Plan Safely Ahead: Robust Optimization for Inventory Management under Demand Uncertainty

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Problem Statement

Fluctuated Demand of Spare Parts

Power plants across the US encounter **unplanned maintenance**. Maintenance and repairs require spare parts from warehouses in time to avoid out of service penalty

High Operation Cost

1. Warehouse inventory across the U.S.
2. Air shipment for urgent demand is costly

Objective

Get ~95% of parts at any power plant within same day at the lowest cost possible

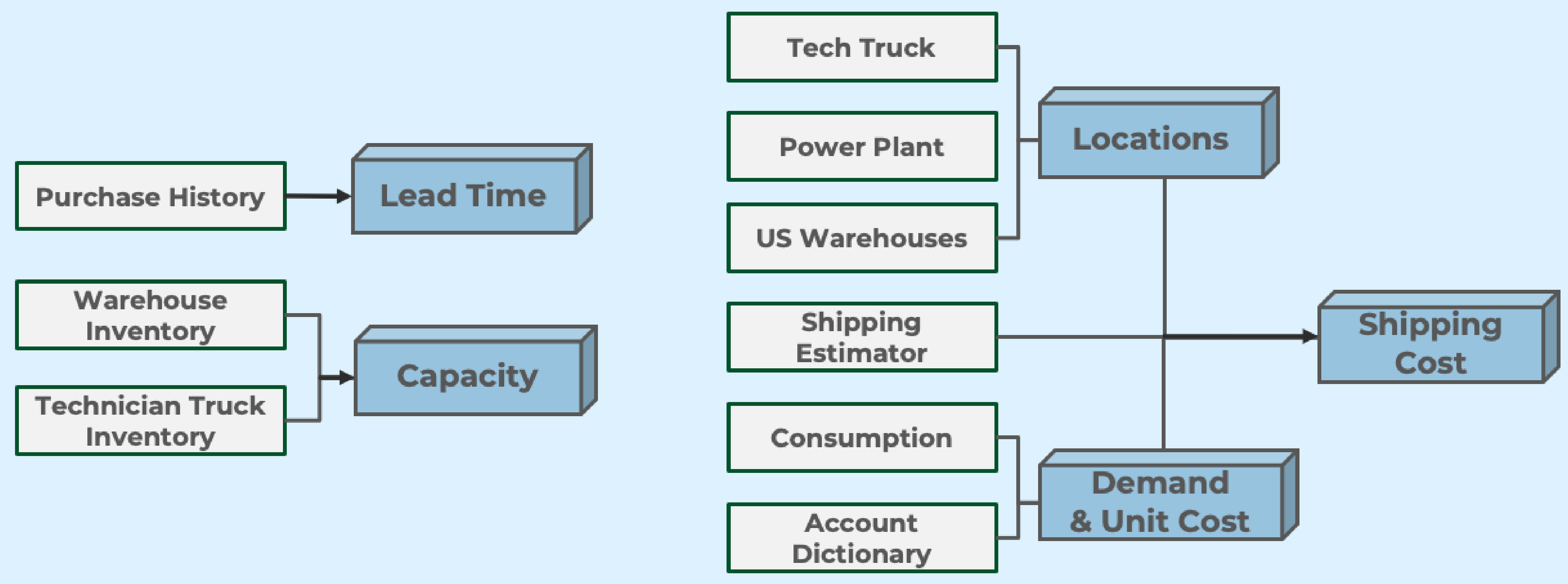
Cost components:
Inventory holding cost in warehouses

Shipment cost between warehouses & warehouse -> power plant

Data Description and Processing

Datasets

Location | Shipment | Procurement | Inventory Record



Statistics

$Millions	Hundreds	Years
Inventory Value	Selected Spare Parts	Valid Data Time Range

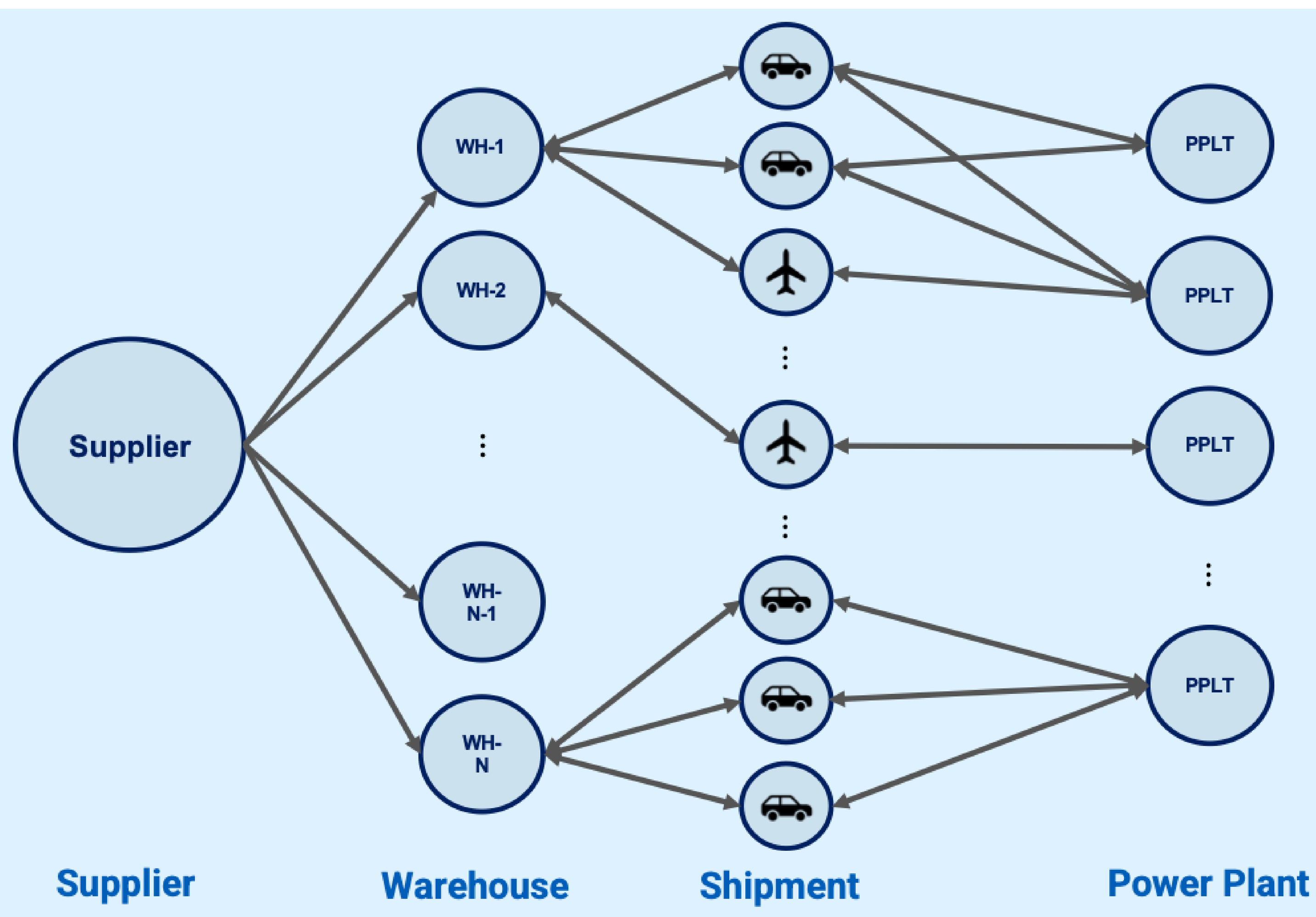
Methodology

Provide monthly inventory recommendation up to **6 months** into the future for supplier lead time

Analyze demand pattern and account for **fluctuation** across multiple power plants

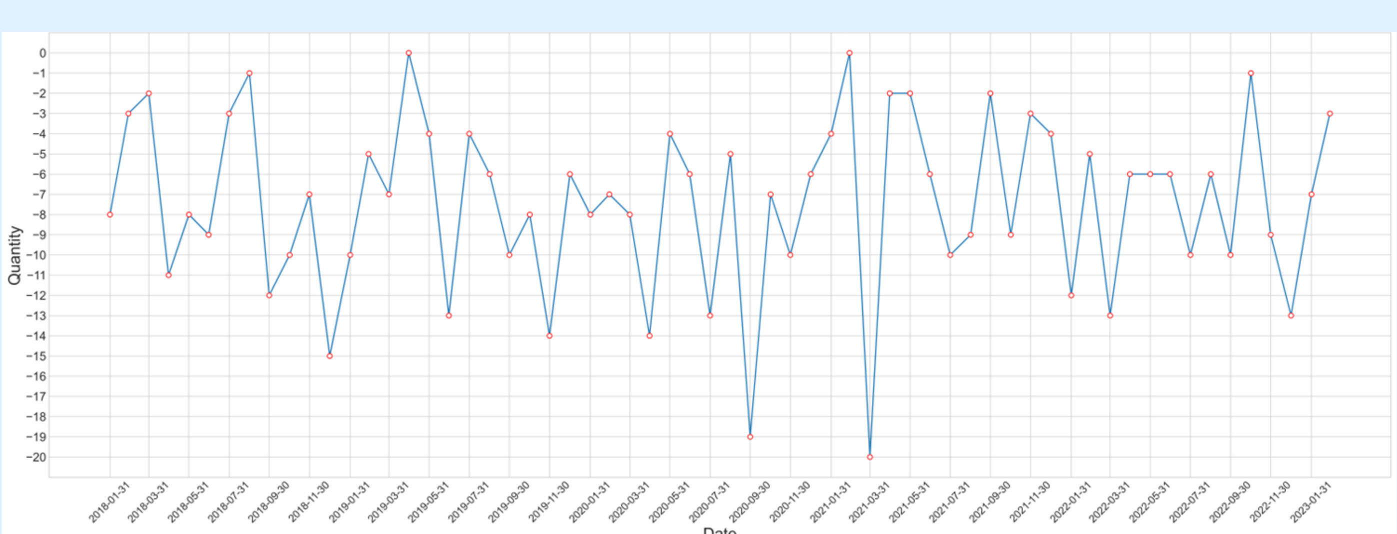
Encode geographical distance and enforce **same-day limit** for transportation

Network Flow Model



Optimization

- Conduct time series analysis for every **(part, site)** pair
- Estimate demand **average** and **standard deviation** to plug in optimization model



Inventory Holding & Shipment Cost
$$\min_{N_{ikt}, T_{ijkt}, S_{ikt}} \sum_{t=1}^{\tau}\sum_{i=1}^{n}\sum_{k=1}^{K} c_{ik}N_{ikt} + \sum_{t=1}^{\tau}\sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{K} h_{ijk}T_{ijkt}$$

Inventory Balance
$$s.t. N_{ikt} = N_{ik(t-1)} + \sum_{j=1}^{n}(T_{jikt} - T_{ijkt}) + S_{ikt} - \sum_{j=n+1}^{N} T_{ijkt}, \forall i \in [1,n], \forall k, \forall t$$

Warehouse Capacity
$$\sum_{k=1}^{K} c_{ik}N_{ikt} \le C_i, \forall t, \forall i \in [1,n]$$

Demand
$$\sum_{i=1}^{n} T_{ijkt} = \max_{z_{jk}}(\mu_{jk} + \delta_{jk}z_{jk}), \forall j \in [n+1,N], \forall k, \forall t$$

No Shipment from Power Plant
$$T_{ijkt} = 0, \forall i \in [n+1,N], \forall j, \forall k, \forall t$$

Same Day Delivery Limit
$$T_{ijkt} = 0, \forall (i,j) \in \{(i,j) \mid i \in [1,n], j \in [n+1,N], Time(i,j) \ge 1\}, \forall k, \forall t$$

Demand Uncertainty Set
$$Z = \{ z_{jk}: |z_{jk}| \le 2, \forall j \in [n+1,N], \forall k\}$$

Results

Cost Improvement on Company's Current Safety Stock Model

	$z_{jk} = 0$	$z_{jk} = 1$	$z_{jk} = 2$	$z_{jk} = 3$
Relax Same Day Delivery Constraint	82.03%	82.13%	82.18%	82.22%
Enforce Same Day Delivery Constraint	30.44%	30.99%	31.14%	31.28%

Impacts

Established **automatic data analysis** and **inventory optimization** process

Identified spare parts with **high/low usage** frequency to more **efficiently address inventory allocation**

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