Robust Storage Systems Design

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Warehouse Operations
Flow Path Schematic (FFN)

Receiving

Cross Docking

Storage

Full Pallet Picking

Case Picking

Item Picking

Sortation

Packaging

Shipping

Sharp et al. 1991
### Research Goal

- **Design framework for storage systems**
  - Unit loads
    - Single and dual command
  - Direct access
    - Single-deep rack and single-load high floor stacks
  - Comprehensive
    - Rich set of facility configurations and storage policies
  - Robust: efficiency and risk (stochastic)
  - Component of design methodology for warehousing systems
Empty Single-Deep Pallet Rack with Four Levels
ASRS Pallet Unit Load High-Rise Storage
Wine Barrels in a Cantilever Rack
Definitions

- **Storage Policy**
  
  ✓ Set of rules that determine where to store arriving SKUs in a warehousing system

- **Unit Load**
  
  ✓ A collection of materials that can be transported, stored, and controlled (managed) as a single unit
    
    • Examples
    
    • Vast majority of discrete goods
Warehousing Storage Objectives: Back to Basics

- Minimize the cost of expected travel time for given input-output operations
  - Minimize MH equipment and personnel
  - Variable (marginal) costs

- Minimize the cost of required storage space for given stored inventory
  - Minimize capital investment
  - Fixed costs
Main Design Observation

- Very few configuration decisions
- Most compared with complete enumeration (user driven comparison)
  - Technology, type of material handling equipment, aisles have ladder structure or not, aisle orientation, location of the input/output points, storage policy
  - Many combinations
    - Need computational support to evaluate designs quickly
Design Decision Variables

- Main design decision variables
  - Number of aisles, number of levels (rack height), number of columns (aisle length)

- Secondary decisions
  - Load locations, number of personnel and MH equipment

- Decomposition

- Pareto optimal comparison of efficiency versus risk
Pareto Risk versus Efficiency Comparison

![Graph showing Pareto Risk versus Efficiency Comparison. The graph displays the relationship between Standard Deviation of Total Cost (M$) and Average Total Cost (M$), with different symbols representing N=5 and MVP.](image-url)
Prior Research on Storage Systems
Design and Storage Policies

- Long research history and still active area
  - Heskett (COI) 1963,…to Ang et al. 2012
  - Most recent reviews Gu et al. 2007 + 2010
  - Contemporary blogs
  - Industry norms FEM, VDI

- Results and algorithms are strongly assumption driven
  - Integration and unified assumptions are the challenge
Storage Policies Classification

- **Storage Policies**
  - Non Unit Load
    - No Information
      - Random Closest Open Location
    - Product Based
      - Factoring
        - Demand Ranked
          - Inventory Ranked
        - Assignment Formulation
      - Non-Factoring
    - Load Based
      - Factoring
        - Perfectly Balanced
          - Duration of Stay
        - Non Perfectly Balanced
          - #-Zone
      - Non-Factoring
        - Vector Assignment Formulation
Storage Policy Classification: Additional Considerations

- Stationary or not warehousing operations
  - Repetitive, seasonal, build-up (single use), random events
Decomposition Algorithm

- **One user-specified design**
  - E.g. ASRS, random storage

- **Master problem: determine NA, NL, NC**

- **Sub problem:**
  - Split by scenario
  - Compute assignment costs (parameters)
  - Optimize scenario variables and (objective) cost
  - Return EV and SD of scenario costs
Two Examples

- **General load-based assignment (VAP)**
  - Most general, very large MIPs, most computationally demanding
  - Ultimate verification algorithm

- **Technology comparison with random storage**
  - Using FEM travel time norms
  - Different risk measures
Occupancy Gantt Chart: Rack Based Direct Access
VAP Conclusions

- Very large integer optimization problem
- Very tight LP relaxation
- Efficient sub problem and problem size indicate decomposition
- Very small gap for Lagrangean relaxation upper bound
- Highly primal and dual degenerate
- Acceptable penalty for primal heuristic
Technology Comparison Example

- Automated storage and retrieval system (ASRS) versus person-controlled narrow aisle reach truck (NAT)
- System and construction, operations, and maintenance costs
- ASRS
  - Simultaneous travel, aisle-captive crane
- NAT
  - Sequential travel in the aisle, non aisle-captive
Technology Comparison Example

- **Model characteristics**
  - Cubic space constraint (master), volume and area cost terms (sub) become parameters, quadratic sub objective (risk = variance), efficiency versus risk tradeoff weight

- **Algorithm**
  - Finite ranges for NA, NL, NC
  - Solved by complete enumeration in master
Technology Comparison Example: Standard Deviation Risk
Technology Comparison Example: Downside Risk (Semi-Deviation)
Unit Load Storage Policy

Conclusions

- Unit load systems are very common
- Single or dual command cycles
- Two main objectives:
  - Cost of storage space,
  - Cost of total travel time
- Three planning problems
  - Strategic configuration and sizing
  - Tactical storage policy
  - Operational storage & retrieval sequence
Operator-controlled systems are less expensive, but have larger cost variability.

Above is true regardless of the risk measure (standard deviation or downside risk).

On an equal low-risk basis automated systems are less expensive.
May I answer any questions?