amazon

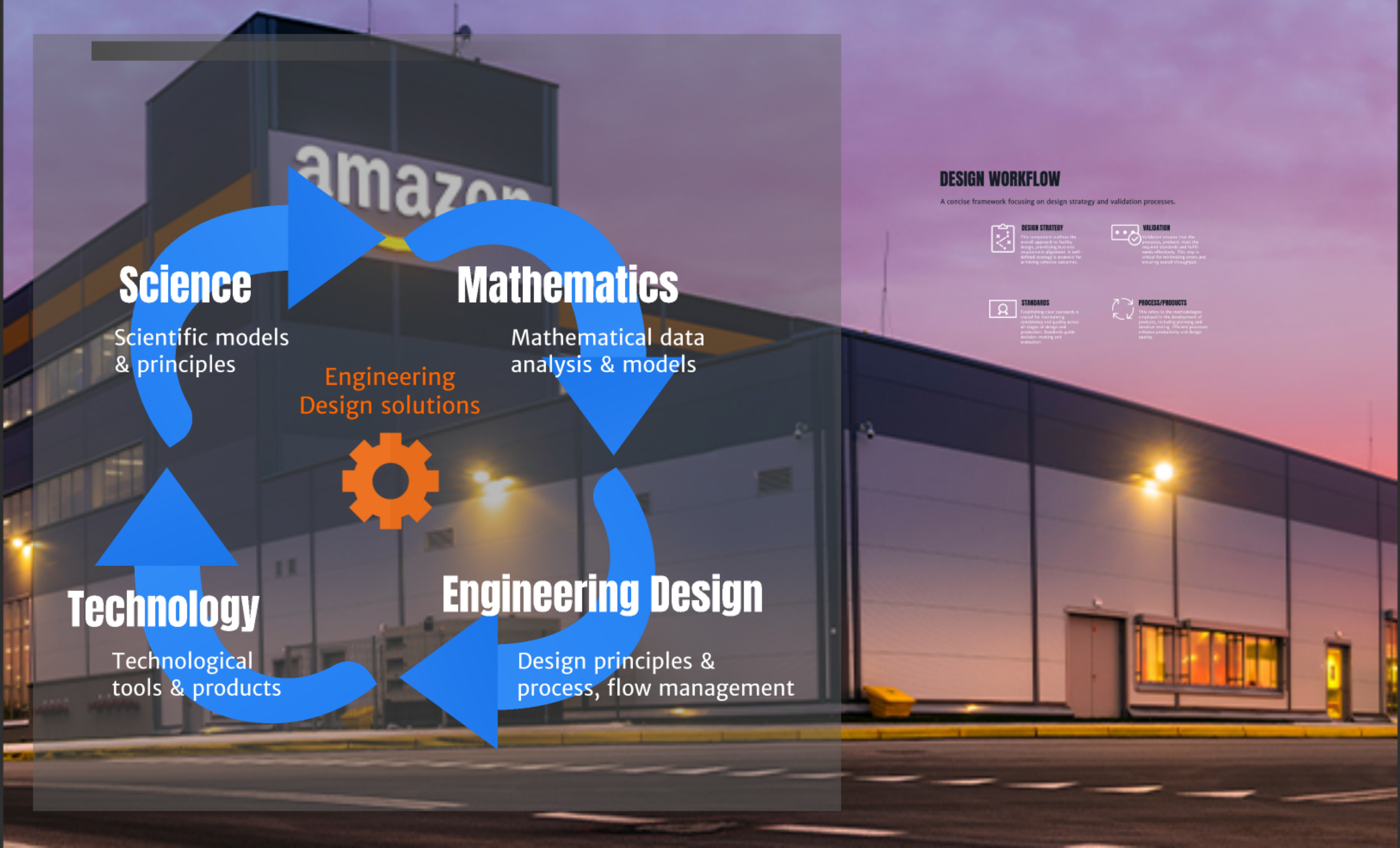
Network Science for Facility Design

Designing Amazon facilities from a network perspective & with a global objective

Presenters: Team WWDE

Siva Veluchamy
Prasad Rao
Mahek Chheda

Worldwide Design Engineering



DESIGN WORKFLOW

A concise framework focusing on design strategy and validation processes.

DESIGN STRATEGY

This component outlines the overall approach to facility design, prioritizing business requirement alignment. A well-defined strategy is essential for achieving cohesive outcomes.

VALIDATION

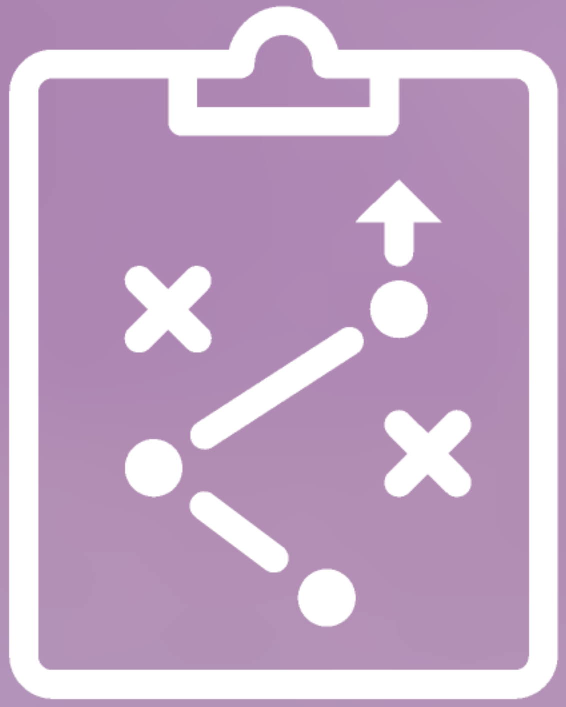
Validation ensures that the processes, products meet the required standards and fulfill needs effectively. This step is critical for minimizing errors and ensuring overall throughput.

STANDARDS

Establishing clear standards is crucial for maintaining consistency and quality across all stages of design and production. Standards guide decision-making and evaluation.

PROCESS/PRODUCTS

This refers to the methodologies employed in the development of products, including planning and iterative testing. Efficient processes enhance productivity and design quality.



DESIGN STRATEGY

This component outlines the overall approach to facility design, prioritizing business requirement alignment. A well-defined strategy is essential for achieving cohesive outcomes.

VALIDATION

Validation ensures that the processes, products meet the required standards and fulfill needs effectively. This step is critical for minimizing errors and ensuring overall throughput.

PROCESS/PRODUCTS

This refers to the methodologies employed in the development of products, including planning and iterative testing. Efficient processes enhance productivity and design quality.

STANDARDS

Establishing clear standards is crucial for maintaining consistency and quality across all stages of design and production. Standards guide decision-making and evaluation.

DESIGN WORKFLOW

A concise framework focusing on design strategy and validation processes.

DESIGN STRATEGY

This component outlines the overall approach to facility design, prioritizing business requirement alignment. A well-defined strategy is essential for achieving cohesive outcomes.

VALIDATION

Validation ensures that the processes, products meet the required standards and fulfill needs effectively. This step is critical for minimizing errors and ensuring overall throughput.

STANDARDS

Establishing clear standards is crucial for maintaining consistency and quality across all stages of design and production. Standards guide decision-making and evaluation.

PROCESS/PRODUCTS

This refers to the methodologies employed in the development of products, including planning and iterative testing. Efficient processes enhance productivity and design quality.

TEAM - IDEAS

- **I** — Innovation
- **D** — Data Analytics
- **E** — Emulation
- **A** — Artificial Intelligence
- **S** — Simulation

Importance of Network Science in Facility Design

Facilities - Integral part of the supply chain

Majority of the decisions on the commodity happens under the roof while it is within a facility

Hardware and Software of fulfillment

Facilities and the process/ products under the roof can be considered the hardware while the decision systems acting upon it are the softwares. Compatibility is inevitable.

Local objectives

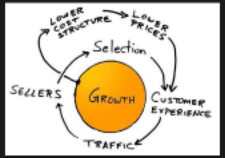
Every facility is designed for a business requirement which varies dynamically as the market adjust its supply and demand. Relationship between capacities and volume flow needs to be taken into account.

Global objectives

Global insights into the network building metrics tree which feeds to the following pillars of optimization,

1. Safety - Employees
2. Speed/Quality - Customer
3. Cost/Efficiency - Amazon
4. Sustainability - Environment
5. Future adaptability and market trends

Amazon flywheel Principle



Facilities - Integral part of the supply chain

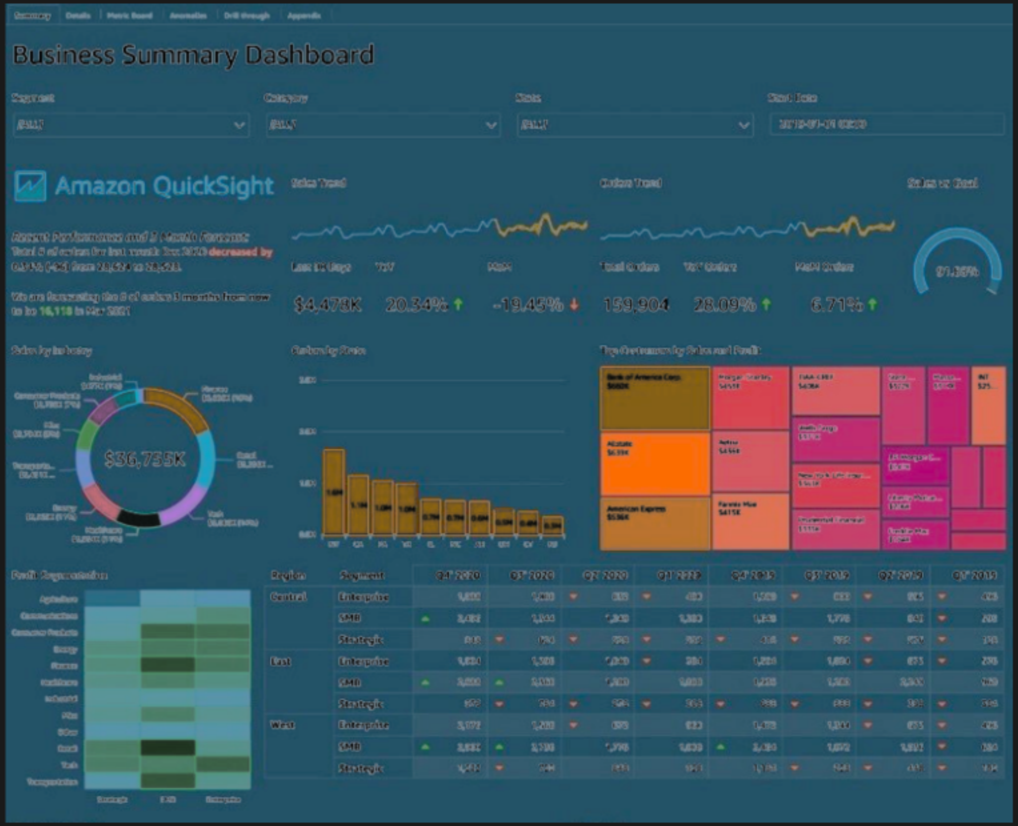
Majority of the decisions on the commodity happens under the roof while it is within a facility

Hardware and Software of fulfillment

Facilities and the process/ products under the roof can be considered the hardware while the decision systems acting upon it are the softwares. Compatibility is inevitable.

Local objectives

Every facility is designed for a business requirement which varies dynamically as the market adjust its supply and demand. Relationship between capacities and volume flow needs to be taken into account.

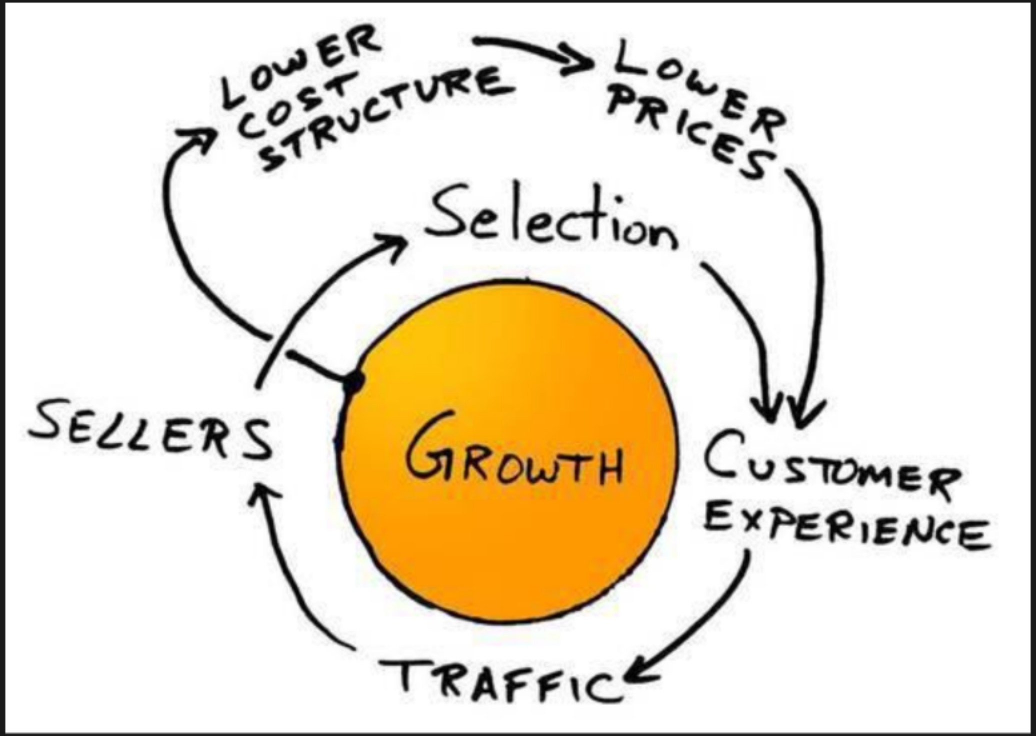


Global objectives

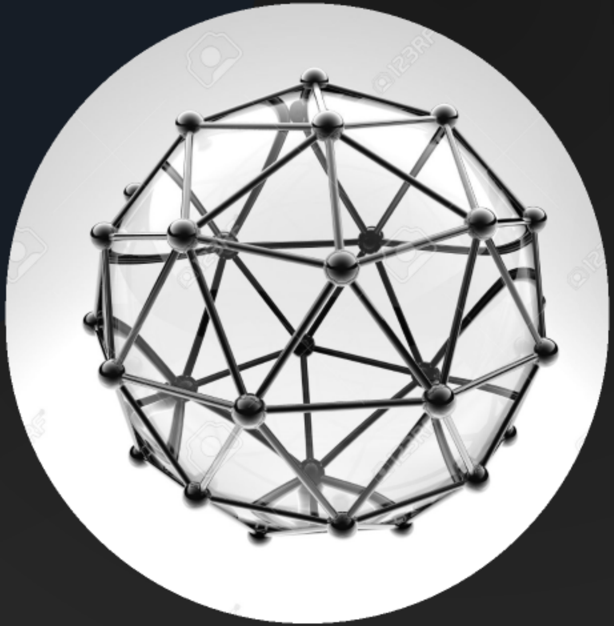
Global insights into the network building metrics tree which feeds to the following pillars of optimization,

1. Safety - Employees
2. Speed/Quality - Customer
3. Cost/Efficiency - Amazon
4. Sustainability - Environment
5. Future adaptability and market trends

Amazon flywheel Principle



Key features of Network Science Models



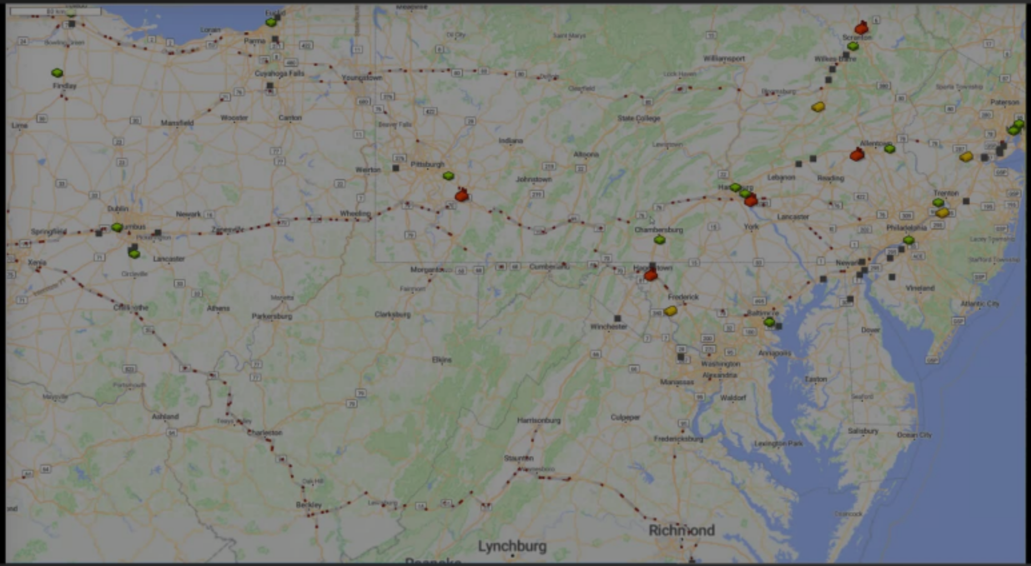
- Models the micro and the macro within the same model
- Track unit level, facility level and network level metrics
- Balances mutiple conflicting objectives like efficiency vs speed
- Modularity & Integration capability with optimization softwares, ML libraries
- Capture and visualize critical metrics

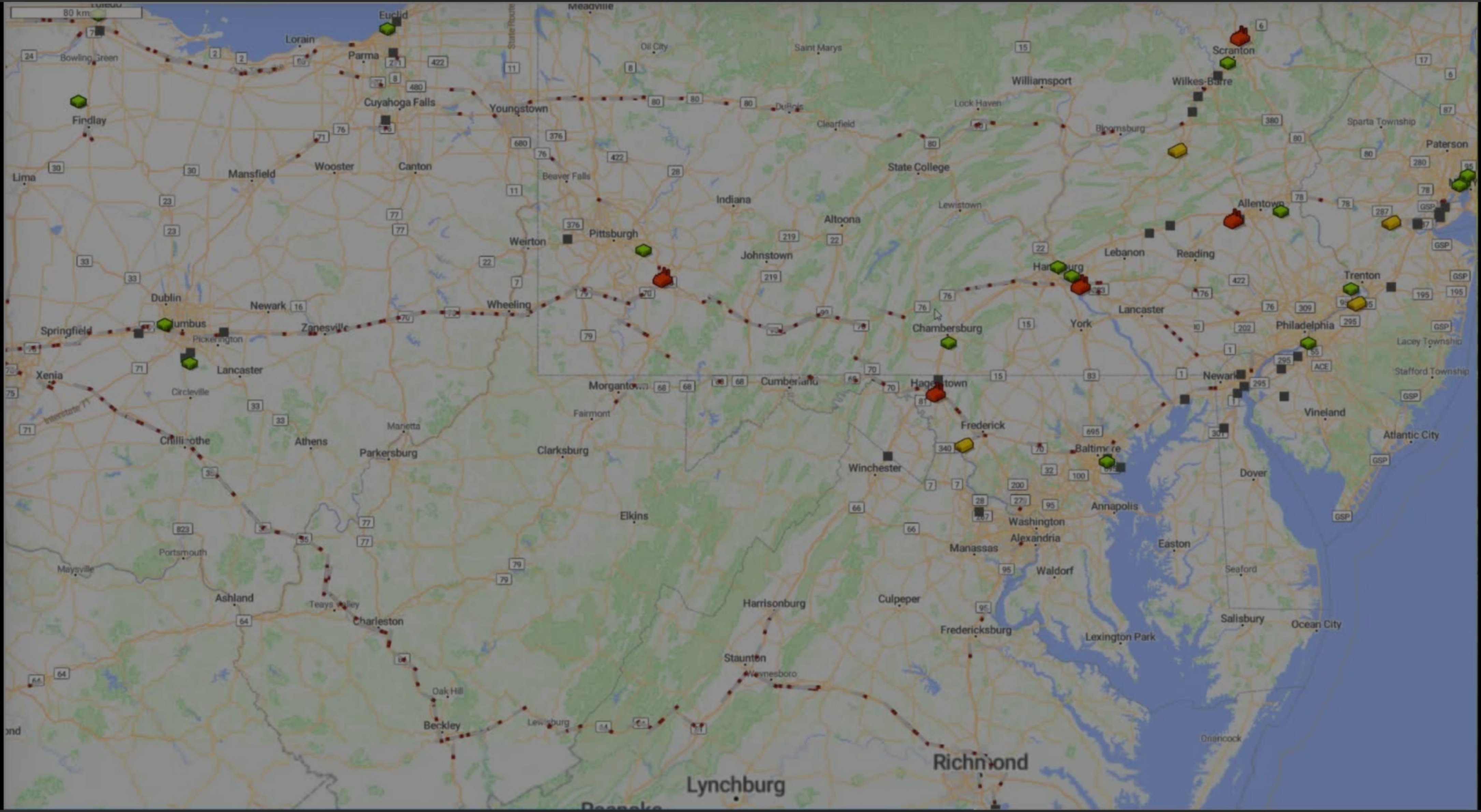
Recap - ALC 2023

Highlights of 3 different usecases where simulation was used as a framework to recreate the environment and used optimization solvers and ML libraries to solve complex real world problems like route optimization, facility location etc.

Network Science

A hybrid simulation built using multiple tools like Simudyne, Anylogic to simulate the entire inbound network for 3 weeks in less than an hour. The model can simulate placement, topology or both for any retrospective, counterfactual or prescriptive scenarios.





Lorain
Parma
Euclid
Bowling Green
Findlay
Lima
Cuyahoga Falls
Youngstown
Mansfield
Wooster
Canton
Meadville
Oil City
Saint Marys
Williamsport
Lock Haven
Clearfield
State College
Scranton
Wilkes-Barre
Bloomsburg
Sparta Township
Paterson
Beaver Falls
Indiana
Altoona
Lewistown
Pittsburgh
Weirton
Johnstown
Allentown
Lebanon
Reading
Trenton
Dublin
Newark
Springfield
Zanesville
Wheeling
Lancaster
York
Chambersburg
Philadelphia
Lacey Township
Stafford Township
Xenia
Circleville
Morgantown
Cumberland
Fairmont
Vineland
Atlantic City
Chillicothe
Athens
Marietta
Parkersburg
Clarksburg
Winchester
Frederick
Baltimore
Dover
Washington
Alexandria
Annapolis
Manassas
Easton
Elkins
Portsmouth
Maysville
Waldorf
Seaford
Ashland
Charleston
Harrisonburg
Culpeper
Fredericksburg
Salisbury
Ocean City
Lexington Park
Staunton
Waynesboro
Oak Hill
Beckley
Lewisburg
Richmond
Lynchburg

Case Studies in Network Science for Amazon Network

Illustrating successful applications of network science principles in architecture through key examples.

2023

Evaluated multiple network level strategies for the inbound network

2024

Evaluated strategies for mode of transportation network level

2025

Evaluated under the roof strategies for outbound loading/containerization

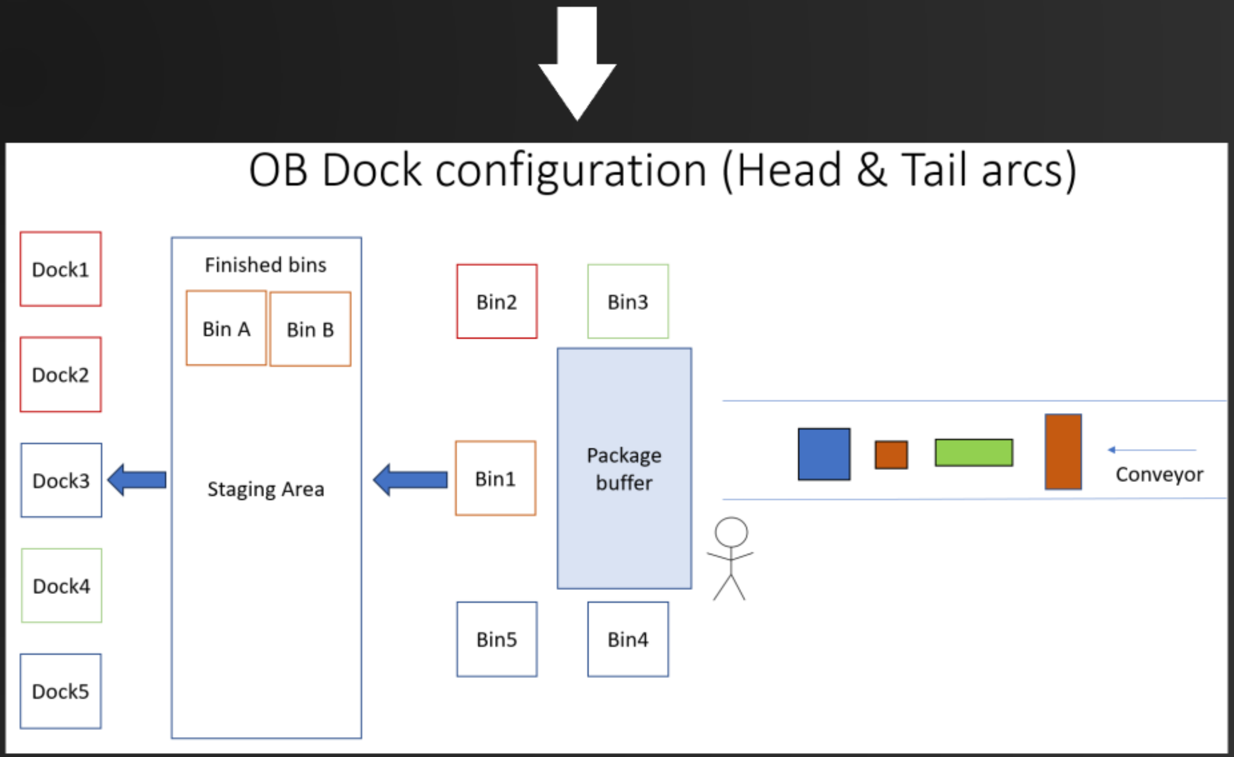
Outbound Loading Types

Fluid Loading:

Pros:
Trailer utilization

Cons:
Safety challenges
Variability in process paths

Can we evaluate an option where we have control over the loading medium considering the uncertainity and volume swings?



Current Trend in Trailer Composition

60 - 70% of trailers leaving first/middle mile facilities utilize fluid loading and remaining is palletized or mixed loading

Goal - What if we convert 100% of fluid trailers -> palletized trailers, how will it impact trailer utilization and eventually number of additional trailers generated?

Tote fluid -> Tote pallet (Arithmetic)
Case fluid -> Case pallet (3D bin packing)

Data Availability:
Trailer summary - number of cases, totes and pallets
Case dimensions per lane (OD pair)

3D Bin Packing Heuristic - Extreme Points Method

Assumptions:

- Simulated for 2 weeks in history for all inbound nodes
- Assumes random sampling of package dimensions(LxBxH in) for cases on OD pair level
- Assumes conversion of current fluid loaded trailers to palletized loads
- Assumes ‘x’ (x=3 TBD) pallet positions for each trailer loaded but then vary x from 1 through 6 for sensitivity
- Tote dimension – 2.3 cubic ft
- Maximum pallets per trailer – 52
- UPP dimensions (64 cu. ft 4x4x4 ft)

3D Bin Packing Heuristic - Model Details

Input

Boxes $B = \{1,2, \ldots n\}$

Dimensions of the box $w_i,\ h_i,\ d_i$

6 different orientations for each box O_i

Number of bins $j \in D = \{1,2, \ldots m\}$

Bin dimensions (4x4x4) - W, H, D

Support overlap upper level - $r_{support} = 80\%$

Bin close threshold - $r_{close} = 95\%$

M – Large constant *Big(M)* for disjunctive constraint

Placement constraints

$$\sum_j \sum_{o \in O_i} x_{i,j,o} = 1\ \forall i \in B \left(\begin{matrix} Every\ box\ needs\ to \\ be\ placed\ else\ throw\ error \end{matrix}\right)$$

- $x_i + w_i^o \le W\ \forall (i, j, o: x_{i,j,o} = 1)$
- $y_i + h_i^o \le H\ \forall (i, j, o: x_{i,j,o} = 1)$
- $z_i + d_i^o \le D\ \forall (i, j, o: x_{i,j,o} = 1)$

Non-overlap constraints

$\forall$ *pair of boxes* $i \neq k$ *placed in the same bin* j

$L_{ijk} + F_{ijk} + B_{ijk} \ge 1$ *where* $L_{ijk}, F_{ijk}, B_{ijk}$ *are binary variables*

$L_{ijk} = 1 \rightarrow x_i + w_i^o \le x_k$

$F_{ijk} = 1 \rightarrow y_i + h_i^o \le y_k$

$B_{ijk} = 1 \rightarrow z_i + d_i^o \le z_k$

with M: (*Linear inequalities*)

$x_i + w_i^o \le x_k + M(1 - L_{ijk})$ $L_{ijk} = 1$ *if box i is placed to the left of box k*

$y_i + h_i^o \le y_k + M(1 - F_{ijk})$ $F_{ijk} = 1$ *if box i is placed in front of box k*

$z_i + d_i^o \le z_k + M(1 - B_{ijk})$ $B_{ijk} = 1$ *if box i is placed below box k*

Decision variables

$\forall$ *box i, each bin j, each orientation o* $\in O_i$: $x_{i,j,o} \in \{0,1\}$

$x_{i,j,o} = 1$ *if box i placed in bin j with orientation o*

$\forall$*box i placed in any bin* $(x_i, y_i, z_i) \ge 0$

$\forall$*bin j*: $u_j \in \{0,1\}$ $u_j = 1$ *if bin is used*

Support constraints

$Support_i \ge r_{support} \cdot (w_i^o \cdot d_i^o)$

Can be varied from 55% – 80%

Bin close condition

$Utilization_j \ge r_{close} \rightarrow u_j = 1$

where $Utilization_j = \sum_i \frac{(w_i^o \cdot h_i^o \cdot d_i^o \cdot x_{i,j,o})}{W \cdot H \cdot D}$ or $\sum_i \frac{V_i^o \cdot x_{i,j,o}}{V_{bin}}$

Objective

$\max \sum_j Utilization_j$

Time complexity: $O(n^2)$

Key takeaways from network science in outbound containerization

Enhancing Efficiency

The recommendation is tailored to the current and future network setup with efficiency in perspective by enabling a hybrid setup with lane level recommendations

100% vs 85% Palletization

By understanding the unique lane level dynamics on volume flow 100% fluid conversion lead to adding hundreds of trailers vs eliminating the top 3 head arcs results in only adding a handful of trailers

Pallet Utilization

The pallet utilization results shows promising effects by tactically controlling the open pallet position leading to improvement upto 85%. Therefore, pallet utilization is a function of open pallet position for each destination.

Enhancing Efficiency

The recommendation is tailored to the current and future network setup with efficiency in perspective by enabling a hybrid setup with lane level recommendations

100% vs 85% Palletization

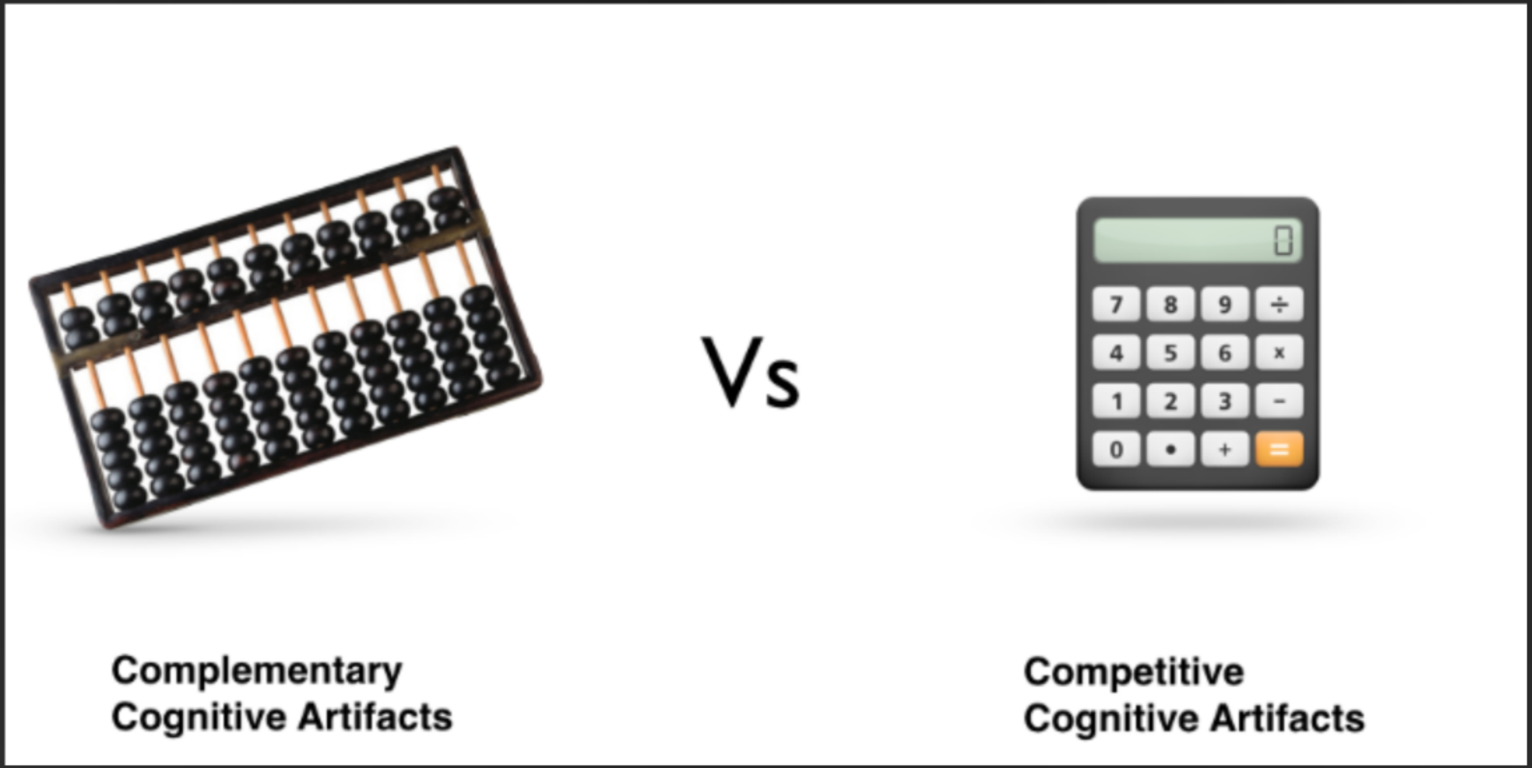
By understanding the unique lane level dynamics on volume flow 100% fluid conversion lead to adding hundreds of trailers vs eliminating the top 3 head arcs results in only adding a handful of trailers

Pallet Utilization

The pallet utilization results shows promising effects by tactically controlling the open pallet position leading to improvement upto 85%. Therefore, pallet utilization is a function of open pallet position for each destination.

What's next?

What's next?



Vs
Complementary
Cognitive Artifacts
Competitive
Cognitive Artifacts

References:

• Coffman, E. G., Garey, M. R., & Johnson, D. S. (1996). "Approximation algorithms for bin packing: An updated survey." Algorithmica.

• Martello, S. & Toth, P. (1990). "Knapsack Problems: Algorithms and Computer Implementations." Wiley.

amazon

Network Science for Facility Design

Designing Amazon facilities from a network perspective & with a global objective

Presenters: Team WWDE

Siva Veluchamy
Prasad Rao
Mahek Chheda