WAREHOUSE ROBOTICS:
STATE OF THE ART AND RESEARCH OPPORTUNITIES

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2018 FRANQUI CHAIR, UNIVERSITY OF HASSELT

The business school that thinks and lives in the future

AUTOMATED STORAGE SYSTEMS

Classic automation

Robotic/autonomous systems

Crane/truck-based

Shuttle/lift based

Single/multi deep

• AS/RS

• AVS/RS

• Perfect pick

• Shuttle/transfer car

• Rackracer

• Flow rack

• (Mobile) Pick AGVs

Static rack

Moveable rack

• RMFS

Loads on shuttles

• PBS

Pick stations

• Manual picking

• Robot picking

R. de Koster (c), Warehouse Robotics, LSCM2018, 5 Oct 2018
FULLY ROBOTIC WAREHOUSES?

FULLY ROBOTIC WAREHOUSES EXIST

Inbound truck arrives → 1. Palletized goods arrival

Conveyor transport → 2. Storage in AS/RS system

Unit load retrieval → 3. Robot destack pallet

3. Robot destack pallet → 4. Store individual cases in AVS/R system

Ordered case retrieval → 5. Sequence cases in customers' layout sequence

5. Sequence cases in customers' layout sequence → 6. Build pallet/roll cage


Ship to store → Outbound truck arrives
THE LAST FRONTIER: ROBOTIZED ROLL CAGE STACKING

It is already there!

• Picking robots (still slow, expensive)
• Dispensing systems with roll cage stacking (becoming common in warehouses of retail chains)

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moveable rack
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  • Perfect pick
  • Autostore
  • Shuttle/transfer car

Loads on shuttles
  • PBS
  • Shuttle sorting

Picks stations
  • Manual picking
  • Robot picking

AGV based
  • PS AGVs
  • (Mobile) Pick AGVs
AUTOMATED STORAGE SYSTEMS

- Automated storage systems
  - Crane/truck-based
  - Shuttle/lift based
    - Single/double deep
    - Multi-deep:
      - AS/RS
      - Captive satellite
      - Roaming satellite
      - Conveyor
      - Rotating conveyor
      - Push-back rack
      - Flow rack
  - Single/multi deep
    - AVS/RS
    - Rackracer
    - Perfect pick
    - Autostore
    - Shuttle/transfer car
  - Loads on shuttles
    - PBS
    - Shuttle sorting
  - Pick stations
    - Manual picking
    - Robot picking
  - AGV based
    - PS AGVs
    - (Mobile) Pick AGVs
  - Moveable rack
    - RMFS
  - Static rack

R. de Koster (c), Warehouse Robotics, LSCM2018, 5 Oct 2018
AUTOMATED STORAGE SYSTEMS

**Crane/truck-based**

- Single/double deep
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**Static rack**

- Loads on shuttles
  - PBS
  - Shuttle sorting

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**Moveable rack**

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**AGV based**

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**Single/multi deep**

- Captive satellite
- Roaming satellite
- Conveyor
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Single/double deep
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Static rack

Load on shuttles
  • RMFS
  • (Mobile) Pick AGVs

AGV based
  • PS AGVs

NEW, ROBOTIZED STORAGE/PICKING SYSTEMS

A. Shuttle based (AVS/R) systems
   – Horizontal (Autostore)

B. Shuttle based, dynamic racks: Movable robots (RMFS: Kiva)

C. Loads on shuttles
   – Puzzle-based storage: PBS
   – Shuttle-based sorting

D. Pick stations

E. Picking with AGVs
   – PS AGVs
   – Mobile pick AGVs
FULLY ROBOTIC WAREHOUSES EXIST

A. AVS/R SYSTEMS
(AUTONOMOUS VEHICLE-BASED STORAGE AND RETRIEVAL)

Horizontal movement only:
- Savoye
- Symbolic
- Knapp
- Vanderlande (Adapto)
- Dematic
- SSI Schafer
- Etc.

Horizontal + vertical movement:
- Autostore (lifting capabilities)
- OPEX: Perfect Pick
- Exotec Skypods

Horizontal + diagonal movement:
- Fraunhofer IML (rack creeper)
A. AVS/R SYSTEMS

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- Savoye
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RESEARCH ON AUTOSTORE

Zou, De Koster, Xu, Transportation Science, 2018

Research questions
- Dedicated storage, or shared storage?
- Zoned storage or not?
- ...

R. de Koster (c), Warehouse Robotics, LSCM2018, 5 Oct 2018
Autostore—System cost optimization

Given: throughput, storage capacity, #products

\[N = 10,000\]
\[C_R = \€ 30,000 \text{ amortized in 7 years}\]
\[C_{FS} = \€ 40 \text{ amortized in 10 years}\]
\[C_S = \€ 500/m^2 \text{ amortized in 30 years}\]

4 pick stations
\[\lambda = 300 \text{ picks/hour, 10 sec/pick}\]

\[\min TC(H, r, R, P_A, P_B, P_C) = C_R \cdot R + C_{SP} \cdot L \cdot W + C_{FS} \cdot L \cdot W \cdot H\]

\[N_{st} \leq L \cdot W\]
\[THT_{DC}(L, W, H, R) \leq THT_{DC_{max}}\]
\[L \leq L \text{, } W \leq W \text{, } H \leq H\]

\[s.t.\]
\[D_i = s(i/N)^{(r-1)}, i = 1, 2, \cdots, N\]
\[r = \frac{H \cdot W}{L}\]
\[P_A + P_B + P_C = 1, 0 < P_A < 1, 0 < P_B < 1, 0 < P_C < 1\]
\[N, \lambda, t_{move}, K, r \text{ are given}\]
Autostore—System cost optimization

\[ N = 10,000 \]
\[ C_R = € 30,000 \text{ amortized in 7 years} \]
\[ C_{SP} = € 40 \text{ amortized in 10 years} \]
\[ C_{FS} = € 500/m^2 \text{ amortized in 30 years} \]

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\[
\begin{align*}
\min \, TC & (H, r, R, P_A, P_B) = C_R \cdot R + C_{SP} \cdot L \cdot W + C_{FS} \cdot L \cdot W \cdot H \\
N_{st} & \leq L \cdot W \\
THT_Dc (L, W, H, R) & \leq THT_{DC, \text{max}} \\
L & \leq L, W \leq W, H \leq H \\
D_i & = s(i/N)^{(s-1)}, i = 1, 2, \ldots, N \\
r & = \frac{W}{r} \\
P_A + P_B + P_C & = 1, 0 < P_A < 1, 0 < P_B < 1, 0 < P_C < 1 \\
N, \lambda, \tau_{wo}, \lambda, r & \text{ are given}
\end{align*}
\]

B. ROBOTIC MOBILE FULFILMENT SYSTEMS
MOVABLE ROBOTS (AGV)

AGVs transporting racks
- Kiva (Amazon Robotics)
- Grey Orange
- Swisslog/Grenzebach
- Scallog
- Suning
- Etc.
RECENT RESEARCH ON RMF SYSTEMS

- Lamballais et al. (EJOR, 2017)
  Objective: minimizing order throughput time.
- Zou et al. (EJOR, 2017)
  Objective: impact of battery charging policies
- Boysen et al. (EJOR, 2017)
  Objective: determine slotting strategy for pods

...
LOADS ON SHUTTLES - SORTING

GridStore/GridSort – Gue/Furmans

R. de Koster (c), Warehouse Robotics, LSCM2018, 5 Oct 2018

PUZZLE-BASED STORAGE/SORTING

Little literature yet

- Gue, Kim, *NRL*, 2007: optimal movement patterns
D. ADVANCED PICK STATIONS

1. Palletized goods arrival
2. Storage in AS/RS system
3. Robots destack pallet
4. Store individual cases in AVS/RS system
5. Sequence cases in customers' layout sequence
6. Build pallet/roll cage
7. Buffer pallets/roll cages in OCB

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E. PICKING WITH AGVS
MANUAL WORKING WITH THE ROBOT/AGV

Fetch Robotics

MODELING PS-AGVS
ROBOTIZED: FULLY AUTOMATED PICKING?

TORU - Magazino

RESEARCH OPPORTUNITIES
RESEARCH OPPORTUNITIES

Most systems shown have hardly been researched
Only (to some extent): RMF, AVS/R systems

Opportunities:
• Manual order picking with AGVs
  – Routing, control, assignment
• Integrated systems: AVS/R system with order picking
• Interaction man – robot: Operator 4.0

Research questions:
• How do they compare to other (manual) systems?
• How to divide work in robot and human tasks?
• How do humans perform with such systems?
• How to select systems?
• How to design: layout, #workstations, #robots?
• How to control for performance (throughput, flow times, response)?
• How to flexibly handle peaks?
• How to integrate them in supply chain concepts?
ROBOTIZED WAREHOUSES

It is not yet so far

We still have a long way to go

But we are on the way

Great opportunities for Research!

Interested in Review Paper?  
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