Advanced Planning in Supply Chains - Illustrating the Concepts Using an SAP APO Case Study

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8.1 Introduction to Deployment

- Deployment Planning
  - Determine detailed distribution plan by matching *actual* supply to *planned* supply
    - Appropriately fulfill promised sales orders
    - Determine how to replenish inventories
  - Distribution plan determines: Source, destination, quantity and date of each shipment
  - Make adjustments to the plan created by SNP, in case of:
    - Insufficient quantities available to fulfill demand
    - Available quantities exceed demand
  - Time buckets of SNP disaggregated into smaller time buckets
  - Aggregate representation of transportation capacity taken into account
8.1 Introduction to Deployment

- Necessity of Deployment Planning
  - Integration of planning modules
    - Connecting planning modules with different aggregation levels
  - Inventory shortage or surplus
    - Aggregation-disaggregation errors in forecasts and capacities
    - Deviation of the realized supplies from their expected amounts
  - Literature gap for deployment planning

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Advanced Planning in Supply Chains
8.1 Introduction to Deployment

• Deployment - Question

Why is only the aggregate transport capacity taken into account in the deployment model?
8.1 Introduction to Deployment

- **Basic Deployment Problem**
  - Two echelon supply chain
  - Determine an optimal distribution of given *inventories* from *source locations* to *customer locations* in each period of the deployment planning horizon
8.1 Introduction to Deployment

• Basic Deployment Problem
  • Problem definition and assumptions:
    • Customer demand served from inventories of source locations
    • Stocks are replenished according to a detailed production plan
    • Different transportation modes between source and customer location
    • Transportation and inventory capacities are limited
    • Inventory status of customer locations is not known by source locations
    • Transportation and holding costs are linear in the amount transported/ held on stock
    • Consumption of aggregate transportation capacities is linear in quantity and transportation time of shipments
    • Shortage costs are linear in the amount of unfulfilled orders
8.1 Introduction to Deployment

• Basic Deployment Problem

Symbols

Dimensions

\( QU \) Quantity Unit

\( MU \) Monetary Unit

Indices

\( j \) product \( j \in J \)

\( i \) customer location \( i \in I \)

\( l \) source location \( l \in L \)

\( t \) periods of the planning horizon \( t \in T = \{1, \ldots, T'\} \)

\( m \) transportation mode \( m \in M \)
8.1 Introduction to Deployment

• Basic Deployment Problem

Symbols

Data

d_{ijt} \quad \text{demand size of customer location } i \text{ for product } j \text{ in period } t \quad [\text{QU}]

\bar{\rho}_{lim} \quad \text{actual transportation time from location } l \text{ to location } i \text{ with transportation mode } m \text{ expressed in fraction of periods}

\rho_{lim} \quad \text{transportation lead time from source location } l \text{ to customer location } i \text{ with transportation mode } m \text{ expressed in number of periods: } (\rho_{lim} = \lceil \bar{\rho}_{lim} - 1 \rceil)

s_{ljt} \quad \text{planned production of product } j \text{ at source location } l \text{ in period } t \quad [\text{QU}]

c_{limt} \quad \text{cost of delivering one product unit from source location } l \text{ to customer location } i \text{ with transportation mode } m \text{ in period } t \quad [\text{MU/QU}]
8.1 Introduction to Deployment

• Basic Deployment Problem

Symbols

Data

$c'_i$ penalty cost of not fulfilling one unit of demand at customer location $i$ [MU/QU]

$h_{lj}$ cost of storing one unit of product $j$ at source location $l$ for one period [MU/QU]

$v_{lm}$ aggregate transport capacity of transport mode $m$ at source location $l$ per period [QU]

$u_l$ inventory capacity at source location $l$ [QU]

$b_j$ inventory capacity consumption coefficient of product $j$ [QU]

$I_{lj0}$ initial inventory of product $j$ at source location $l$ [QU]
8.1 Introduction to Deployment

• Basic Deployment Problem

Symbols

Variables

\( I_{l,j,t} \) \quad \text{inventory of product } j \text{ at source location } l \text{ at the end of period } t \text{ [QU]}

\( Z_{l,i,j,m,t} \) \quad \text{amount of delivery from source location } l \text{ to cover demand of customer location } i \text{ for product } j \text{ with transportation mode } m \text{ in period } t \text{ [QU]}

\( Z'_{i,j,t} \) \quad \text{amount of unfulfilled demand of customer location } i \text{ for product } j \text{ in period } t \text{ [QU]}
8.1 Introduction to Deployment

- Basic Deployment Problem

Objective function

\[
\begin{align*}
\text{Min} & \quad \sum_{t \in T} \sum_{j \in J} \sum_{l \in L} h_{lj} \cdot I_{ljt} \\
& + \sum_{t \in T} \sum_{m \in M} \sum_{j \in J} \sum_{i \in I} \sum_{l \in L} c_{limt} \cdot Z_{lijmt} \\
& + \sum_{t \in T} \sum_{j \in J} \sum_{i \in I} c_{i}' \cdot Z_{ijt}'
\end{align*}
\]

s.t.

Inventory Balance

\[
I_{ljt} = I_{lj,t-1} - \sum_{m \in M} \sum_{i \in I} Z_{lijmt} + s_{ljt} \quad \forall l \in L, j \in J, t \in T
\]
8.1 Introduction to Deployment

- **Basic Deployment Problem**
  
  **Demand Coverage**
  \[
  \sum_{m \in M} \sum_{l \in L} Z_{lijm, t-\rho_{lim}} + Z'_{ijt} = d_{ijt} \quad \forall i \in I, j \in J, t \in T \tag{3}
  \]

  **Inventory Capacity**
  \[
  \sum_{j \in J} b_j \cdot I_{ljt} \leq u_l \quad \forall l \in L, t \in T \tag{4}
  \]

  **Transport Capacity**
  \[
  \sum_{j \in J} \sum_{i \in I} Z_{lijmt} \cdot \bar{\rho}_{lim} \leq v_{lm} \quad \forall l \in L, m \in M, t \in T \tag{5}
  \]

  **Non-Negativities**
  \[
  I_{ljt}, Z'_{ijt}, Z_{lijmt} \geq 0 \quad \forall l \in L, i \in I, j \in J, m \in M, t \in T \tag{6}
  \]
8.1 Introduction to Deployment

• Deployment - Question

What are the advantages and disadvantages of using a discrete vs. a linear optimization method for deployment planning?
8.1 Introduction to Deployment

- Deployment - Answer

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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8.1.1 Deployment Modeling Framework

- Deployment Planning Attributes

![Diagram showing deployment planning attributes and their relationships]

Figure 8.1
8.1.1 Deployment Modeling Framework

- a.1 Product Attributes: Perishability
  - Two types of product perishability
    - Products with fixed shelf life and stable quality
    - Products that continuously degrade in quality

- Average product quality at customers
  - Reflected in deployment objective
  - Quality, a measure of fairness
  - Complex multi-objective

- Minimum level of observed quality at customers
  - Considered in a set of side constraints
8.1.1 Deployment Modeling Framework

**Exercise (Perishability)**

- How can the basic deployment model be extended to account for limited shelf lives of products? The following additional notation is given:

**New Index**

- \( \tilde{t} \) \hspace{1cm} production period

**New Data**

- \( I_{\tilde{t},l,j_0} \) \hspace{1cm} initial inventory of product \( j \) at source location \( l \) from products produced in period \( \tilde{t} \) [QU]

- \( r_{i,j}^t \) \hspace{1cm} maximum age of product \( j \) to fulfill the shelf life requirements of customer location \( i \) expressed in number of periods

**New variables**

- \( I_{\tilde{t},l,j,t} \) \hspace{1cm} inventory of product \( j \) at source location \( l \) at the end of period \( t \) with products produced in period \( \tilde{t} \) [QU]

- \( Z_{\tilde{t},l,i,j,m,t} \) \hspace{1cm} amount of product \( j \) produced in period \( \tilde{t} \) in source location \( l \) and shipped in period \( t \) with mode \( m \) to cover the demand of customer location \( i \) [QU]
8.1.1 Deployment Modeling Framework

- **Exercise (Perishability)**

  **Inventory balance**

  \[ I_{tljt} = s_{ljt} - \sum_{m \in M} \sum_{i \in I} Z_{tlijmt} \quad \forall t \in T, l \in L, j \in J \]

  \[ I_{iljt} = I_{ilj,t-1} - \sum_{m \in M} \sum_{i \in I} Z_{ilijmt} \quad \forall t \in T, l \in L, j \in J, \tilde{t} < t \]

  **Demand coverage**

  \[ \sum_{m \in M} \sum_{l \in L} \sum_{i=t-r_{ij}}^{t-\rho_{lim}} Z_{tlijm,t-\rho_{lim}} + Z_{ijt}' = d_{ijt} \quad \forall i \in I, j \in J, t \in T \]
8.1.1 Deployment Modeling Framework

- **a.2 Product Attributes: Substitutability**
  - Shortage planning in multi-product environments where products can be used interchangeably
  - Trade-off between incurring a shortage (shortage cost incurred) or sending a substitute product (penalty cost incurred)
8.1.1 Deployment Modeling Framework

- **b.1 Location Attributes: Sourcing**
  - Enlarging the solution space
    - Sourcing decisions are given by the long term plan (SNP)
  - Introduction of new challenges
    - Priority definition in flexible sourcing
  - SAP APO supports sourcing flexibility
    - Priority settings on transport connections between every source and destination (priority based planning)
    - Explicit definition of new transport costs (cost based planning)
  - Transshipment links as an alternative approach
8.1.1 Deployment Modeling Framework

b.2 Location Attributes: Customer Priority

- ABC classification
- Two potential approaches
  - Soft customer priorities
    - Different shortage penalties for different combinations of products and customers
    - Low priority customer might be served while a high priority customer is not fully covered!
  - Cost-based deployment planning
- Hard customer priorities
  - Explicit priority numbers
  - No priority violation
  - Priority-based deployment planning
8.1.1 Deployment Modeling Framework

- c.1 Modelling Attributes: Demand Data
  - Supply disruptions (e.g. machine breakdown)
    - Reactive policy
      - Re-running the deployment module
  - Demand uncertainty
    - Safety stocks
    - Forecast consumption method
8.1.1 Deployment Modeling Framework

• c.2 Modelling Attributes: Shortage Modelling
  • Late-delivery (back-orders)
    • Customers accept late delivery until a certain time threshold
    • Incur backlogging penalty
  • Lost sales
    • Source locations cannot fulfill the demand of customers with late delivery
    • Penalty cost incurred

• SAP APO supports both shortage types for deployment planning
8.1.1 Deployment Modeling Framework

- c.3 Modelling Attributes: Central Inventory Surplus Management
  - Local inventory control
    - Customers order based on their inventory status
    - Deployment plan covers customer orders
    - Surplus inventory held at source locations
  - Vendor Managed Inventory (VMI)
    - Central inventory control
    - Suppliers control inventory status of customers
      - Higher planning flexibility
    - The deployment plan guarantees a certain service level
      - Min/max inventory level of customer locations
      - Unfulfilled demand
    - Surplus inventory held at source and customer location
8.1.1 Deployment Modeling Framework

- c.3 Modelling Attributes: Central Inventory Surplus Management
  - Intra-company surplus management
    - Source location: production site
    - Demand location: distribution center
    - Commonly products are pushed to DC
    - Distribute the surplus among DCs according to their share of total demand
    - Surplus completely divided between DCs

- SAP APO’s deployment module supports both attributes
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- Deviations between actual orders and forecasts

Figure 8.2
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...
8.2 Planning Tasks and Data for Frutado

- Deployment for the Frutado Company
  - Determine detailed distribution of produced beverages
    - From production sites to DCs
    - From DCs to customers
  - Revise medium-term distribution plan from SNP in case of inventory shortage or surplus
  - Time horizon: 2 weeks with granularity level of days
- Products only stored in DCs
- Always sufficient inventory capacities at DCs
- Aggregate transportation capacities
8.2 Planning Tasks and Data for Frutado

- Characteristics of the Problem
  - Sourcing
    - Each customer served through one DC
    - Each DC can be supplied by any production site
  - Customer priority
    - ABC customer classification
  - Shortage management through back-ordering
    - Late deliveries and no-deliveries penalties
  - Inventory control
    - Central inventory system manages inventory status at DC
    - No VMI at customer
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8.3 Modeling Deployment for Frutado

- Two sub-models:
  1. Deployment planning model between production sites and DCs (see book page 235)
  2. Deployment planning model between DCs and customer locations (see book page 237)
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- Interaction with other SAP APO Modules

Figure 8.3

- The two arrows in dashed line provide information for both PP/DS and Deployment planning modules.
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8.4.2 Solution Methods in SAP APO

• Deployment Optimization
  • Optimizer creates a distribution plan for all chosen products for all chosen locations of the supply chain model
  1. Check what product quantities are available at the source locations (available-to-deploy quantity (ATD))
  2. Determine how the ATD quantity is to be distributed to destination locations
8.4.2 Solution Methods in SAP APO

Deployment Optimization

Inventory shortage

1. Cost optimal plan
   - Considers costs and constraints
   - Possible that demand at one location not covered because cheaper to fulfill other location

2. Fair-share plan
   - A distribution plan such that shortage is split among all or some of the customers

3. Fair-share and earliest delivery
   - Fulfill earliest demands if possible

Advanced Planning in Supply Chains
• Deployment Optimization

Inventory surplus

1. Cost optimal plan
   • Distributes excess stock to lowest cost locations

2. Fair-share push plan
   • Distributes quantities evenly
   • A distribution plan that delivers more than the requested products (if possible)

3. Fair-share and earliest delivery
8.4.2 Solution Methods in SAP APO

• Fair-Share Rules in Deployment Optimization
  1. *Fair-share distribution by demand*: Distribution of available products evenly among all customer orders.
  2. *Fair-share distribution by demand and earliest delivery*: Fulfilling customer orders by giving priority to orders with earlier requested delivery dates. For customer orders with the same requested delivery date, fair-share rule 1 is applied.

• Push Rules in Deployment Optimization
  1. *Push distribution by demand*: Distributing the supply surplus evenly among all customers during the entire planning horizon.
  2. *Push distribution by demand and earliest delivery*: Applying the push rule 1 but through pushing the supply surplus to earliest possible demand day.
8.4.2 Solution Methods in SAP APO

• **Exercise**
  
  • *Fair-share rules for deployment optimization:*
  
  • The following data is given:

<table>
<thead>
<tr>
<th>Period</th>
<th>ATD quantity (supply quantity)</th>
<th>Demand of customer 1</th>
<th>Demand of customer 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>900</td>
<td>300</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>3</td>
<td>200</td>
<td>500</td>
<td></td>
</tr>
</tbody>
</table>

a) Find a deployment plan based on fair-share rule 1
b) Find a deployment plan based on fair-share rule 2
Exercise - Solution

a) Find a deployment plan based on fair-share rule 1:

**Rule 1 - Fair-share distribution by demand:**
*Distribution of available products evenly among all customer orders.*

<table>
<thead>
<tr>
<th>Period</th>
<th>ATD quantity (supply quantity)</th>
<th>Distribution to customer 1</th>
<th>Distribution to customer 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>900</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Exercise - Solution

a) Find a deployment plan based on fair-share rule 2:

**Rule 2 - Fair-share distribution by demand and earliest delivery:**
Fulfilling customer orders by giving priority to orders with earlier requested delivery dates. For customer orders with the same requested delivery date, fair-share rule 1 is applied.

<table>
<thead>
<tr>
<th>Period</th>
<th>ATD quantity (supply quantity)</th>
<th>Distribution to customer 1</th>
<th>Distribution to customer 2</th>
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<tbody>
<tr>
<td>1</td>
<td>900</td>
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<tr>
<td>3</td>
<td></td>
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</tr>
</tbody>
</table>
8.4.2 Solution Methods in SAP APO

- **Deployment Heuristics**
  - Different variants of the fair-share and push rules
  - Consider each product and each supply source separately

<table>
<thead>
<tr>
<th>Fair-share rules (inventory shortage)</th>
<th>Push rules (inventory surplus)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A.</strong> Proportional distribution based on demands</td>
<td>1. Pull Distribution</td>
</tr>
<tr>
<td><strong>B.</strong> Proportional distribution based on target stock</td>
<td>2. Pull/Push Distribution</td>
</tr>
<tr>
<td><strong>C.</strong> Percentage distribution based on quota arrangements</td>
<td>3. Push Distribution by Demand</td>
</tr>
<tr>
<td><strong>D.</strong> Distribution based on distribution priority</td>
<td>4. Push Distribution by Quota Arrangement</td>
</tr>
<tr>
<td><strong>X.</strong> User defined fair-share distribution</td>
<td>5. Push Distribution Taking the Safety Stock Horizon into Account</td>
</tr>
<tr>
<td></td>
<td>6. User defined push rule</td>
</tr>
</tbody>
</table>
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• Deployment Planning Learning Units

Figure 8.4: SAP-Screenshot
Deployment planning learning units
### 8 Deployment

8.5 Deployment Learning Units

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8.5.3 In-depth Stream

- Optimization Profile

Figure 8.5: SAP-Screenshot Optimization profile

The safety stock section determines how the penalty cost is calculated if the defined safety stocks are violated.


