Flow Model: Focus on Inventory

Aug 2017 US retail inventory: 625,351 m$
CSCMP’s estimate of inventory carrying cost: 19%

How do we improve inventory performance measures?
### Inventory Planning: Nordstrom

1. Create Sales Plans for each channel
2. Determine How Much Inventory is Needed to Support Sales
3. Overestimate Sales: Too much inventory  
   Underestimate Sales: Too little inventory
4. Too much inventory: Reprice, Return, Markdown  
   Too little inventory: Expedite orders, Move $s elsewhere

**Metrics:**  
Sales, Inventory Turns (YTD Net Sales/Avg Inventory)  
Stock to Sales (STS) (Beg. Month Stock/ Month End Sales)

The most important decision is  
2. How Much Inventory?  
Our Model to Understand and Improve this decision:  
**Newsvendor Model**

---

**Nordstrom invests in supply chain software firm. July 2016. BI**  
.. to develop new initiatives, like using historical inventory data to predict future stock levels, further reducing the potential for stock shortages.

---

### A Thought Experiment

Demand in a period can be any number between 1 and 6 with equal probability. Buy a unit for $80. If you can sell it, you will get a per unit revenue of $100. If it does not sell in that period, discount it for a salvage value of $30. Each period is independent; no inventory carried between periods.

What order size decision will maximize average profit across periods?

<table>
<thead>
<tr>
<th>Period</th>
<th>Order - Size (a)</th>
<th>Demand (b)</th>
<th>Sold (c)</th>
<th>Excess (d)</th>
<th>Shortage (e)</th>
<th>Cost $80*(a)</th>
<th>Revenue $100*(b)</th>
<th>Salvage $30*(c)</th>
<th>Profit= 100*(b) - 80*(a) + 30 *(c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>320</td>
<td>400</td>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>Example</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>320</td>
<td>300</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Developing Newsvendor Model:

### Table

<table>
<thead>
<tr>
<th>Decision: How much to order/What is the starting inventory=3</th>
<th>Exp. Values are sum of (probability*value) in each case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Possible cases of demand values</td>
<td>Exp. Demand = 3.5</td>
</tr>
<tr>
<td>1/6 1/6 1/6 1/6 1/6 1/6</td>
<td>Service Demand is the fraction of cases where all demand is met.</td>
</tr>
<tr>
<td>Probability of each case</td>
<td>1/6</td>
</tr>
<tr>
<td>Meet all demand?</td>
<td>Yes</td>
</tr>
<tr>
<td>How much Sales?</td>
<td>1/6</td>
</tr>
<tr>
<td>How much Shortage?</td>
<td>0/6</td>
</tr>
<tr>
<td>How much Excess?</td>
<td>2/6</td>
</tr>
</tbody>
</table>

**Expected Profit**

\[
\text{Expected Profit} = 100 \times \text{Exp. Sales} - 80 \times \text{Order Size} + 30 \times \text{Exp. Excess}
\]

\[
= 100 \times 2.5 - 80 \times 3 + 30 \times 0.5 = 25
\]

\[
= (100-80) \times 3.5 - [ (100-80) \times 1 + (80-30) \times 0.5 ]
\]

\[
= \text{Profit without Uncertainty- Mismatch Cost} (see next slide)
\]

### Defining Service Level, Mismatch Cost

Newsvendor model: a single-period problem in which demand is uncertain

**Decision:** How much to order at the beginning of period or equivalently how much inventory to have at the start of the period

**Objective:** Maximize \(\text{Exp. Profit}\)

**Service Level:** For a given decision, what is the fraction of possible demand cases in which we can meet all demand.

\[
\text{Exp. Profit} = \text{revenue} \times \text{Exp. Sales} - \text{cost} \times \text{order} + \text{salvage} \times \text{Exp. Excess}
\]

Maximizing Exp. Profit is the same as Minimizing Mismatch cost

\[
\text{Mismatch Cost} = (\text{revenue-cost}) \times \text{Exp. Shortage} + (\text{cost-salvage}) \times \text{Exp. Excess}
\]

**Marginal cost of shortage**

\[
Cs = \text{revenue-cost}
\]

**Marginal cost of excess**

\[
Ce = \text{cost-salvage}
\]

Mismatch cost is the total cost of not being able to match demand & supply due to uncertainty
Marginal Costs of Shortage & Excess

Marginal Cost of shortage (understocking)
cost of making a mistake of buying one less than necessary.
\[ C_s = \text{revenue } r - \text{cost } c \]

Marginal Cost of excess (overstocking)
cost of making a mistake of buying one more than necessary.
\[ C_e = \text{cost } c - \text{salvage } s \]

Definition remains the same but, depending on the context, formulas may change.

Reinforcing Definitions

A publisher’s per-book publishing/delivery cost is $9; sales price is $15. What is \( C_s \)?

A mobile phone’s mfg./delivery cost is $150. If not sold in six months, unsold units are sold in Asia at $110 net. What is \( C_e \)?

A retailer operates at a targeted 98% service level for fresh milk. What is the chance that, on a late night grocery-run, you will find no milk?
Newsvendor model: Service Level Optimization

To Maximize Exp. Profit or To Minimize Mismatch Cost:

Optimal service level = \( \frac{C_s}{C_s + C_e} \)

Optimal inventory level (order size):
(newsvendor decision rule)
Order minimum quantity that matches or exceeds the optimal service level

Trade-off: Shortage Cost vs. Excess Cost

Our Experiment: Optimal Service Level

Per unit: revenue \( r=100 \), cost \( c=80 \), salvage \( s=30 \).

Step 1: Compute \( C_s \), \( C_e \), and optimal service level=
\( C_s=100=80=20 \), \( C_e=80-30=50 \), Optimal S.L. = \( 20/(20+50)=0.285 \)

Step 2: (Discrete demand) compute service levels for different order sizes

<table>
<thead>
<tr>
<th>Order</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand Prob.</td>
<td>1/6</td>
<td>1/6</td>
<td>1/6</td>
<td>1/6</td>
<td>1/6</td>
<td>1/6</td>
</tr>
<tr>
<td>Service level</td>
<td>1/6 = 0.167</td>
<td>2/6 = 0.33</td>
<td>3/6 = 0.5</td>
<td>4/6 = 0.67</td>
<td>5/6 = 0.83</td>
<td>6/6 = 1</td>
</tr>
</tbody>
</table>

Step 3: Use newsvendor decision rule to find optimal order quantity
2 is the minimum order quantity at which the service level meets or exceeds Optimal S.L. ; therefore buy and stock 2.
A Moment of Reflection

Can you think of a decision you or your company makes in which the outcome is uncertain and cost-implications are asymmetrical?

Introduction to Operations Management
Prof. Apurva Jain
OPMGT 502

Section 3 Contents

Session 11
7. Compute Inventory Performance
   □ 7.1 Newsvendor Model
      Marginal Costs of Shortage/Excess
      Optimal Service Level
   □ 7.2 Mismatch Cost Calculation
Newsvendor model

Demand follows normal distribution

Use spreadsheet to analyze newsvendor model with normal demand.

Start with Inputs:
- Demand Average (Mean), Std. Dev.
- Marginal cost of shortage Cs
- Marginal Cost of Excess Ce

Decisions:
Spreadsheet computes optimal service level and optimal inventory level. You can then input your chosen inventory level.

Outputs:
Spreadsheet computes service level and mismatch cost corresponding to your inventory level.

Practicing Newsvendor Model

A publisher’s per-book publishing/delivery cost is $6; sales price is $12. Unsold books can be salvaged at $3. Demand is normally distributed with mean 6.5 and standard deviation 1.11 What is the optimal inventory level and corresponding mismatch cost? [Decimals ok.]

Determine Inputs for spreadsheet:

<table>
<thead>
<tr>
<th>Demand Average</th>
<th>Demand Std. Dev.</th>
<th>Marginal Cost Cs</th>
<th>Marginal Cost Ce</th>
</tr>
</thead>
</table>

Decisions:

<table>
<thead>
<tr>
<th>Optimal Order Quantity</th>
<th>Optimal Service Level Inventory</th>
</tr>
</thead>
</table>

Read Outputs:

<table>
<thead>
<tr>
<th>Service Level</th>
<th>Exp. Exp. Mismatch Exp. Mismatch Cost Profit</th>
</tr>
</thead>
</table>

What is the effect of reducing demand standard deviation on mismatch cost?
Estimating Inputs in Practice:

Estimating Demand Standard Deviation:

- When it is a new product, the variation in experts’ opinions is a great predictor of demand variability.
- When it is an old product, then the historical forecast error (actual – forecast) is a great predictor of demand variability.

Estimating Marginal Costs of Shortage Cs and Excess Ce:

- Depending on the context, the basic definitions may change.
- For example, if there is a possible cost of losing a dissatisfied customer’s future business, Cs will increase. If there is sales commission, Cs will decrease.

Sport Obermeyer
Improvement Idea: Quick Response:
Reduce Leadtime → Reduce demand variability → Reduce Mismatch cost

Introduction to Operations Management
Prof. Apurva Jain
OPMGT 502

Understand the fundamental trade-off in inventory: too much vs. too little and how optimal service level resolves it. Many other contexts and decisions under uncertainty have similar structure.

Section 3 Contents

Session 11
7. Compute Inventory Performance
   □ 7.1 Newsvendor Model
      Marginal Costs of Shortage/Excess
      Optimal Service Level
   □ 7.2 Mismatch Cost Calculation
      Spreadsheet
      Sport Obermeyer Introduction

Next: Spreadsheet, Survey, Practice
7.3 Types of Stocks
7.4 Improvement Ideas

Experience Inventory Flow in a Supply chain
8. Generate Supply Chain Improvements
Examples

- Publishing, Electronics
- Overbooking in Airlines
- Blood Bank Stock
- NFL Merchandise
- Fast Fashion: Zara
- ….

Matching Supply with Demand in an Uncertain World: Newsvendor Model

*iPhone X supply crunch mean you may wait till February to get one... Sep 2017*

A mammoth first printing of 1.5 million copies has been ordered.
Overbooking in Airlines:
Improvement Idea: Optimize overbooking level

Blood Bank Stock:
Improvement idea: Optimize collection levels
NFL Merchandise Supply Chain

How much inventory?

Superbowl Merchandise:
Improvement idea: Increase Salvage Value

The NFL used to destroy all the loser merchandise, but thanks to a partnership with Federal Way-based World Vision it now goes to needy people all over the world.

This reduces Ce and Mismatch cost. Also increases the optimal service level.
Overproduce? Mark-Down Pricing
Improvement idea: Ask Customer for Salvage Value

Examples: Quick Response at Zara
## Practicing Newsvendor Model

A publisher’s per-book publishing/delivery cost is $6; sales price is $12. Unsold books can be salvaged at $3. Demand is normally distributed with mean 6.5 and standard deviation 1.11. What is the optimal order quantity and corresponding mismatch cost? [Decimals ok.]

<table>
<thead>
<tr>
<th>Demand Average</th>
<th>Demand Std.Dev.</th>
<th>Marginal Shortage Cost Cs</th>
<th>Marginal Excess Cost Ce</th>
<th>Optimal Service level $Cs/(Cs + Quantity)</th>
<th>Optimal Order Quantity</th>
<th>Your Order Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.5</td>
<td>1.11</td>
<td>6</td>
<td>3</td>
<td>0.666667</td>
<td>6.978107</td>
<td>6.978107</td>
</tr>
</tbody>
</table>

### Outputs: (performance of your order quantity)

<table>
<thead>
<tr>
<th>Service Level</th>
<th>Exp. Shortage Cost $</th>
<th>Exp. Excess Cost $</th>
<th>Mismatch Cost $</th>
<th>Exp. Profit $</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.666667</td>
<td>0.244227</td>
<td>0.722334</td>
<td>3.632362</td>
<td>35.36764</td>
</tr>
</tbody>
</table>