Warehousing Systems

Why Have a Warehouse?

- Warehouses require many expensive resources:
  - capital
  - labor
  - facilities
  - management systems
  - etc.
Product Buffer

- Can provide and inventory buffer for:
  - variability in demand
    - E.g., seasonality
  - uncertainty in demand

Economies of Scale

- To realize economies of scale from price breaks (purchasing)
- To realize economies of scale in storage (equipment, space)
Product Positioning

- Position product close to the customer
- Speed!

Distribution from multiple warehouses

- Pros and cons
  - High investment costs
  - Shorter delivery times
Product Consolidation

- There is a cost associated with each product movement
- Distributor can consolidate shipments for downstream customers
  - can reduce transportation costs
  - can facilitate downstream receiving

Distribution from a centralized warehouse

FedEx dedicated e-distribution facility in Memphis
**Value Adding**

- Some warehouses are used to add value to the product
  - packaging
  - assembly
- Postponement

**Warehousing Evolution**

- The role of warehousing has evolved over the years:
  - 1950-1970 - primary role of the warehouse was the storage function
  - 1970-1990 - the rise of distribution centers (DC) which included order assembly as a key component
  - 1990-present - the rise of the logistics center which included value added services on top of the DC functions
- Storage (though still important!) is not the key driver that it once was.
E-Retail Home Delivery

Shipping directly from the suppliers

Traditional retailer
- Farm → Importer → Wholesale → Florist → Customer
  - 8-12 days

National retailer
- Farm → Florist → Customer
  - 3-5 days

Direct from farms
- Farm → Proflowers.com → Customer
  - 1-2 days

Potential problems
- out-of-stock items, late deliveries
- multiple items from the same order arrive at different times
- tracking, tracing and returns are more complicated
Warehousing Functions

Receiving Function
- Unload
- Inspect
- Put Away
- Cross Dock

Storage Function

Shipping Function
- Load
- Pack
- Order Pick

Items and storage equipment in a warehouse

- Pallet
- Case
- Piece

- Pallet rack
- Gravity flow rack
- Bin shelving
- Carousel
Current Key Warehousing Issues

- Increased use of cross docking
- Increased use of “fast-pick”
- Increased use of value added services and customization
- Need to deal with reverse logistics (e.g. returns, recycling)
- Increase in complexity (e.g. SKU proliferation)
- Increased accuracy requirements

Warehousing Objective

- Minimize the set of costs:
  - labor
  - space
  - capital
  - IT, etc.
- Subject to constraints from customer
  - fill rate
  - response time
  - accuracy

Hard Problem!
What is activity profiling?

- A systematic analysis of the activity of order (and item) activity during warehousing operations

- It helps us to identify
  - Policy improvement opportunities
  - Equipment selection/use changes
  - Layout redesign opportunities
  - Key SKUs

- Data is key!
Pick sheet

<table>
<thead>
<tr>
<th>SKU</th>
<th>Quantity</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>026596</td>
<td>4</td>
<td>...</td>
</tr>
<tr>
<td>278538</td>
<td>1</td>
<td>...</td>
</tr>
<tr>
<td>093478</td>
<td>22</td>
<td>...</td>
</tr>
</tbody>
</table>

Number of lines (or line items or pick lines): 3
Number of picks: 3
Number of grabs: 27

Example statistics

- Average number of
  - shipments per day
  - SKUs in the warehouse
  - lines per order
  - units (pieces, cases) per line
  - order-pickers devoted to pallet movement, case-picking, and to broken-case picking

- Seasonalities
- etc.
Basics of profiling

- Simple statistics can give a quick (albeit rough) description of the warehouse. However, looking at averages can hide complexity (including correlation, confounding, etc.)

Example

- For our warehouse, the average lines per order is 10
- If we look at the actual distribution of lines per order we see the following:
  - 50% of the time the lines per order is 1
  - 50% of the time the lines per order is 19
Time-based analysis

- Several things change for a warehouse of time
  - monthly seasonality of total demand
  - weekly seasonality of SKUs
  - daily “seasonality” of orders

- Issue: a warehouse needs to be designed to handle the peaks not just the average!
  - opportunity to reduce some of these requirements by properly planning ahead

Monthly Loads

![Chart showing monthly loads with peaks and average values for returns and orders]
Variability-based profiling

- Often times when we report averages, we “smooth” over the true variability of the process
- Example

<table>
<thead>
<tr>
<th>Time</th>
<th># Picks</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:00-9:00</td>
<td>110</td>
</tr>
<tr>
<td>9:00-10:00</td>
<td>40</td>
</tr>
<tr>
<td>10:00-11:00</td>
<td>33</td>
</tr>
<tr>
<td>11:00-12:00</td>
<td>35</td>
</tr>
<tr>
<td>12:00-1:00</td>
<td>29</td>
</tr>
<tr>
<td>1:00-2:00</td>
<td>180</td>
</tr>
<tr>
<td>2:00-3:00</td>
<td>140</td>
</tr>
</tbody>
</table>

Example continued

- For this example, if we staffed to the average, then we would need to be able to handle 81 picks per hour.
- However - the standard deviation for this process is very high (>61) and if we designed to the average, then for 3 of the hour periods, we would be SEVERELY understaffed.
Categorization of items

- There are several different ways in which SKUs can be “ordered”
  - based on dollar annual volume
  - based on case movements
  - based on number of times picked
  - based on weight moved
  - etc.

- Each of these can give a very different picture of warehouse operations and ABC classification of items

ABC analysis

- In a warehouse, “20% of the SKUs account for 80% of the activity”.
**ABC classification**

Number of SKUs

- 5-10%: A
- 45-50%: B
- 40-50%: C

Annual Investment $

- 50%: A
- 45%: B
- 5%: C

---

**Top 10 items by # cases**

<table>
<thead>
<tr>
<th>SKU</th>
<th>Pcs/Case</th>
<th>Pieces</th>
<th>Cases</th>
<th>Picks</th>
</tr>
</thead>
<tbody>
<tr>
<td>UL Slimfast Bonus Choc Royale</td>
<td>6</td>
<td>3085</td>
<td>514</td>
<td>525</td>
</tr>
<tr>
<td>Bandaid Family Twin pack</td>
<td>12</td>
<td>4488</td>
<td>374</td>
<td>374</td>
</tr>
<tr>
<td>Sathers Pixy Stix</td>
<td>12</td>
<td>4320</td>
<td>360</td>
<td>267</td>
</tr>
<tr>
<td>Gemini Video Tape T-120</td>
<td>24</td>
<td>7260</td>
<td>303</td>
<td>471</td>
</tr>
<tr>
<td>House Brand Aspirin 5 Gr.</td>
<td>12</td>
<td>3144</td>
<td>262</td>
<td>255</td>
</tr>
<tr>
<td>House Brand Complete Allergy Caps</td>
<td>24</td>
<td>5850</td>
<td>244</td>
<td>538</td>
</tr>
<tr>
<td>Act II Micro Butter</td>
<td>144</td>
<td>34362</td>
<td>239</td>
<td>806</td>
</tr>
<tr>
<td>House Brand Pain Rel Caplets 500MG</td>
<td>24</td>
<td>5604</td>
<td>234</td>
<td>569</td>
</tr>
<tr>
<td>House Brand Gescic</td>
<td>24</td>
<td>5562</td>
<td>231</td>
<td>486</td>
</tr>
<tr>
<td>Sathers S/F Asst Sour Mix</td>
<td>12</td>
<td>2520</td>
<td>210</td>
<td>206</td>
</tr>
</tbody>
</table>
### Top 10 items by # of customer requests (picks)

<table>
<thead>
<tr>
<th>SKU</th>
<th>Pcs/Case</th>
<th>Pieces</th>
<th>Cases</th>
<th>Picks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Act II Micro Butter</td>
<td>144</td>
<td>34362</td>
<td>239</td>
<td>806</td>
</tr>
<tr>
<td>Beach Bag Set</td>
<td>6</td>
<td>815</td>
<td>136</td>
<td>781</td>
</tr>
<tr>
<td>Act II Micro Lite Butter</td>
<td>144</td>
<td>21276</td>
<td>148</td>
<td>570</td>
</tr>
<tr>
<td>House Brand Pain Rel Caplets 500MG</td>
<td>24</td>
<td>5604</td>
<td>234</td>
<td>569</td>
</tr>
<tr>
<td>Act II Micro White Cheddar</td>
<td>120</td>
<td>15870</td>
<td>132</td>
<td>553</td>
</tr>
<tr>
<td>House Brand Complete Alergy Caps</td>
<td>24</td>
<td>5850</td>
<td>244</td>
<td>538</td>
</tr>
<tr>
<td>House Brand Ointment Triple Antibio</td>
<td>144</td>
<td>4776</td>
<td>33</td>
<td>534</td>
</tr>
<tr>
<td>Wrigley Plen-T-Pak Big Red</td>
<td>192</td>
<td>12792</td>
<td>67</td>
<td>530</td>
</tr>
<tr>
<td>Wrigley Plen-T-Pak Doublemint</td>
<td>192</td>
<td>14736</td>
<td>77</td>
<td>526</td>
</tr>
<tr>
<td>UL Slimfast Bonus Choc Royal</td>
<td>6</td>
<td>3085</td>
<td>514</td>
<td>525</td>
</tr>
</tbody>
</table>

### Top 10 items by # of pieces sold

<table>
<thead>
<tr>
<th>SKU</th>
<th>Pcs/Case</th>
<th>Pieces</th>
<th>Cases</th>
<th>Picks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Deck Baseball Low #</td>
<td>432</td>
<td>70524</td>
<td>163</td>
<td>425</td>
</tr>
<tr>
<td>Act II Micro Butter</td>
<td>144</td>
<td>34362</td>
<td>239</td>
<td>806</td>
</tr>
<tr>
<td>Score Baseball Series II</td>
<td>720</td>
<td>25344</td>
<td>35</td>
<td>348</td>
</tr>
<tr>
<td>Act II Micro Lite Butter</td>
<td>144</td>
<td>21276</td>
<td>148</td>
<td>570</td>
</tr>
<tr>
<td>Topps Wax Pack Baseball</td>
<td>720</td>
<td>18684</td>
<td>26</td>
<td>276</td>
</tr>
<tr>
<td>Act II Micro White Cheddar</td>
<td>120</td>
<td>15870</td>
<td>132</td>
<td>553</td>
</tr>
<tr>
<td>Wrigley Plen-T-Pak Doublemint</td>
<td>192</td>
<td>14736</td>
<td>77</td>
<td>526</td>
</tr>
<tr>
<td>Act II Micro Natural</td>
<td>144</td>
<td>13284</td>
<td>92</td>
<td>377</td>
</tr>
<tr>
<td>Wrigley Plen-T-Pak Big Red</td>
<td>192</td>
<td>12792</td>
<td>67</td>
<td>530</td>
</tr>
<tr>
<td>Hershey Resse Peanut Butter Cp</td>
<td>432</td>
<td>12708</td>
<td>29</td>
<td>310</td>
</tr>
</tbody>
</table>
Observations

Different views tell us different things
- Cases moved is of interest to receiving, put-away, and restocking operations because each case must be handled separately to put it on a shelf
- Picks give us a view of which SKUs have the highest labor requirements
- Pieces sold give us a view of sales clerk effort (notice they spend most of their time ringing up popcorn and baseball cards)

Observations continued

- In this example, highest SKUs in terms of cases moved have very few pieces per case and hence a relatively small number of pieces moved
- Mature products (e.g., staples) tend to be “balanced” in the number of picks
- Fashion products are often skewed in the number of picks (e.g., the top 100 selling music CDs out of over 100000 make up 25% of all sales)
Understanding and improving warehouse operations

- If we want to give “priority” to certain items, how do we decide which items go to the priority area?
- Should we have separate areas for pallet picking and case picking?
- How effective will zoning strategies be for our operations?
- Are there ways we can anticipate customer actions?

SKU level (pallet vs case vs …)

- Pallet versus case and case versus broken case profiles in terms of % of orders:

<table>
<thead>
<tr>
<th></th>
<th>Form % of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case</td>
<td>56%</td>
</tr>
<tr>
<td>Pallet</td>
<td>27%</td>
</tr>
<tr>
<td>Mixed</td>
<td>17%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Form % of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case</td>
<td>16%</td>
</tr>
<tr>
<td>Broken Case</td>
<td>17%</td>
</tr>
<tr>
<td>Mixed</td>
<td>67%</td>
</tr>
</tbody>
</table>
What do we learn?

- The distribution of pallet and full case are such that we can separate pallet picking and zone picking operations and not pay a large penalty for mixed orders within a warehouse!
- The same is not true when comparing full and broken case. The cost will probably be too high to separate these operations.

Distribution of order mix of families

- Suppose we support 3 families of SKUs (F1, F2 and F3). We observe the following percentage of total orders:
  - F1 only occurs 25% of the time
  - F2 only occurs 30% of the time
  - F3 only occurs 20% of the time
  - F1 and F2 occur 2% of the time
  - F1 and F3 occur 5% of the time
  - F2 and F3 occur 13% of the time
  - F1 and F2 and F3 occur 5% of the time
What do we learn?

- Zoning by family will be a very effective strategy
- F2 and F3 should be located close to each other

- Related issue - family specification
  - by item type
  - by item form - very useful to have family types with same material handling requirements

Correlation

- In many cases, if one item is ordered, then there is often times a “complementary” good ordered
How do we profile?

- Simple techniques
  - Excel spreadsheets
  - Access databases

- Software solutions
  - Data mining software

Warehousing Systems

*Design of a Fastpick Area*
Fastpick Area

- The fastpick area can be considered as a “warehouse within a warehouse” (note it is often also called the “forward” or “forward reserve” area).
- It allows picking operations to be concentrated in a small area thus:
  - reducing pick costs
  - increasing responsiveness to customer demand

Over 80% of picking time is spent on travel!
Design Issues

1. What SKUs should we put in the fastpick area?
2. For those SKUs stored in fastpick, how much volume should we allocate to them?
3. How big should the fastpick area be?

Cost Tradeoffs

- Each item in fastpick requires an additional restock from storage (compared to if that item were only picked from the storage area)
- Any time an item is picked from fastpick, the cost is less than if that item were picked from storage
  - smaller area and hence travel distance
  - 80% of picking time is spent on travel
- Tradeoff
  - Extra cost of restocking vs. lower cost of picking
Estimating Restocks

- The fastpick area is maintained by restocking
- One way to estimate restocks is to approximate product by fluid flow. In this case, let:
  - $f_i$ is cubic feet per year that SKU $i$ “flows” through the warehouse
  - $v_i$ is volume (cubic feet) of SKU $i$ stored in fastpick
- The number of restocks per year, then is:
  $$\frac{f_i}{v_i}$$

2. Allocation of Fastpick Volume

- $c_r$ : the cost per restock
- $V$ : the volume of the fastpick area
- We want to determine the volume for each SKU in fastpick so that total restock costs are minimized.

$$\min \sum_{i=1}^{n} c_r \frac{f_i}{v_i} = \sum_{i=1}^{n} \frac{f_i}{v_i}$$

s.t.
$$\sum_{i=1}^{n} v_i \leq V$$
$$v_i \geq 0$$

Solution using Lagrangean relaxation
2. Allocation of Fastpick Volume

- If we use some special mathematical techniques, we can show that the optimal space value for each SKU in fastpick is given by:

\[
v_i = \left( \frac{\sqrt{f_i}}{\sum_{j=1}^{n} \sqrt{f_j}} \right) V
\]

Other Possible Policies

- Which of these two policies is best?
  - Equal Space Allocation - assign each SKU in fastpick the same amount of space
  - Equal Time Allocation - assign each SKU in fastpick an equal time supply
Example

- 2 SKUs: A and B  \( f_A = 16 \)  \( f_B = 1 \)  \( V = 1 \)
- Two heuristics:
  - Equal space allocation
    \[
    v_A = \frac{\sqrt{16}}{\sqrt{16 + 1}} \times 1 = 0.8 \quad \text{and} \quad v_B = 0.2
    \]
    Total restocks: 34
  - Equal time allocation
    \[
    \frac{16}{17} \quad \frac{1}{17} \quad 17 + 17 = 34
    \]
  - Optimal
    \[
    v_i = \frac{\sqrt{16}}{\sqrt{16 + 1}} \times 1 = 0.8 \quad \text{and} \quad v_A = 0.2
    \]
    Restocks:  \( A: \frac{16}{0.8} = 20 \)  \( B: \frac{1}{0.2} = 5 \)  \( \text{Total} = 25 \)
    Volume ratio:  \( \frac{0.8}{0.2} = 4 \)  Restock ratio:  \( \frac{20}{5} = 4 \)

Observations (items i and k)

Volume ratio :  \( \sqrt{f_i} \)  \( \sqrt{f_k} \)
Restock ratio :  \( \frac{f_i}{\sqrt{f_j}} \)  \( \frac{f_k}{\sqrt{f_j}} \)

Each “unit volume” of storage (e.g., a bay, i.e., shelf section) should be restocked at the same rate
Observations Continued

- The last observation has some important managerial properties:
  - Restocks should be distributed uniformly with no storage areas that are more active than others.
  - If your restockers are restocking some areas more than others (ask them!), then your policy is out of balance. More space should be given to those that are restocked more frequently.

Hot and Cold Spots

Allocate more volume to i and j and less to k.
Observations

- No difference in other policies, and both can be bad!
- The more different the SKU rates of flow \( f_i \) values are, the more important it is to use the optimal allocation
- It can be shown that equal time and equal space allocations can have as many as twice as many restocks as the optimal policy

1. Which SKUs Go Into Fastpick?

- The fastpick area is the “prime real estate”. As such we do not need to consider very slow moving parts. However, which do we need to consider?
- \( s \) : the savings realized when a pick is from fastpick rather than regular (reserve) storage
- \( p_i \) : Number of picks per item \( i \)
- \( c_r \) : cost of restock
How to compute the “benefit”?

- There are two cost components of the benefit:
  - Savings for each SKU for each of its $p_i$ picks
  - Cost for each SKU for each of its picks and $f_i/v_i$ restocks

\[ c(v_i) = sp_i - \left( c_r \frac{f_i}{v_i} \right) \]

The "benefit" of putting $i$ into fastpick

- $c_r$ : cost per restock
- $p_i$ : number of picks for item $i$
- $f_i/v_i$ : number of restockings per unit time (e.g., per month)

Minimum Sensible Storage

- If we are going to put an SKU into fastpick, then it shouldn’t be too small of an amount.
- The minimum amount to put is given by:

\[ \frac{c_r f_i}{sp_i} \]

since this is the value of $\nu$ that results in a net benefit of 0.
Problem Formulation

Formally, we want to choose the SKUs to place in fastpick in order to maximize this benefit:

$$\max \sum_{i=1}^{n} c_i(v_i)$$

s.t.

$$\sum_{i=1}^{n} v_i \leq V$$

$$v_i \geq 0$$

Solution

If we solve the formulation mathematically, we find a very important ratio:

$$A_i = \frac{p_i}{\sqrt{f_i}}$$

which we will call “labor efficiency” or “viscosity”. It represents the labor effort required to move a given flow through the warehouse.

It turns out the SKUs that are put in fastpick are those with the highest labor efficiency.
Procedure for deciding which items go into fastpick

- Sort all SKUs in decreasing order of viscosity
- Successively evaluate the total net “benefit” of the following strategies
  - no SKUs in fastpick
  - first SKU in fastpick
  - first two SKUs in fastpick
  - ...
  - Continue until the “benefit” starts decreasing
- The strategy that maximizes the “benefit” is best

Example
How Big Should Fastpick Be?

- The larger that fastpick becomes:
  - the more SKUs we can fit in which means more pick savings, or
  - the larger the amounts in fastpick which means less restock.
  - BUT - we get less savings per pick since the volume is larger and hence there is additional walking.
- Need to model this tradeoff

Fastpick Size

- Can show that the optimal size $V$ of the fastpick area is given by:

$$V = \frac{\sum_{i=1}^{k} \sqrt{f_i}}{\sqrt{s \sum_{i=1}^{k} P_i}}$$
Summary

- Many opportunities in warehouse design and operations present themselves when profiling
- Activity profiling is a continuous process
- Appropriate design of the fastpick area can save a lot of money (and time)
- Don’t forget to look at the big picture!