VALUE OF PHYSICAL INTERNET-DRIVEN COLLABORATIVE MANAGEMENT IN MULTI-ACTOR SUPPLY AND DISTRIBUTION NETWORKS

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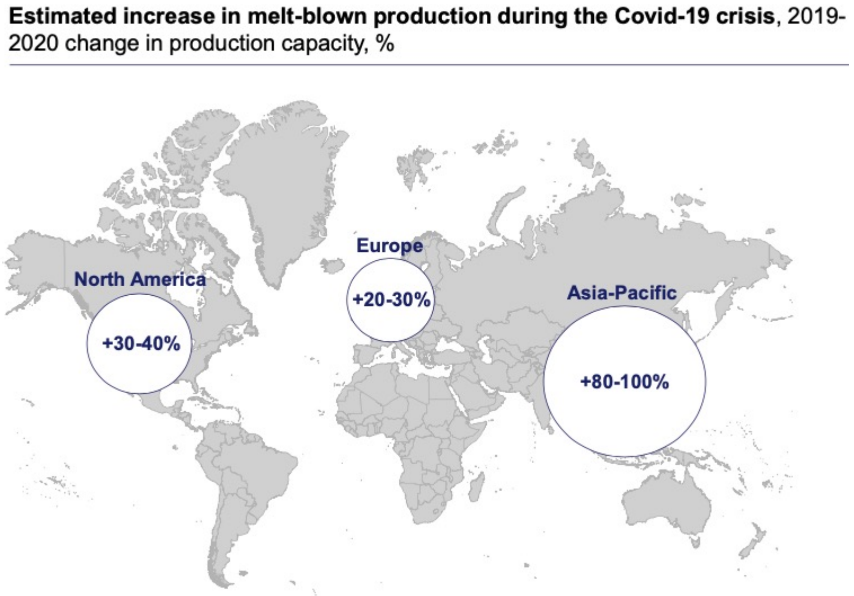
Georgia Tech

Motivation

Societally Critical Products are essential to the well-being and functioning of society. Their availability has a high impact on economic activity, social welfare and health and whose supply is subject to scarcity, uncertainty, disruptions and threats.

- *High impact on industries that provide items that are essential for the health and well-being of all*
- *High dependency on international trade to get access to these goods*

Source: https://www.myamericannurse.com/survey-nurses-fear-going-to-work-due-to-lack-of-protection-from-virus/



Source: https://www.ifc.org/wps/wcm/connect/1d32e536-76cc-4023-9430-1333d6b92cc6/210402_FCDO_GlobalPPE_Final+report_v14updated_gja.pdf?MOD=AJPERES&CVID=nyiUnTU

Source: https://www.theguardian.com/business/2021/oct/20/supply-chain-crisis-california-ports-cargo-ships

Motivation

- During the COVID-19 pandemic, demand for critical consumables skyrocketed while the supply was scarce due to limited production capacity
- Demand-induced scarcity is caused by panic-buying consumers who exhibit hoarding behaviour under conditions of perceived scarcity
- In such a disruption, suppliers display a high variance where deliveries may be late, made in entirety or partially, or may not be made at all. In short, the suppliers may not be able to hold the promise of delivery.

Our Approach : A Living Lab Initiative

Controlled Strategies
Strategies that should be in place during undisrupted supply

Contingency Strategies
Strategies that can be used during periods of anticipated shortages

Crisis Strategies
Strategies that can be used when supplies are highly disrupted

An end-to-end integrated and shared supply and distribution system of personal protective equipment to safely continue essential operations amid the pandemic

- *Develop & provide user protocols*
- *Consider consumption behavior*
- *Inclusive and participative*
- *Minimal burden on users*

- *Guarantee access to PPE while maintaining lean inventory*
- *Minimize extra labor*
- *Seamless persistent response*

- *Persistent protection of users during Covid-19*
- *Minimize contact*
- *Safe packaging*

Our Living Lab Approach – Key Aspects

Value:
Focus on understanding needs and motivators

Influence:
Input from stakeholders is used

Sustainability:
Continuous Learning

Openness:
Engagement of multi stakeholders to participate

Realism:
Make real world implementations and simulations

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Sources: [Steen, Kris & van Bueren, Ellen. (2017). Urban Living Labs: A Living Lab Way of Working.], [Dr. Marita Holst, Botnia LL Director. Presented at CSC 2016: Living Labs and Open Innovation], [Institute of Medicine. 2012. Crisis Standards of Care: A Systems Framework for Catastrophic Disaster Response]

Proposed System Layers

- **Physical layer:** *Multi-tier physical network structure*
- **Organizational layer:** *Four-tier network of functional nodes and their responsibilities*
- **Informational layer:** *Emphasizes information sharing for effective coordination*
- **Decisional layer:** *Governance framework for decision-making and resource allocation*

Physical Layer

- Multi-tier physical network structure
- Physical nodes → facilities active in the system
- Tiers include tier-0, tier-1, tier-2, tier-3, with higher tiers possible

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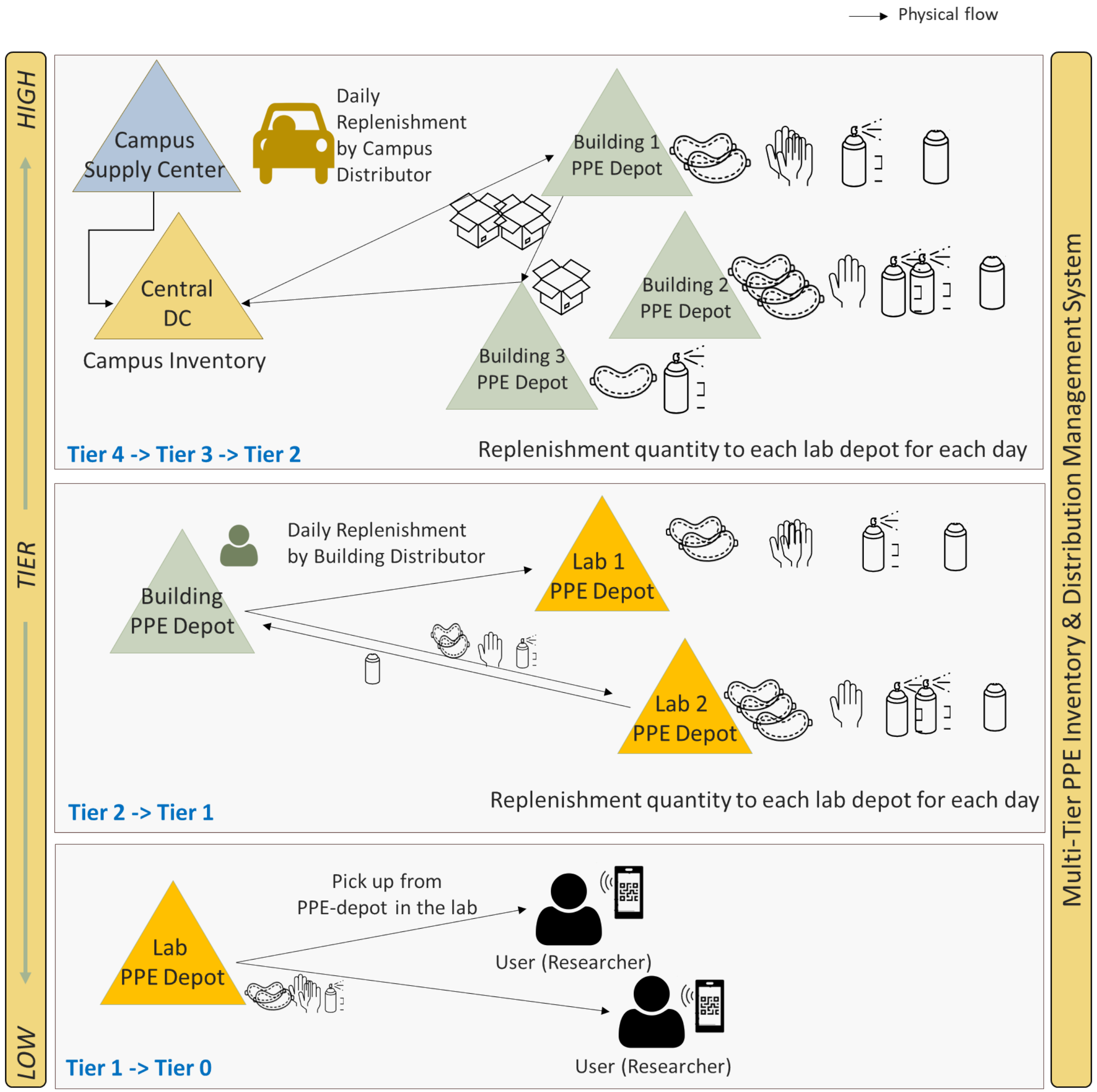
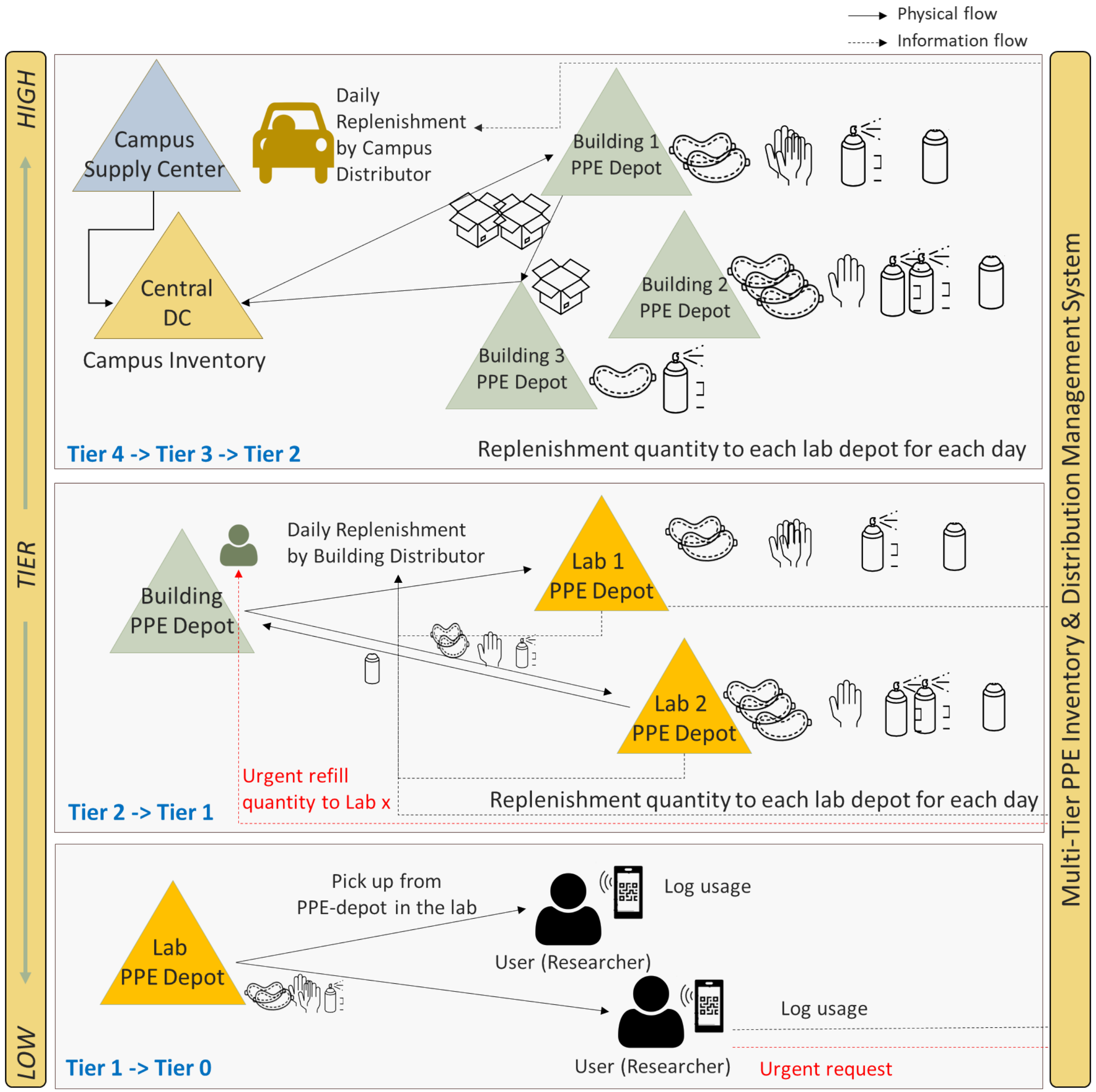
Organizational Layer

- Functional nodes and their responsibilities
- Tier-1 lab depots
  - → Nano-fulfillment centers in each lab
- Tier-2 building depots
  - → Micro-fulfillment centers for lab depots
- Downstream flows are usual
- Lateral and upstream flows allowed in some cases

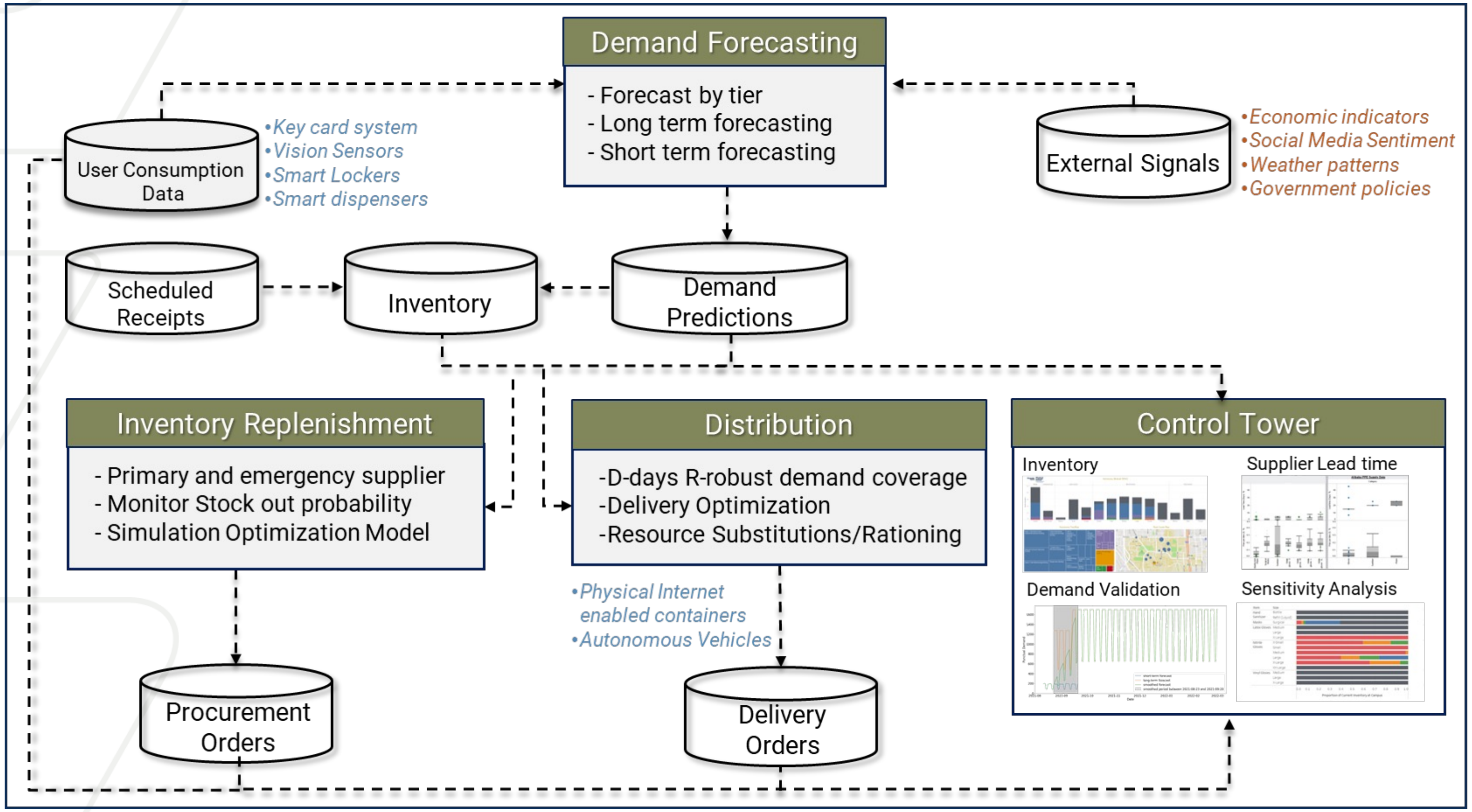


Informational Layer

- Information sharing for effective coordination
- User data and resource burn rates are crucial
- Electronic key card systems used for access authorization and location estimation
- ServiceNow platform facilitates reporting on PPE consumption and inventory
- Appropriate data dissemination crucial for stakeholders



Decisional Layer



- User data used to update demand forecasting models
- Inventory at each tier evaluated with respect to forecasted inventory days
- Campus supply center triggers supply re-orders, accounting for lead time uncertainty
- Decisional layer enables effective governance and resource allocation

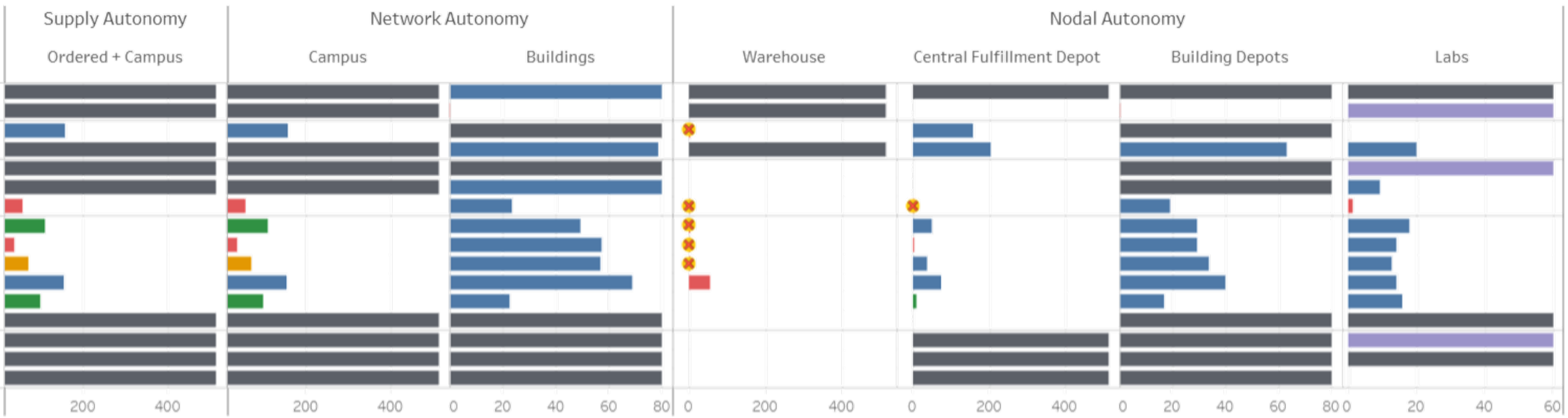
System Performance

Robust Autonomy

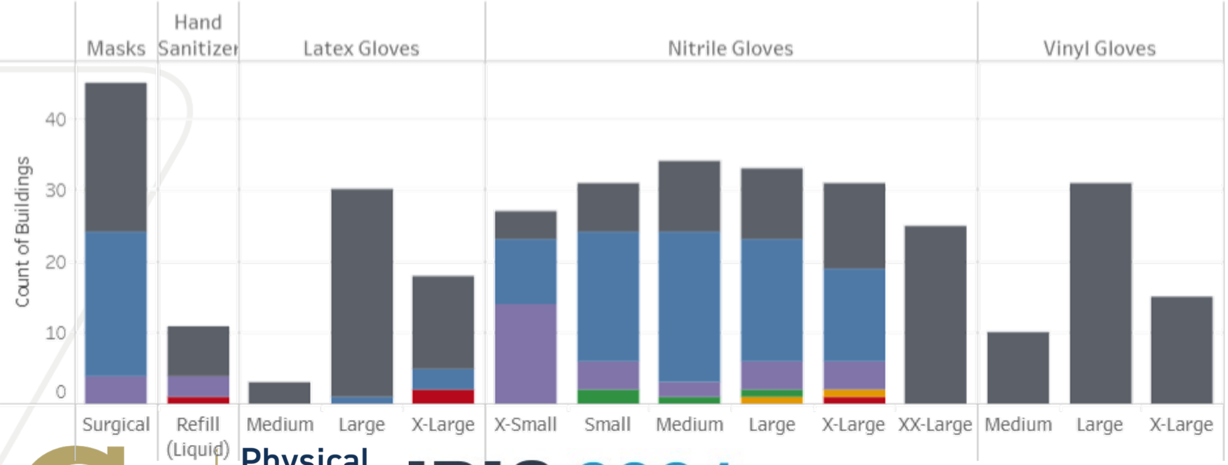
Days of On-Hand Inventory (DOHI) at 99% Confidence

Low | Insufficient | Sufficient | Pack Constrained | Overstocked | Extremely Overstocked

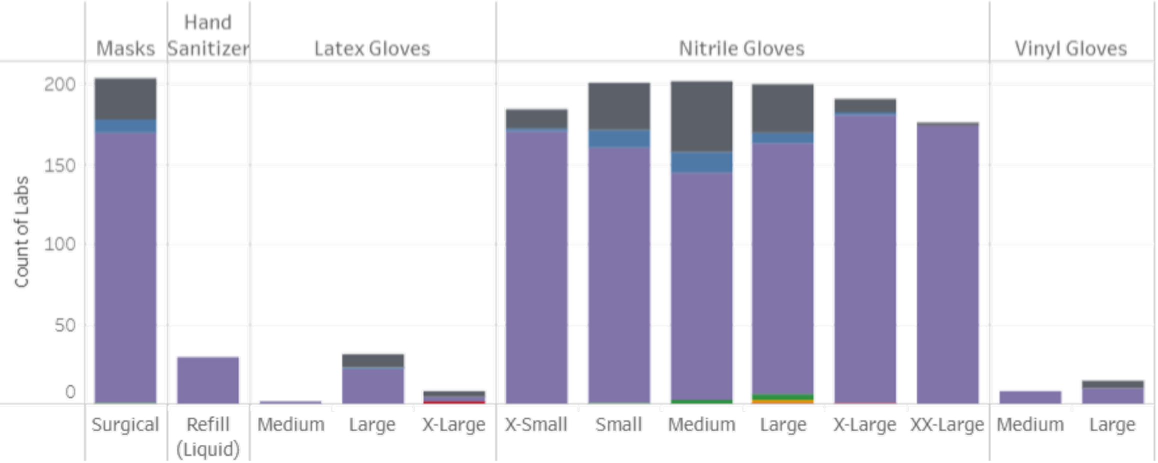
Item	Size	Excess Inventory beyond 12/22	Robust Inventory upto DOHI or 12/22
Hand San..	Bottle	23,576	0
	Refill (Liquid)	574,053	0
Masks	Cloth	28,693	32,752
	Surgical	486,800	311,852
Latex Gloves	Medium	2,500	0
	Large	33,236	0
	X-Large	0	6,816
Nitrile Gloves	X-Small	0	89,155
	Small	0	121,390
	Medium	0	319,139
	Large	0	505,653
	X-Large	0	58,650
	XX-Large	18,596	0
Vinyl Gloves	Medium	25,440	0
	Large	204,930	0
	X-Large	19,200	0



Building Autonomy (Robust DOHI)

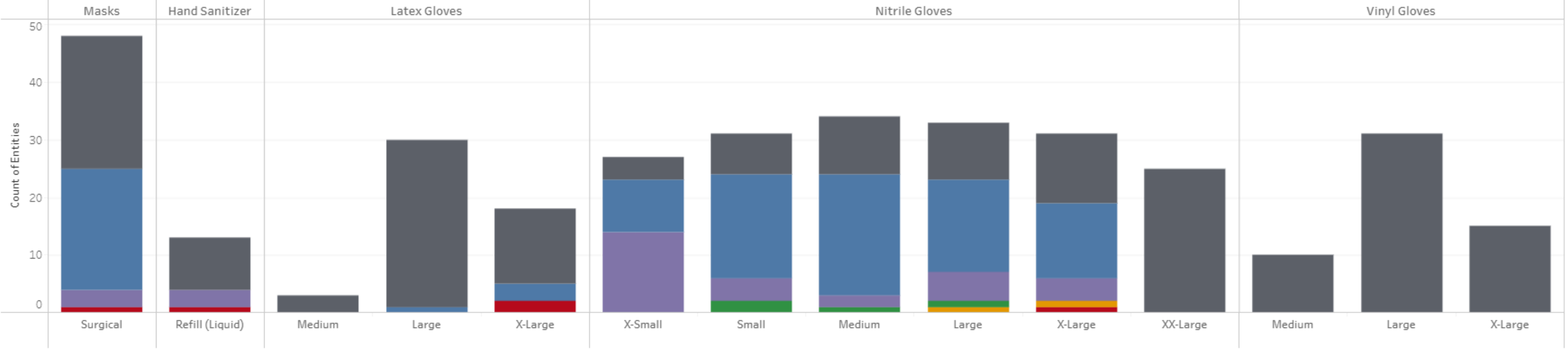


Lab Autonomy (Robust DOHI)

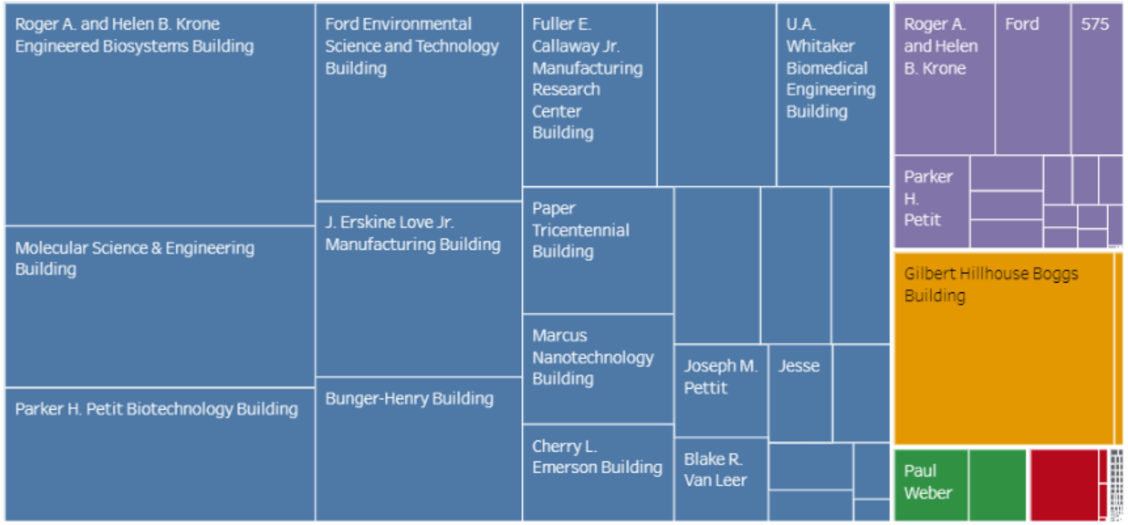


Performance Measures

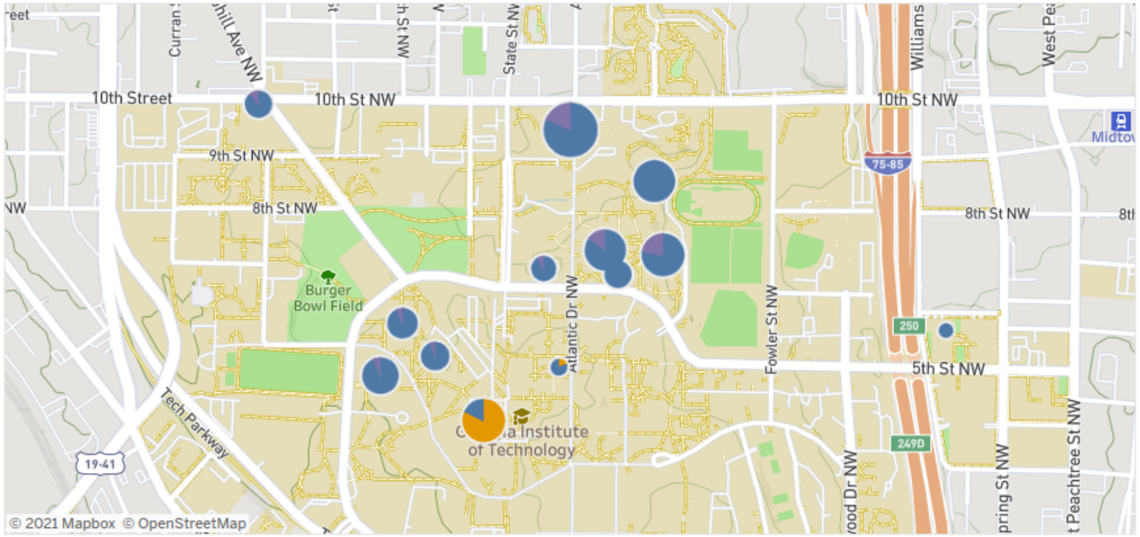
Autonomy (Robust DOHI)



Autonomy TreeMap

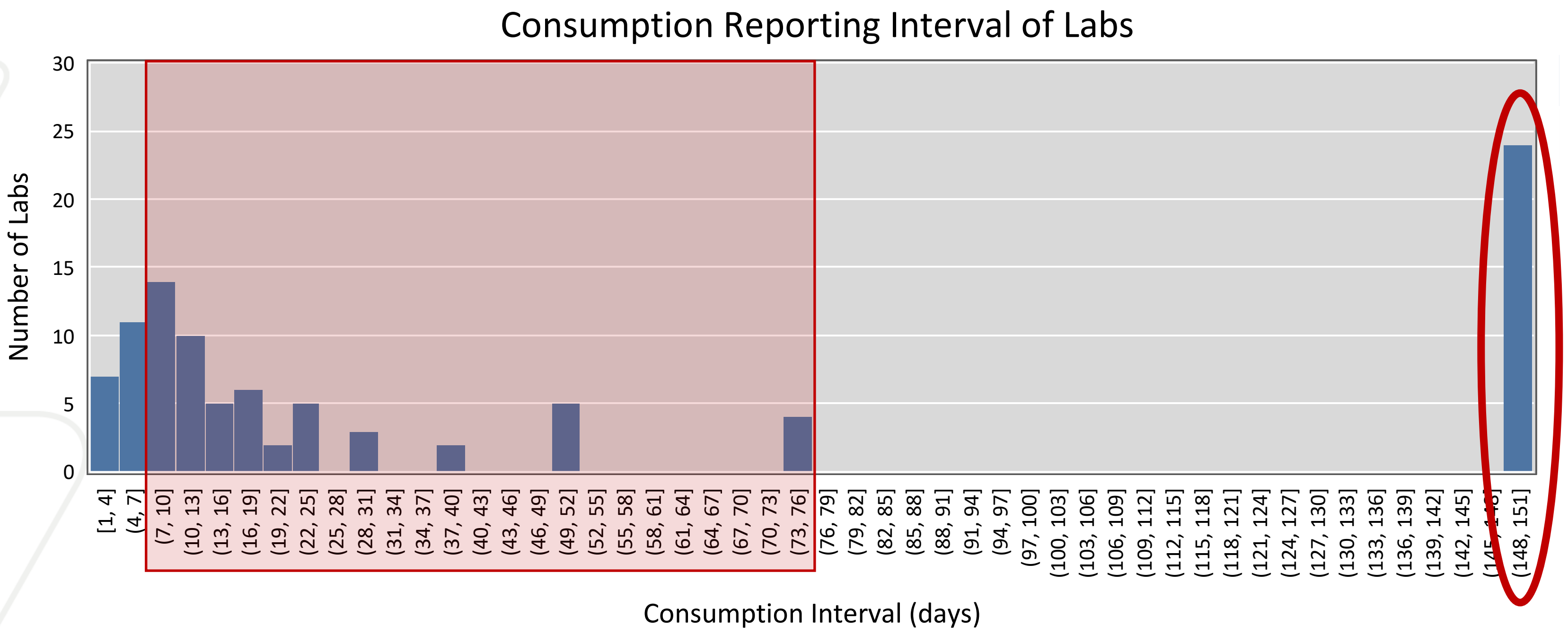


Root Cause Map



Challenges

- Lack of consumption reporting discipline
- Lack of transaction reporting discipline



Consumption Interval	% of Labs
≤7 days	17%
≤14 days	44%
≤30 days	64%
≤45 days	66%
≤60 days	71%
≤75 days	76%
>75 days	24%

Some users did not record transactions rigorously → system unable to develop better predictions

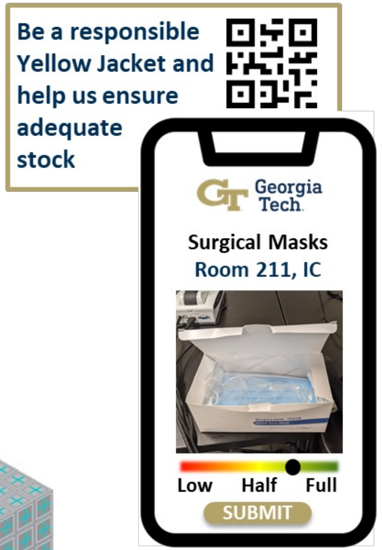
Challenges

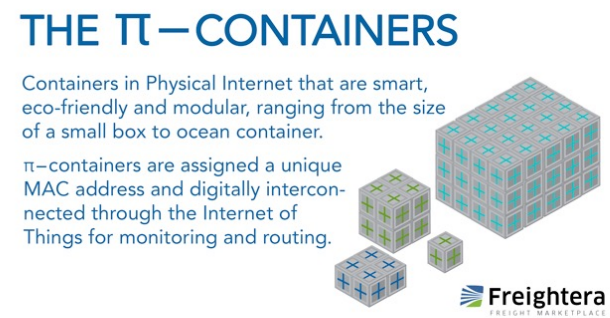
- Lack of consumption reporting discipline
- Lack of transaction reporting discipline
- Workload burden on distribution staff
- Inability to split stock-keeping units (SKUs)

PPE order preparation for Buildings & Labs

PPE distribution
to Building Depots from Campus Depot

Enabling Technologies





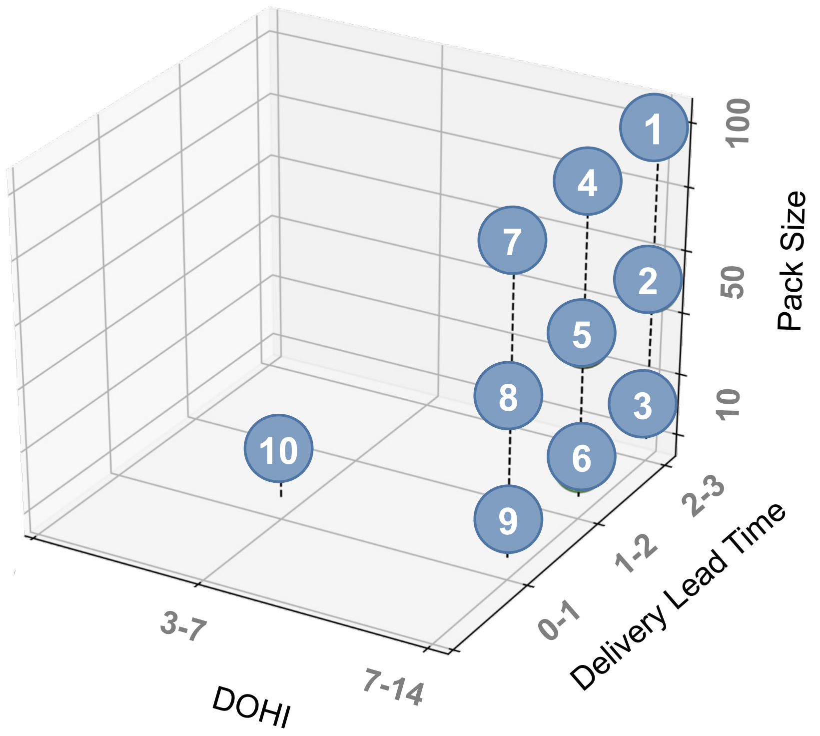
Technologies	Challenges: Consumption Reporting Discipline	Challenges: Transaction Reporting Discipline	Challenges: Workload on Distribution Staff	Challenges: Split Stock-keeping Units (SKUs)
Modular π - Containers		✓	✓	
Vision Sensors	✓			
Smart Dispensers	✓	✓	✓	✓
Smart Lockers	✓	✓	✓	
Drones, Droids and Robots			✓	✓

Proposed enabling technologies to meet the challenges

Scenarios

Primary variables under investigation:
- Reduction in delivery lead time → *attributed to autonomous mobility solutions*
- Decrease in pack size → *enabled by the adoption of smart lockers and robotic operations*

Scenario	DOHI (Lab, Building)	Delivery Lead Time (To Lab, Building)	Pack Size
1	7-14	2-3	100
2	7-14	2-3	50
3	7-14	2-3	10
4	7-14	1-2	100
5	7-14	1-2	50
6	7-14	1-2	10
7	7-14	0-1	100
8	7-14	0-1	50
9	7-14	0-1	10
10	3-7	0-1	10

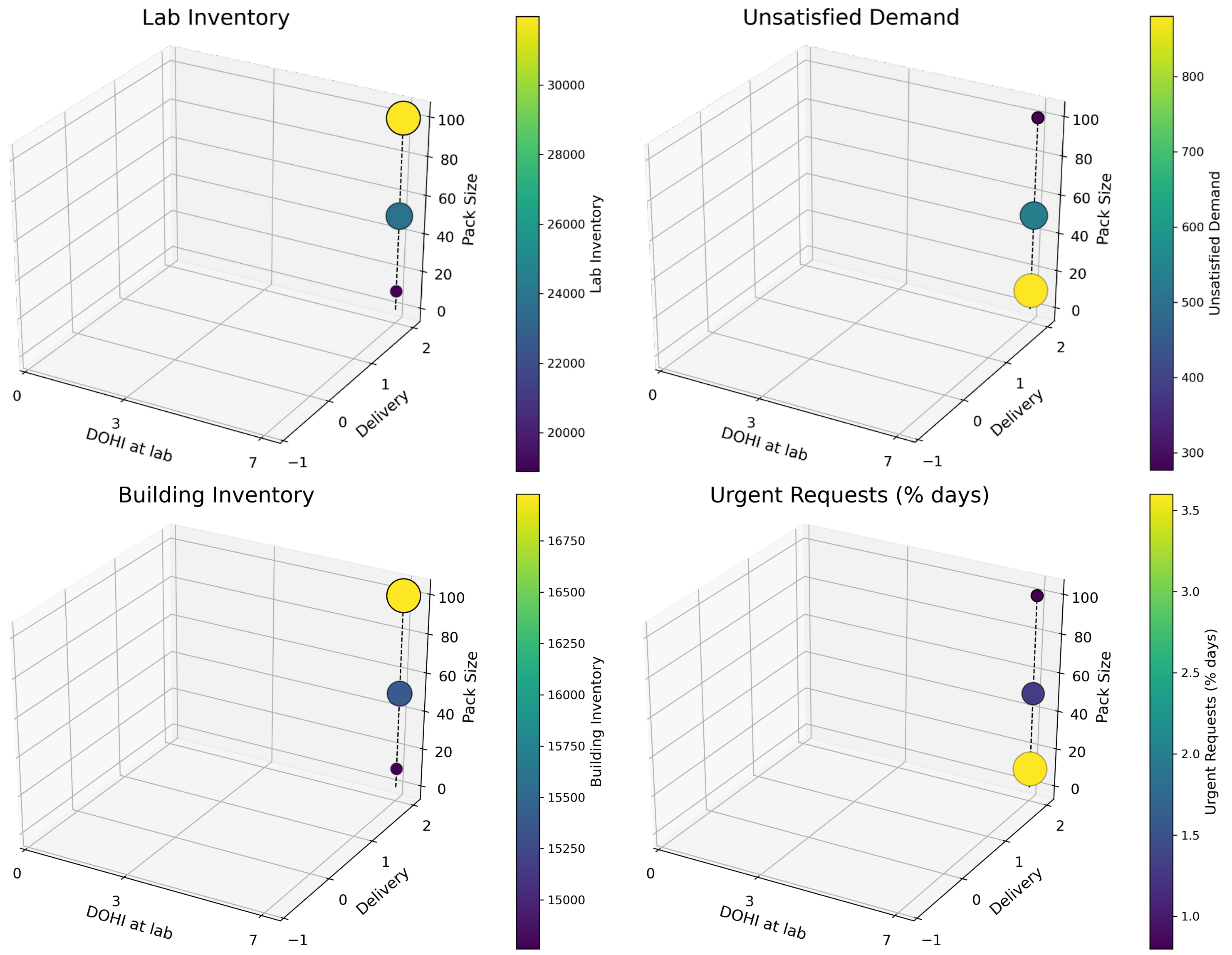


DOHI: Robust (99%) Days of On-Hand Inventory

Varying Pack Sizes Potential Impact

By reducing pack size from 100 to 10 units:

- 12.7% ↓ in building inventory
- 40.2% ↓ in lab inventory
- Higher unsatisfied demand observed (0.015% vs. 0.005% of total demand)

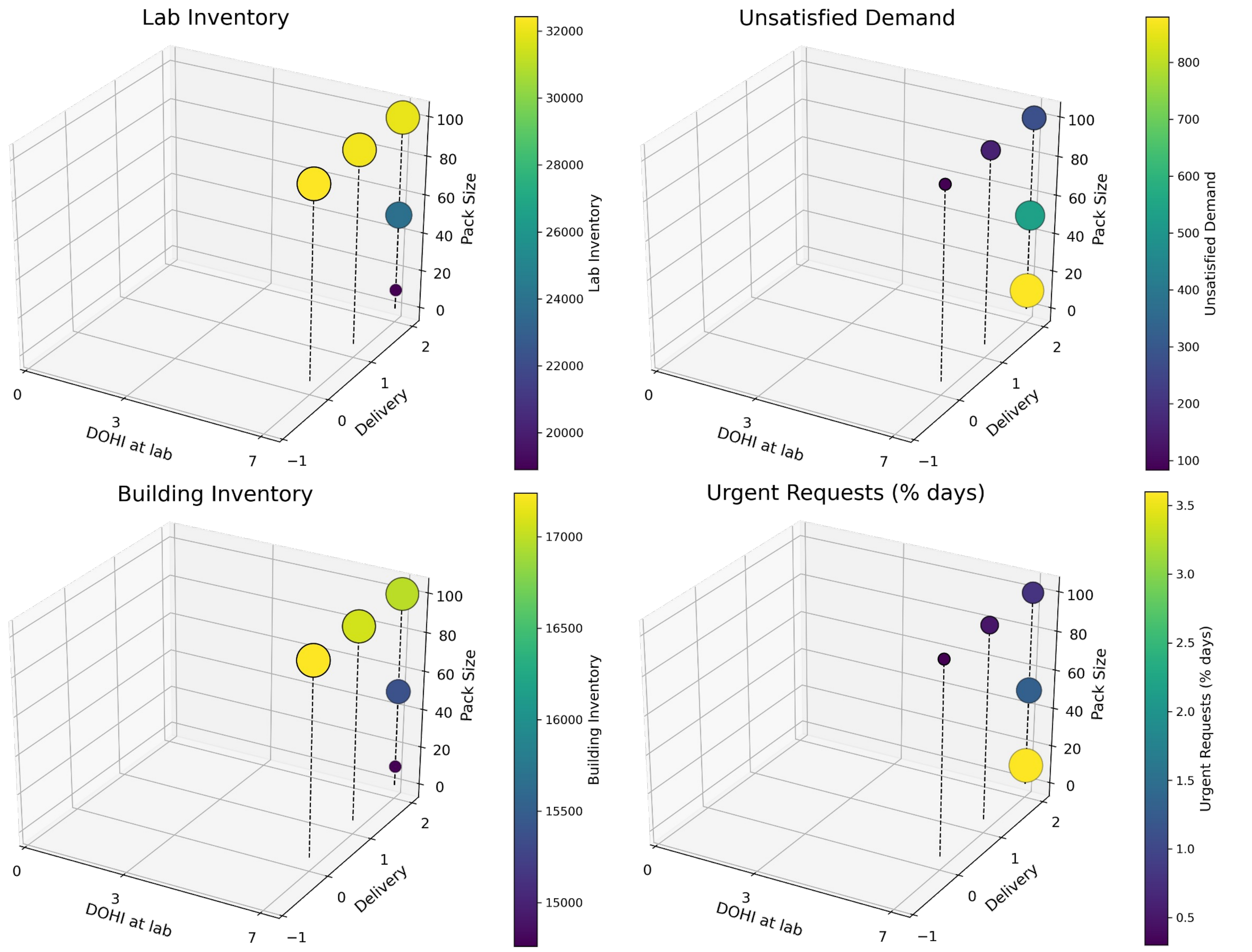


Pack Size	Building Inventory (Units)	Lab Inventory (Units)	Unsatisfied Demand	Unsatisfied Demand (%)	Urgent Requests (% days)
10	14,762	18,893	880	0.015%	3.6%
50	15,386	23,833	536	0.009%	1.3%
100	16,978	31,971	277	0.005%	0.8%

Varying Delivery Time Potential Impact

- 4.4% ↓ in building inventory
- 2.6% ↓ in lab inventory
- Lowest unsatisfied demand at 0-1 day lead time (83 units, 0.001% of total demand)
- Percentage of urgent requests decreased with shorter lead times, reaching 0.3% at a 0-1 day lead time.

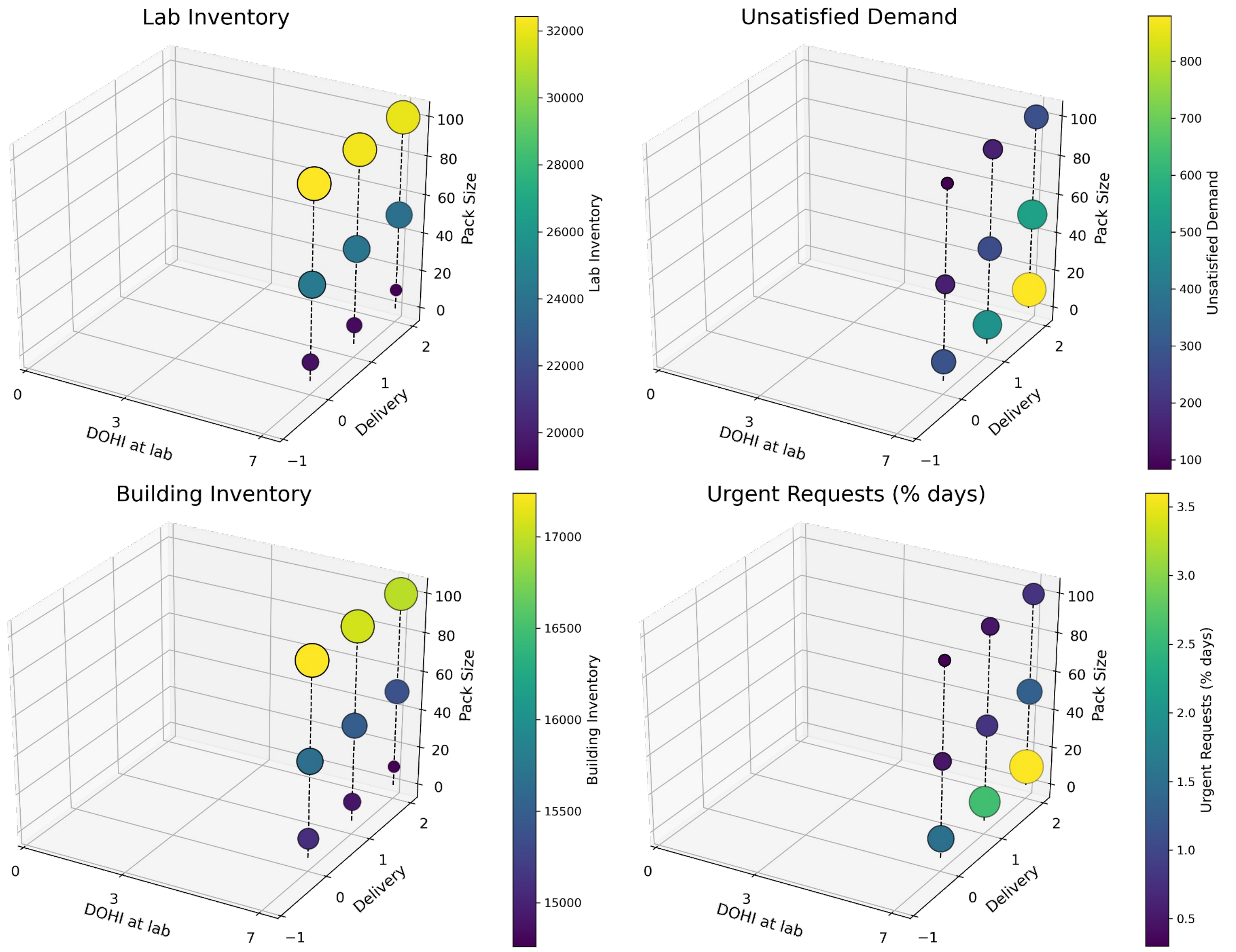
Delivery Time	*Building Inventory (Units)*	*Lab Inventory (Units)*	*Unsatisfied Demand*	*Unsatisfied Demand (%)*	*Urgent Requests (% days)*
0	17,238	32,437	83	0.001%	0.3%
1	17,065	32,213	157	0.003%	0.5%
2	16,978	31,971	277	0.005%	0.8%



Varying Pack Sizes and Delivery Time Potential Impact

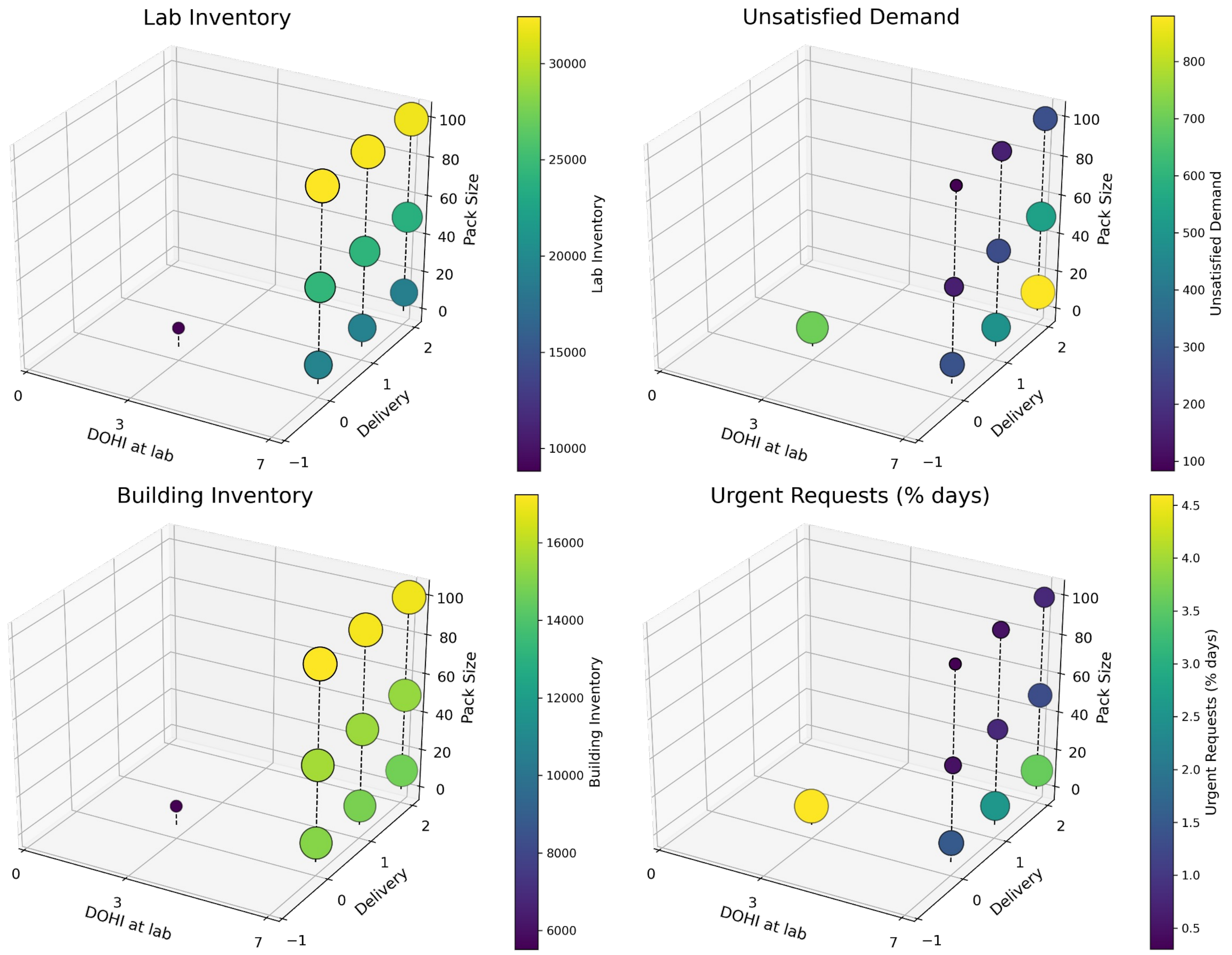
- Reduced pack size and delivery lead time resulted in the lowest building and lab inventory levels
- Indicates that smaller pack sizes and faster deliveries can contribute to better inventory management

Delivery Time	Pack Size	Building Inventory (Units)	Lab Inventory (Units)	Unsatisfied Demand	Unsatisfied Demand (%)	Urgent Requests (% days)
0	10	15,092	19,498	288	0.005%	1.5%
1	10	14,902	19,287	490	0.008%	2.6%
2	10	14,762	18,893	880	0.015%	3.6%
0	50	15,654	24,397	151	0.003%	0.5%
1	50	15,493	24,179	268	0.005%	0.8%
2	50	15,386	23,833	536	0.009%	1.3%
0	100	17,238	32,437	83	0.001%	0.3%
1	100	17,065	32,213	157	0.003%	0.5%
2	100	16,978	31,971	277	0.005%	0.8%



Varying Pack Sizes, Delivery Time and DOHI Potential Impact

- Significantly decreased inventory requirements:
  - Building inventory ↓ ~91.1% to 1,507 units.
  - Lab inventory ↓ ~88.6% to 3,644 units.
- Despite the reductions, unsatisfied demand remained low at 48 units, accounting for only 0.008% of the total demand
- Urgent requests were recorded <5% days during the experiment → satisfactory level of service while substantially reducing inventory levels



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Conclusion

Implemented a hyperconnected supply system for essential products at Georgia Tech, addressing challenges arising from human intervention

The system optimizes PPE supply and distribution using autonomous technologies and can be extended to multi-state networks

A potential to create a nationwide, distributed stockpile of essential supplies using real-time descriptive, predictive, and prescriptive analytics

Future research includes simulation studies to evaluate the transition to autonomous operations, resilience against disruptions, and modelling user behaviors in different industries

Thank you!

***Reference**: Shaikh, Pothen, and Montreuil (2023) Hyperconnected Critical-Product Supply and Distribution System: Towards Autonomous Operations. Proceedings of the 22nd International Federation of Automatic Control (IFAC) World Congress, 2023.*

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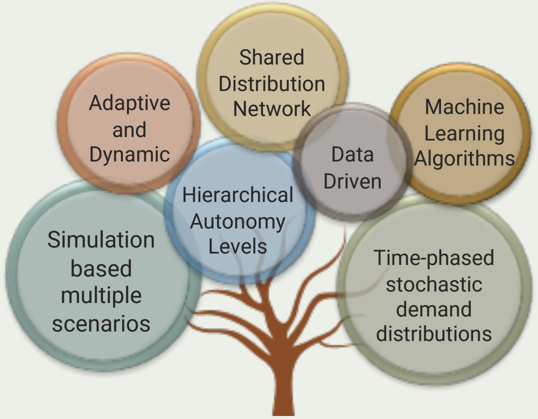
Overview of PPE Supply & Distribution System

Scenario based Forecasting System

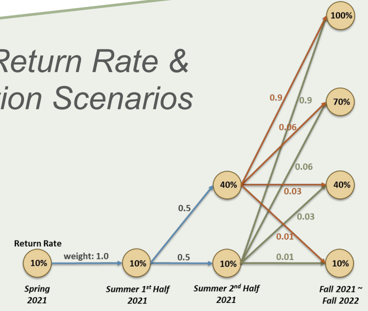
Optimization based Distribution System

Simulation-Optimization based Replenishment Management

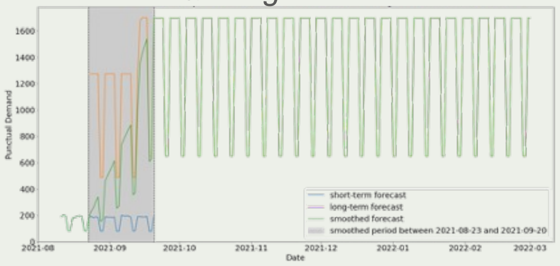
Control Tower for effective monitoring



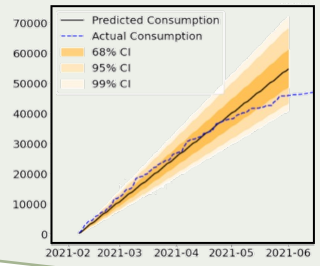
Campus Return Rate & Consumption Scenarios



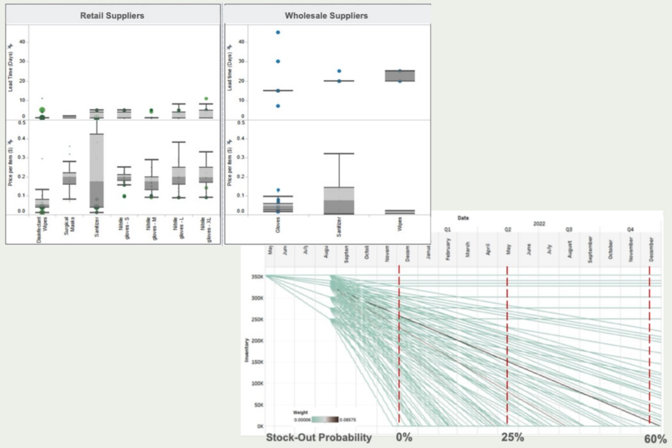
Short & Long-term Forecasts



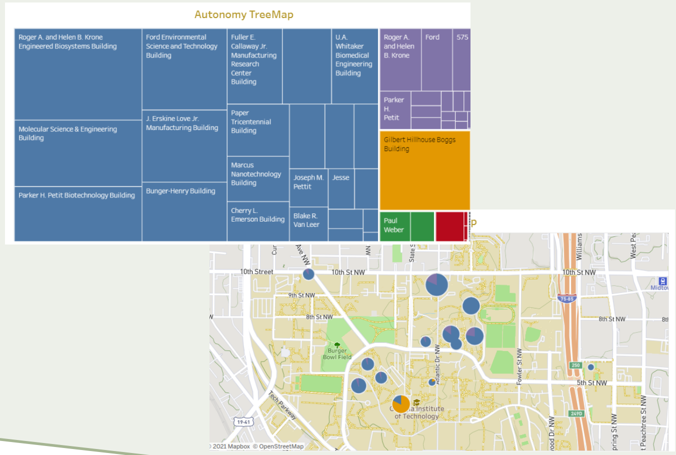
Forecast Performance Tracking



Live Supplier & Inventory Stockout Monitoring



Root-Cause Dashboards



PPE System in Numbers

Active Buildings	Active Labs
45	205

Masks Distributed	Gloves Distributed
199,000	451,000

Sanitizer Distributed

221 gallons

Although the project began in May 2020, these numbers are only for the year 2021

Future Research

SCOPE | TECH

SCOPE

01
Organizational
Focus on other supply chains within the organization

02
Geographical
Implement across other organizations

03
Critical Supply Chains
Expand to critical supply chains

TECH

01
Tech Platforms
Expand to a more robust platform and GUI

02
Autonomy
Use sensors and smart dispensers

03
Digital Intelligence
Artificial intelligence for decision processes