Introduction to Warehousing

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What is a warehouse

- Warehouse: “a structure or room for the storage of merchandise or commodities” – Merriam-Webster
- Distribution center (DC): flow through or cross docking centric
- Reasons to have warehouse
  - Mostly discussed in inventory section
- Reason to have DCs
  - Transportation consolidation
  - Product positioning
  - Break bulk
  - ... 
- In house warehouse or DC is normally a cost center
Some functions of a distribution center (DC)

- A structure that receives and distributes merchandise or commodities.
  - Important element in supply chain
  - Consolidation
  - Reduce wait time...

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References

- Text B
  - Ch 1, 2, Intro
  - Ch 3 operations
  - Ch 5 equipment
  - Ch 6 – 6.2 COI, terrain
  - Ch 7, to page 63 order picking

- Follow link: Warehouse & Distribution Science
Birdeye view: a X-dock and a DC

In US (survey by SCL and Logistics Resources)

- > 300,000 large warehouse or DCs
- 2.5 million employees
- Cost > 5% of the Gross National Product
- TLI survey of ~ 150 companies, median
  - Size: 150,000 ft² (2.6 football fields)
  - Height: 28 ft
  - 15 dock doors
  - 60 FTE
  - 564,000 lines/year, 60,500 orders/year, 9 lines/order
  - 5,001 skus, 3,502 active
  - Inventory turns 5.1
  - Fill rate 97.1
Examples in US

- K-Mart DC: 2 mil ft² (or about 35 football fields)
- Walmart
  - RDC at LaGrange: 1.3 mil ft²
  - Port DC at Stateboro: 2 mil + 1.4 mil
- American Cancer Society: 50,000 ft²

Examples where land is scarce

- Often multi-story
- 50,000 is considered good size
- Use high space efficiency and technology to compensate for lack of space
**Loads and handling**

**Distribution network example: Whirlpool**

- **Home appliances**
  - Refrigerators, washer/driers, water heaters, microwave, etc.
  - 1500 skus
  - Revenues > $10 bil
- World wide, 39 manufacturing facilities in 13 countries
- US, 10 Factory Distribution Centers in US
- Customers
  - Stores: Lowe’s, H H Gregg,
  - Builders
  - Individuals (< 5%)

Figure 2.2: A product is generally handled in smaller units as it moves down the supply chain. (Adapted from “Warehouse Modernization and Layout Planning Guide”, Department of the Navy, Naval Supply Systems Command, NAVSUP Publication 520, March 1991, p 6-17).
Where to position inventories

- Response time vs. cost
- Response time
- Cost
  - Land, economy of scale…
  - Pooling effect example
    - 1 RDC support $n$ LDCs
    - LDC demand iid, $N(\mu, \sigma)$ (not necessarily normal), $CV_{LDC} = \mu / \sigma$
    - $\sigma_{RDC}$
    - $CV_{RDC}$
**Atlanta DC**
- 657,000 ft² (14 football fields), 140,000 unit storage
- Throughput per day
  - Receiving 50 - 75 truckloads
  - Shipping: 100 truckloads
- Supports 7 + 1 LDCs
- Holds 4 weeks of inventory

**Walmart in US (2004)**
- ~ 100,000+ merchandise skus
  - ~ 3,000 from far east, high % revenues
  - A lot from NAFTA countries
  - 288 bil revenue
- 4 port DCs: LA, Houston, Stateboro GA, James City VA
- 50 Regional DCs (LaGrange in GA)
- 3,000 stores and supercenters
Supply Chain

Port DC and RDC for Wal-Mart

<table>
<thead>
<tr>
<th>Measure</th>
<th>Port DC</th>
<th>RDC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>2 mil ft² (35 football fields)</td>
<td>1.3 mil ft²</td>
</tr>
<tr>
<td>People ~</td>
<td>500</td>
<td>400</td>
</tr>
<tr>
<td>Skus ~</td>
<td>3,000</td>
<td>50,000</td>
</tr>
<tr>
<td>Function</td>
<td>Support RDCs and stores</td>
<td>Support 85 stores</td>
</tr>
<tr>
<td>Throughput</td>
<td>25,000/day</td>
<td>15,000/hour</td>
</tr>
<tr>
<td>Productivity</td>
<td>45 cases/man hour</td>
<td>100 cases/man hour</td>
</tr>
</tbody>
</table>
RDC – X-dock vs. storage/pick

- Response time
- System wide inventory level
- Handling cost

Trends
- Value added services (in-sourcing)
  - Customization (refrigerator door)
  - Merge in transit
  - …
- Consolidations
- Conveyorized merge and sortation systems
Warehouse operation objectives

- Minimize costs
  - Labor
  - Space and utilities
  - Capital
  - IT
- Subject to constraints
  - Fill rate
  - Throughput
  - Timely
  - Accuracy
  - Visibility

Which is the most important? To a manager?

Operational decisions (some already in other modules)

- How much stock in a DC
- Schedule of receiving & shipping, fleet routing
- Where to put what: layout
- Storage method: racks, mobile racks, floor, floor stack, …
- Order picking method
- Order picking equipment
- …
Summary

- Warehouses and DCs are necessary but often cost centers
- Can help to reduce cost and response times by
  - Consolidation
  - Coordination
  - Value added services
    - Delayed customization
    - Merge in transit
  - …
- Major operational decisions
  - Storage
  - Order picking method
  - …

Layout and Layout in Warehouse

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Fall, 08
Ealing hospital in London

A warehouse
Others

- Restaurants
- Offices
- Schools
- …

The problem
- Where and how much space is for which activity to optimize w.r.t …

An abstract problem

- Consider: assign $n$ equal sized activities into $n$ locations.
- What is the number of possible layouts?
- $n!$
- If $n = 15$, ____________
- There can be additional complications
Objective of layout

- Facility cost
- Space utilization
- Operating cost
- …

- Most direct important quantitative objective
  - Average (total) material flow
  - Average people travel distance in an airport, hospital,

Who does layout?

- IE(s) or other engineers in a company
- Consulting firms
- Independent consultant
Approaches

- State of the industry: Systematic layout planning (SLP, Richard Muther, 60s)
- It's an qualitative, greedy algorithm with improvement
- Quantified then computerized versions

- State of the art: applying optimization tools to solve sub-problems in SLP

- SLP overview

SLP flow chart

1. Input data and activities
2. Flow of materials
3. Activity relationship
4. Relationship diagram
5. Space requirements
6. Space available
7. Space relationship diagram
8. Modifying considerations
9. Practical limitations
10. Develop layout alternatives
11. Evaluation
Green Chemical plans to construct a 4,000 ft² (50' * 80') maintenance facility located in New Jersey. It stores pipes, fittings for its own 4 plants and other plants in the area. There will be 11 activities. An excellent Jacket IE was assigned the job to design a layout for the new building. She performed quantitative analysis of flows and a survey of the current employees. She summarized the data in a relationship chart. However, she was promoted to the assistant general manager. You are hired to continue her job. Please apply SLP procedure to get alternative block layouts.

Information collected

<table>
<thead>
<tr>
<th>No</th>
<th>Activity Name</th>
<th>Space required</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fittings</td>
<td>550</td>
</tr>
<tr>
<td>2</td>
<td>Valve</td>
<td>600</td>
</tr>
<tr>
<td>3</td>
<td>Hi-value item</td>
<td>500</td>
</tr>
<tr>
<td>4</td>
<td>Tubing</td>
<td>250</td>
</tr>
<tr>
<td>5</td>
<td>Misc Supplies</td>
<td>800</td>
</tr>
<tr>
<td>6</td>
<td>Floor Dry</td>
<td>300</td>
</tr>
<tr>
<td>7</td>
<td>Fabrication</td>
<td>400</td>
</tr>
<tr>
<td>8</td>
<td>Pack and trash</td>
<td>200</td>
</tr>
<tr>
<td>9</td>
<td>Office</td>
<td>200</td>
</tr>
<tr>
<td>10</td>
<td>Dock</td>
<td>100</td>
</tr>
<tr>
<td>11</td>
<td>Rest rooms</td>
<td>75</td>
</tr>
</tbody>
</table>

Total: 3975
Information collected

- **Algorithm**
  - Select the activity with most As.
  - Select an activity with A to the first activity, and with most A, then Es. Put it next to first, draw 4 lines.
  - Repeat until all placed.
  - Improve based on visual inspection.

<p>| | | | | | | | | | |</p>
<table>
<thead>
<tr>
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<td></td>
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<td></td>
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<tr>
<td>2</td>
<td>Valve, 600</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Hi-value item, 500</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Tubing, 200</td>
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<td></td>
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</tr>
<tr>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Fabrication, 400</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Pack and Ship, 200</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Office, 200</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Dock, 100</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Rest rooms, 75</td>
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<table>
<thead>
<tr>
<th>Code</th>
<th>Reason</th>
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<tbody>
<tr>
<td>1</td>
<td>Highly similar</td>
</tr>
<tr>
<td>2</td>
<td>Similar</td>
</tr>
<tr>
<td>3</td>
<td>Related in orders</td>
</tr>
<tr>
<td>4</td>
<td>Movement of materials</td>
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<td>5</td>
<td>Security</td>
</tr>
<tr>
<td>6</td>
<td>Supervision</td>
</tr>
<tr>
<td>7</td>
<td>Personal convenience</td>
</tr>
<tr>
<td>8</td>
<td>Similar building services</td>
</tr>
</tbody>
</table>

Space relationship diagram (Activity relation omitted)

- **Algorithm**
  - Select the activity with most As.
  - Select an activity with A to the first activity, and with most A, then Es. Put it next to first, draw 4 lines, or a coarse line
  - Repeat until all placed.
  - Improve based on visual inspection.
Distance measurement and objective function

- From where to where? Centroids

- Distance metrics

  Euclidean: $d_E = \sqrt{(x_2-x_1)^2 + (y_2-y_1)^2}$

  Rectilinear: $d_R = |x_2-x_1| + |y_2-y_1|$

  Chebychev: $t_C = \max(|x_2-x_1|, |y_2-y_1|)$

- Objective function, between $m \times n$ nodes
E.g. Rectilinear distances between centroid

<table>
<thead>
<tr>
<th>Block layout</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Centroids</th>
<th>x</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>B</td>
<td>5.5</td>
<td>4.5</td>
</tr>
<tr>
<td>C</td>
<td>1.4</td>
<td>2.3</td>
</tr>
<tr>
<td>D</td>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>E</td>
<td>5.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Rectilinear distances

<table>
<thead>
<tr>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4</td>
<td>3.3</td>
<td>4.5</td>
</tr>
<tr>
<td>B</td>
<td>6.3</td>
<td>5.5</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>2.4</td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>2.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$x_c = \frac{1*6 + 2*4}{10} = 1.4$

$y_c = \frac{1.5*6 + 3.5*4}{10} = 2.3$

Equal distance contours

- In Euclidean distance, what is the shape of the contour that have equal distance to the point given?

$$\sqrt{(x_i - x_c)^2 + (y_i - y_c)^2} = R$$
In Rectilinear distance

\[ |x_1 - x_2| + |y_1 - y_2| = R \]

- Think of origin, and 1st quadrant, any point \((x + y)\) on a line that has constant distance to origin satisfies \(x + y = R\)

Warehouse with single receiving/shipping

- Consider pallet in single command operations
- I/O is at the corner
- Each location
  - 1 trip to store, 1 trip to pick
  - \(x_s + y_s + x_p + y_p = \text{constant}\)
Warehouse with separate shipping/receiving

- $x_s + y_s + x_p + y_p = \text{constant}$
- Where are the locations with minimum travel?
- Where are the others?

Another example
Consider the average distances if loads are evenly distributed among docks
- From center dock = \[ \frac{1}{4} L \]
- From corner dock = \[ \frac{1}{2} L \]
- In between?

Other situations
- Different R/S door locations
- Pallet-in, carton-out
Layout Summary

- SLP
  - Divide and conquer
  - Greedy heuristics
  - Improvement
- Objectives
- Distance metrics
- Equal distance contours