Robust Storage Systems Design

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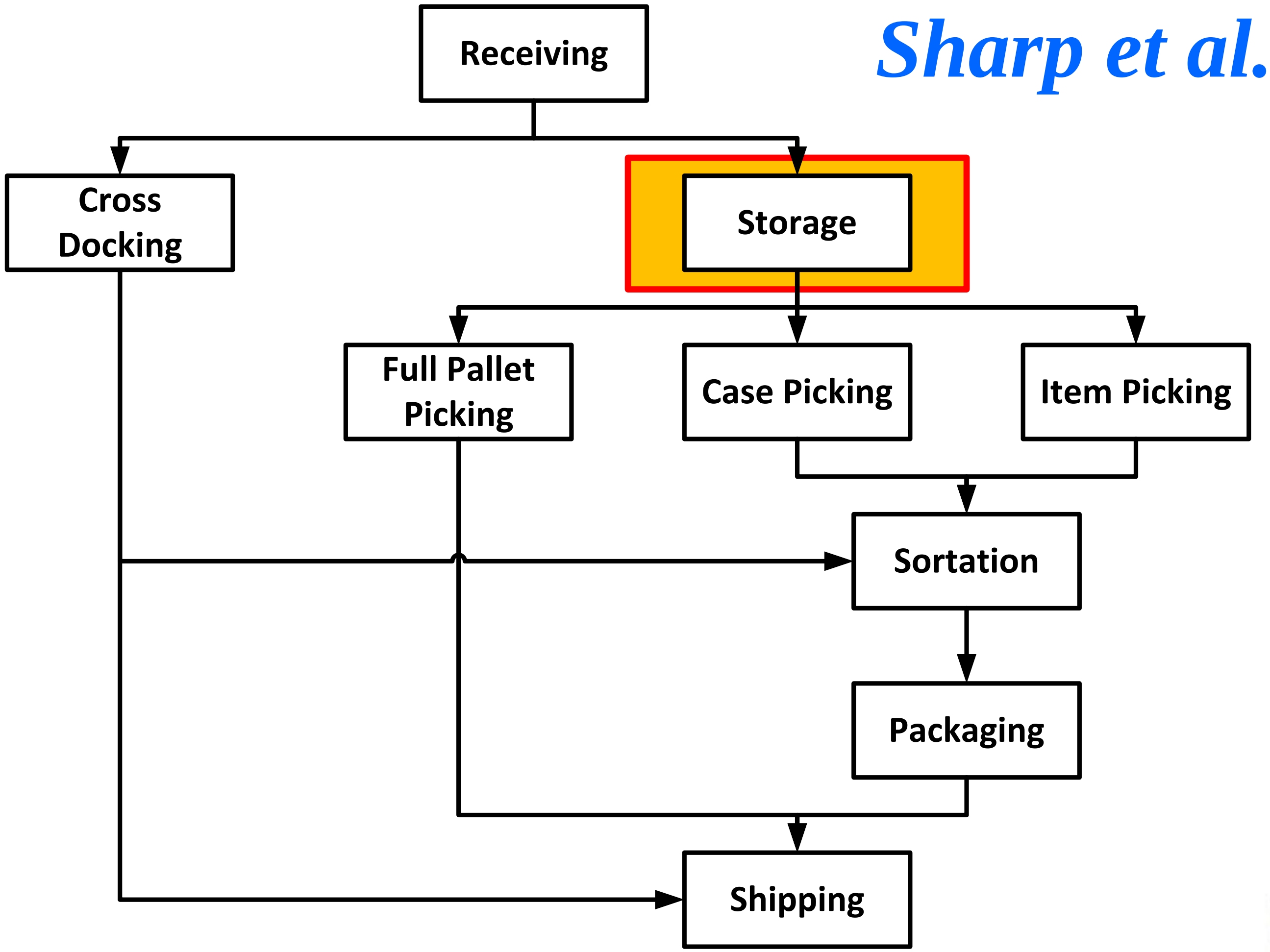
Warehouse Operations
Flow Path Schematic (FFN)

Sharp et al. 1991

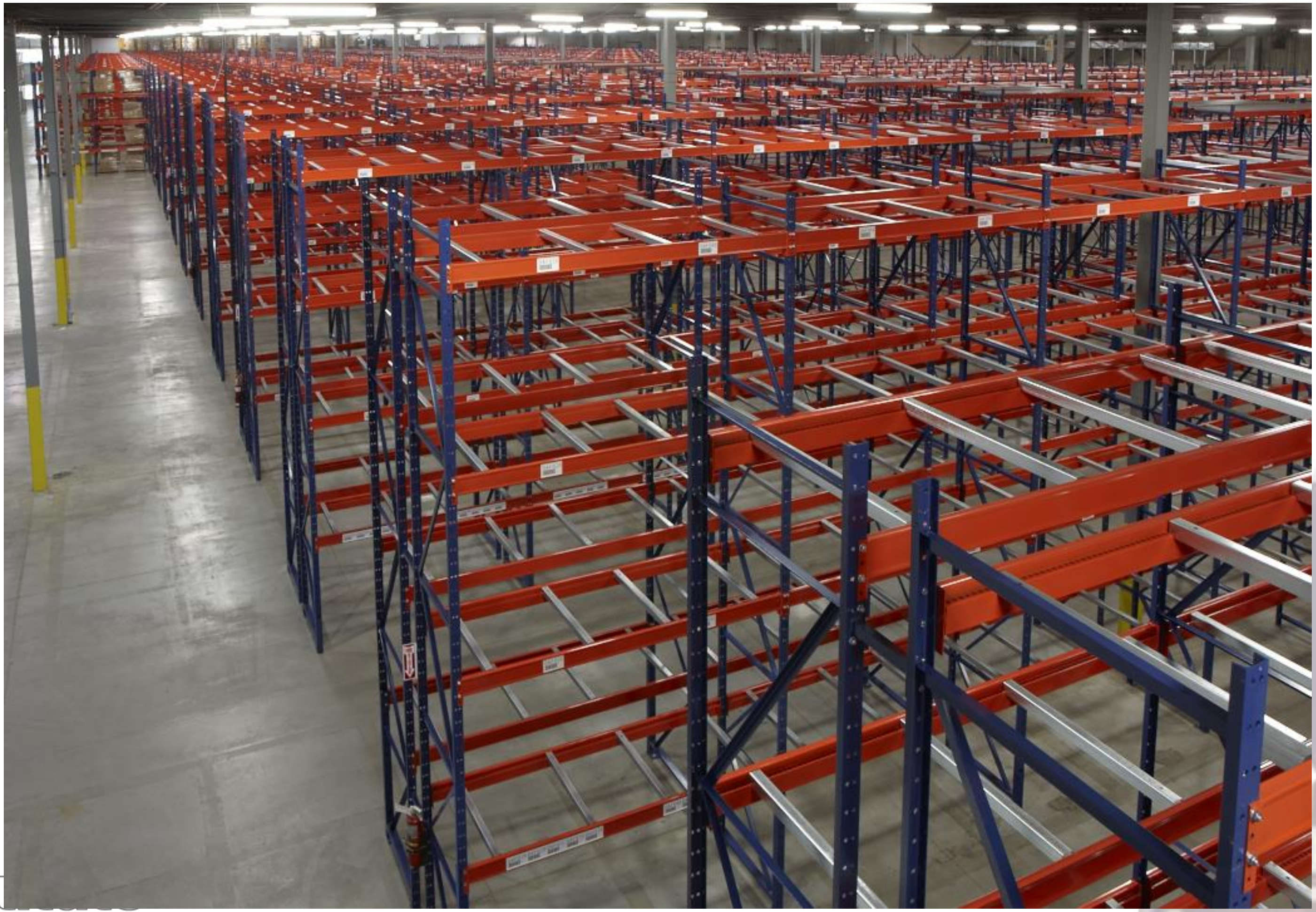


Research Goal

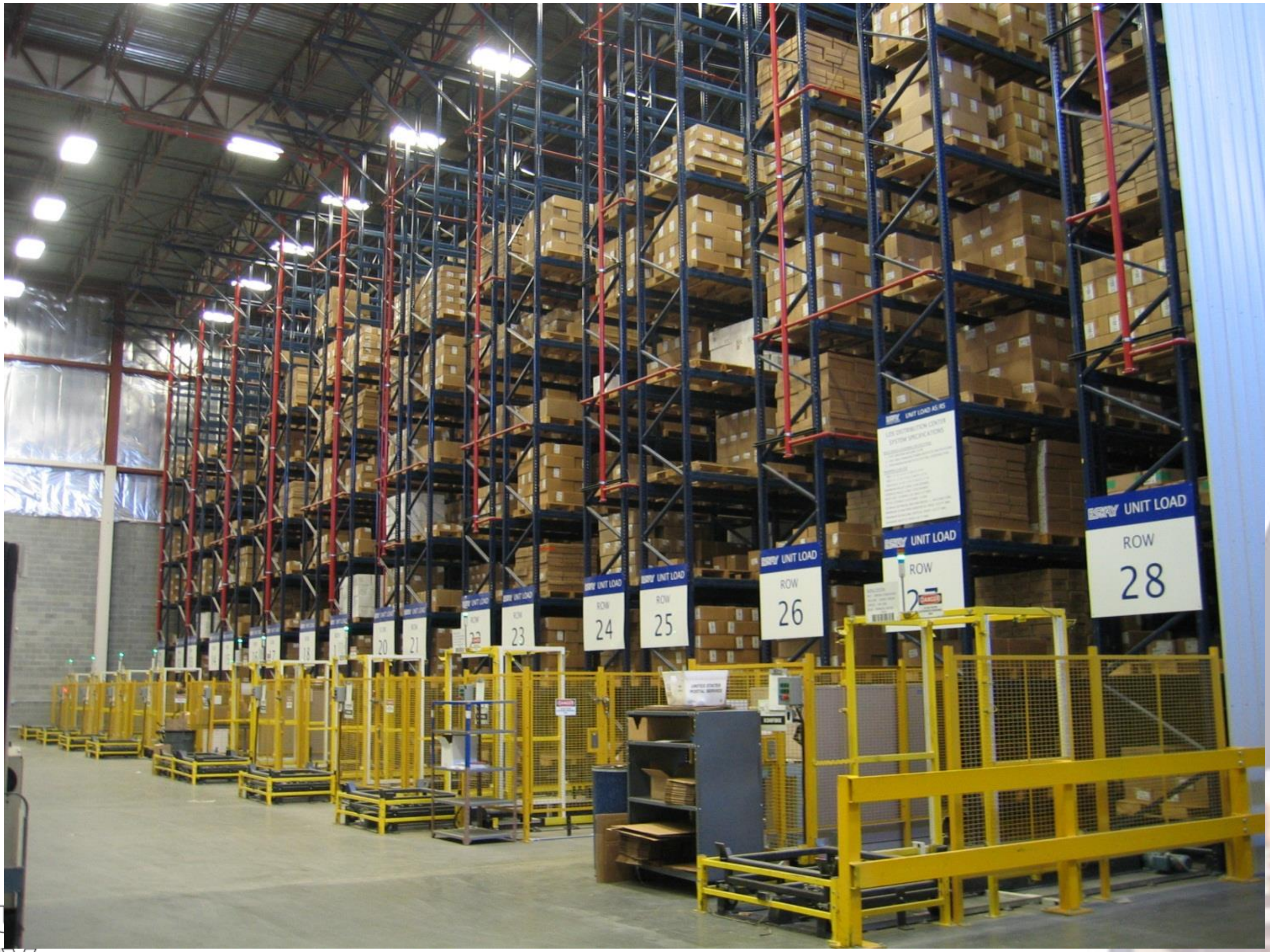
- **Design framework for storage systems**
  - ✓Unit loads
    - Single and dual command
  - ✓Direct access
    - Single-deep rack and single-load high floor stacks
  - ✓Comprehensive
    - Rich set of facility configurations and storage policies
  - ✓Robust: efficiency and risk (stochastic)
  - ✓Component of design methodology for warehousing systems

Sainsbury's Grocery Distribution Center

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

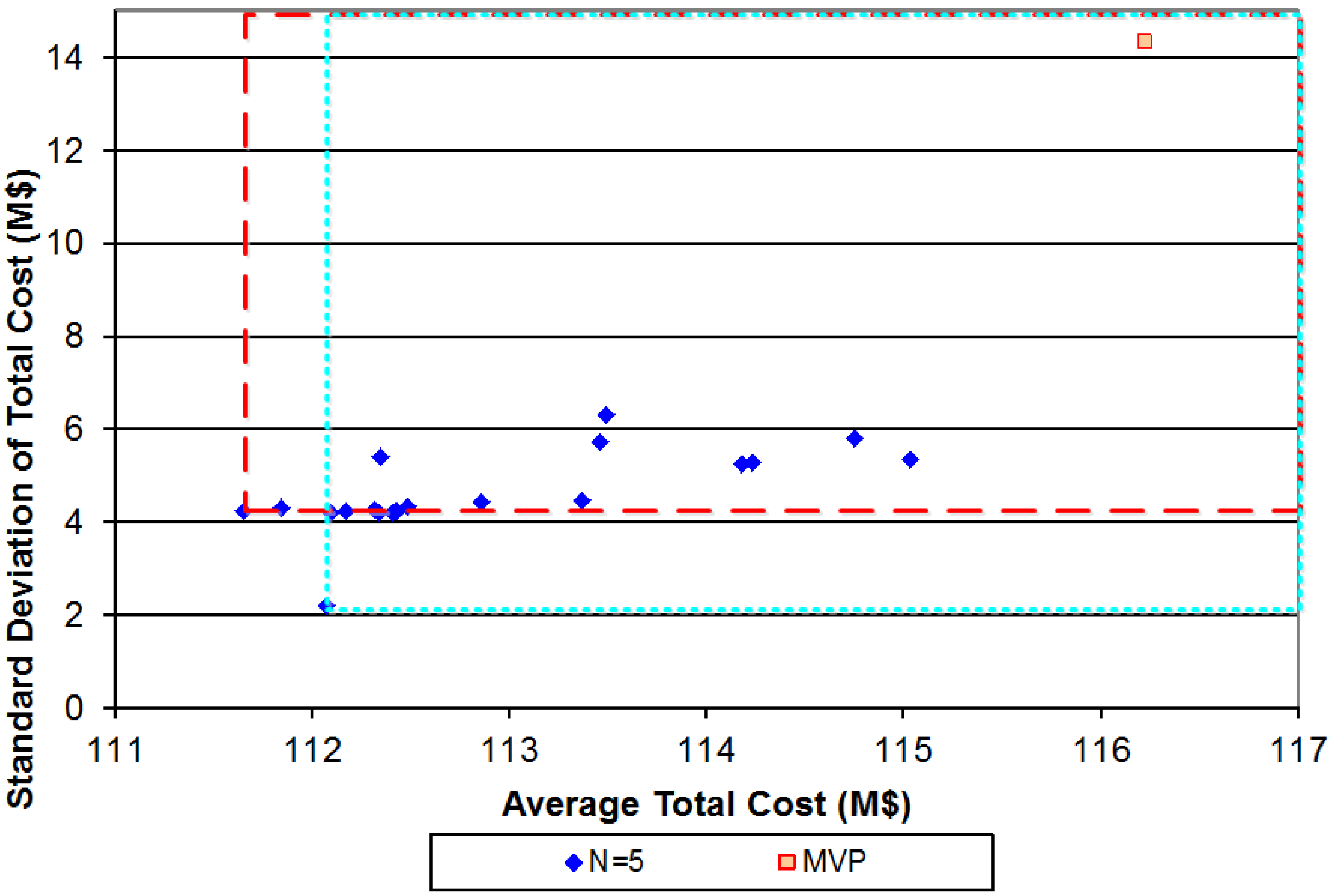
Main Design Observation

- **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



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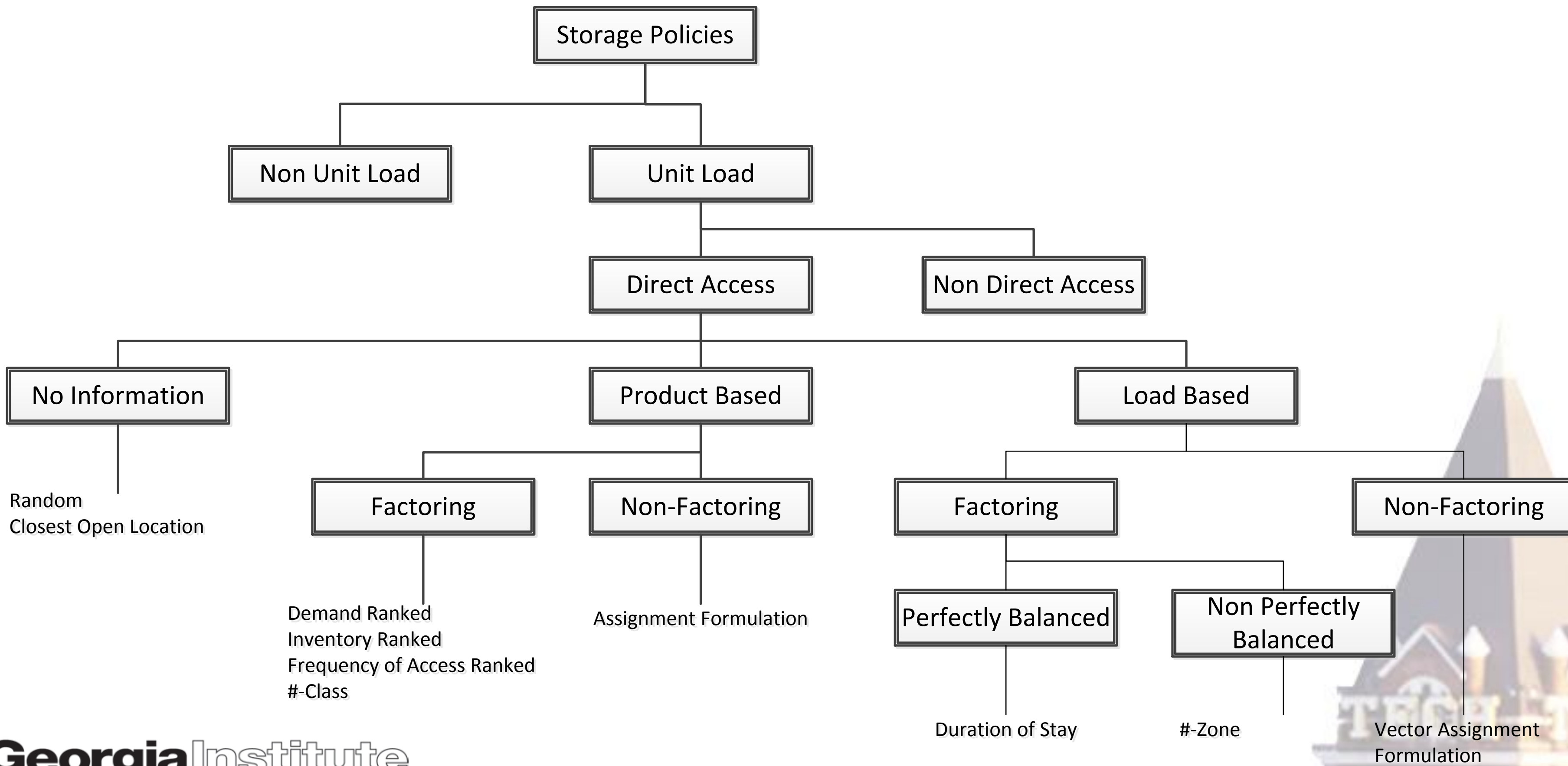
Prior Research on Storage Systems Design and Storage Policies

- **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 Policy Classification: Additional Considerations

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

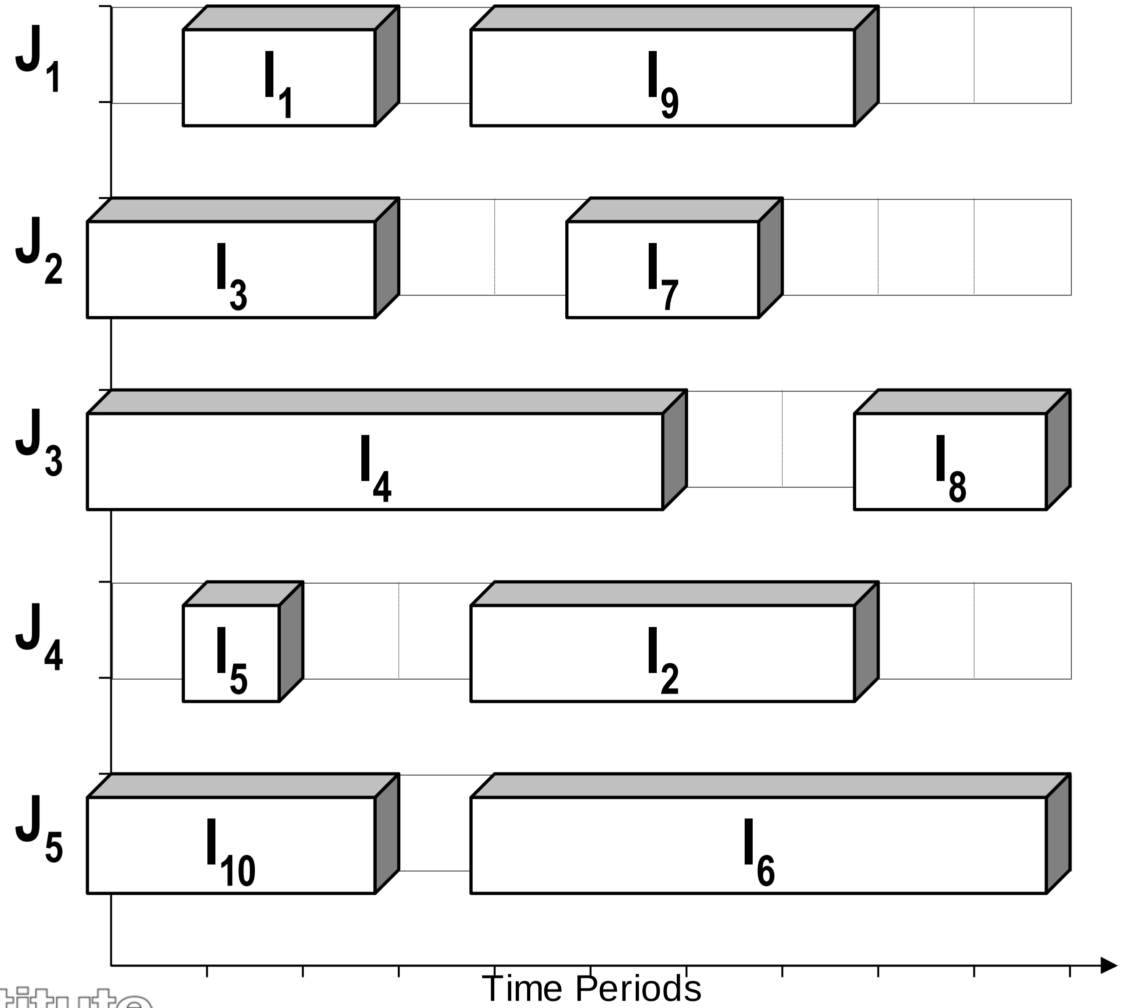
Decomposition Algorithm

- **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

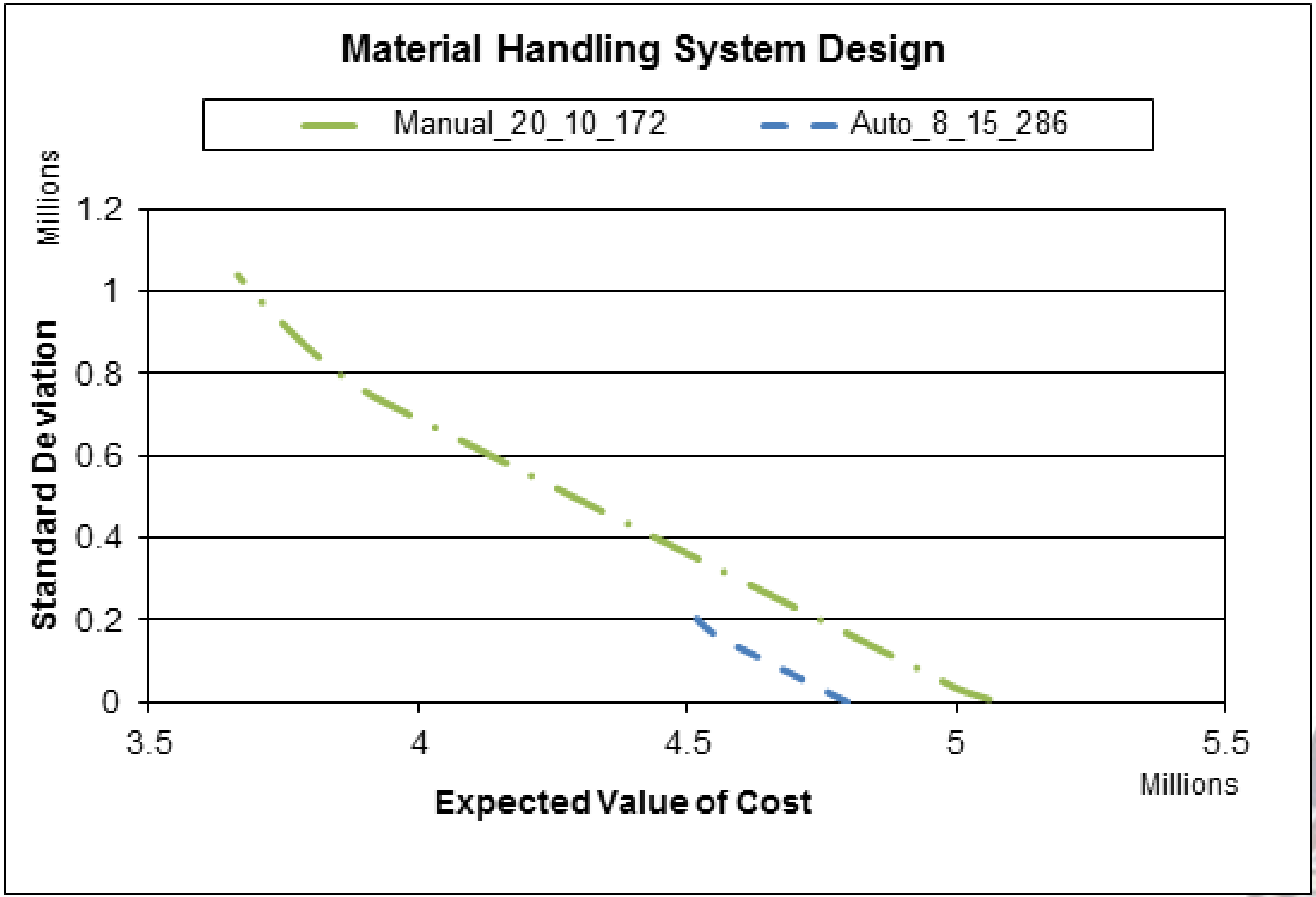
Technology Comparison Example

- **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

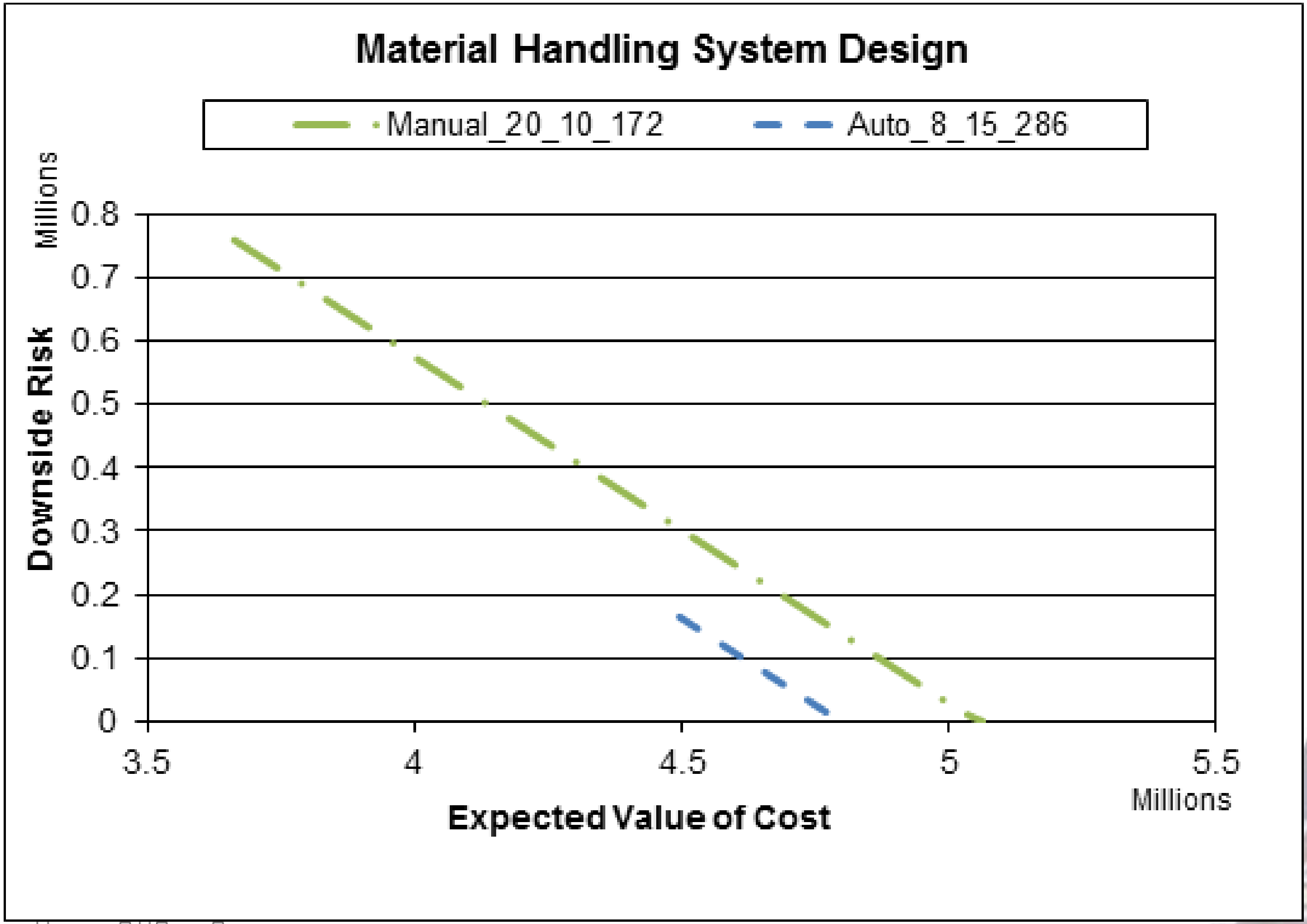
Technology Comparison Example

- **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)



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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

Unit Load Storage Policy Conclusions Continued

- **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?