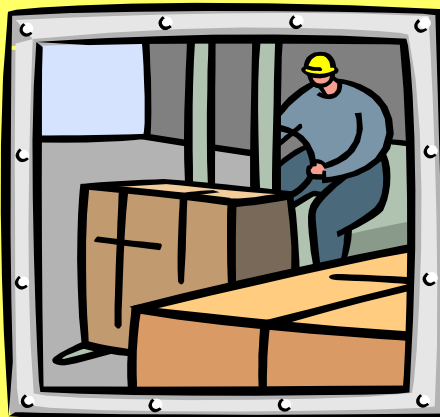


Warehousing Systems



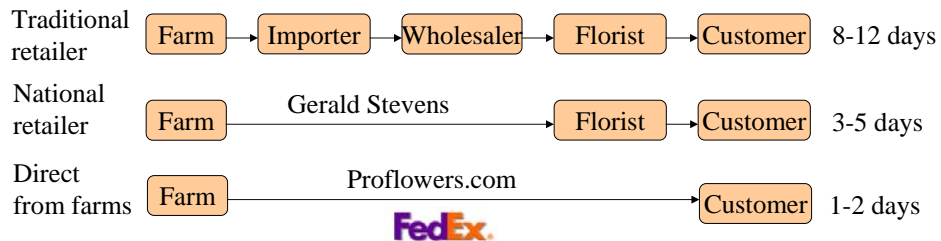
Most of these slides are courtesy of Professor Paul Griffin

Why Have a Warehouse?



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

Shipping directly from the suppliers

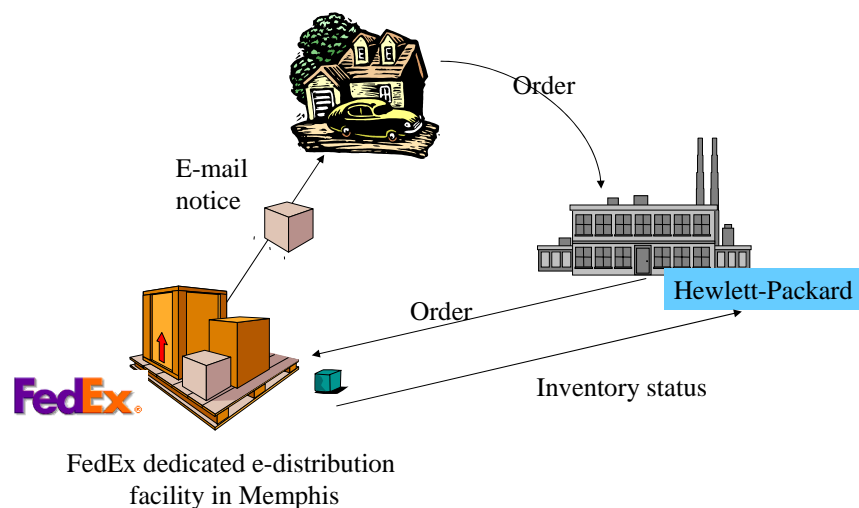


Potential problems

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

3

Distribution from a centralized warehouse



4

Distribution from multiple warehouses

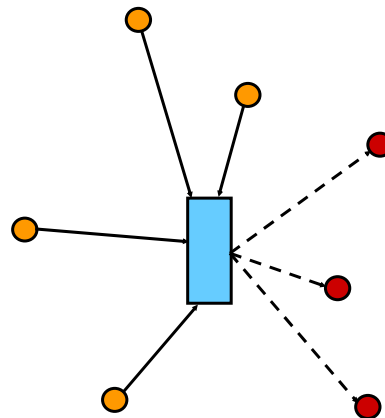
- Peapod
- Amazon.com
 - ▣ \$300 million distribution-center initiative; giant facilities in Nevada, Kentucky and Kansas
- Barnesandnoble.com

- Pros and cons
 - ▣ High investment costs
 - ▣ Shorter delivery times

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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



6

Product Positioning

- Position product close to the customer
- Speed!



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Economies of Scale

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

8

Product Buffer

- Can provide an inventory buffer for:
 - ▣ variability in demand
 - ▣ seasonality of demand



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Value Adding

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



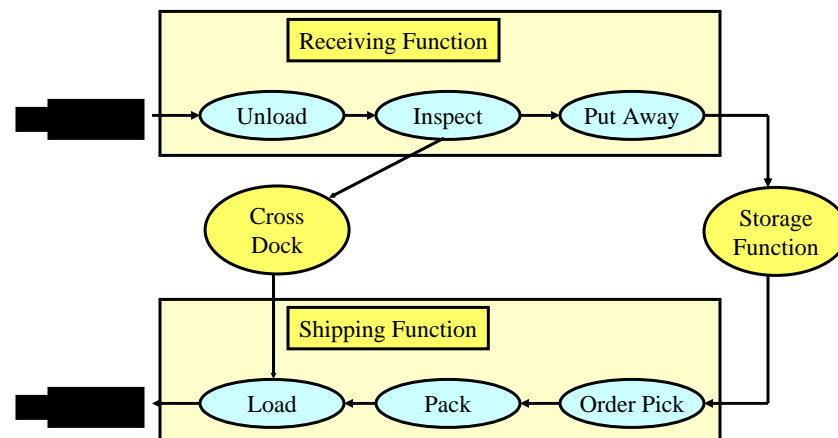
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Warehousing Evolution

- 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.

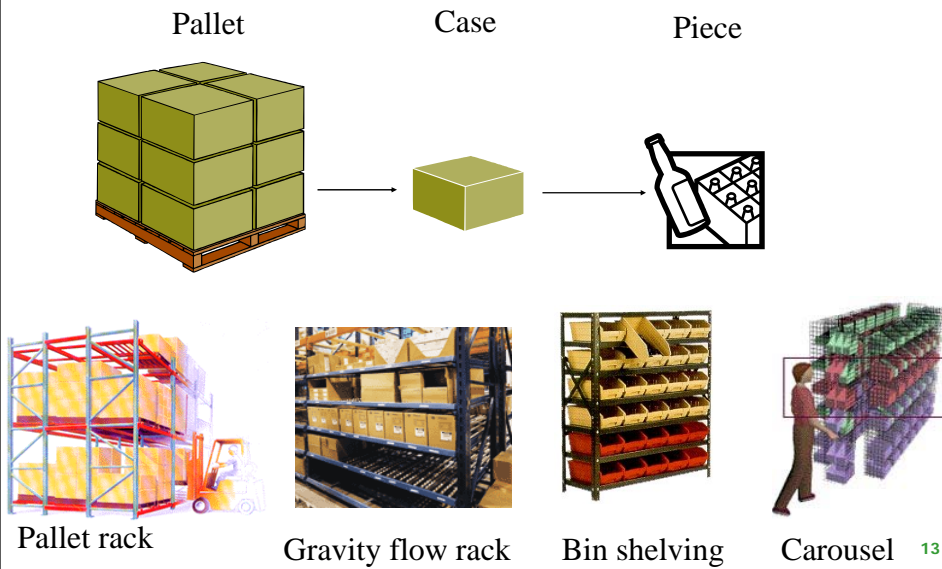
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Warehousing Functions



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Items and storage equipment in a warehouse



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)
- 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!

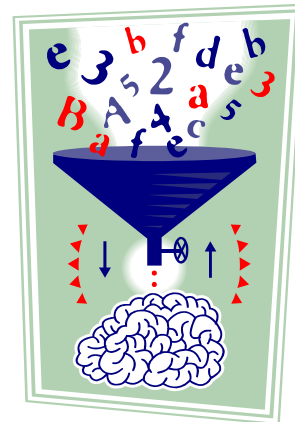
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Warehousing Systems *Activity Profiling*



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
- The data is key!



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Pick sheet

SKU	Quantity	Location
026596	4	...
278538	1	...
093478	22	...

Number of *lines* (or line items or pick lines): 3

Number of *picks* : 3

Number of *grabs* : 27

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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.

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Basics of profiling

- Important to realize that there is a tradeoff between:
 - ▣ Simple (aggregate) statistical description
 - ▣ Complex description
- Simple statistics can give a quick (albeit rough) description of the warehouse. However, looking at averages can hide complexity (including correlation, confounding, etc.)

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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



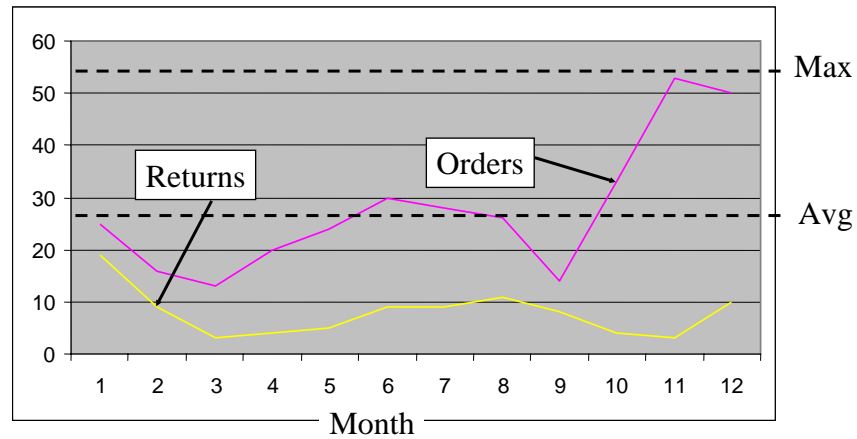
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Time-based analysis

- Several things change for a warehouse of time
 - weekly seasonality of SKUs
 - monthly seasonality of total demand
 - 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

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Monthly Loads



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Variability-based profiling

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

Time	# Picks
8:00-9:00	110
9:00-10:00	40
10:00-11:00	33
11:00-12:00	35
12:00-1:00	29
1:00-2:00	180
2:00-3:00	140



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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 under-designed.

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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

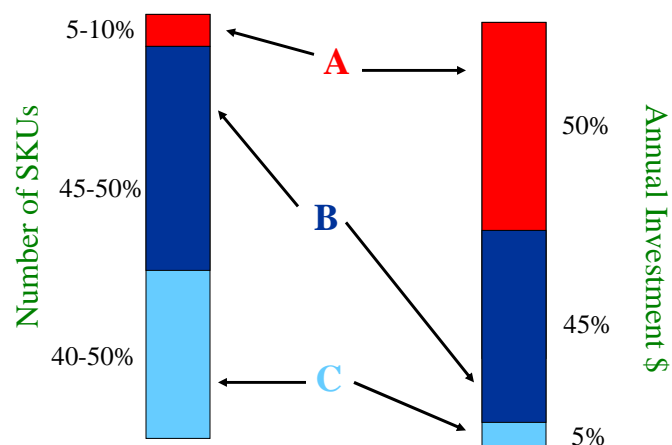
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ABC analysis

- In a warehouse, "20% of the SKUs account for 80% of the activity".

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ABC classification



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Top 10 items by # cases

SKU	Pcs/Case	Pieces	Cases	Picks
UL Slimfast Bonus Choc Royale	6	3085	514	525
Bandaid Family Twin pack	12	4488	374	374
Sathers Pixy Stix	12	4320	360	267
Gemini Video Tape T-120	24	7260	303	471
House Brand Aspirin 5 Gr.	12	3144	262	255
House Brand Complete Allergy Caps	24	5850	244	538
Act II Micro Butter	144	34362	239	806
House Brand Pain Rel Caplets 500MG	24	5604	234	569
House Brand Gesic	24	5562	231	485
Sathers S/F Asst Sour Mix	12	2520	210	206

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Top 10 items by # of customer requests (picks)

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

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Top 10 items by # of pieces sold

SKU	Pcs/Case	Pieces	Cases	Picks
Upper Deck Baseball Low #	432	70524	163	423
Act II Micro Butter	144	34362	239	806
Score Baseball Series II	720	25344	35	348
Act II Micro Lite Butter	144	21276	148	570
Topps Wax Pack Baseball	720	18684	26	276
Act II Micro White Cheddar	120	15870	132	553
Wrigley Plen-T-Pak Doublemint	192	14736	77	526
Act II Micro Natural	144	13284	92	377
Wrigley Plen-T-Pak Big Red	192	12792	67	530
Hershey Resse Peanut Butter Cp	432	12708	29	310

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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)

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Observations continued

- There can be some surprising issues with ABC analysis. For example, notice that the highest SKUs in terms of cases moved has very few pieces per case and hence a relatively small number of pieces moved.
- When considering mature products (e.g. staples), they tend to not be skewed in the number of picks (i.e. it falls off slowly) compared to fashion products (e.g. the top 100 selling music CDs out of over 100000 make up 25% of all sales).

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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?

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SKU level (pallet vs case vs ...)

- What if we looked at pallet versus case and case versus broken case profiles in terms of %orders:

Form	%of Total
Case	56%
Pallet	27%
Mixed	17%

Form	%of Total
Case	16%
Broken Case	17%
Mixed	67%

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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
 - ☐ warehouse 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

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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

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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

 - ▣ Can family redesign lead to useful patterns?

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Correlation

- In many cases, if one item is ordered, then there is often times a “complementary” good ordered



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How do we profile?

- Simple techniques
 - Excel spreadsheets
 - Access databases
- Software solutions
 - Data mining software



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Warehousing Systems *Design of a Fastpick Area*



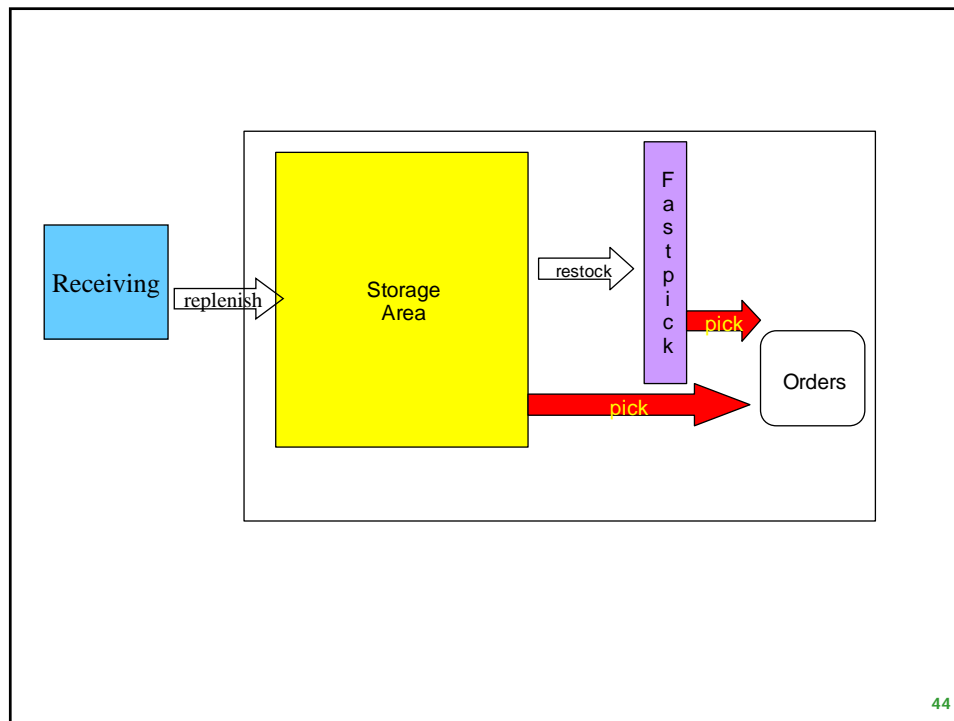
Overview

- What is "fastpick"?
- Cost tradeoffs
- Design Issues
- Example
- Slotting complications
- Managerial Insights

Fastpick Area

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

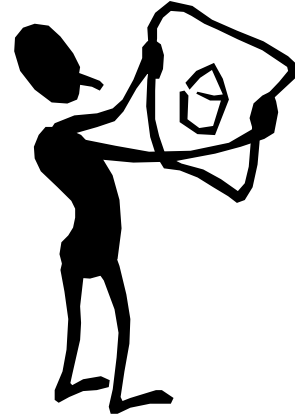
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Design Issues

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



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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

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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:

$$\frac{f_i}{v_i}$$

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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.

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

s.t.

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

$$v_i \geq 0$$

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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:

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

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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

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Example

- 2 SKUs: A and B $f_A=16$ $f_B=1$ $V=1$
- Two heuristics:

	v_A	v_B	Total restocks
Equal space allocation	$\frac{1}{2}$	$\frac{1}{2}$	$32+2=34$
Equal time allocation	$16/17$	$1/17$	$17+17=34$

- Optimal

$$v_A = \left(\frac{\sqrt{16}}{\sqrt{16} + \sqrt{1}} \right) \times 1 = 0.8 \quad v_B = 0.2$$

$$\text{Restocks: } A: \frac{16}{0.8} = 20 \quad B: \frac{1}{0.2} = 5 \quad \text{Total} = 25$$

$$\text{Volume ratio: } \frac{0.8}{0.2} = 4 \quad \text{Restock ratio: } \frac{20}{5} = 4$$

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Observations

- The fraction of available storage that should be devoted to an SKU is:

$$\frac{\sqrt{f_i}}{\sum_{j=1}^n \sqrt{f_j}}$$

- Each storage bay (i.e. shelf section) should be restocked at the same rate

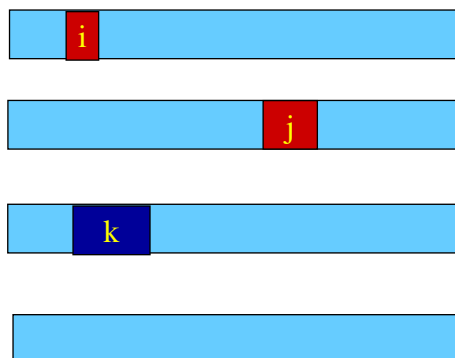
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Observations Continued

- 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.

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Hot and Cold Spots



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

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Observations

- No difference in other policies, and both are 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

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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

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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/v_i restocks

$$c(v_i) = sp_i - \left(c_r \frac{f_i}{v_i} \right) \text{ "benefit" of putting } i \text{ into fastpick}$$

c_r : cost per restock p_i : number of picks for item i

$\frac{f_i}{v_i}$: number of restockings per unit time (e.g., per month)

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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 v that results in a net benefit of 0.

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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.

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

$$v_i \geq 0$$

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Solution

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

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

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

- It turns out the the SKUs that are put in fastpick are those with the highest viscosity.

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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

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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

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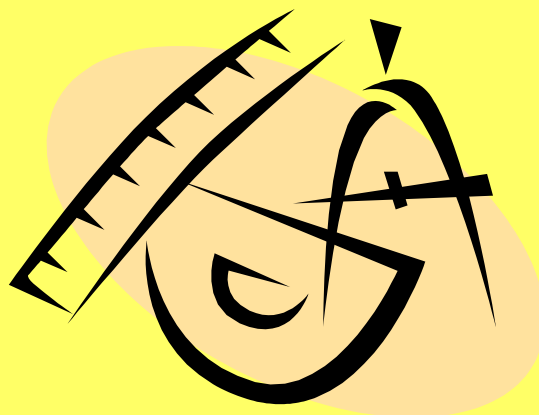
Fastpick Size

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

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

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Example



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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!