Warehouse Inbound and Storage

Chen Zhou
Fall, 08

Major operations in a DC or warehouse

Receiving Function
- Unload/stage
- Inspect
- Put Away

Cross Dock

Shipping Function
- Load
- Pack
- Order Pick

Storage Function

Avg Operation Cost 55%
Receiving

- Tasks
  - Check, inspect, unload, Record, stage, re-palletize
- Facilities
  - Docks, lift trucks, forklift, mobile conveyors, cart,
  - Computer terminals, bar code printer
- Decisions
  - Schedule of arrivals
  - Priorities
  - Staging
  - Problem handling
- Cost ~ 10% of operation cost

Putaway

- Tasks
  - Move goods storage locations
- Facility
  - Pallet truck
  - Lift truck
  - ... more in following slides
- Decisions
  - Where
  - When
  - Equipment
- Cost ~ 15%
Counter-balanced forklift

- Most popular
- Requires 12' - 18' aisle
- Capacities 3000 lbs - 80,000 lbs
- Can stack two up
- Can go high
- Gasoline, propane, natural gas, electric

Narrow Aisle straddle trucks

- Require 7' - 8' aisles
- Capacities available are 3000# & 4000#
- Load must be uniform
- Load must fit between outriggers
- Bottom beam in rack recommended
- Typically custom built
- Require floor with high flatness, especially when heavy loads are going high
Turret truck (for very narrow aisles)

- Requires 48” - 72” aisle
- 25’ & higher
- Up to 4000# capacity
- Ability to be maneuvered in & out of aisle
- Services both sides of aisle
- Full pallet put away
- Full or partial pallet picking
- Loads must be positions at the aisle by other equipment
- Demand high quality floors

Storage and Handling

Chen Zhou
Summer, 08
Storage

- Tasks
  - Hold inventory
- Methods
  - Floor, floor stacking
  - Pallet rack
  - Gravity flow rack, push back
  - Bin shelving
- Objectives
  - Space utilization
  - Response
  - Labor cost
- Decisions
  - Floor, equipment, slotting,
  - How to measure the efficiency of storage?

Warehouse parameters: pick face

- 2 - D space with direct access of unique skus
Warehouse parameters: sku density

- Sku density = No. of skus / unit floor footage
- In floor stacking example
  - Floor: 30 foot length, 4 skus. Sku density = 4/30 = 0.133
- In bins
  - Rack: 12 foot, 360 skus, Sku density = 360/12 = 30
- The higher the sku density, the higher the potential for shorter travel in order picking
- What do we lose with higher sku density?

Warehouse parameters: pick density

- Pick density = picks / unit distance traveled
- Eg.
  - In a large warehouse, the distance from the I/O to the far most corner is 400 meters. Each pick is for one pallet which is uniformly distributed throughout the warehouse. The average pick density is 1 per 200 meters traveled.
  - In a picking zone that is 50 meters long, a picker on an average picks 100 skus in each sweep, the average pick density is 2 skus per meter traveled.
- Is higher density good?
- How to gain higher pick density? A major design and operation challenge.
Storage: floor stacking

- No storage equipment is required
- Items must be able to support the weight: special packaging may be required
- Can achieve good space utilization with limited SKUs
- Does not support FIFO
- Low sku density

Floor storage with tier racks

- More flexible than pallet racks
- Often used for storage centric applications
Pallet racks and bin shelving

Gravity flow racks

- Allows higher sku density while maintain high volume for each sku
- YOU may have seen gravity flow storage in supermarket: milk
Effectiveness of pallet flow racks

Carousels: parallel processing
Vertical carousels

- Small items
- Valuable items

AS/RS with stacker crane

- Miniload
- Unitload
Space requirements estimates

- Recall 3PL for home appliance company?
- Throughput per day
  - Receiving 50 - 75 truckloads, Assume 2,560 ft³/truck
- Holds 4 weeks of inventory
- Little’s Law
  - \[ WIP = TH \times CT \]
  - \[ WIP = 75 \times 2,560 \text{ ft}^3/\text{day} \times 4 \text{ weeks} \times 5.5 \text{ days/week} = 4,224,000 \text{ ft}^3 \]
- Assume stacking 20 ft high, space for storage = 211,200 ft²
- Space utilization: 50 (70%), plus aisles, etc.
- Reality: 657,000 ft² (14 football fields), 140,000 unit storage

Slotting priority: cubit-per-order index (activity ratio)

- What factor (s) should we consider to prioritize the slotting with known economic terrain (contours)?

- Pick (restock) frequency: fast movers should occupy better locations.

- Space requirement for the item. This may not be obvious.
E.g.

- Skus A and B have same pick frequency of 10/day. A takes 2 pallet slots and B takes 1 slot (can be due to lower inventory turns or smaller cases). Which one should be placed in more convenient location?

\[
TC_{AB} = \sum_{i=1}^{2} f_i D_i = \]

\[
TC_{BA} = \sum_{i=1}^{2} f_i D_i = \]

\[
\text{Does this make sense}
\]

- The objective is to visit closer cell more frequently, regardless of what is in there.
- \( p_i \) pick frequency picks/week
- \( v_i \) vol in storage \( \text{ft}^3 \)
- The cell visit frequency is equal to

\[
\text{Activity Ratio (or COI)} = \]

- For the example: \( AR_A = \) \( AR_B = \)
What can impact the storage requirements

- Item size, storage/handling characteristics
- Replenishment frequency

E.g.

Top 6 items has steady daily demand in a small warehouse using dedicated storage. All orders consists of single item and there is no batching. The items are stored in pallets on shelves. Someone used EOQ model to decide the replenishments frequencies. Please find assignment priority. Let 1 week = 5 days.

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<th>B</th>
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Dedicated vs. randomized (shared) storage

Dedicated storage: \( V_D = \sum_{1 \leq i \leq n} \max_{1 \leq j \leq m} v_{ij} \)

Shared storage: \( V_S = \max \sum_{1 \leq i \leq n} v_{ij} \)

- Dedicated storage is more convenient
- Shared storage provides higher storage efficiency
- Hybrid
  - Dedicated zones but shared within zones
  - Dedicated in pick and shared in reserve

Comparison of randomized/dedicated

- Randomized takes less storage requirements since averages variability across products
- Which provides higher pick density?
  - If all skus have similar activity ratio, the smaller space in randomized storage should lead to higher pick density
  - If activity ratios vary a lot, the frequent visit to convenient locations in dedicated storage can lead to higher pick density
- Hybrid - zone based storage
Inbound and storage summary

- DC operations
- Inbound operations
- Storage methods
- Equipment and handling
- Storage metric
- Slotting priorities

Questions

- What are the important operations in a warehouse or DC?
- What are the pros and cons of high SKU density?
- What can be used to achieve high SKU density while maintaining volume?
- Why DCs often use different equipment for transport and rack handling?
- What factors affect slotting priorities?
- What affects the storage volume requirement?
Order picking

- Most demanding: ~ 63% of operating costs in a typical warehouse, survey by the Warehouse Education and Research Council. It was identified as #1 area for improvement.
- Become more significant due to emphasis on just-in-time (JIT), cycle time reduction, quick response, and marketing strategies such as micro marketing and megabrand strategies.
  - Smaller orders more frequently and more accurately.
  - More stock keeping units (SKUs) be available for the customers.
- What is involved to ensure high efficiency:
  - Layout and storage strategies
  - Slotting
  - Order processing
  - Order picking system design
  - Order picking operational specifics
    - Sequencing
    - Batching
    - ...
Order processing

Pick List for 7/1/2002
Last P : 1

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<tr>
<th>Description</th>
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Form of pick list: sequenced labels

- Sequenced sticky labels

4/14/2005
Other form of pick list

- Data table for PLC for pick to light
- Sequenced voice instructions to pick to voice (later)
- Instructions to automated systems

Issues in order processing

- Objectives
  - Minimize travel (or other handling)
- Subject to
  - Throughput
  - Cycle time
  - Line balancing
  - Time window, batch to waves
    - Day in a week
    - Departing time
    - Items to pass to other DCs
  - ...
- WMS normally support this function.
  - It requires customization and adaptation
Order picking

Chen Zhou
Summer 08

What is involved in order picking

- Travel
- Search
- Pick
- (sort)
- Put
- (sort)
What affects order picking

- Storage
  - Type of storage affects SKU density
  - SKU density affects pick density
  - Slotting affects total travel
- Order picking system design
  - One at a time
  - Batching in various ways
  - ...
- Operations
  - Sequencing
  - Schedule
  - ...
- Technologies
  - Pick to light can reduce search time and improve accuracy

Parameters of orders

- Number of line items
- Number of items in a line
- Size and weight of an item
  - Pallet
  - Cases (cartons)
  - Break pack
  - ...

Pick List for 7/1/2002

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Picking strategies

- One item or one line per trip
  - Big
  - Sorting or consolidation is needed later
- One order per trip

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Picking strategies

- A batch of orders per trip
  - Sort while pick or sort after

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Picking strategies

- A portion of an order (zoning)
  - Too big
  - For faster response
  - Consolidation while picking or later

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Picking strategies

- A portion of many orders (batching + zoning)
  - Economy of scale
  - Higher pick density
  - Sorting while picking or sort after

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Travels

- Pick one at a time

One order at a time

- Benefit/drawback
  - Travel: down
  - Search: no change
  - Pick: may have some change due to handling
  - Put: may have some change
Batch picking: multiple-order-one-picker

- Benefit/drawback
  - Travel: down
  - Searching: not much
  - Picking: not much
  - Putting:
    - up if sorting on the tour
    - no change if sort later but sorting is required downstream

- Almost always good for single line orders

Batch picking of large orders with truck
Batching picking with push carts

Pick to order specific containers, no sorting is required afterwards

4/14/2005

Time based batching: wave picking

- Many DCs organize batches based on time window
  - Truck/ship/train departure times
  - Shifts
  - Cycle times
  - Delivery requirements

- Designations
  - Macon wave
  - 10 AM wave
  - Yellow wave

4/14/2005
Zone picking: one-order-multiple-picker

**Benefit/drawback**
- Travel: not much change
- Search: down
- Pick: no change
- Put: no change
- Less training, higher accuracy

Zone picking examples

- No Sorting is required
- Sorting is required
**Batching + Zoning**

- Very useful in regional distribution centers that supply many stores
- Benefit/drawback
  - Travel: down
  - Search: down
  - Pick: can go down with sophisticated design.
  - Put: down because sorting is normally later

---

**Order picking strategy: fast pick area**

- Benefit/drawback
  - Travel: down in pick area
  - Search: not much
  - Pick: may reduce if more convenient
  - Put: similar
  - Require replenishment or double handling
Forward/reserve

- The forward takes convenient locations
  - Near the shipping
  - At floor level
  - Near conveyor
- The reserve takes less convenient locations
  - Far away
  - Higher levels that require special equipment for picking
- Forward requires
  - Quick search
  - Easy management
  - Often dedicated storage
- Reserve requires
  - Space utilization
  - Often shared or randomized storage
  - The share may be restricted to a special area, like one rack - hybrid

A pick/reserve module
Pick from pallet in a rack module

- Fast pick from front
- Pick from reserve in the back
- Replenish from back

Pick from reserve

- Requires expensive equipment
- Takes more time
Pick from pallet to conveyor

Finding skus and volume for fast pick area

- Engineering for fast pick area
  - Which sku should go to fast pick area
  - How much if know number of skus to share know number of volume?
- \( n \) no. of skus in fast pick
- \( f_i \) flow vol/year, \( m^3 \) / year (month)
- \( p_i \) pick frequency, picks / year,
- \( cpo_i \) cubic per order, \( m^3 \) / order,
- \( v_i \) vol of restock to fast pick area of \( i \), \( m^3 \) / restock
- \( V \) total volume available in fast pick
- \( c_r \) cost of restock, \$/restock (assuming constant)
- \( s \) savings of a pick: fast pick vs. reserve.
Fast pick calculation

- Fast pick priority, descending order of

E.g. Please prioritize the claim to fastpick area

<table>
<thead>
<tr>
<th>Sku</th>
<th>Picks/ mth A</th>
<th>No/mth B</th>
<th>L</th>
<th>C</th>
<th>W</th>
<th>D</th>
<th>H</th>
<th>E</th>
<th>Cpo</th>
<th>Efficiency^2</th>
<th>Priority</th>
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<tbody>
<tr>
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<td>2500</td>
<td>4500</td>
<td>0.5</td>
<td>1</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>1000</td>
<td>1234</td>
<td>0.25</td>
<td>1.5</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>500</td>
<td>750</td>
<td>0.6</td>
<td>0.8</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td>0.72</td>
<td>694</td>
<td></td>
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<tr>
<td>D</td>
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<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td>0.45</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>250</td>
<td>1000</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td></td>
<td></td>
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<td>0.864</td>
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<tr>
<td>F</td>
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<td>1.0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>800</td>
<td>0.4</td>
<td>0.4</td>
<td>0.8</td>
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<td></td>
<td></td>
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<td>1563</td>
<td></td>
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<tr>
<td>I</td>
<td>200</td>
<td>400</td>
<td>0.1</td>
<td>0.3</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td>0.006</td>
<td>33333</td>
<td></td>
</tr>
</tbody>
</table>
Fast pick volume assignment, $n$ skus, vol $V$

- Equal volume
- Equal time
- Optimum with respect to total cost

E.g.

Consider 2 skus. The flows are 16 and 1 $m^3/yr$. They are to share 1 $m^3$ storage in fastpick.

<table>
<thead>
<tr>
<th></th>
<th>Equal Space</th>
<th>Equal time</th>
<th>Optimal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$V$</td>
<td>$f/V$</td>
<td>$V$</td>
</tr>
<tr>
<td>A</td>
<td>C</td>
<td></td>
<td>C</td>
</tr>
<tr>
<td>B</td>
<td>C</td>
<td></td>
<td>C</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Discussions

What does optimum mean?
Order picking summary

- The most important operation in a DC
- Try to reduce time for travel, search and others
- Strategies
  - Storage and handling
  - Slotting
  - Batching
  - Zoning
  - Forward/reserve
  - Technologies (to follow)
    - Conveyors
    - Pick to light (voice), put to light

Order picking review questions

- What is pick list?
- What are the order picking strategies?
- Are the priorities for slotting and fastpick the same?
- What strategy is suitable for which type of orders?
- What is one of the most important direct efficiency objectives in a DC?
Order Picking Technologies

Chen Zhou
Fall, 2008

Popular technologies that assist order picking
- Conveyors
- Pick to light and put to light
- Pick to voice
- “A” frames
- High speed sorting systems
Conveyor

- Conveyors
  - Transport
  - Buffer: smooth flow and improve utilization
  - Extends the good locations throughout the facility
  - Can yield very high throughput
- Important for high throughput systems, more and more popular in US, often miles to tens of miles in a facility
- Requires significant investment

Schematic of a picking zone

- Pick module
- Forward
- Reserve
- Receiving docks
- Sort to shipping docks

How to draw economic terrain contours
A graphical view of a pick module

- A case picking zone

---

Pick to light in station lighting

- Reduce search time
- Increase accuracy
- Reduce training
**Put-to-light**

- Present one SKU to the picker
- Scan the SKU
- Lights associated with order containers will come on
- Put items into light indicated boxes

**Differences between pick to light & put to light**

- **Pick to light**
  - SKUs are stationary and wait to be picked
  - Orders triggers the light
- **Put to light**
  - Orders are batched and wait
  - SKU triggers the light
Application example

- A DC has two types of products
  - Staple
  - Flow through
- Sales would try to convince you their technology is best for both
- What do you think?

Pick to voice

- Scan the order
- Activate voice instructions for the picker
- Picker pick and place into the order container
- Picker confirm picking complete verbally
- No Sorting is required in this example
Comparison of pick to light and pick to voice

- Sales people will try convince you their technology is the best in terms of
  - Cost
  - Accuracy
  - ...

- Voice: number of players required is proportional to
- Light: number of lights required is proportional to

- Voice: Serial media
- Vision: Parallel media

Automated picking with A - Frame

- A frame
- Automated dispensing
Automated order fulfillment initiation

- Container types
- Labels and tracking

Sorting

- Manual
- Barcode directed
- Vision directed
- High speed sorters
### Sorting: High Rate Tilt Tray

- 12,000 items/hr.
- Unit sorter
- Can sort to two sides

### High speed conveyor sorters

- Roller sorter
- Shoe sorter
Other Outbound Operations

Checking, packing and packaging
Shipping

Other: returns
Warehousing review questions

- What does SLP stand for and what does it involve?
- What is the default measure of distance between activities in typical software?
- What is the most direct quantitative measure of operational efficiency in layout problems?
- Are you comfortable with equal distance contours?

Warehousing intro

- What are the purposes of a warehouse (DC)?
- What are the main operations in a warehouse?
- Inventor positioning considerations
- What are the direct and concrete objectives in a warehouse?
Warehouse operations

- What are some of the material movement equipment used?
- What are categories of loads moved?
- What are the storage methods?
- How do you measure the storage methods?
- What factors are the most important in deciding an SKU's location?
- What are the advantages of carousel vs. bin shelving?
- What is the advantage of flow racks (pallet or case)?

Order picking

- How do storage strategies affect order picking?
- What are the order picking strategies?
- What strategy is suitable for which type of orders?
- What are some of the technologies used to improve accuracy and speed?
- What does conveyor achieve in a DC?
- What are the pros and Cons of pick to light, put to light and pick to voice?
- What is one of the most important efficiency objectives in a DC?
### 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>~5,000</td>
</tr>
<tr>
<td>Function</td>
<td>Support RDCs and stores</td>
<td>Support 85 stores</td>
</tr>
<tr>
<td>Throughput</td>
<td>6,250/hour</td>
<td>15,000/hour</td>
</tr>
<tr>
<td>Productivity</td>
<td>45 cases/man hour</td>
<td>100 cases/man hour</td>
</tr>
<tr>
<td>Comments</td>
<td>Fast movers are in pallets</td>
<td>Pallets are separate, some cases contain multiple skus</td>
</tr>
</tbody>
</table>

4/14/2005
Overview of port DC and RDC

- Port DC
  - Goods come in mostly in cases in containers
  - Palletization
  - Storage
    - Pick area: shared slots in zones in pallet racks
    - Reserve: tier racks, deep lane storage, floor stacking, high density difficult to pick
  - Picking
    - Pallets
    - Cases

- RDC
  - Goods come in from
    - Port DC
    - Manufacturers
    - Other RDCs
  - Depalletization/palletization
  - Storage
    - Racks
    - Staging
  - Picking
    - Cases
    - Break pack
    - 23 miles of conveyors

Robotic de-palletizer
Port DC case picking

- Order -> Barcode -> pallet(s),
- An associate places the pallet into pick area
- Picker drives a fork lift picks cases in that aisle to the pallet, scan the case and the pallet
- Once completed, a pallet truck driver is informed to move the pallet to the dock

Order picking schematic in port DC

- Vertical economic terrain
- Pallet picking vs. case picking
  - Slow moving takes better locations
- Separation of picking and transporting
Lagrange DC Operation
Material Flow

Outbound

Shipping Dock

Sorter

Main Merging (4 to 2)

Staple Receiving Dock

Pick module in conveyorized system

Pick module

Forward

Reserve

Receiving docks

Sort to shipping docks

4/14/2005

Georgia Tech College of Engineering

4/14/2005
Order Picking

- Pick to conveyor
  - Stack of bar code labels
  - Place the label on carton, put the carton on conveyor
  - Base pick rate: 450 cases/hour, or 8 second/case, including other times.
  - Conveyor capacity: 20,000 cases/hour

- Break pack
  - People to storage
  - Pick to light
  - Put to light
    - Wal-Mart do not open a case unless the orders will require its entire content
    - What does this mean in fill rate and inventory level?
    - What will be the alternatives?

Discussions

- What additional “engineering” is needed to achieve high pick rate?
  - Sec
  - Use
  - ...

4/14/2005
Questions and discussions