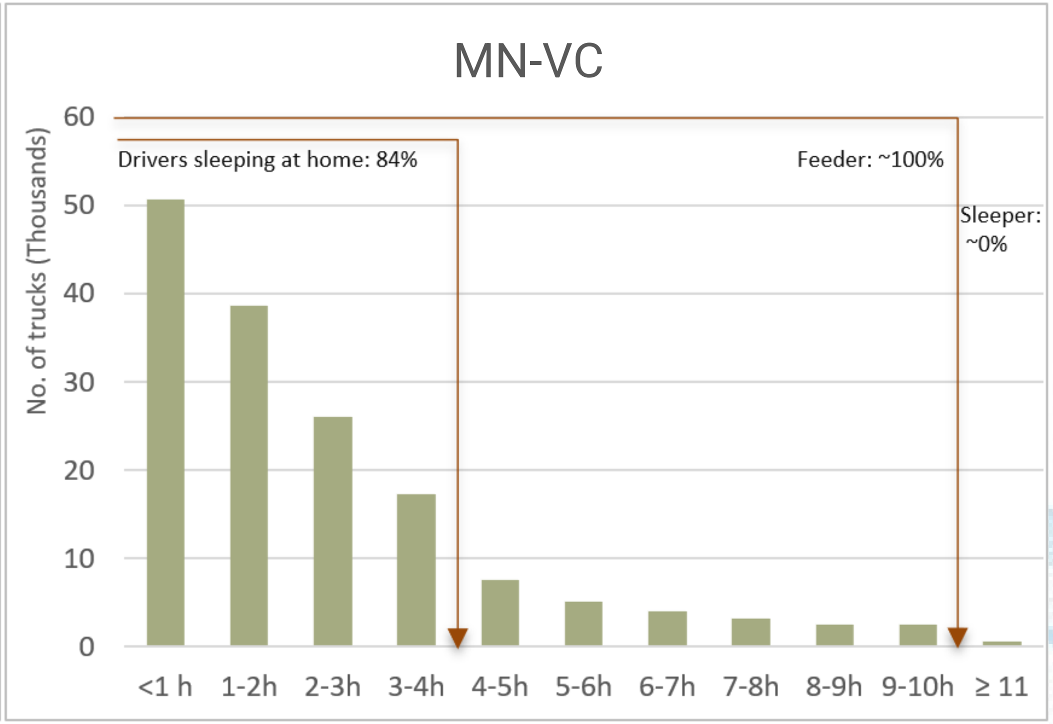
Reduction of CO_2 emissions from transportation activity **by over 60%**

This significant decrease contributes to a ***greener and more sustainable future***

Empowering Drivers

Enhancing Operational Performance





- In Mesh network, **truck leg length average is shorter**
- **Base** network → **48%** of truck legs are short enough (<4 hours)
- **Mesh** network → **84%** of truck legs are short enough (<4 hours) for **drivers can sleep at home**
- Almost all legs can be covered by **feeder truck** whereas currently **10% of legs** require **sleeper teams** in base network

Concluding Remarks & Future Work

Examine containerization and mesh networks' impact on costs, space utilization, and environmental factors

Emphasize benefits of strategies, highlight driver well-being and reduced driving distances' significance

- Key areas to explore include:
  - Influence of other factors on transportation costs and efficiency, such as the nature of the cargo, the size and capacity of trucks, and the geographical location of transportation hubs
  - Application of advanced technologies, including automation and artificial intelligence, in transportation operations to optimize efficiency further

Questions?