Design and Operational Insights for Autonomous Vehicle-based Storage and Retrieval Systems

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Outline

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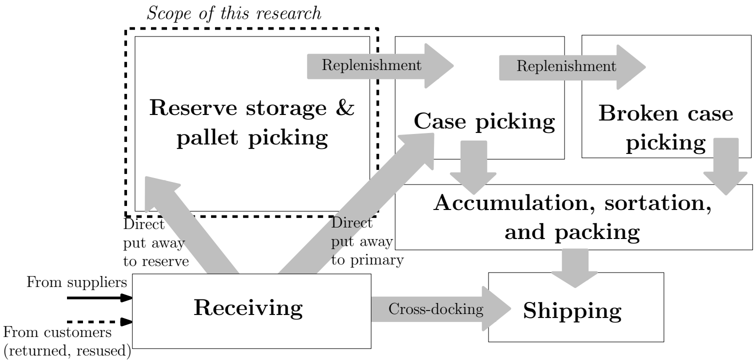
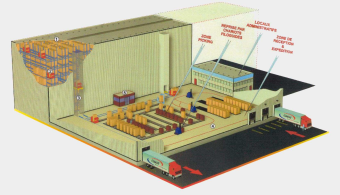
Typical Warehouse Functions and Flows

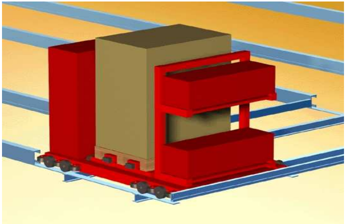


- Reserve picking area handles unit-load operations
- Operations require high flexibility and responsiveness

AVS/R System: Overview

- AVS/RS: Uses autonomous vehicles
- System configuration
  - Rectilinear movement
  - Horizontal movement (x and y axes) by autonomous vehicles
  - Vertical movement (z axis) by lifts
  - Vehicles move between tiers using lifts
- Modular and adaptive design





Comparison: AS/RS and AVS/RS

Category	AS/RS	AVS/RS
Physical Configuration	Conveyors and Aisle-captive cranes as S/R devices	Vehicles and Lifts as S/R devices
Load Movement	Simultaneous	Sequential
Load/Unload Point	One per aisle	One per zone
System Throughput	Determined by capacity of crane per aisle and number of aisles	Determined by number of vehicles and lifts

AVS/RS has potential to improve system efficiency, reliability, and throughput flexibility

Outline

Design Parameters in AVS/RS

System Sizing Decisions

- Number of vehicles and lifts, Depth/Width ratio
- Location of cross-aisle, number of zones

Operational Decisions

- Vehicle assignment rule, dwell point policy, command cycle
- Storage policy, transaction scheduling policy (FCFS, Random)

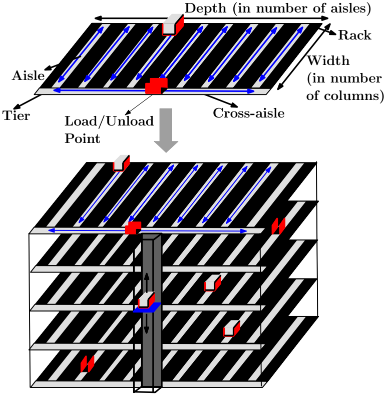
Need for Analytical Models

- Estimate transaction cycle time, queue lengths, throughput, vehicle utilization
- Quickly identify efficient operating range of design parameters

Research Questions

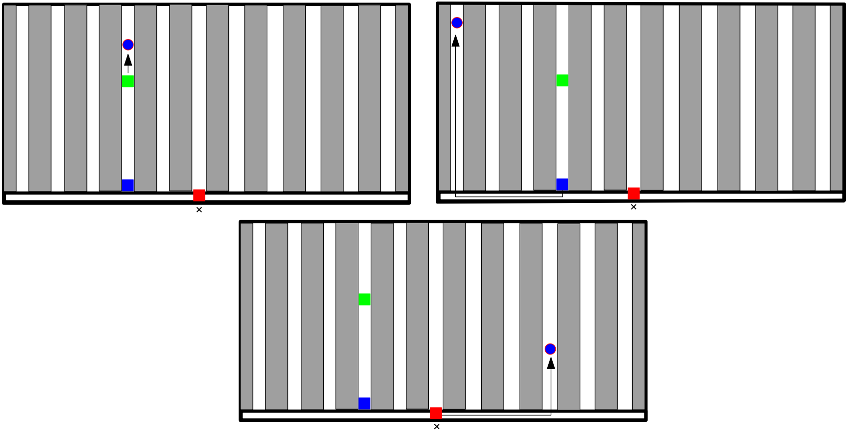
- **Influence of Depth/Width Ratio**
  - How does the Depth/Width ($\frac{D}{W}$) ratio (deep aisles and shallow cross-aisle or shallow aisles and deep cross-aisle or somewhere in between) affect the system performance?
- **Influence of dwell point policies**
  - How does the dwell point policy (Point of Service Completion (POSC), End of Aisle (EOA), and Load/Unload point (LU)) affect the system performance?
- **Influence of zones**
  - How does the number of zones affect the system performance?

Modeling Approach - Single Tier, a Building Block



- **What are the tradeoffs involved in single tier system with autonomous vehicles?**
- Efficient single tier systems form effective building blocks for multi-tier systems

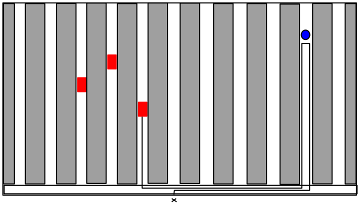
Effect of Dwell Point Policy: Retrieval



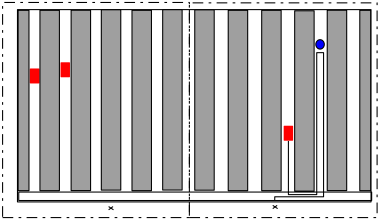
How does the dwell point policy influence storage and retrieval cycle times?

Effect of Number of Zones: Retrieval

Case 1 - One Zone **Case 2 - Two Zones**



vs.



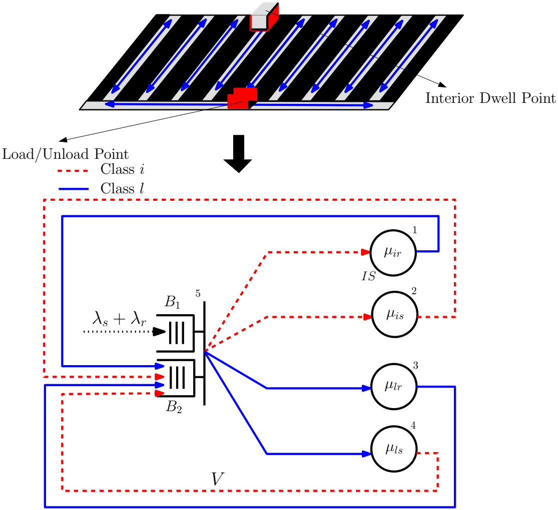
Tradeoffs between: reduced horizontal travel and loss of vehicle pooling

Outline

Assumptions

- System Design Assumptions
  - One Load/Unload point (relaxed later)
  - Single command cycle
  - Random vehicle assignment
  - POSC dwell point policy (relaxed later)
  - Random storage policy
  - FCFS transaction scheduling
- Model Assumptions
  - Poisson arrivals
  - No blocking during vehicle movement

Queuing Model to Analyze Design Trade-offs



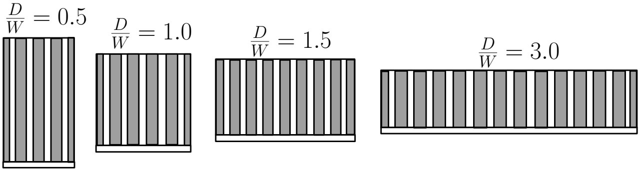
Model solved using a decomposition-based approach

Performance Measures

1. Vehicle utilization
2. Average number of transactions waiting for service
3. Expected storage cycle time and retrieval cycle time
4. Distribution of vehicles in the tier

Model Validation against Simulation

1. Depth/Width Ratio=0.5, 1, 1.5, 3



2. Number of storage locations = 2000, 4000, 7300
3. Number of vehicles = 1, 3, 5, 10
4. Transaction arrival rate (pallets/hr) = 20-430 in increments of 10 pallets/hr

- 240 cases analyzed using AutoMod© simulation package
- Maximum absolute percentage errors in vehicle utilization and cycle times are 2% and 10% respectively

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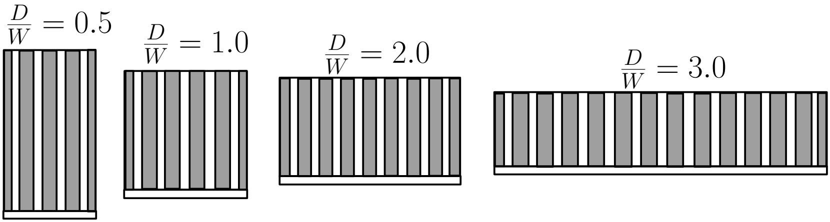
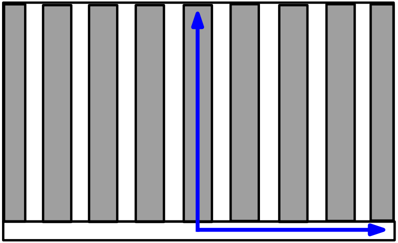
Effect of $\frac{D}{W}$ Ratio: Insight 1

What is the optimal Depth/Width Ratio=0.5, 1, 2 or 3?



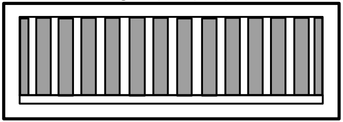
Effect of $\frac{D}{W}$ Ratio: Insight 1

Depth/Width Ratio= 2 is the best choice

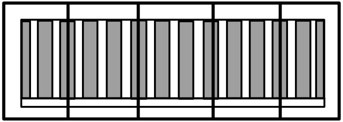


Effect of Number of Zones: Insight 2

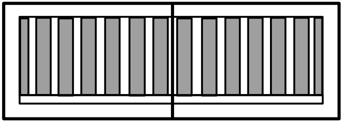
One zone



Five zones

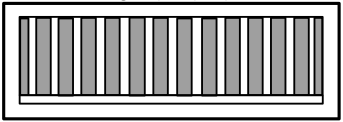


Two zones



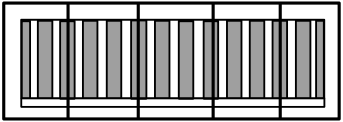
Effect of Number of Zones: Insight 2

One zone



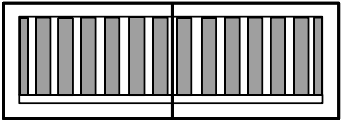
Increases vehicle travel times

Five zones



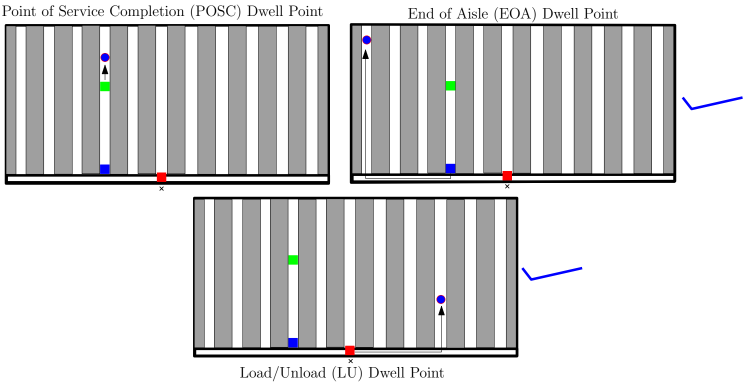
Increases transaction waiting times

Two zones



Typically 2-3 zones improves system performance

Effect of Dwell Point Policy: Insight 3



LU and EOA dwell point policies are better than POSC

Overall Impact of Design Parameters Setting

Example: 7300 Locations, 6 Vehicles, λ_s, λ_r=(75,75) pallets/hr

Comparison of Scenarios	$E[CT_s]$(sec)	$E[CT_r]$(sec)
One Zone, POSC Dwell, $\frac{D}{W} = 1.5$	147	187
Two Zones, LU Dwell, $\frac{D}{W}$ for each zone =2	97	128

$\sim$34% reduction in $E[CT_s]$ and $\sim$32% reduction in $E[CT_r]$ with Two Zones, LU Dwell, and $\frac{D}{W} = 2$ for each zone

Outline

Conclusions

- Developed analytical model of a single tier
- Model validates well against simulation
- Computationally inexpensive – quick results
- Provided design insights for a single tier
- The number of zones and the Depth/Width ratio have a significant impact on system performance.