

# Multi-Objective Optimization of Container Load Plans for Modulating Inventory Flow



## BUSINESS PROBLEM

Global retailers face growing challenges in managing the flow of goods from manufacturing sites to distribution centers. Conventional container load planning (CLP) approaches focus solely on maximizing container utilization, which overlook broader supply chain considerations and lead to mistimed delivery, inventory pileups, higher storage and transportation costs, and operational inefficiencies at distribution centers. The core business problem is to rethink how CLP can be optimized to balance cost efficiency, space utilization, and delivery timing to lower costs, improve service levels, and ensure smoother inventory flow.

## DATA SOURCES

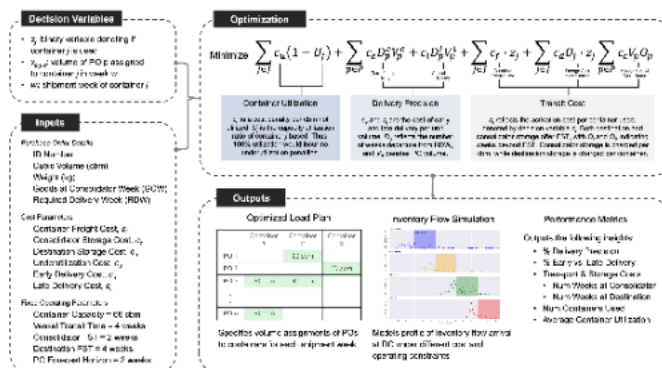
The model uses 200K+ purchase order records from a high-volume shipping lane. Data was sourced from ERP systems (order volumes, product details), sales order systems (required delivery dates), and transportation management systems (shipment timestamps), providing full visibility into baseline container usage, shipment timing, and purchase order volume allocations.

## Data Types and Format

Structured tabular data, including time series (PO volumes by shipment week), categorical variables (product type), and numerical fields (purchase order volume and quantities).

## APPROACH

A multi-objective MILP-based emulator using a branch-and-bound structure was developed using a dataset of 200K+ purchase orders. The model evaluates trade-offs between transportation and storage costs, container utilization, and delivery precision and generates an optimized load plan that specifies container selection, shipment week, and allocation of purchase order volumes per container.



## IMPACT

The solution enables a more strategic and prescriptive approach to container load planning (CLP). Rather than relying on FIFO or manual consolidator decisions, businesses can assess the impact of different loading configurations on key metrics such as delivery precision (early vs. late delivery rate), container utilization, transportation costs, and storage fees. The model allows logistics practitioners to evaluate metrics trade-offs, simulate different planning scenarios in real time, and visualize inventory flow across downstream warehouses and distribution centers. Simulation results highlight that rigidly maximizing container utilization can lead to high early delivery rates, inflating inventory holding costs and causing warehouse congestion. By balancing multiple operational objectives, the model reduces deviations in inventory arrival time and decreases pre-season inventory surges. The model also enables targeted policy analysis—for example, testing the business impact of relaxing co-loading restrictions or shipment volume thresholds—to understand which constraints can be modified to improve performance. Overall, the solution provides logistics practitioners with a decision-support tool that customizes container load planning with broader operational goals.

### DRIVERS

Key drivers faced by the global retail industry include rising freight transportation and inventory storage costs, volatile freight rates, and increasing complexity in inventory flow management due to seasonal demand and omnichannel fulfillment.

### BARRIERS

Key barriers included limited visibility into third-party consolidator decision-making, lack of standardized digital load plans, and fragmented data across systems. Modeling complexity was also high due to multiple, often conflicting objectives and operational constraints (e.g., co-loading rules, shipment thresholds).

### ENABLERS

Key enablers included strong cross-functional collaboration across supply chain, logistics, and data teams, as well as access to high-quality, granular PO-level data across systems. Leadership support for innovation in transportation planning and openness to testing advanced analytics also created the runway for model development and scenario simulation.

### ACTIONS



A site visit to a major shipping port provided firsthand insight into container operations. Interviews with subject matter experts allowed us to map the end-to-end load planning process to identify decision points and visibility gaps. These insights informed the development of the optimization model, integration of cross-system data, and simulation test cases for scenario analyses.

### INNOVATION

Innovative aspects include a multi-objective MILP-based emulator that balances container utilization, delivery precision, and transportation and storage costs—moving beyond traditional volume-maximization models. The model supports real-time scenario simulation, policy testing (e.g., load rule relaxation), and visualizes downstream inventory flow, enabling more adaptive and data-driven load planning decisions.

### IMPROVEMENT

The container load plans generated through the optimization model reduced early deliveries by up to 35%, increasing delivery precision (the percent of purchase orders arriving exactly on their target delivery week) by 73.9% from the baseline. The model also demonstrated a roughly 9% reduction in the number of containers used and fewer pre-season inventory peaks.

### BEST PRACTICES

Best practices for replicating the approach include: 1) full process mapping to identify where optimization will have the most impact, 2) start with a focused lane or use case to pilot the model before scaling, 3) incorporate business constraints (like co-loading rules) to ensure practical applicability, and 4) enable scenario testing to build stakeholder buy-in and support decision-making.

### OTHER APPLICATIONS

Potential applications include truck load optimization for middle- and last-mile operations. There is also opportunity in supporting strategic network design by simulating flow patterns under different flow models or demand scenarios. Additionally, the modeling framework can be extended to multi-echelon supply chains, enabling synchronized planning across factories, consolidators, and distribution centers.