Lecture Outline

- Elements of Inventory Management
- Inventory Control Systems
  - Continuous Inventory Systems
  - Periodic Inventory Systems
  - Single Period Model for Yield Management

Elements of Inventory Management

1. What is inventory?
2. Customer demand
3. Why do we hold inventory?
4. Inventory Costs
Elements of Inventory Management

What Is Inventory?

- Definition
  - Stock of items held to meet future demands/needs

- Types of Inventory
  - Raw materials, component parts
  - Work in process
  - Finished products
  - Supplies

Customer Demand

- Inventory exists to meet customer demands.
- The demand can be either dependent or independent.
  - Dependent demand (internal demand) items: used internally to produce a final product (Ex. Tires)
  - Independent demand (external demand) items: final products demanded by external customers (Ex. Cars)

Why do we hold inventory?

Raw Material Inventory

- To take advantage of scale economy in purchasing
  - price discount of large order
  - transportation and other fixed order cost
- To safeguard variations in supplier deliveries
Work in Progress

- To maintain independence of operations
  - Production can continue smoothly and avoid work stoppages in the case of machine breakdowns or uneven operation times
- To have large batch size

Finished Goods Inventory

- To meet demand immediately and no wait
- To reduce risk of stock-out in an uncertain environment
- To smooth the production if the demand is seasonal or cyclical

Elements of Inventory Management

Inventory Costs

- Carrying (or holding) costs
  - Storage cost (space, utilities, personnel)
  - Opportunity cost of capital
  - Insurance, taxes, possible loss of value
- Ordering or Setup (production change) costs
  - Order processing cost
  - Transportation and receiving cost
- Shortage (or stockout) costs
  - Backorder related cost (tracking, rush shipment)
  - Lost sales/profit
Objective of Inventory Management

- Minimizing the sum of the inventory carrying, ordering and shortage costs by determining:
  - the type of inventory control system to use
  - how much to order
  - when to order

Inventory Control Systems

- Multi-Period Inventory Systems
  - Continuous (fixed-order-quantity) system
    - A continual record of the inventory level for every item is maintained
    - A constant amount is ordered when inventory declines to a predetermined level
  - Periodic (fixed-time-period) system
    - The inventory on hand is counted at specific time intervals
    - An order is placed for a variable amount after a fixed passage of time

- Single-Period Inventory Systems
  - Inventory used only for one-period (Example: special t-shirts at a football game)

How to Classify Inventory?
- The ABC Classification System
The ABC Classification System

Classifying inventory according to some measure of importance and allocating control efforts accordingly.

- **A** - very important
- **B** - mod. important
- **C** - least important

### ABC Classification

- **Class A**
  - about 5-15% of units with 70-80% of value
  - requires very tight control, complete and accurate records

- **Class B**
  - about 30% of units with 15% of value
  - requires less attention than A items, and good records

- **Class C**
  - about 50-60% of units with 5-10% of value
  - requires least control, and minimal records

### ABC Classification Example

<table>
<thead>
<tr>
<th>PART</th>
<th>UNIT COST</th>
<th>ANNUAL USAGE (Demand)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$60</td>
<td>90</td>
</tr>
<tr>
<td>2</td>
<td>350</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>130</td>
</tr>
<tr>
<td>4</td>
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<tr>
<td>5</td>
<td>30</td>
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</tr>
<tr>
<td>6</td>
<td>20</td>
<td>180</td>
</tr>
<tr>
<td>7</td>
<td>10</td>
<td>170</td>
</tr>
<tr>
<td>8</td>
<td>320</td>
<td>50</td>
</tr>
<tr>
<td>9</td>
<td>510</td>
<td>60</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>120</td>
</tr>
</tbody>
</table>
ABC Classification Example

1. Calculate the Value of Each Item

<table>
<thead>
<tr>
<th>PART</th>
<th>UNIT COST</th>
<th>ANNUAL USAGE</th>
<th>TOTAL VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$60</td>
<td>90</td>
<td>$5,400</td>
</tr>
<tr>
<td>2</td>
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<td>$14,000</td>
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<td>$3,900</td>
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<tr>
<td>4</td>
<td>80</td>
<td>60</td>
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<td>5</td>
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<tr>
<td>6</td>
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<tr>
<td>7</td>
<td>10</td>
<td>170</td>
<td>$1,700</td>
</tr>
<tr>
<td>8</td>
<td>320</td>
<td>50</td>
<td>$16,000</td>
</tr>
<tr>
<td>9</td>
<td>510</td>
<td>60</td>
<td>$30,600</td>
</tr>
<tr>
<td>10</td>
<td>20</td>
<td>120</td>
<td>$2,400</td>
</tr>
</tbody>
</table>

ABC Classification Example

2. Rank with Total Value (High to Low)

<table>
<thead>
<tr>
<th>PART</th>
<th>TOTAL VALUE</th>
<th>ANNUAL USAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>$30,600</td>
<td>60</td>
</tr>
<tr>
<td>8</td>
<td>16,000</td>
<td>50</td>
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<tr>
<td>1</td>
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<td>90</td>
</tr>
<tr>
<td>4</td>
<td>4,800</td>
<td>60</td>
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<td>3</td>
<td>3,900</td>
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<td>3,000</td>
<td>100</td>
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<td>1,700</td>
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<tr>
<td></td>
<td>$85,400</td>
<td>1,000</td>
</tr>
</tbody>
</table>

ABC Classification Example

3. Compute Percentage Value and Percentage Quantity

<table>
<thead>
<tr>
<th>PART</th>
<th>TOTAL VALUE</th>
<th>% OF TOTAL VALUE</th>
<th>% CUM. VAL.</th>
<th>% OF TOTAL QUANTITY</th>
<th>% CUM.QNT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>$30,600</td>
<td>35.9</td>
<td>35.9</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>8</td>
<td>16,000</td>
<td>18.7</td>
<td>54.6</td>
<td>5.0</td>
<td>11.0</td>
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<tr>
<td>2</td>
<td>14,000</td>
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<td>71.0</td>
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<tr>
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<td>77.3</td>
<td>9.0</td>
<td>24.0</td>
</tr>
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<td>4,800</td>
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<td>82.9</td>
<td>6.0</td>
<td>30.0</td>
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<td>3,000</td>
<td>3.5</td>
<td>95.2</td>
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<td>71.0</td>
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<tr>
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<td>2,400</td>
<td>2.8</td>
<td>98.0</td>
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<td>83.0</td>
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<tr>
<td>7</td>
<td>1,700</td>
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<td>100.0</td>
<td>17.0</td>
<td>100.0</td>
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<td>$85,400</td>
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</tr>
</tbody>
</table>
ABC Classification Example

4. Classify the Items

<table>
<thead>
<tr>
<th>PART</th>
<th>TOTAL VALUE</th>
<th>% OF TOTAL VALUE</th>
<th>% CUM. VAL.</th>
<th>% OF TOTAL QUANTITY</th>
<th>% CUM. QNT.</th>
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</thead>
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<tr>
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<td>1,700</td>
<td>2.0</td>
<td>100.0</td>
<td>17.0</td>
<td>100.0</td>
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</table>

$85,400

ABC Classification Example

Summary

<table>
<thead>
<tr>
<th>CLASS</th>
<th>ITEMS</th>
<th>% OF TOTAL VALUE</th>
<th>% OF TOTAL QUANTITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>9, 8, 2</td>
<td>71.0</td>
<td>15.0</td>
</tr>
<tr>
<td>B</td>
<td>1, 4, 3</td>
<td>16.5</td>
<td>28.0</td>
</tr>
<tr>
<td>C</td>
<td>6, 5, 10, 7</td>
<td>12.5</td>
<td>57.0</td>
</tr>
</tbody>
</table>

Continuous Inventory Systems

Economic Order Quantity Models

- Assumptions of the Basic Economic Order Quantity (EOQ) Model
  - Demand is known with certainty and is constant over time
  - No shortages are allowed
  - Lead time for the receipt of orders is constant
  - The order quantity is received all at once
  - Purchase price is constant
The Basic EOQ Model

- If annual demand is \( D \), order quantity is \( Q \), then
  - Average Inventory = \( \frac{Q}{2} \)
  - Number of Orders per year = \( \frac{D}{Q} \)
  - The Order Cycle Time = Time between 2 orders = \( \frac{Q}{D} \)
    \[ D \times CT = Q \Rightarrow CT = \frac{Q}{D} \]

The Basic EOQ Model

Model Development

- Cost of placing one order: \( C_o \)
- Annual per-unit carrying cost: \( C_c \)
- Annual demand: \( D \)
- Order quantity: \( Q \)

Annual ordering cost = (# orders)\( \times \)cost/order = \( \frac{D}{Q} \) \( \times \) \( C_o \)
Annual carrying cost = (avg. inventory)\( \times \)unit cost = \( \frac{Q}{2} \) \( \times \) \( C_c \)
Total cost = \( \frac{C_o D}{Q} + \frac{C_c Q}{2} \)
The Basic EOQ Model

Cost Function Illustrations

- Slope = 0
- Total Cost
- Minimum total cost
- Annual cost ($)
- Carrying Cost = $C_c Q$
- Ordering Cost = $C_o \frac{D}{Q}$
- Optimal order quantity, $Q_{opt}$
- Order Quantity, $Q$

The optimal order quantity occurs at the point where the total cost curve is at a minimum, or in the basic EOQ model case, where the carrying cost curve intersects the ordering cost curve. That is,

$$\frac{Q}{2} C_c = \frac{D}{Q_{opt}} C_o$$

Solve this equation for $Q$, we get the optimal order quantity $Q_{opt}$ formula as ...

The Basic EOQ Model

Model Solution

The optimal order quantity occurs at the point where the total cost curve is at a minimum, or in the basic EOQ model case, where the carrying cost curve intersects the ordering cost curve. That is,

$$\frac{Q}{2} C_c = \frac{D}{Q_{opt}} C_o$$

Solve this equation for $Q$, we get the optimal order quantity $Q_{opt}$ formula as ...

The Basic EOQ Model

Optimal Order Quantity

$$Q_{opt} = \sqrt{\frac{2DC_o}{C_c}} = \sqrt{\frac{2(\text{Annual Demand}) \times (\text{Order Cost})}{\text{Annual Carrying Cost}}}$$

The minimum cost of carrying and ordering inventory is

$$TC_{min} = \frac{C_c Q_{opt}}{2} + \frac{C_o D}{Q_{opt}}$$
Basic EOQ: Order Quantity

An Example

A computer manufacturer needs to decide how many keyboards to order at a time from its supplier.

- They use 10,000 keyboards per year, and pay $25 per unit.
- The annual carrying cost for each keyboard is $6.25
- The per ordering cost is $300.

\[ D = 10,000 \text{ keyboards per year.} \]
\[ C_c = 6.25 \text{ per keyboard per year} \]
\[ C_o = 300 \]

\[ Q_{opt} = \sqrt{\frac{2CD}{C_c}} = \sqrt{\frac{2 \times 300 \times 10000}{6.25}} = 980 \]

Basic EOQ: Order Quantity

An Example (cont.)

- The total annual inventory cost:

\[ TC = \frac{D}{Q} C_o + \frac{Q}{2} C_c = \frac{10000}{980} \times 300 + \frac{980}{2} \times 6.25 = $ 6123.72 \]

- Order Cycle Time:

\[ Q / D = 980 / 10,000 = 0.098 \text{ year} = 0.098 \times 365 \approx 36 \text{ days} \]

- Average Inventory

\[ Q / 2 = 980 / 2 = 490 \text{ keyboards} \]

EOQ Models

When to Order?

- Reorder point: inventory level at which a new order is placed
  - Case 1: Constant demand
  - Case 2: Variable demand
Reorder Point

Case 1: Constant Demand

\[ R = \text{Lead time demand} = dL \]

where \( d \) = demand rate per period, \( L \) = Lead time

Reorder Point

Example

The computer manufacturer needs to decide how many keyboards to order at a time from its supplier. 

\[ D = 10,000 \text{ keyboards per year.} \]
\[ C_c = $6.25 \text{ per keyboard per year} \]
\[ C_o = $300 \text{ / order} \]

- If the delivery lead time is 7 days, what is the reorder point?
  \[ R = dL = \frac{10,000}{365} \text{ units/day} \times 7 \text{ days} \]
  = 192 keyboards

**Inventory Control Policy:** *When the inventory level drops to 192 keyboards, order 980 units.*

EOQ Models

**EOQ with Variable Demand**

- When demand is variable (uncertain), shortage (stockout) is possible
- Shortage can only occur during the lead time
- Safety stock is often used to reduce the risk of stockout
  - Safety stock is the additional inventory held above the expected demand
  - Service level is often used to determine safety stock
    - The probability that the inventory available during lead time will meet demand
EOQ Model with Variable Demand

Without Safety Stock

Reorder point, \( R \)

\[ \text{Inventory level} \]

\[ \text{Time} \]

\[ \text{Order placed} \]

\[ \text{Order receipt} \]

\[ \text{Order placed} \]

\[ \text{Stockout occurs} \]

EOQ Model with Variable Demand

With Safety Stock

Reorder point, \( R \)

\[ \text{Inventory level} \]

\[ \text{Safety Stock} \]

\[ \text{Time} \]

\[ \text{Order placed} \]

\[ \text{Order receipt} \]

Reorder Point

Case 2: Variable Demand

\[ R = \bar{d} L + z \sigma_d \sqrt{L} \]

where:

\( \bar{d} \) = average daily demand

\( L \) = lead time

\( \sigma_d \) = the standard deviation of daily demand

\( z \) = number of standard deviations based on the service level probability (obtained from Appendix A, p. 755)
Reorder Point, Safety Stock, and Service Level

Probability of meeting demand during lead time = service level

<table>
<thead>
<tr>
<th>Probability of a stockout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety stock</td>
</tr>
<tr>
<td>$z_0 \sqrt{L}$</td>
</tr>
<tr>
<td>$d$</td>
</tr>
<tr>
<td>$L$</td>
</tr>
</tbody>
</table>

Probability of a stockout

A service level of 95% means that there is a 0.95 probability that demand will be met during the lead time, and the probability that a stockout will occur is 5%.

Reorder Point for Variable Demand

Example

The Uptown Bar and Grill serves Rainwater draft beer to its customers. The daily demand for beer is normally distributed, with an average of 18 gallons and a standard deviation of 4 gallons. The lead time required to receive an order of beer from the local distributor is 3 days.

Determine the safety stock and reorder point if the restaurant wants to maintain a 90% service level? What about 95% service level?
Reorder Point for Variable Demand

Example (cont.)

Average daily demand: \( \bar{d} = 18 \) gallons
Lead time: \( L = 3 \) days.
The standard deviation of daily demand: \( \sigma_d = 4 \) gallons
Service level = 90%

Step 1: Look the table in the appendix A and find the z value
\[ Z = 1.29 \]

Step 2: Calculate the reorder point
\[
R = \bar{d}L + z\sigma_d \sqrt{L} = 18 \times 3 + 1.29 \times 4 \times \sqrt{3} = 62.94 \\
\text{Safety stock} = 1.29 \times 4 \times \sqrt{3} = 8.94
\]

Safety Stock Reduction

- As safety stock deceases, the risk of stockout increases; but the cost of carrying extra inventory decreases
- So there is a trade-off between safety stock and risk of stockout
- Question: how can a company guarantee the same service level while reducing the safety stock level?

\[ \text{Safety Stock} = z\sigma_d \sqrt{L} \]
Periodic Inventory Systems

- Check the inventory once every review period and then order a quantity that is large enough to cover demand until the next order will come in
  - time between orders is constant
  - order size may vary
  - safety stock is used to protect against variable demand

Order Quantity

\[ Q = \bar{d}(t_b + L) + z\sigma_d\sqrt{t_b + L} - I \]

where

- \( \bar{d} \) = average demand rate
- \( t_b \) = the fixed time between orders
- \( L \) = lead time
- \( \sigma_d \) = standard deviation of demand
- \( z\sigma_d\sqrt{t_b + L} \) = safety stock
- \( I \) = inventory in stock

Example

The Mediterranean Restaurant stocks a red Chilean table wine it purchases from a wine merchant in a nearby city. The daily demand for the wine at the restaurant is normally distributed, with a mean of 18 bottles and a standard deviation of 4 bottles. The wine merchant sends a representative to check the restaurant’s wine cellar every 30 days, and during a recent visit there were 25 bottles in stock. The lead time to receive an order is 2 days. The restaurant manager has requested an order size that will enable him to limit the probability of stockout to 2 percent. What is the order size?
**Periodic Inventory System**

**Example (cont.)**

Average demand rate \( d = 18 \) bottles

The fixed time between orders \( b = 30 \) days

Lead time \( L = 2 \)

Standard deviation of demand \( \sigma_d = 4 \)

Inventory level \( I = 25 \)

Service Level = 1 – 2% = 98%

Step 1: Look the table in the appendix A and find the z value

\[ Z = 2.06 \]

Step 2: Calculate the order quantity

\[ Q = 18 \times (30 + 2) + 2.06 \times 4 \times \sqrt{30 + 2} - 25 = 598 \]

Safety stock = 46.61

---

**Periodic Inventory System**

**In-class Exercise**

Average demand rate \( d = 18 \) bottles

The fixed time between orders \( b = 30 \) days

Lead time \( L = 2 \)

Standard deviation of demand \( \sigma_d = 4 \)

Inventory level \( I = 25 \)

Service Level = 95%

Step 1: Look the table in the appendix A and find the z value

Step 2: Calculate the order quantity

---

**Single Period Inventory Model**

- Also called Newsvendor model
- Useful for ordering perishables and other items with a limited useful life
- Main issue: how much to order?
The basic tradeoff:
- If the order amount $Q$ is too low, the firm loses an opportunity to sell.
- If the order amount $Q$ is too high, the firm may not sell all of the items.
- Therefore it is needed to balance the cost of inventory overstock ($C_o$) and the cost of under-stock ($C_u$)

Single Period Model

Model Solution: find the order quantity ($Q$) that satisfies

$$P \leq \frac{C_u}{C_o + C_u}$$

- $C_u = \text{Cost per unit of demand underestimated}$
- $C_o = \text{Cost per unit of demand overestimated}$
- $P = \text{Cumulative probability or } P = \text{Prob}[\text{demand} < Q]$

Example

Sam’s Bookstore purchases calendars from a publisher. Each calendar costs the bookstore $5 and is sold for $10. Unsold calendars can be returned to the publisher for a refund of $2 per calendar. The demand distribution is

<table>
<thead>
<tr>
<th>Demand</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.30</td>
</tr>
<tr>
<td>150</td>
<td>0.20</td>
</tr>
<tr>
<td>200</td>
<td>0.30</td>
</tr>
<tr>
<td>250</td>
<td>0.15</td>
</tr>
<tr>
<td>300</td>
<td>0.05</td>
</tr>
</tbody>
</table>

$C_u = $10 - $5 = $5$

$C_o = $5 - $2 = $3$

$P = \frac{5}{5+3} = 0.625$

Therefore, $Q = 200$
Applications of Newsvendor Models for Yield Management

- Yield management (YM) seeks to maximize yield or profit from time-sensitive products and services
- YM Practices
  - Overbooking
  - Fare classes
  - Dynamic pricing

Single Period Model for Yield Management

Example

Surfside Hotel would like to know the best overbooking strategy based on the following no-show data collected in the past.

<table>
<thead>
<tr>
<th>No-shows</th>
<th>Prob</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.07</td>
</tr>
<tr>
<td>1</td>
<td>0.19</td>
</tr>
<tr>
<td>2</td>
<td>0.22</td>
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<tr>
<td>3</td>
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<td>4</td>
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<tr>
<td>5</td>
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<tr>
<td>6</td>
<td>0.07</td>
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<tr>
<td>7</td>
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<tr>
<td>8</td>
<td>0.02</td>
</tr>
<tr>
<td>9</td>
<td>0.01</td>
</tr>
</tbody>
</table>

A room that remains vacant due to no-shows results in an opportunity loss of $40 room contribution. However, if a guest holding a reservation is turned away owing to overbooking. Then the hotel has to pay for the nearby hotel for $100.
The best strategy is overbooking by two rooms.

\[ P \leq \frac{C_u}{C_u + C_o} \]

\[ C_u = \text{cost of underbooking} \]
\[ C_o = \text{cost of overbooking} \]

\[ \frac{C_o}{C_u + C_o} = \frac{\$40}{\$40 + \$100} = 0.2857 \]

No-show | prob | \( P \)  
--- | --- | ---  
0 | 0.07 | 0.00  
1 | 0.19 | 0.07  
2 | 0.22 | 0.26  
3 | 0.16 | 0.48  
... | ... | ...  

The best strategy is overbooking by two rooms.