Introduction to Logistics Systems

École Polytechnique Fédérale de Lausanne
Urban Transport Systems Laboratory

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Outline

- Intro/Definitions
- Distribution strategies
- Inventory control
- Newsvendor model

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What is “Logistics?”

The word originated from the Greek word “logistikos”
   The science of computing and calculating.

“The careful organization of a complicated activity so that it happens in a successful and effective way”
(Cambridge dictionary)

“process of planning, implementing, and controlling the efficient, effective flow and storage of goods, services, and related information from point of origin to point of consumption for the purpose of conforming to customer requirements.”
(Council of Logistics Management)
The concept of “Logistics” was initially used by Greek generals (Leon the Wise, Alexander the Great) in order to describe all the procedures or the army’s procurement on food, clothing, ammunition, etc.

Alexander the Great was a big fan of the mobility of his troops and he didn’t want his troops to stay in one place waiting for supplies from Macedonia. Thus, he tried to resolve the issues of supplies by using supplies from the local resources of his defeated enemies.

For many years, logistics were always an issue in war affairs. Kingdoms and generals with strategic planning on logistics were those who won the war.

World War II was the major motivation of logistics to increase recognition and emphasis, following the clear importance of their contribution toward the Allied victory.

Starting from the early ‘60s, many factors, such as deregulation, competitive pressures, information technology, globalization, profit leverage, etc., contributed to the increase of logistics science in the form we know it today.
The Value-Adding Role of Logistics

• Space Utility
  • Addition of economic value to goods by moving them from production surplus points to points where demand exists
  • Essentially extends the physical boundaries of the market area

• Time Utility
  • Addition of economic value to goods (at a demand point at a specific time)
  • Economies of scale
Logistic Activities and Decisions

Procurement, Production, Storage, Inventory management, Distribution

Decisions types:
Procurement policy, supplier selection, supply contracts
Inventory policy – product variety, Inventory levels, shipping frequency
Number and location of warehouses
Distribution policy

Product design? Information technology?
Decision Levels

- **Strategic**  
  (long term decision ~ many years)

- **Tactical**  
  (~ annually, semi-annually)

- **Operational**  
  (short-term, daily, hourly)
Strategic

- Strategic network optimization, including the number, location, and size of warehouses, distribution centers and facilities.
- Strategic partnership with suppliers, distributors, and customers.
- Product design coordination so that new and existing products can be optimally integrated into the supply chain.
- Information Technology infrastructure to support supply chain operations.
- Where-to-make and what-to-make-or-buy decisions.
- Aligning overall organizational strategy with supply strategy.
Tactical

- Sourcing contracts and other purchasing decisions.
- Production decisions including contracting, locations, scheduling, and planning process definition.
- Inventory decisions including quantity, location, and quality.
- Transportation strategy including frequency, routes, and assignment.
- Benchmarking of all operations
- Flow of money
Operational

- Daily production and distribution planning
- Production scheduling for each manufacturing facility in the supply chain (minute by minute).
- Demand planning and forecasting, coordinating the demand forecast of all customers and sharing the forecast with all suppliers.
- Inbound operations—transportation from suppliers and receiving inventory.
- Outbound operations—fulfillment activities and transportation to customers.
- Order promising, accounting for all constraints in the supply chain, including suppliers, facilities, distribution centers, and other customers.
Goals

• Integration of all logistic activities in order to: provide the right product, to the right place, in the right quantity, at the right time, in the right price

• Provide the customer a high quality of service

• Maximize profits / Minimize costs of the system
Difficulties

• Obtaining local optimum does not guarantee the global optimum of the system

• Specifically: sequential optimum does not guarantee the global optimum
Why is it difficult to obtain a global optimum?

- The logistic system is very complicated – Many details to take into account: dates, times, locations, costs, capacities etc..
- The logistic system is very dynamic – each component of the system may be highly affected by other components of the system
- The logistic system continuously changes
- Conflicting inner goals
California, US
Apple designs the iPhone at its headquarters in California. It sends out orders for parts to dozens of companies all around the globe.
Texas Instruments makes the touchscreen controller

Micron makes the flash memory

Dialog semiconductors makes the power management components

ST Microelectronics makes the accelerometers and gyroscope

Samsung makes memory and applications processor

Cirrus Logic makes the audio controller

Murata makes the Bluetooth and WiFi components

Infineon makes the phone network components
What is missing from this description of the iPhone supply chain?
Another example: Supply chain of oil
Distribution strategies

52 Retail outlets

Source: Prof. Campbell lectures. http://www.umsl.edu/~campbelljf/
...served by 5 Warehouses

Single stop and multi-stop routes
2 Plants, 5 Warehouses

Plants:
- P1
- P2

Warehouses:
- SEA
- LA
- NY
- ATL
- CHI
Outbound Distribution System

2 Plants, 5 Warehouses, 52 Retail outlets

Source: Prof. Campbell lectures. http://www.umsl.edu/~campbelljf/
Inbound Distribution System

9 Suppliers, 3 Sub-assembly plants, 2 Plants

- Plants
- Warehouses
- Supply Points
- Sub-assembly plants
Total Distribution System

9 Suppliers, 3 Sub-assembly plants, 2 Plants, 5 Warehouses, 52 Retail outlets
Total Distribution System

9 Suppliers, 3 Sub-assembly plants, 2 Plants, 5 Warehouses, 52 Retail outlets
https://www.youtube.com/watch?v=SRq-U1m2dwg&t=2s
Logistics Strategies

Logistic methods and strategies are based on two main principles:

• Global optimization
• Management of uncertainty
Uncertainty

• Uncertainty is inherent
  Travel times
  Breakdowns of machines and vehicles
  Weather, natural catastrophe, war
  Local politics, labor conditions, border issues

• Adapting supply to demand is a hard task!
• Forecasting does not solve the problem
• Inventory levels (surpluses and shortages) May vary along the supply chain

• How to handle uncertainty?
Development of strategies to optimize the logistic system, given the uncertainty (and reduction of uncertainty as much as possible)
Additional strategies

• Risk pooling
• Standardization
• Vendor Managed Inventory
• Long-term contracts
• Partnerships
• Supply chain coordination by incentives
• Information sharing
• Outsourcing
• Risk diversification
Inventory Control - Repetitive Ordering

- Treat each stocking point independently.
- Consider 1 product and 1 location.

<table>
<thead>
<tr>
<th>Determine:</th>
<th>Reorder Point System</th>
<th>Periodic Review System</th>
</tr>
</thead>
<tbody>
<tr>
<td>How much to order:</td>
<td>Q</td>
<td>M-q_i</td>
</tr>
<tr>
<td>When to (re)order:</td>
<td>ROP</td>
<td>T</td>
</tr>
</tbody>
</table>
Reorder Point System

Order amount Q when inventory falls to level ROP.

- Constant order amount (Q).
- Variable order interval.

Order amount Q when inventory falls to level ROP.

Constant order amount (Q).

Variable order interval.
Periodic Review System - $T=20$ days

Order amount $M-q_i$ every $T$ time units.

- Constant order interval ($T=20$ below).
- Variable order amount.

Each increase in inventory is size $M$-amount on hand. ($M=90$ in this example.)
Example: Inventory Variables

\[
\begin{align*}
D &= \text{demand (usually annual)} \\
S &= \text{order cost ($/order)} \\
I &= \text{holding cost} \\
\text{(\% of value/unit time)} \\
Q &= \text{order quantity} \\
N &= \text{number of orders/year} \\
TC &= \text{total cost (usually annual)} \\
ROP &= \text{reorder point} \\
T &= \text{time between orders}
\end{align*}
\]

d = \text{demand rate} \\
LT = \text{(average) lead time} \\
C = \text{item value ($/item)}
Simplest Case - Constant demand and lead time

No variability in demand and lead time. Will never have a stock out.

Suppose: $d = 4$/day and $LT = 3$ days
Then $ROP = 12$ (ROP = $d \times LT$)
Constant demand and lead time

TC = Order cost + Inventory carrying cost

Order cost = N x S = (D/Q) x S

Holding cost = Average inventory level x C x I
= (Q/2) x C x I
Economic Order Quantity (EOQ)

\[ \text{TC} = \frac{D}{Q} S + IC \frac{Q}{2} \]

Select \( Q \) to minimize total cost.
Set derivative of \( \text{TC} \) with respect to \( Q \) equal to zero.

\[ 0 = -\frac{D}{Q^2} S + \frac{IC}{2} \]

\[ Q^* = \sqrt{\frac{2DS}{IC}} \]
Graphical representation

Q* = 350  
TC = $3500/year
Optimal Ordering

Optimal order quantity: \( Q^* = \sqrt{\frac{2DS}{IC}} \)

Optimal number of orders/year: \( \frac{D}{Q^*} \)

Optimal time between orders: \( \frac{Q^*}{D} \)

Optimal cost: \( TC = \frac{D}{Q^*}S + IC \frac{Q^*}{2} \)
Example

\[ D = 10,000/\text{year} \]
\[ S = $61.25/\text{order} \]
\[ I = 20%/\text{year} \]
\[ C = $50/\text{item} \]

\[ Q^* = \sqrt{\frac{2DS}{IC}} = \sqrt{\frac{2(10,000)(61.25)}{(0.2)(50)}} = 350 \text{ units/order} \]

\[ TC = \frac{D}{Q^*}S + IC \frac{Q^*}{2} = \frac{10,000}{350}(61.25) + (0.2)(50) \frac{350}{2} \]
\[ = 1750 + 1750 = $3500/\text{year} \]

\[ N = \frac{10,000}{350} = 28.57 \text{ orders/year} \]

\[ T = \frac{350}{10,000} = 0.035 \text{ years} = 1.82 \text{ weeks} \]
The Newsvendor Model

Assumptions:
- Plan for single period inventory level
- Demand is unknown
- \( f(y) = \text{probability}(\text{demand} = y), \text{known} \)
- Zero setup (ordering) cost
Example: Mrs. Kandell’s Christmas Tree Shop

Order for Christmas trees must be placed in Sept

Cost per tree: $25  
Price per tree:  
$55 before Dec 25 
$15 after Dec 25

If she orders too few, the unit shortage cost is $c_u = 55 - 25 = $30

If she orders too many, the unit overage cost is $c_o = 25 - 15 = $10

Past Data

<table>
<thead>
<tr>
<th>Sales</th>
<th>22</th>
<th>24</th>
<th>26</th>
<th>28</th>
<th>30</th>
<th>32</th>
<th>34</th>
<th>36</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability</td>
<td>.05</td>
<td>.10</td>
<td>.15</td>
<td>.20</td>
<td>.20</td>
<td>.15</td>
<td>.10</td>
<td>.05</td>
</tr>
</tbody>
</table>

How many trees should she order?
Stockout and Markdown Risks

1. Mrs. Kandell has only one chance to order until the sales begin: no information to revise the forecast; after the sales start: too late to order more.

2. She has to decide an order quantity $Q$ now

$D$ demand realization

$F(x)$ the demand cumulative distribution,

$D > Q \Rightarrow$ stockout, at a cost of: $c_u (D - Q)^+ = c_u \max\{D - Q, 0\}$

$D < Q \Rightarrow$ overstock, at a cost of: $c_o (Q - D)^+ = c_o \max\{Q - D, 0\}$
Key elements of the model

1. Uncertain demand
2. One chance to order (long) before demand
3. (order > demand OR order < demand) ➞ COST
Model development

Stock out cost \( = c_u \max\{D - Q, 0\} \)

Overstock cost \( = c_o \max\{Q - D, 0\} \)

Total cost \( = c_u (D - Q)^+ + c_o (Q - D)^+ \)

Expected cost \( = E(c_u (D - Q)^+ + c_o (Q - D)^+) \)

\[= c_u E(D - Q)^+ + c_o E(Q - D)^+ \]

\[\downarrow\]

\[G(Q) = \int_{x=0}^{Q} c_o (Q - x)f(x)dx + \int_{x=Q}^{\infty} c_u (x - Q)f(x)dx \]
Model solution

\[ G(Q) = \int_{x=0}^{Q} c_o(Q - x)f(x)dx + \int_{x=Q}^{\infty} c_u(x - Q)f(x)dx \]

Minimize \( G(Q) \rightarrow \frac{dG(Q)}{dQ} = 0 \)

\[ \frac{\partial}{\partial Q} \left( \int_{x=0}^{Q} c_o(Q - x)f(x)dx + \int_{x=Q}^{\infty} c_u(x - Q)f(x)dx \right) = 0 \]

Leibniz Integral Rule:

\[ \frac{\partial}{\partial z} \int_{a(z)}^{b(z)} f(x,z)dx = \int_{a(z)}^{b(z)} \frac{\partial f}{\partial z} dx + f(b(z),z) \frac{\partial b}{\partial z} - f(a(z),z) \frac{\partial a}{\partial z} \]

- \( G(Q) \) is a convex function: it has a unique minimum

- when \( G(Q) \) is at minimum value, \( F(Q) = \frac{c_u}{c_u + c_o} \)
The Critical Ratio

Solution to the Newsvendor problem:

\[ F(Q^*) = \frac{c_u}{c_u + c_o} \quad \rightarrow \quad Q^* = F^{-1}\left(\frac{c_u}{c_u + c_o}\right) \]

\[ \beta = \frac{c_u}{c_u + c_o} \] is called the critical ratio

\( \beta \) represents the relative importance of stock out cost vs. markdown cost

\[ \beta \uparrow \quad \Rightarrow \text{ overstock cost less significant} \quad \Rightarrow \text{ order more} \]

\[ \beta \downarrow \quad \Rightarrow \text{ overstock cost dominates} \quad \Rightarrow \text{ order less} \]
Mrs. Kandell’s Problem, solved:

\[ c_u = 55 - 25 = \$30 \quad c_o = 25 - 15 = \$10 \]

\[
\begin{array}{c|c|c|c|c|c|c|c|c}
D & 22 & 24 & 26 & 28 & 30 & 32 & 34 & 36 \\
\hline
\text{Probability} & 0.05 & 0.1 & 0.15 & 0.2 & 0.2 & 0.15 & 0.1 & 0.05 \\
\hline
F(D) & 0.05 & 0.15 & 0.3 & 0.5 & 0.7 & 0.85 & 0.95 & 1 \\
\end{array}
\]

\[
\beta = \frac{c_u}{c_o + c_u} = \frac{30}{30 + 10} = 0.75
\]

\[
E(D) = 22 \cdot 0.05 + 24 \cdot 0.1 + ... + 36 \cdot 0.05 = 29
\]

\( \Rightarrow \text{optimum} \approx 31 \)
Discussion