Maximum Inbound Capacity: Validation, Modeling, and Optimization in Amazon EU Supply Chain

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amazon

UNIVERSITÉ DU LUXEMBOURG

Introduction

Background

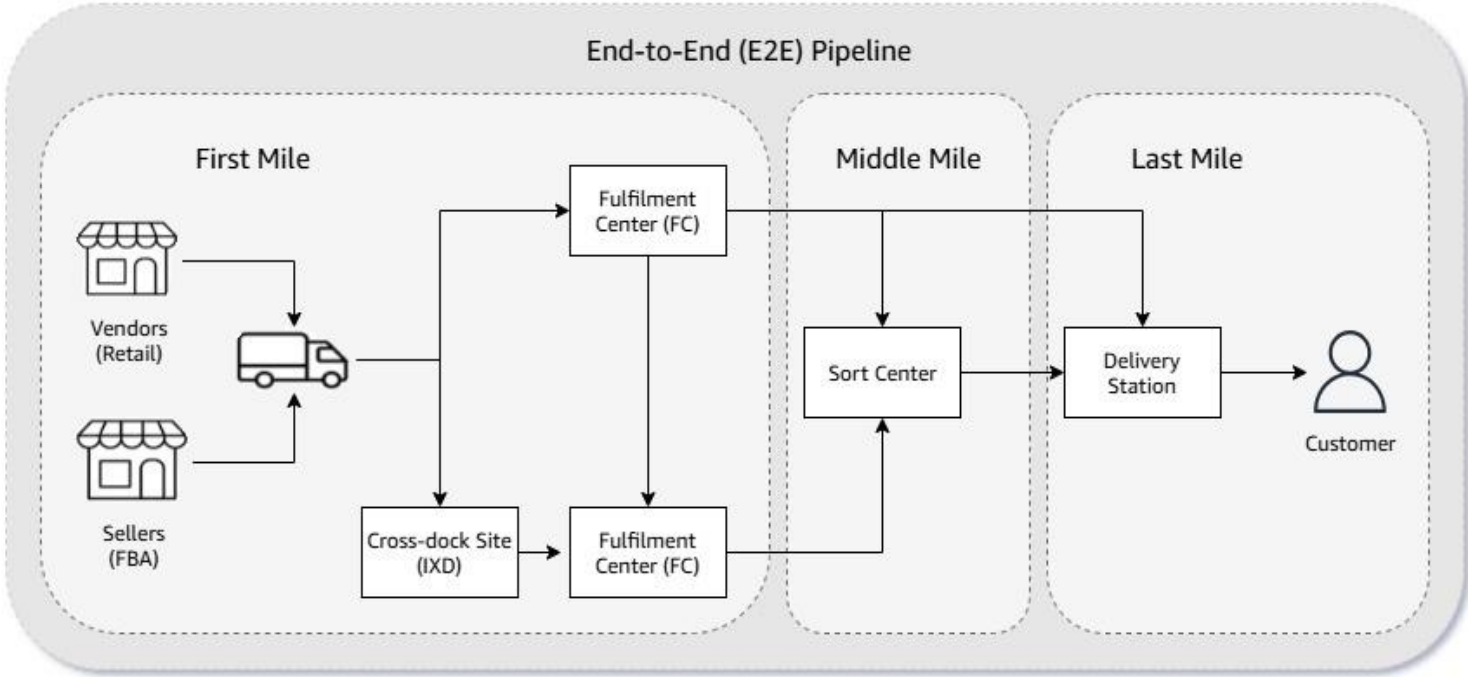
Amazon

Background

Supply Chain

SUPPLY CHAIN

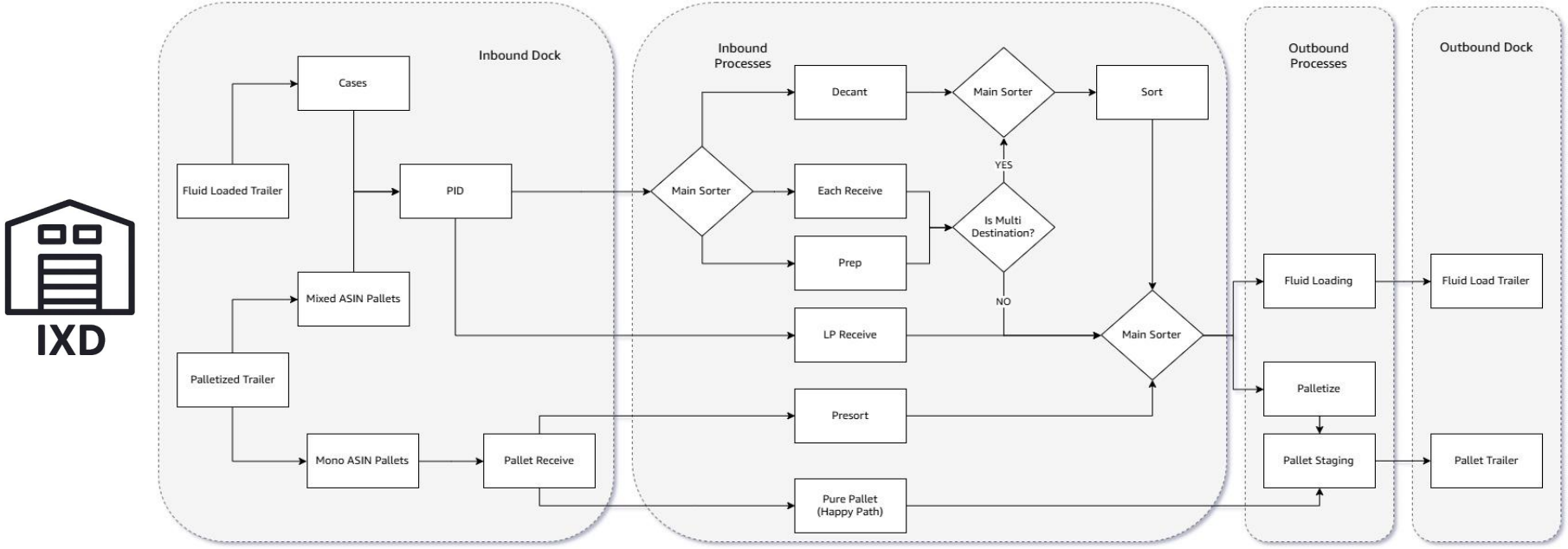
From 20M-40M units weekly!



Background

Facilities: IXD

- Receive inventory from vendors & sellers (New Vendor Fright, NVF) (3 receive funnels)
- Inventory comes in cases (boxes) and pallets (wooden platforms with stacked boxes)



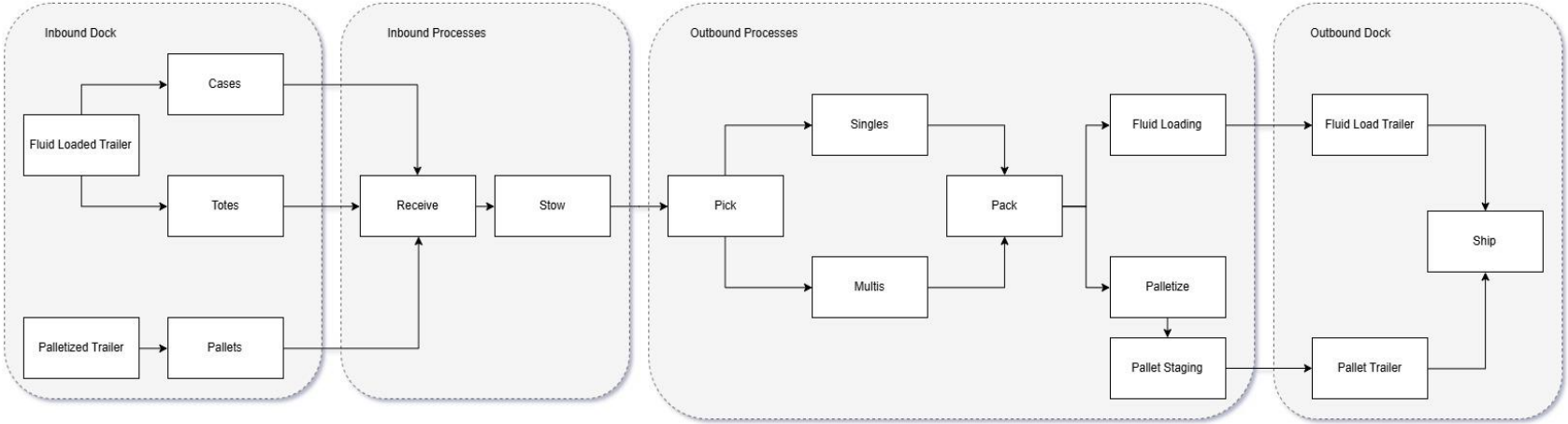
Background

IXD & FC

- Receive inventory from IXDs (Tranship In, TSI) and vendors & sellers (NVF)
- TSI inventory adds 5 more receive funnels
- Inventory comes in cases, pallets, and totes

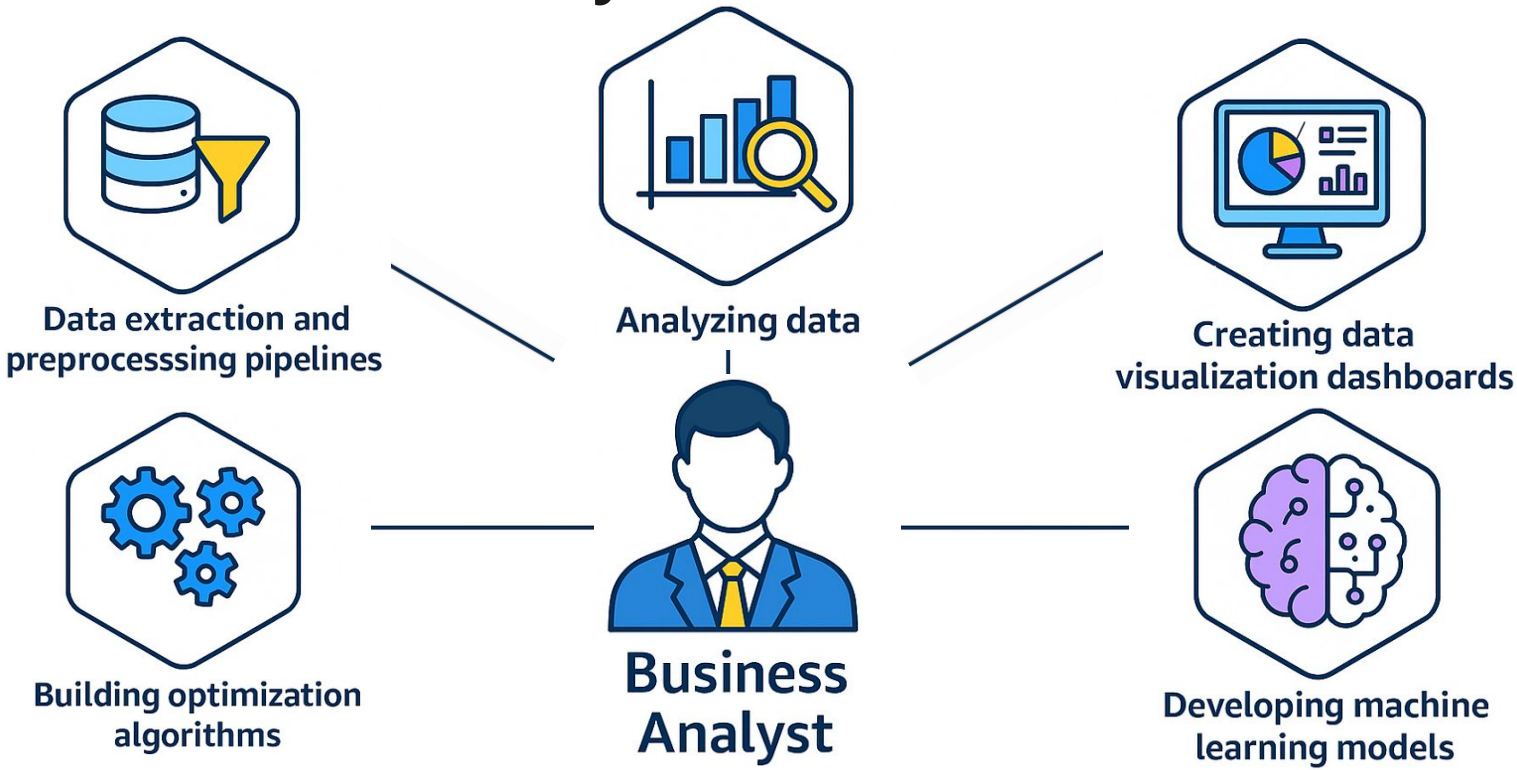
Transport
Stow
Pick

FULFILLMENT CENTER



Background

Business Analyst



Problem Statement

Goal

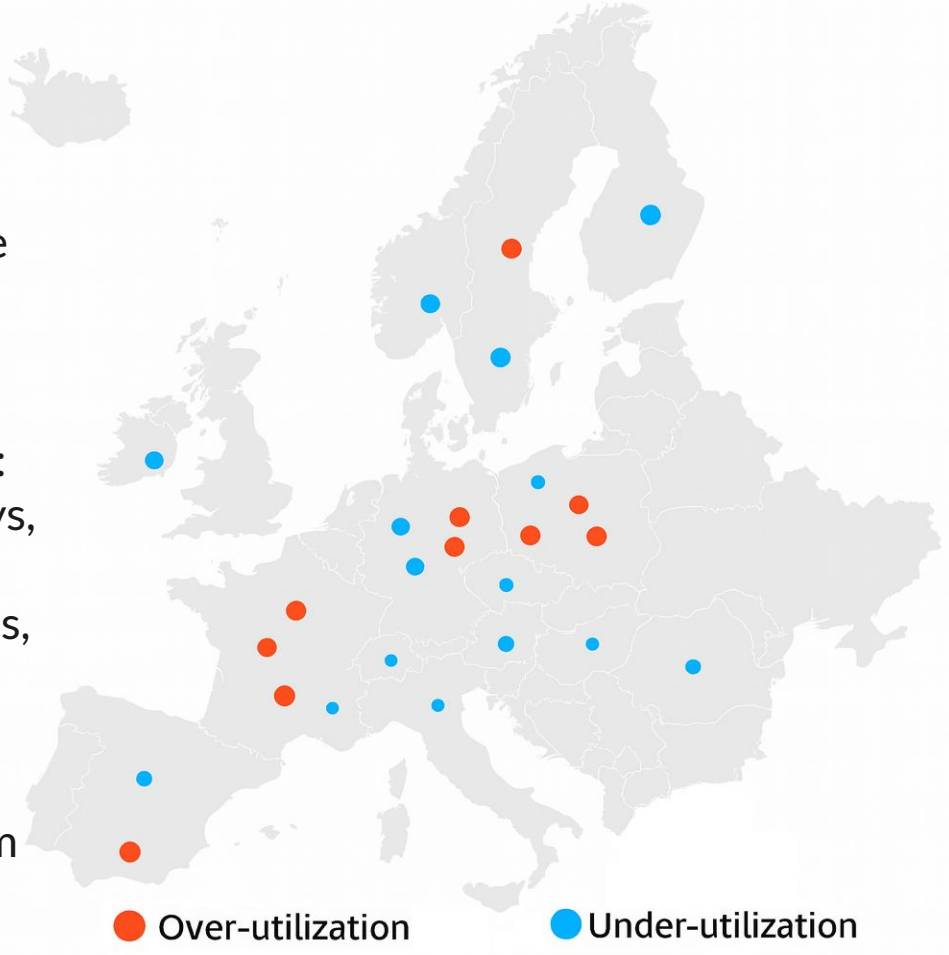
- Identify root causes of inefficiencies in site utilization.
- Enable faster, more accurate planning.

Why this matters

- Ensure efficient use of Amazon's network:
  - Over-utilization → bottlenecks, delays, missed processing targets.
  - Under-utilization → wasted resources, higher costs.

Key Challenges

- Lack of reliable and consistent data.
- Difficulty of accurately modeling maximum processing capacity (MPC).



Objectives

Note: Maximum Processing Capacity (MPC) measures how much inventory a warehouse can handle (in an hour, day). Measured in units, pallets, cases.

Validate

- Ensure MPC models are accurate and reliable.

Monitor & Scenario Planning

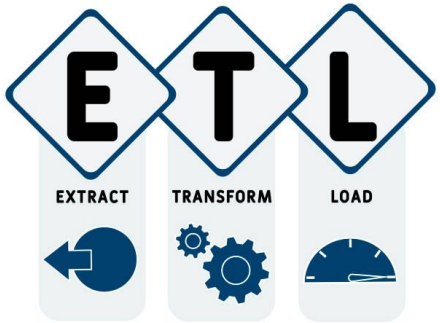
- Build monitoring data visualization dashboards, with planning scenario analysis.

Optimization

- Balance volume across the EU network to avoid over- and under-utilization.

Which Knowledge was Used

- SQL (~30,000 lines)
- QuickSight (4 dashboards)
- S3
- ETL
- Python
- Statistics
  (basic concepts, non-parametric)



Amazon
S3

Project 1: Optimal Backlog Identification

Optimal Backlog Range Identification

Overview

Goal

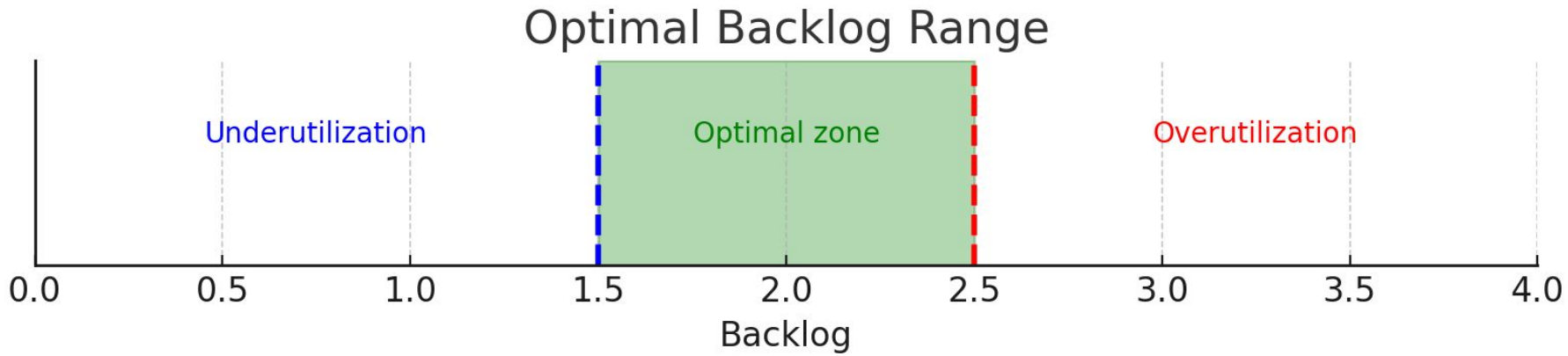
- Identify the optimal backlog range.

Why important

- Avoids wasted capacity, prevents bottlenecks, facilities run at full throughput.

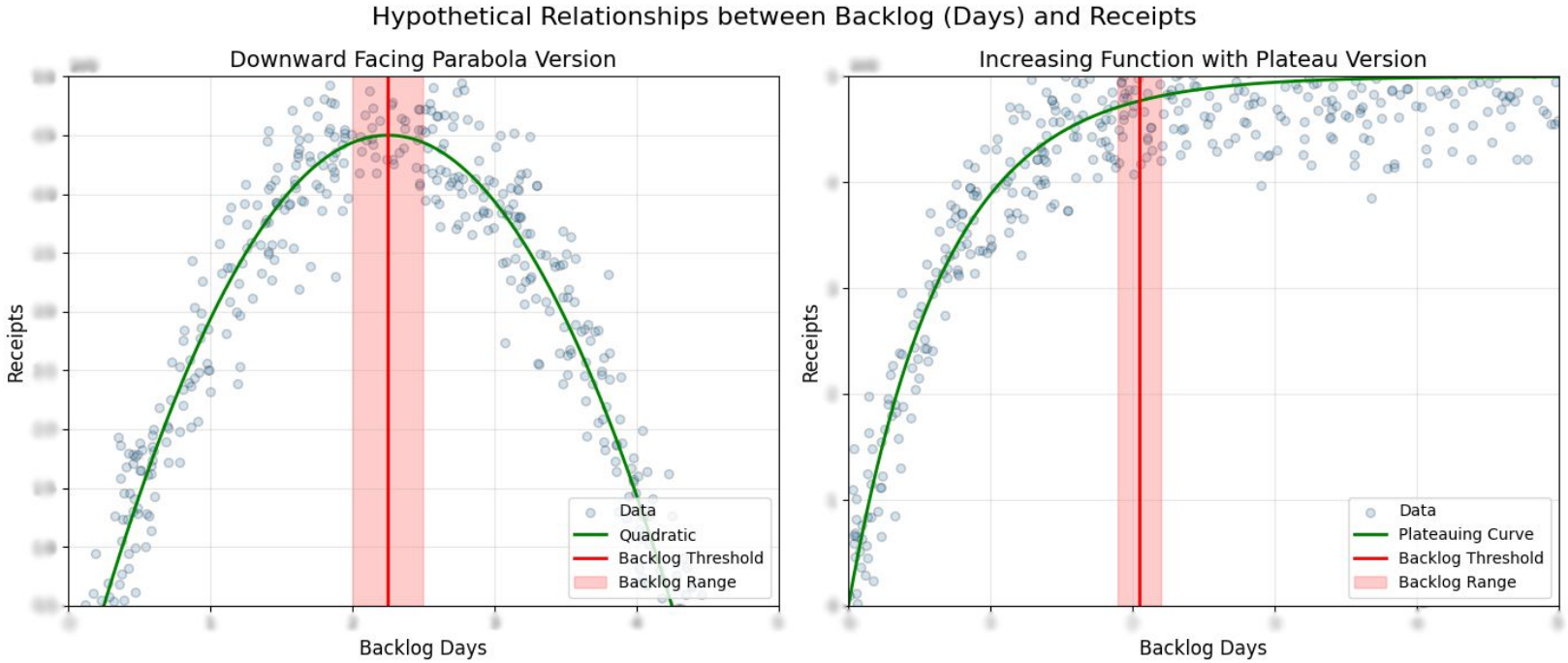
Approach

- Analyze relationship between receipts and backlog.



IXD Optimal Backlog Range Identification

Hypothesis

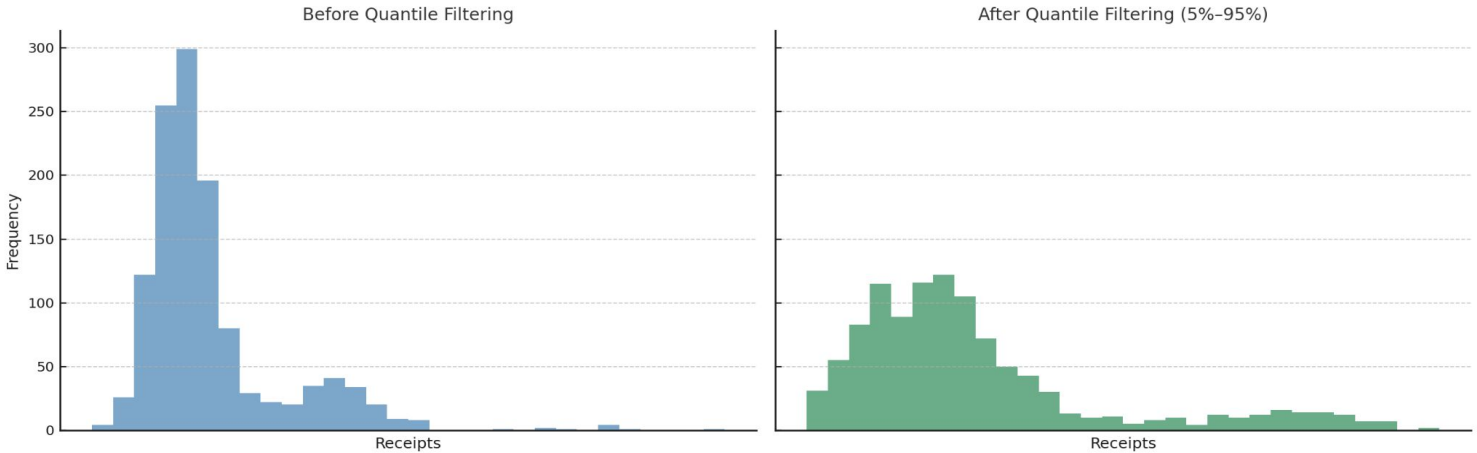


IXD Optimal Backlog Range Identification

Methodology

1. Data preprocessing
   - Quantile filtering.
3. Final approach
   - LOESS smoothing + quadratic fit to extract backlog peak.

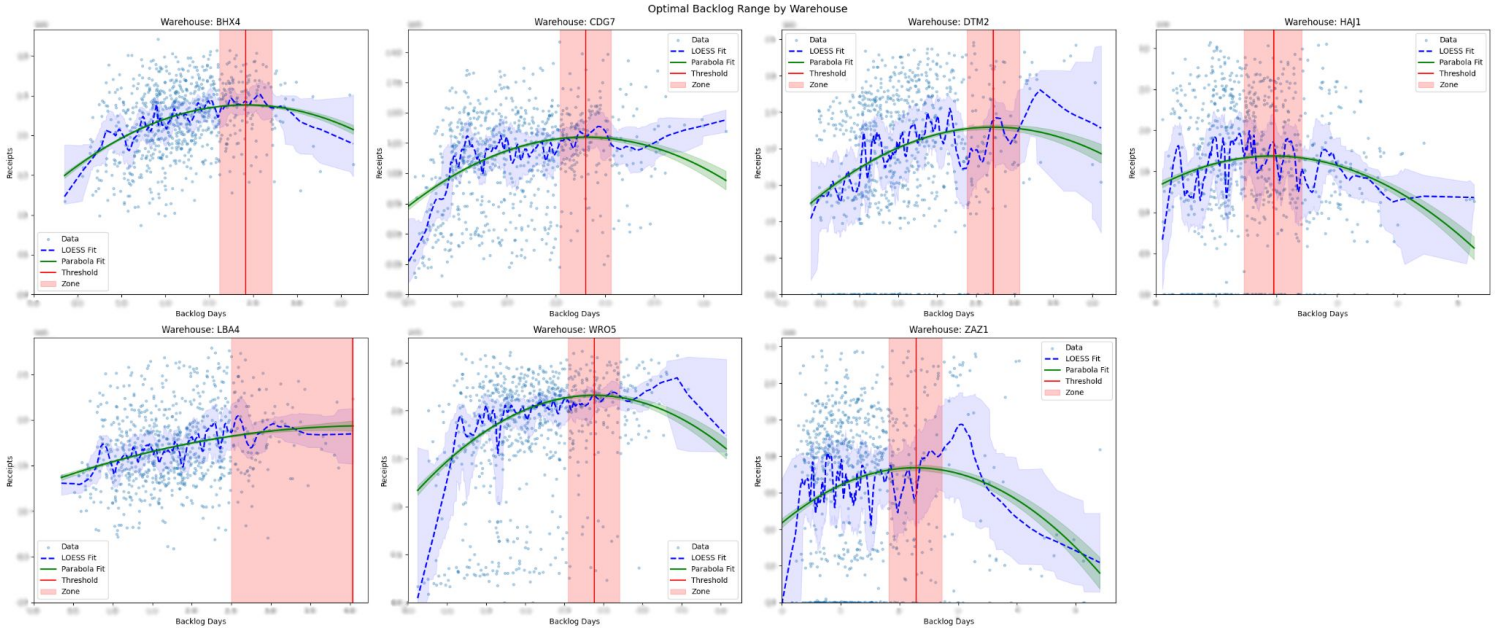
2. Tested methods
   - Correlation analysis (unstable).
   - Quadratic fit (sometimes worked).
   - LOESS smoothing (captured local patterns, but noisy).



IXD Optimal Backlog Range Identification

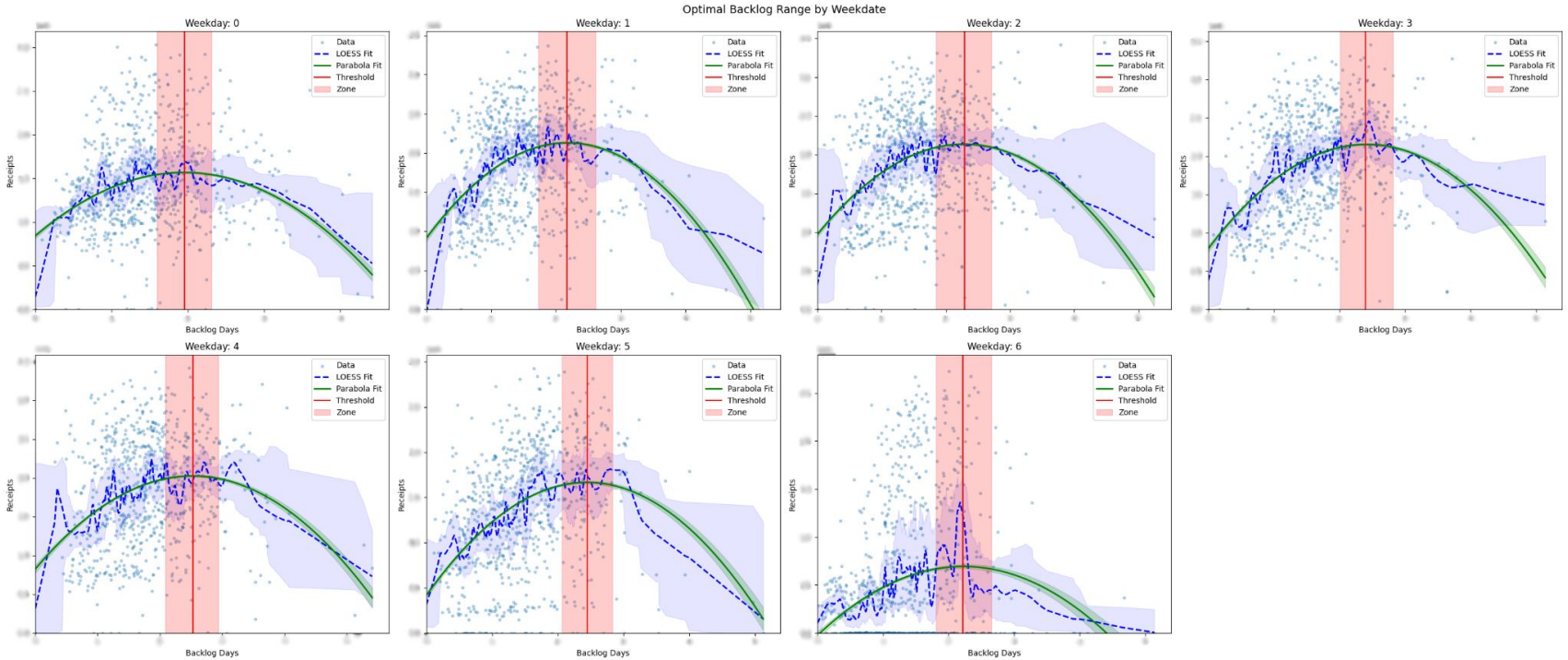
Analysis: per Warehouse

1. Calculate slope.
2. Normalize to [0, 1] range.
3. Identify interval where slope < 0.15 (manually defined threshold, ≈ 0.5 backlog days).



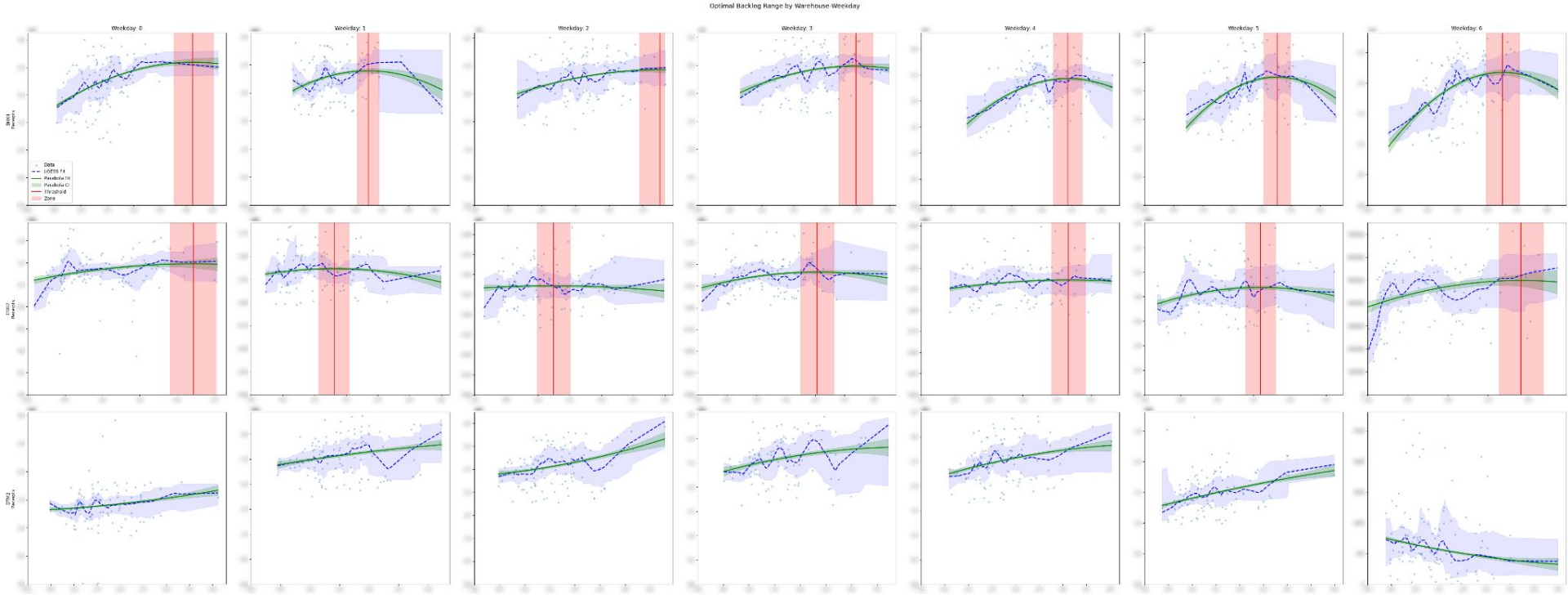
IXD Optimal Backlog Range Identification

Analysis: per Weekday



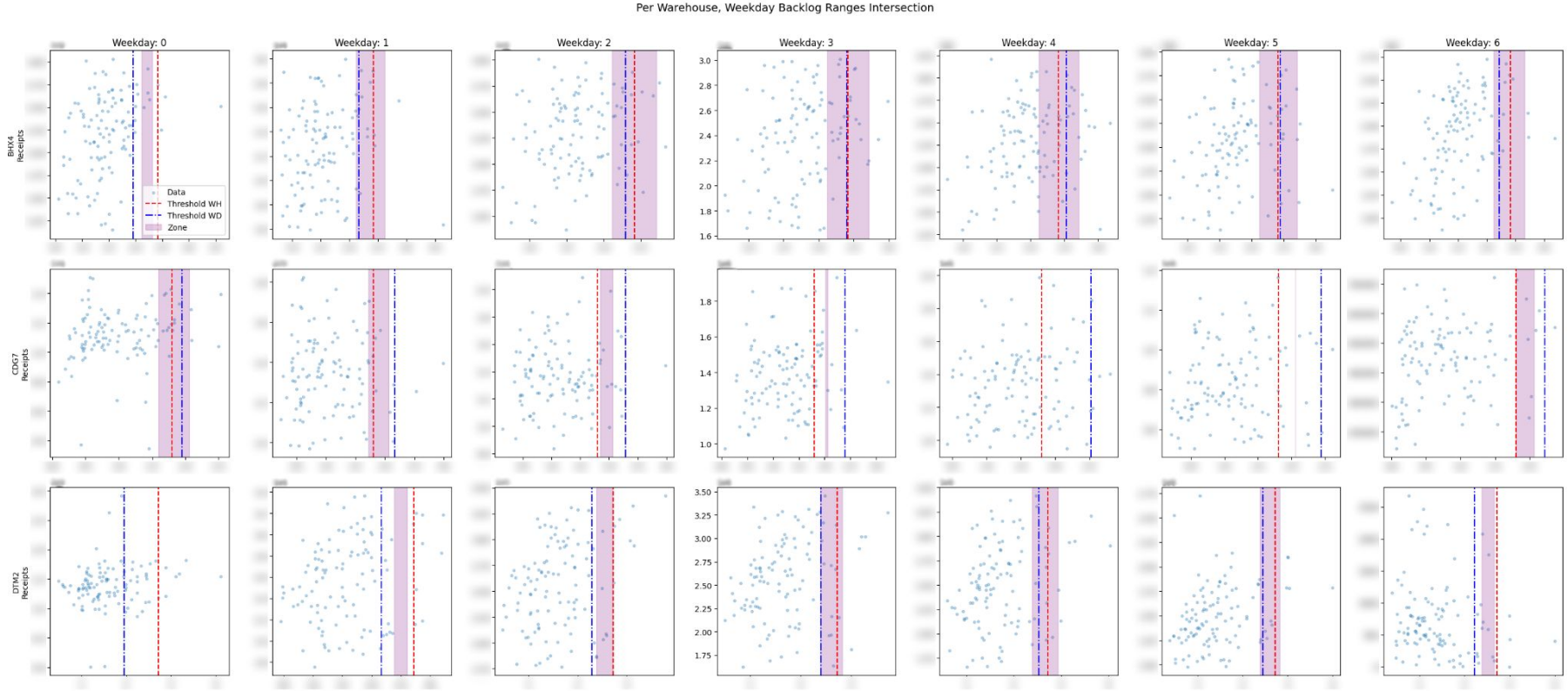
IXD Optimal Backlog Range Identification

Analysis: Combined



IXD Optimal Backlog Range Identification

Analysis: Intersection



IXD Optimal Backlog Range Identification

Outcomes

Feedback

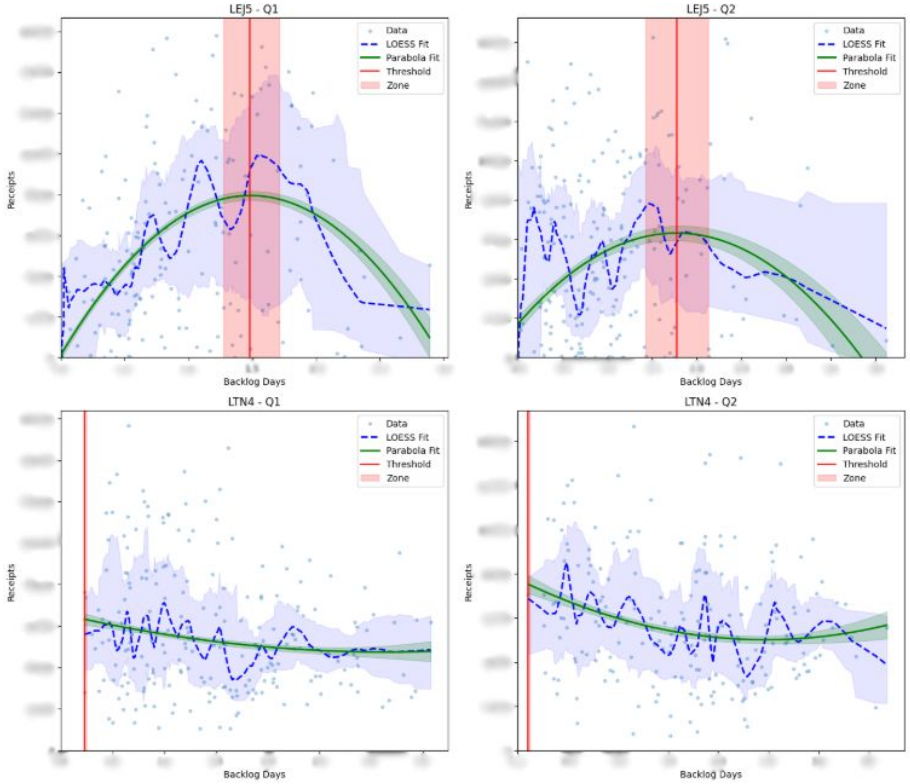
- IBET team (responsible for inbound operations) confirmed ranges useful & reasonable.
- Safety cutoffs needed.
- Extension to seasonal splits.

Findings

- Method worked with enough data.
- Too granular → unstable results.
- Sometimes contradicted hypothesis.

Outcome

- Approach promising but needs stronger preprocessing & more work.



Project 2:
Inbound Maximum Processing Capacity Validation, Modeling, and Optimization

Inbound Maximum Processing Capacity

Overview

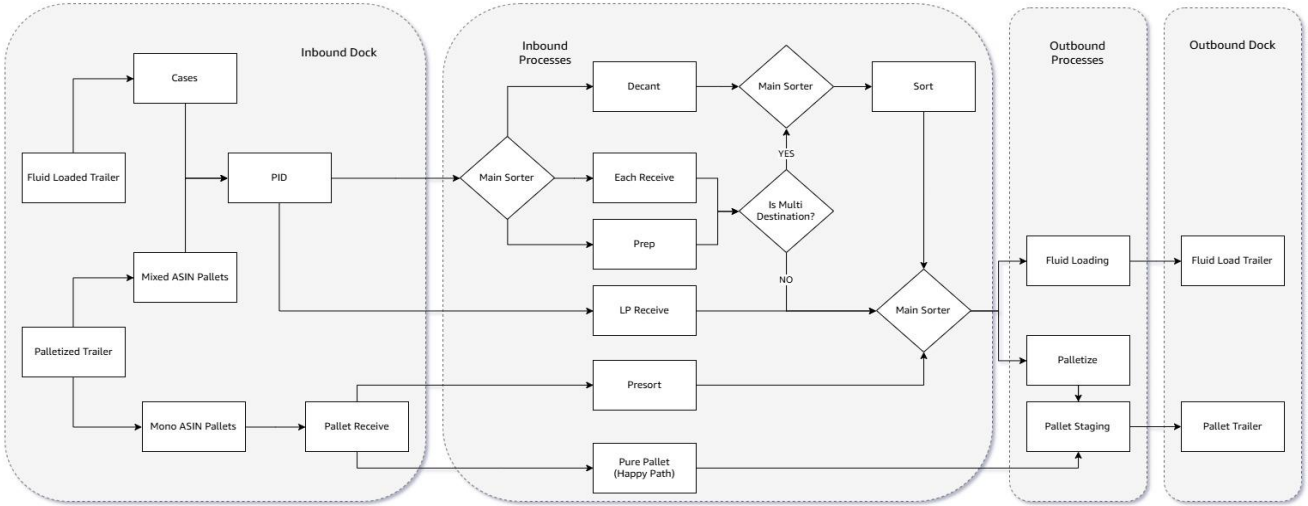
"The success of the supply chain depends on the inbound: if we place inventory in the right locations, we can deliver fast – and accurate maximum processing capacity models tell us where to place it" - Ivano.

1. Validation: Validate maximum processing capacity (MPC) models → improve accuracy and alignment with labor planning.
2. Utilization: Align planned volumes with IB maximum capacities to avoid under/over-utilization.
3. Optimization: recommend volume shifts across the EU network.

Inbound Maximum Processing Capacity

IXD: Overview

- MPC of a warehouse depends on the MPCs of all the processes.
- MPCs depend on static inputs (number of stations, conveyor setup, # dock doors) and dynamic inputs (processing rates, product mix, labor hours).
- ACES developed models that calculate MPCs.
- We cannot rely on them – we need to validate them.



Inbound Maximum Processing Capacity

IXD Validation: Overview

- Validation is performed against peak 2024 (October - December) data.
- Validated total inbound capacity, sortation capacity (including 5LB, 20LB, manual sortation) and inbound receive processes capacities: pallet, fluid.
  - Checked average utilization (historical vs. modeled capacity) across all processes (top 5 inbound volume days).
  - Measured breaches (days when actual volumes > modeled max) with 95% confidence intervals.
  - Compared daily 95th percentiles of historical volumes to modeled maximums.

Inbound Maximum Processing Capacity

IXD Validation: Summary View

Capacity Ratio Average (Top 5)

Average ratio with 95% confidence
Pallet is Mono + Mixed; Case is Fluid + Mixed

	Overall Capacity	Sort	Pallet, pallets	Fluid, cases
DE				
DTM2	119% ± 5%	81% ± 7%	101% ± 27%	115% ± 10%
HAJ1	101% ± 9%	99% ± 9%	62% ± 13%	88% ± 31%
ES				
ZAZ1	63% ± 2%	79% ± 14%	75% ± 10%	58% ± 10%
FR				
CDG7	97% ± 5%	80% ± 1%	87% ± 12%	103% ± 23%
IT				
TRN3	69% ± 4%	58% ± 12%	55% ± 9%	45% ± 7%
PL				
WRO5	115% ± 5%	88% ± 6%	57% ± 6%	99% ± 10%
UK				
BHX4	102% ± 4%	84% ± 6%	78% ± 6%	78% ± 9%
LBA4	83% ± 1%	100% ± 4%	73% ± 12%	108% ± 3%

Average Error (Top 5 Receipts)

Average error with 95% confidence
Pallet is Mono + Mixed; Case is Fluid + Mixed

	Overall Capacity	Sort	Pallets	Fluid, cases
DE				
DTM2	16% ± 3%	22% ± 11%	17% ± 17%	12% ± 9%
HAJ1	5% ± 4%	6% ± 2%	62% ± 36%	29% ± 41%
ES				
ZAZ1	56% ± 5%	27% ± 28%	34% ± 21%	74% ± 30%
FR				
CDG7	4% ± 0%	24% ± 2%	15% ± 17%	15% ± 12%
IT				
TRN3	44% ± 8%	74% ± 34%	81% ± 29%	122% ± 35%
PL				
WRO5	13% ± 4%	13% ± 8%	76% ± 22%	6% ± 5%
UK				
BHX4	2% ± 3%	18% ± 9%	27% ± 10%	29% ± 16%
LBA4	19% ± 2%	2% ± 2%	38% ± 25%	8% ± 3%

Number of Max Capacity Breaches

	Overall Capacity	Sort	Pallets	Fluid, cases
DE				
DTM2	10	0	12	17
HAJ1	2	2	0	1
ES				
ZAZ1	0	0	0	0
FR				
CDG7	0	0	0	12
IT				
TRN3	0	0	0	0
PL				
WRO5	7	0	0	2
UK				
BHX4	1	0	1	0
LBA4	0	1	0	8

Inbound Maximum Processing Capacity

IXD Validation: P95 View

Daily P95 Receipts vs Max Capacity

DTM2 max receive capacity is under deep dive and being revised

	P95 Total	Max Total Capacity	Ratio
DE			
DTM2			
HAJ1			
ES			
ZAZ1			
FR			
CDG7			
IT			
TRN3			
PL			
WRO5			
UK			
BHX4			
LBA4			

Daily P95 Total Sorted Units vs Max Sort Capacity

	P95 Sort	Max Sort Capacity	Ratio
DE			
DTM2			
HAJ1			
ES			
ZAZ1			
FR			
CDG7			
IT			
TRN3			
PL			
WR...			
UK			
BHX4			
LBA4			

Daily P95 Pallets (Mono + Mixed) vs Max Pallet Capacity

DTM2 pallet capacity is under deep dive and being revised

	P95	Max Pallets Capacity	Ratio
DE			
DTM2			
HAJ1			
ES			
ZAZ1			
FR			
CDG7			
IT			
TRN3			
PL			
WRO5			
UK			
BHX4			
LBA4			

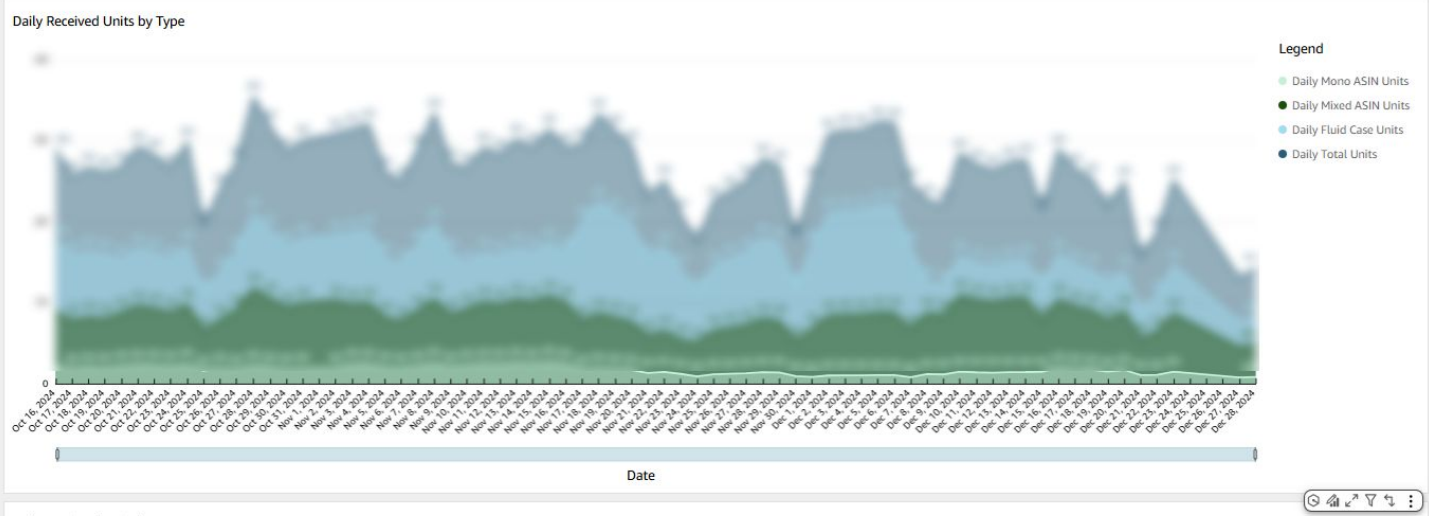
Daily P95 Fluid Cases vs Max Fluid Capacity

DTM2 fluid unloading capacity is under deep dive and being revised

	P95 Fluid	Max Fluid Capacity	Ratio
DE			
DTM2			
HAJ1			
ES			
ZAZ1			
FR			
CDG7			
IT			
TRN3			
PL			
WR...			
UK			
BHX4			
LBA4			

Inbound Maximum Processing Capacity

IXD Validation: Additional Analysis



Daily Received Units by Type %

Date	Oct 16, 2024	Oct 17, 2024	Oct 18, 2024	Oct 19, 2024	Oct 20, 2024	Oct 21, 2024	Oct 22, 2024	Oct 23, 2024	Oct 24, 2024	Oct 25, 2024	Oct 26, 2024	Oct 27, 2024	Oct 28, 2024	Oct 29
Total Receipts														
Fluid %														
Mono %														
Mixed %														

Inbound Maximum Processing Capacity

Side Note: Validation Reasoning

Why perform validation?

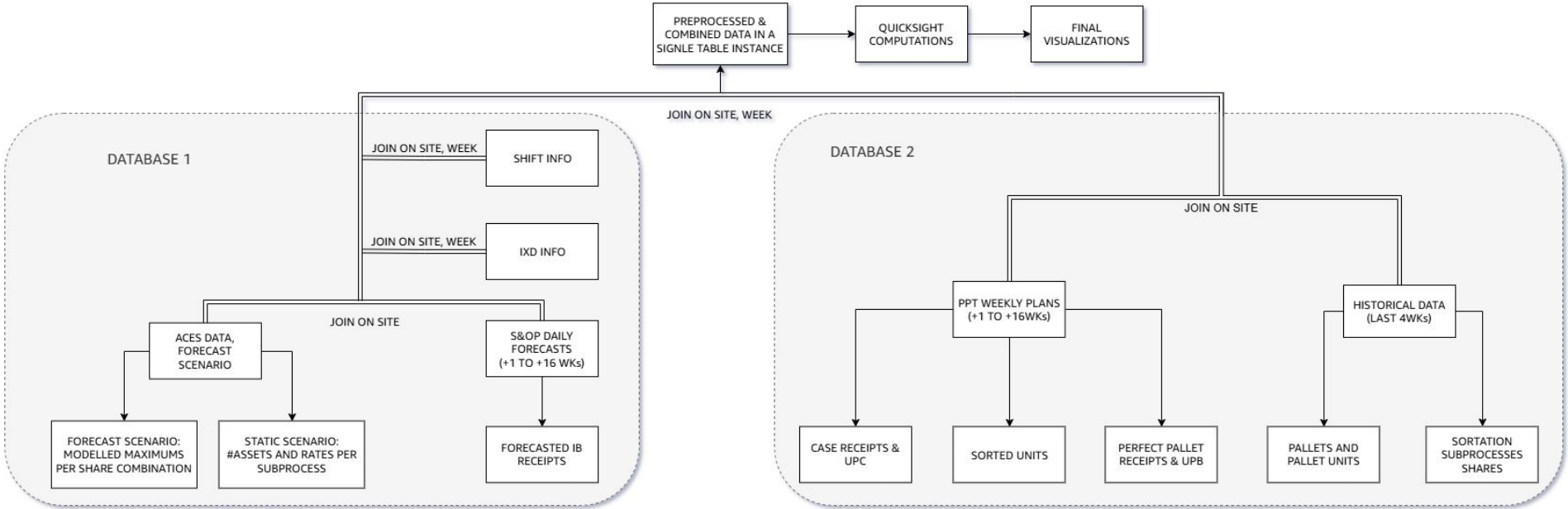
- Align modeled inputs (e.g., stations, hourly rates, product mix) with reality.
- Ensure modeled capacities match historical performance (within 85%–105% utilization range).
- Reduce risk of underestimation → missed deliveries, inefficiency, customer dissatisfaction.

Example result:

- Reduced relative model error by:
  - Total sortation –18%
    - UIS 20LB –38%
    - UIS 5LB –26%
    - Manual sortation –23%
- Final total site capacity average relative error: ~7%

Inbound Maximum Processing Capacity

Side Note: Data Extraction



Inbound Maximum Processing Capacity

IXD Utilization: Overview

- Goal: show planned vs. modeled maximum capacity for each site → identify over- and under-utilization.
- Two views:
  - Daily utilization for total & sortation capacity.
  - Daily utilization for pallet, depalletization, case, and fluid.
- Scenario analysis: dashboards allow adjusting model inputs (e.g., pallet share) to test different planning scenarios.

Inbound Maximum Processing Capacity

IXD Utilization: Receive & Sort Example

Receive and Sort Capacity Utilization Summary

Region	Country	Warehouse		Week Number 33	34	35	36	37	38	39	40	41
CEU	DE	DTM1	IB Capacity Utilization									
			Sort Capacity Utilization									
		DTM2	IB Capacity Utilization									
			Sort Capacity Utilization									
		HAJ1	IB Capacity Utilization									
			Sort Capacity Utilization									
		DE Subtotal	IB Capacity Utilization									
			Sort Capacity Utilization									

Receive Capacity Utilization Deep Dive

Region	Country	Warehouse		Week Number > Date: 33 Aug 12, 2025	Aug 13, 2025	Aug 14, 2025	Aug 15, 2025	Aug 16, 2025	34 Aug 17, 2025	Aug 18, 2025	Aug 19, 2025	Aug 20, 2025	Aug 21, 2025
CEU	DE	DTM1	Plan IB										
			Max IB Capacity										
			IB Capacity Utilization										
		DTM2	Plan IB										
			Max IB Capacity										
			IB Capacity Utilization										
		HAJ1	Plan IB										
			Max IB Capacity										
			IB Capacity Utilization										
		DE Subtotal	Plan IB										
			Max IB Capacity										
			IB Capacity Utilization										

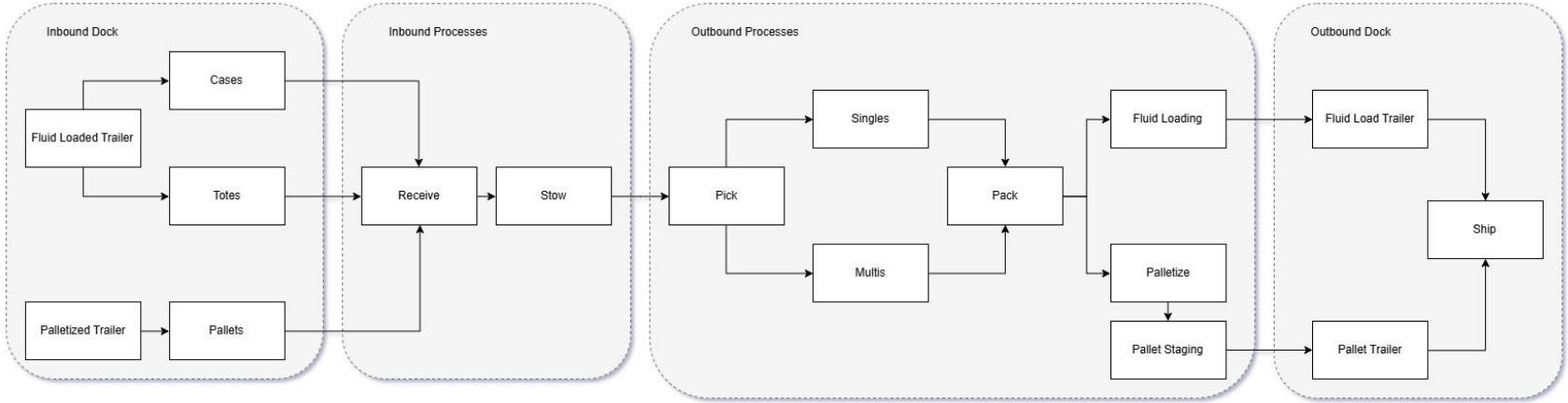
Inbound Maximum Processing Capacity

FC: Overview

- Idea is the same as with the IXD:
  - Perform MPC model validation.
  - Develop utilization dashboard.
- But higher complexity:
  - Receive inventory from IXDs (TSI) and vendors & sellers (NVF)
  - TSI inventory adds 5 more receive funnels.

Transport
Stow
Pick

FULFILLMENT CENTER



Inbound Maximum Processing Capacity

FC Validation: Overview

Transport
Stow
Pick

- Validation focused on:
  1. Unconstrained maximum stow capacity.
  2. Maximum capacity based on the S&OP peak 2025 f
     TSI and TSI tote shares.
  3. Residual IB capacity after accounting for the modeled OB maximum capacities.
- Additional complexity at FCs:
  - More processes (stowing, picking).
  - More inbound funnels (NVF + TSI) and additional receive container type (tote).
  - Extra constraints: drive utilization, bin fullness, ACU.

Inbound Maximum Processing Capacity

FC Validation: Unconstrained

The goal was to validate model inputs:

1. Identified the highest IB volume each FC site was able to achieve during Peak 2024.
2. Modeled the unconstrained IB maximum capacity by multiplying three factors assumed in the model: number of IB stations, number of working hours per day, hourly stow rate.

Stow Unconstrained Max Capacity

Warehouse	Country	IB Max	IB P95	IB Stations (Stow)	Working Hours	Stow Rate Assumption	IB Max Capacity Stow / Unconstrained	Max Stow Capacity Above Historical Max
BCN1	ES							Ratio 50%: No callout
BCN4	FR							Ratio 61%: No callout
BGY1	IT							Ratio 61%: No callout
BLQ1	IT							Ratio 104%: Callout
BRE2	DE							Ratio 67%: No callout
BRE4	DE							Ratio 91%: No callout
BRQ2	CZ							Ratio 59%: No callout
BRS1	UK							Ratio 105%: Callout
BRS2	UK							Ratio 71%: No callout
DSA6	UK							Ratio 70%: No callout
DUS4	DE							Ratio 86%: No callout
EMA1	UK							Ratio 92%: No callout

Inbound Maximum Processing Capacity

FC Validation: Constrained

- Compared the P95 historical inbound volume against the constrained max capacity (realistic).
  - Capacity values heavily depend on factors such as product mix (pallet/case/tote volume split), and units per case, pallet, and tote.
- Using the P95 (instead of the historical max) provides a fairer comparison.

Max Capacities basis S&OP Peak Mix

Warehouse	Country	IB Max	IB P95	Constrained Max IB Capacity	Tote Share Assumption	Constraint	Constraint Capacity	Callout
BCN1	ES					FLUID UNLOADING		Ratio 98%: No callout
BCN4	FR					FLUID UNLOADING		Ratio 118%: Deep Dive Required
BGY1	IT					DISTRIBUTION SORTER		Ratio 111%: Deep Dive Required
BLQ1	IT					CONVEYOR FROM DECANT/RECEIVE LINE		Ratio 87%: No callout
BRE2	DE					DISTRIBUTION SORTER		Ratio 99%: No callout
BRE4	DE					DISTRIBUTION SORTER		Ratio 87%: No callout
BRQ2	CZ					DISTRIBUTION SORTER		Ratio 93%: No callout
BRS1	UK					STOW		Ratio 88%: No callout
BRS2	UK					DECANT/RECEIVE LINE		Ratio 107%: Deep Dive Required
DSA6	UK					DISTRIBUTION SORTER		Ratio 92%: No callout
DUS4	DE					CONVEYOR FROM DECANT/RECEIVE LINE 1 & 2		Ratio 139%: Deep Dive Required
EMA1	UK					SPIRALS		Ratio 87%: No callout
EMA2	UK					DECANT/RECEIVE LINE		Ratio 80%: No callout
EMA4	UK					DECANT/RECEIVE LINE		Ratio 243%: Deep Dive Required

Inbound Maximum Processing Capacity

FC Validation: Residual from OB

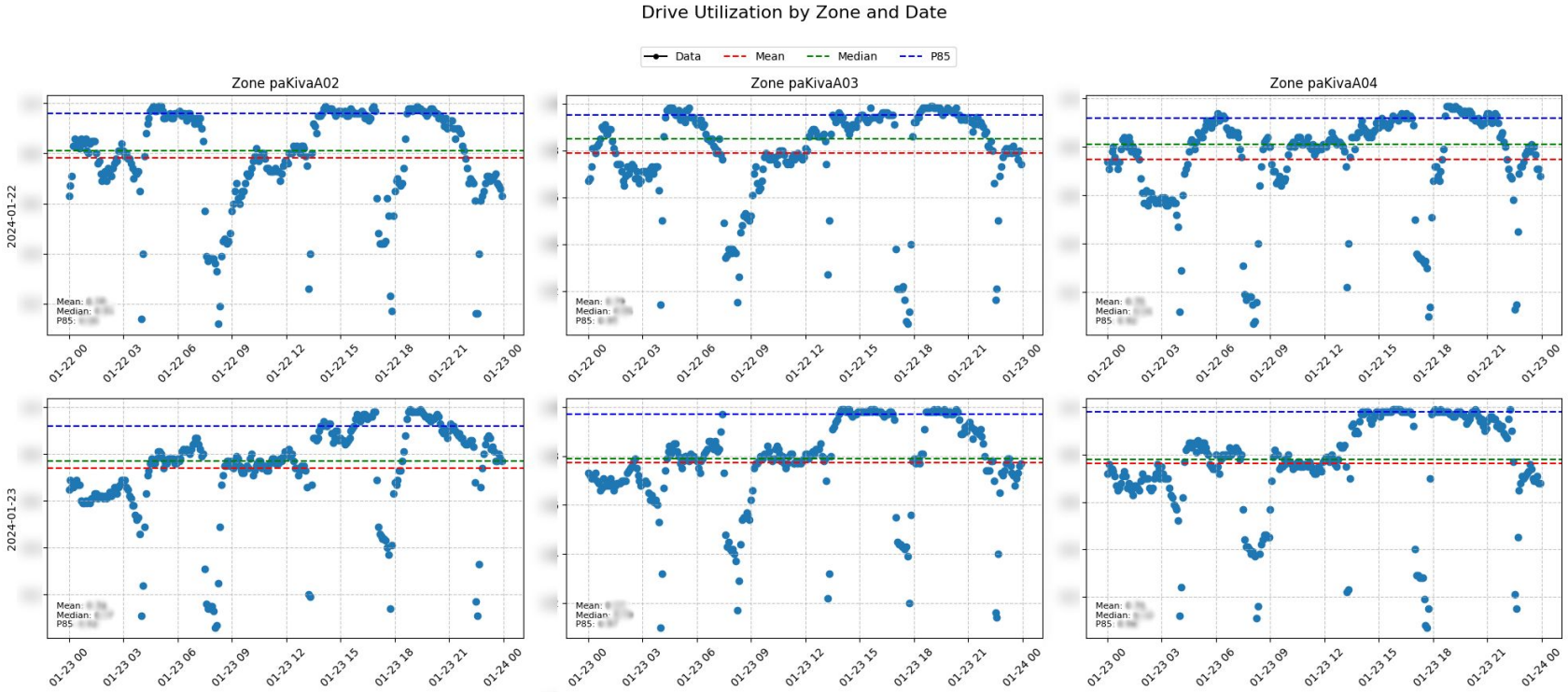
- Tested if modeled IB max at given OB volume matched peak 2024 performance:
  1. Identified modeled OB max and corresponding IB max.
  2. Selected historical days with OB ≥ 90% of modeled max, then compared actual vs. modeled IB.

Residual IB Max Capacity at OB Max

Warehouse	Country	IB Max	IB P95	IB at Max OB Capacity	Max OB Capacity	Closest OB Achieved	Achieved OB / Max OB	Relative IB	Achieved IB / Max IB
BCN1	ES								
BCN4	FR								102%
BGY1	IT								100%
BLQ1	IT								102%
BRE2	DE								73%
BRE4	DE								80%
BRQ2	CZ								71%
BRS1	UK								100%
BRS2	UK								76%
DSA6	UK								89%
DUS4	DE								103%
EMA1	UK								105%

Inbound Maximum Processing Capacity

FC Validation: Drive Utilization



Inbound Maximum Processing Capacity

FC Utilization: Overview

Following the same structure as in the IXD project, the planned capacity monitoring dashboard included three main views:

1. General overview of how much of the total inbound capacity is planned to be utilized, also broken down into TSI and NVF capacities (similar to IXD).
2. IB, TSI, NVF capacity utilization based on fullness levels (scenario analysis).
3. IB, TSI, NVF capacity utilization based on UPT (units per tote) values (scenario analysis). Required modeling.

Inbound Maximum Processing Capacity

FC Utilization: Fullness

- By changing bin fullness %, the maximum capacity either decreases or increases.
- Fullness – how full the bins used for Stowing and Picking are.
- Fullness affects the Pick and Stow throughput rates, which in turn affect the maximum capacity.

Custom Fullness

Same selected fullness across all FCs and across all days

Warehouse		Week Number > Date											
		34							35				
		Aug 17, 2025	Aug 18, 2025	Aug 19, 2025	Aug 20, 2025	Aug 21, 2025	Aug 22, 2025	Aug 23, 2025	Aug 24, 2025	Aug 25, 2025	Aug 26, 2025	Aug 27, 2025	Aug 28, 2025
BCN1	Custom Fullness	122%	122%	122%	122%	122%	122%	122%	122%	122%	122%	122%	122%
	Plan IB												
	Max IB Capacity at Custom Fullness												
	Custom - Baseline Max IB	-262,756	-160,982	-159,639	-237,333	-195,645	-189,007	-76,771	-161,463	-129,376	-150,723	-155,759	-224,684
	IB Capacity Utilization	46%	62%	88%	75%	57%	42%	30%	56%	96%	69%	109%	82%
BCN4	Custom Fullness	122%	122%	122%	122%	122%	122%	122%	122%	122%	122%	122%	122%
	Plan IB												
	Max IB Capacity at Custom Fullness												
	Custom - Baseline Max IB	-219,538	-227,528	-221,536	-229,525	-229,525	-223,533	-126,929	-216,339	-226,532	-232,129	-224,494	-224,494
	IB Capacity Utilization	84%	143%	80%	153%	156%	110%	56%	77%	145%	111%	106%	130%
BGY1	Custom Fullness	122%	122%	122%	122%	122%	122%	122%	122%	122%	122%	122%	122%

Inbound Maximum Processing Capacity

FC Utilization: UPT Modeling

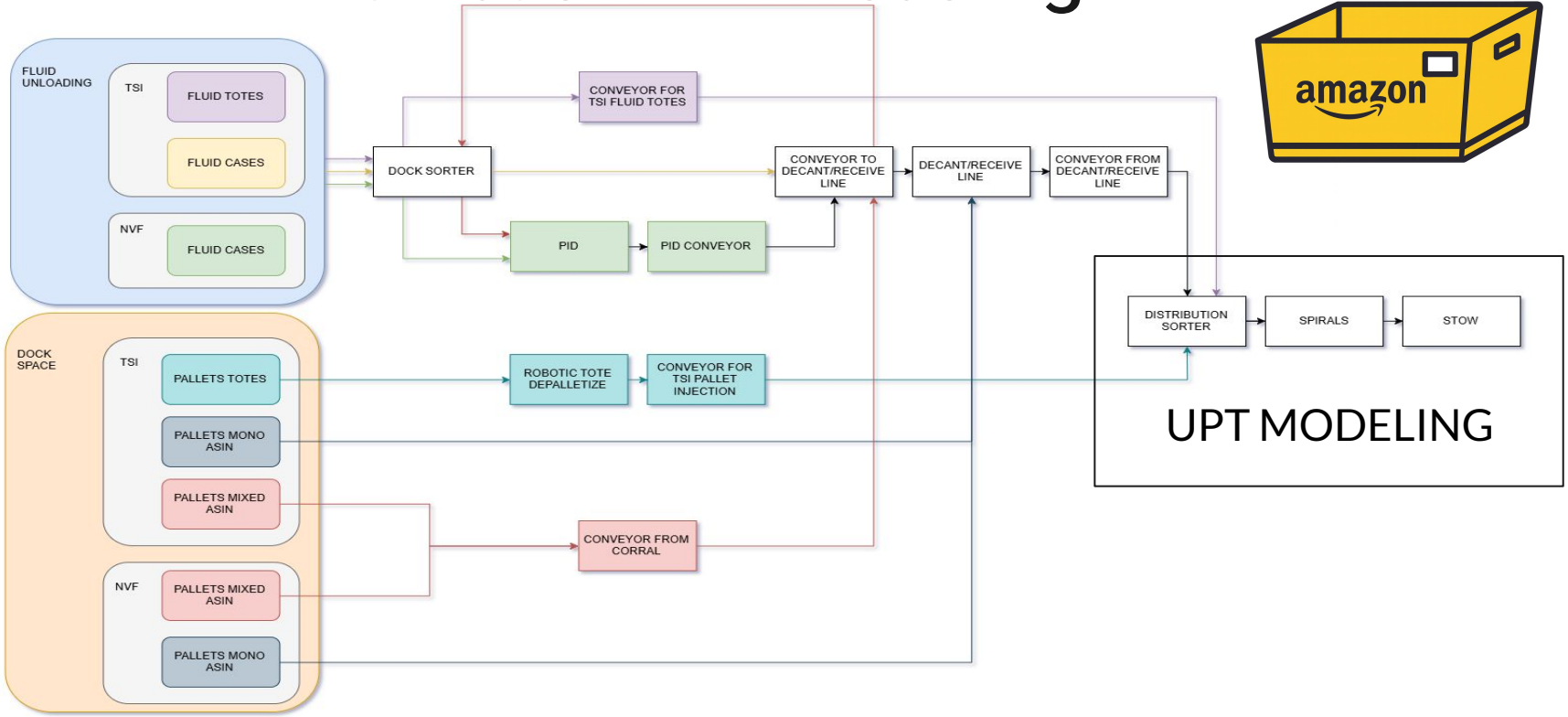
IB Capacity Change at Custom UPT

Max capacity is based on selected UPT (either planned or custom value)
Custom UPT value is same across all FCs and across all days

Warehouse		Week Number > Date												
		34							35					
		Aug 17, 2025	Aug 18, 2025	Aug 19, 2025	Aug 20, 2025	Aug 21, 2025	Aug 22, 2025	Aug 23, 2025	Aug 24, 2025	Aug 25, 2025	Aug 26, 2025	Aug 27, 2025	Aug 28, 2025	Aug 29, 2
BCN1	UPT (at STOW)	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	
	Plan IB Capacity	[illegible]												
	Max IB Capacity	[illegible]												
	IB Capacity Utilization	[illegible]												
BCN4	UPT (at STOW)	[illegible]												
	Plan IB Capacity	[illegible]												
	Max IB Capacity	[illegible]												
	IB Capacity Utilization	[illegible]												

Inbound Maximum Processing Capacity

FC Utilization: UPT Modeling



Inbound Maximum Processing Capacity

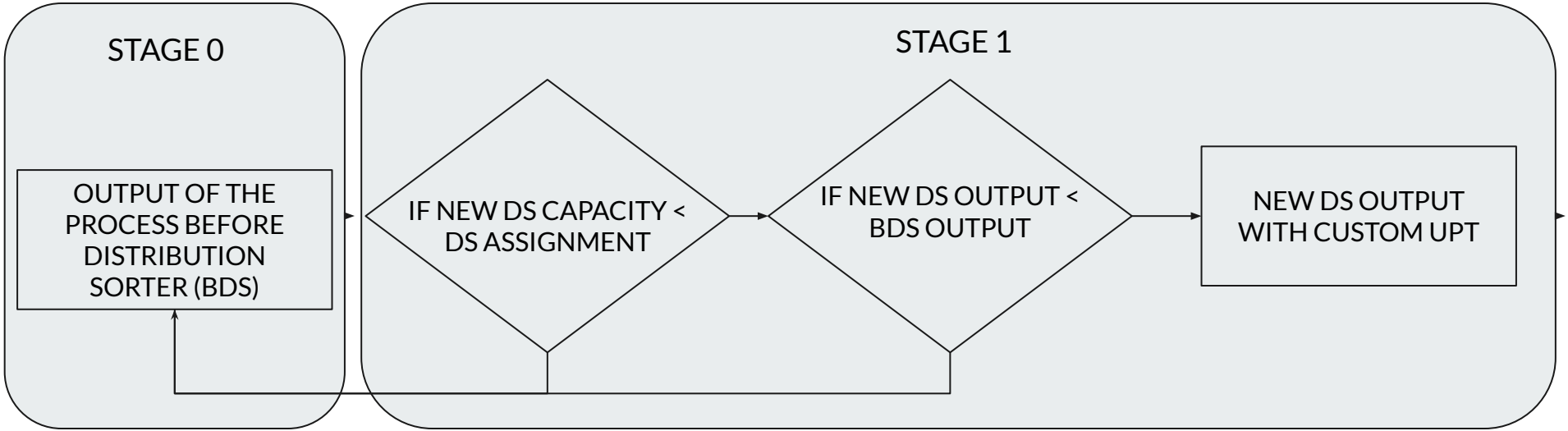
FC Utilization: UPT Modeling

There are

- 8 funnels:
  - TSI: fluid cases, pallets mixed ASIN, pallets mono ASIN, fluid totes, pallets totes.
  - NVF: fluid cases, pallets mixed ASIN, pallets mono ASIN (same as in IXD receive).
- 4 processes:
  - Process before distribution sorter.
  - Distribution sorter.
  - Spirals.
  - Stow.

Inbound Maximum Processing Capacity

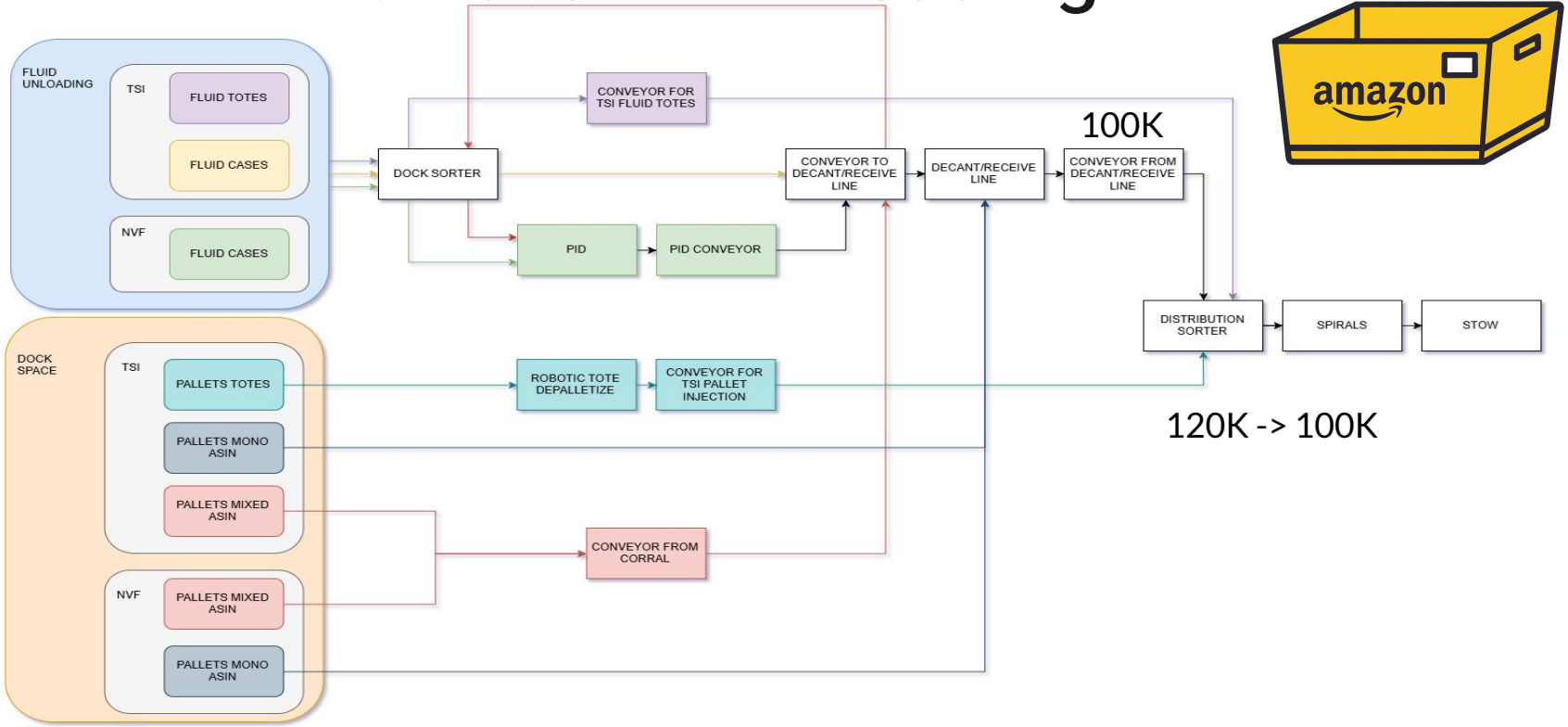
FC Utilization: UPT Modeling



- NEW PROCESS MAX CAPACITY = PROCESS MAX CAPACITY / ASSUMED UPT * CUSTOM UPT
- NEW PROCESS OUTPUT = NEW PROCESS MAX CAP * PROCESS FPP
  - Assignment = Forecasted # of units that will go through that process.
  - FPP = Flow Path Percentage, % of units going through that funnel/process

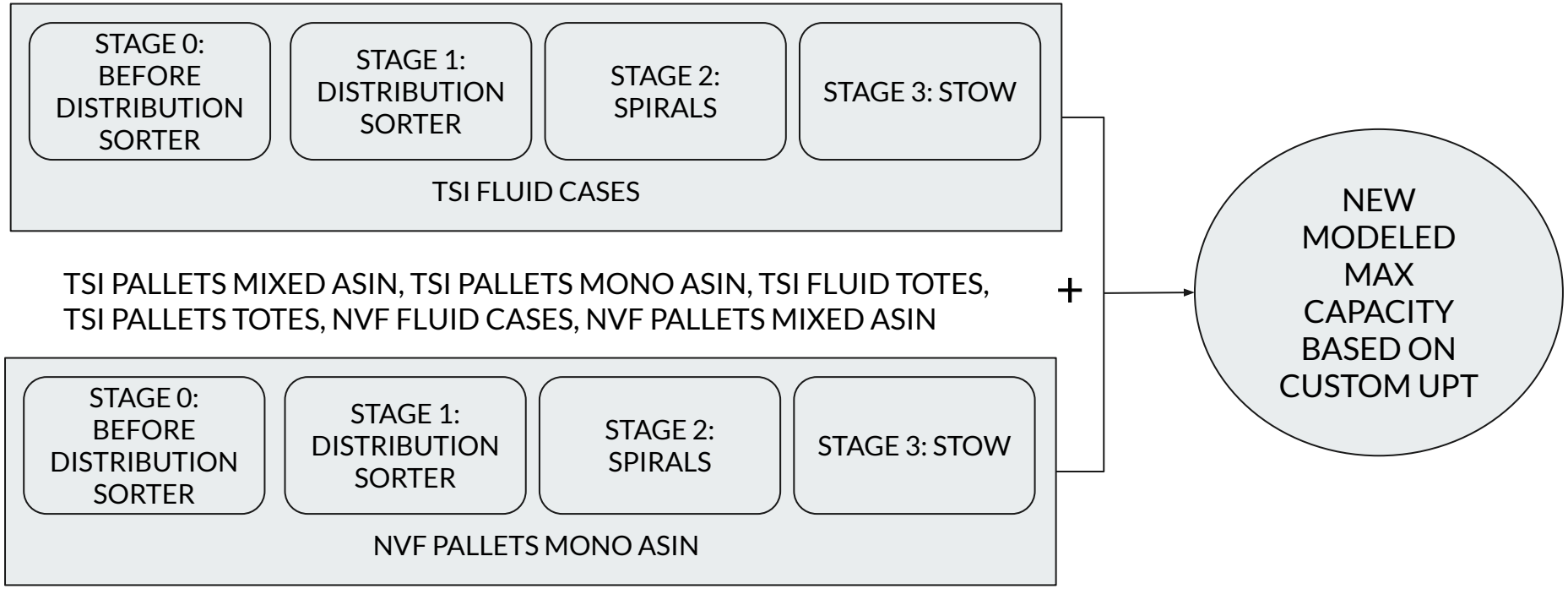
Inbound Maximum Processing Capacity

FC Utilization: UPT Modeling



Inbound Maximum Processing Capacity

FC Utilization: UPT Modeling



Conclusions

Results

Optimal Backlog Range Identification

Objective – Identify optimal backlog levels

- Estimate backlog ranges where facilities operate most efficiently.

Findings

- Method effective with sufficient data
- Over-segmentation → unstable results.
- Some fits contradicted hypothesis.

Impact

- Approach promising but not yet generalizable.
- Needs stronger preprocessing and additional variables for robust use.

Inbound Maximum Processing Capacity

Objective 1 – Validation

- Fixed model inputs & improved accuracy.

Objective 2 – Monitoring & Scenarios

- Built inbound monitoring dashboards.
- Enabled scenario testing.

Objective 3 – Optimization

- Formed basis for EU-wide optimization.

Impact

- Source of truth used by many teams.
- Scheduled for use in peak 2025.
- Supports better decisions, reduces over-/under-utilization.

Conclusion

Key Contributions

- Backlog project: method to identify optimal backlog ranges (needs further development).
- Capacity project: validated models, built monitoring dashboards, prepared foundation for EU-wide optimization.

Takeaways

- Importance of simple, interpretable solutions over complexity.
- Importance of explaining complex solutions in simple, understandable terms.
- Strengthened skills in SQL, data validation, pipelines, and visualization, and writing scalable code.
- Value of clear communication between technical and business teams.

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Thank you for your time and attention

Questions?