ROTTERDAM SCHOOL OF MANAGEMENT
ERASMUS UNIVERSITY

LSCM2018, LOGISTICS SUMMIT, 5 OCTOBER 2018, HONG KONG

WAREHOUSE ROBOTICS:

STATE OF THE ART AND RESEARCH OPPORTUNITIES

RENE DE KOSTER
ERASMUS UNIVERSITY ROTTERDAM

2018 FRANCQUI CHAIR, UNIVERSITY OF HASSELT

The business school that thinks
and lives in the future

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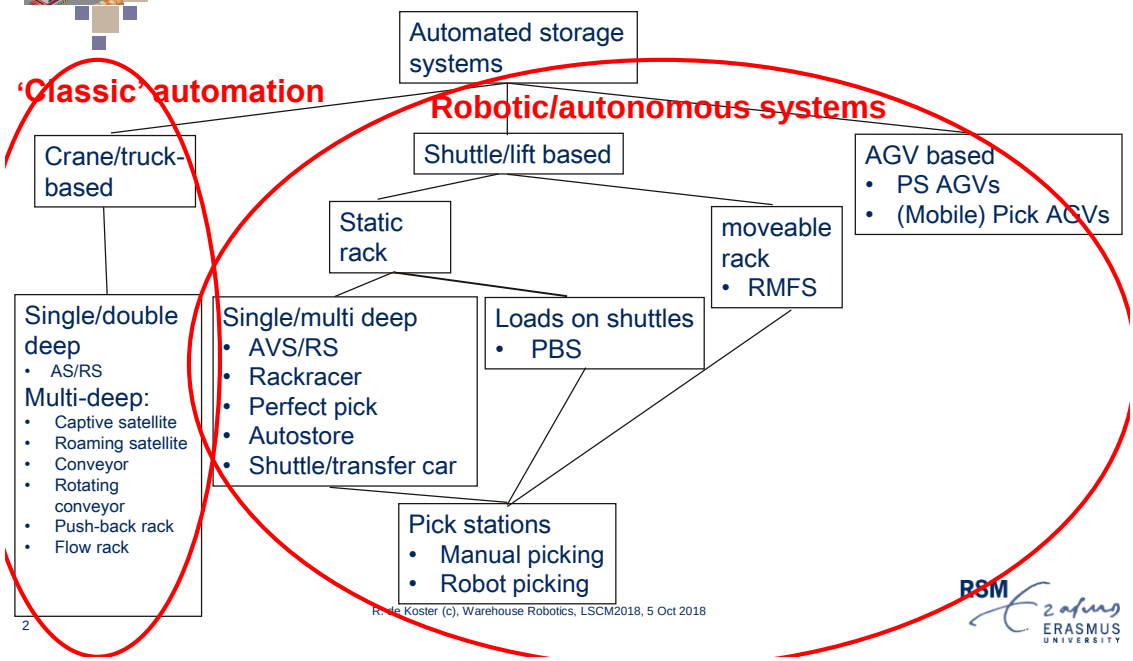
AUTOMATED STORAGE SYSTEMS



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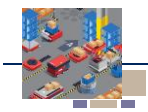
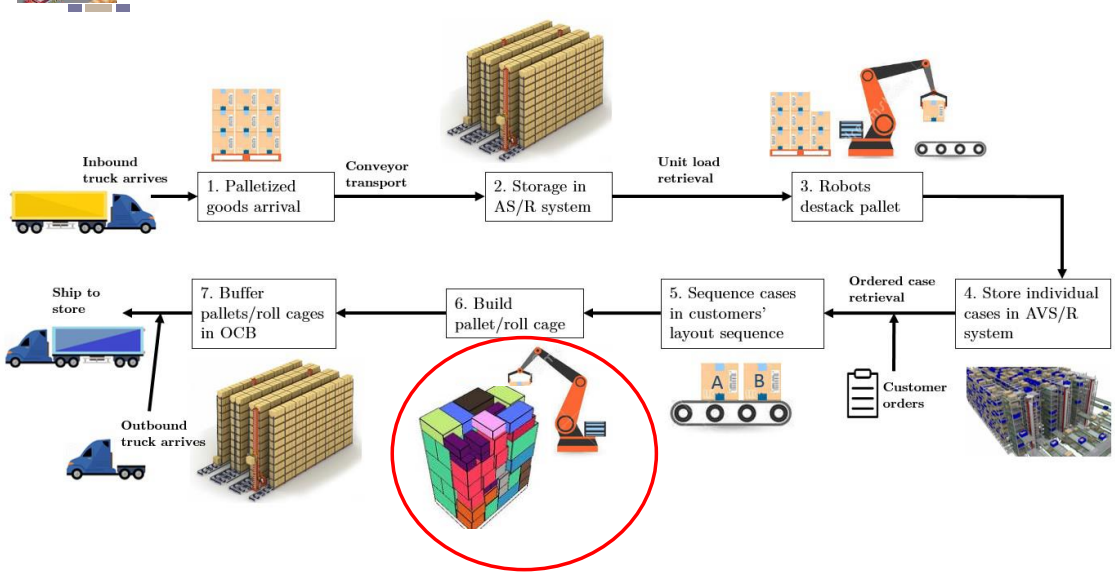
FULLY ROBOTIC WAREHOUSES?



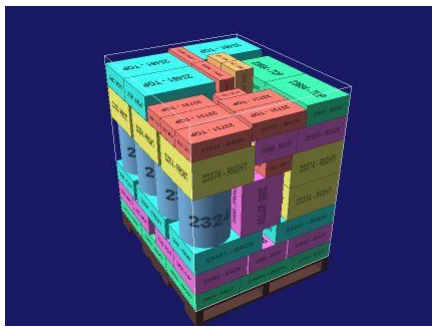
FULLY ROBOTIC WAREHOUSES EXIST

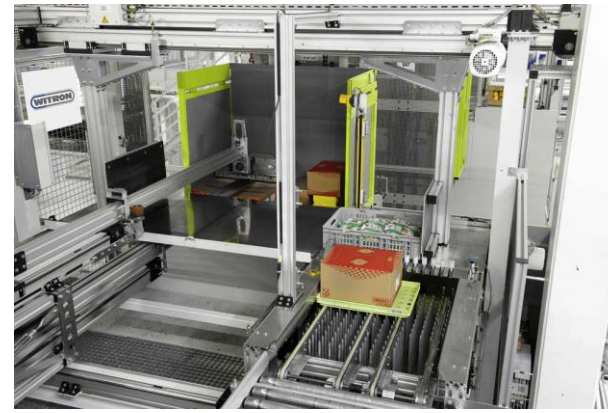


THE LAST FRONTIER: ROBOTIZED ROLL CAGE STACKING

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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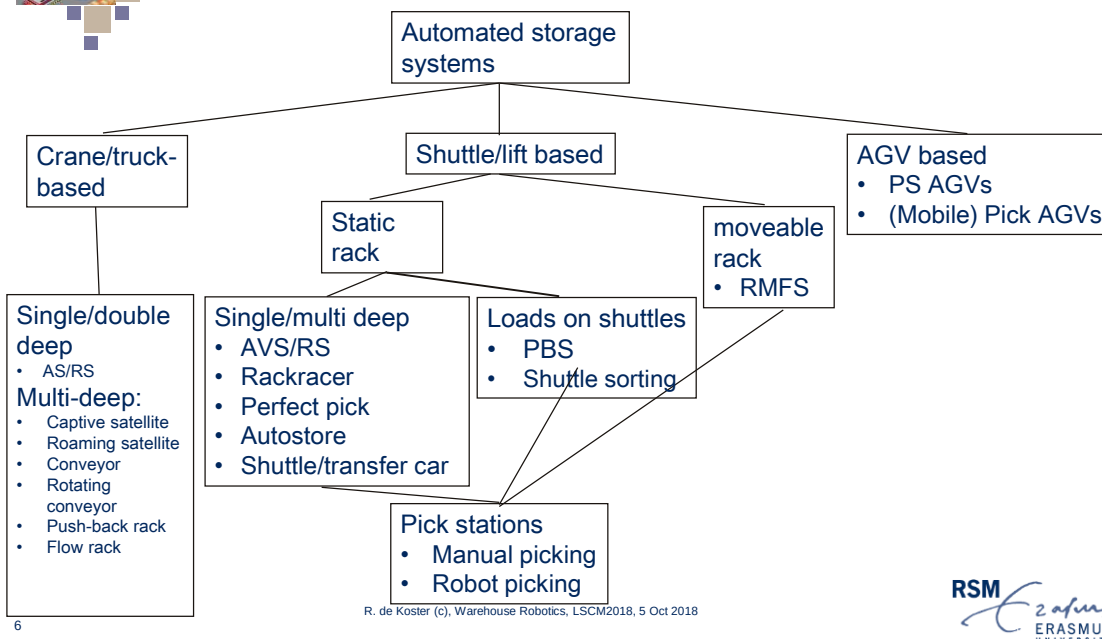

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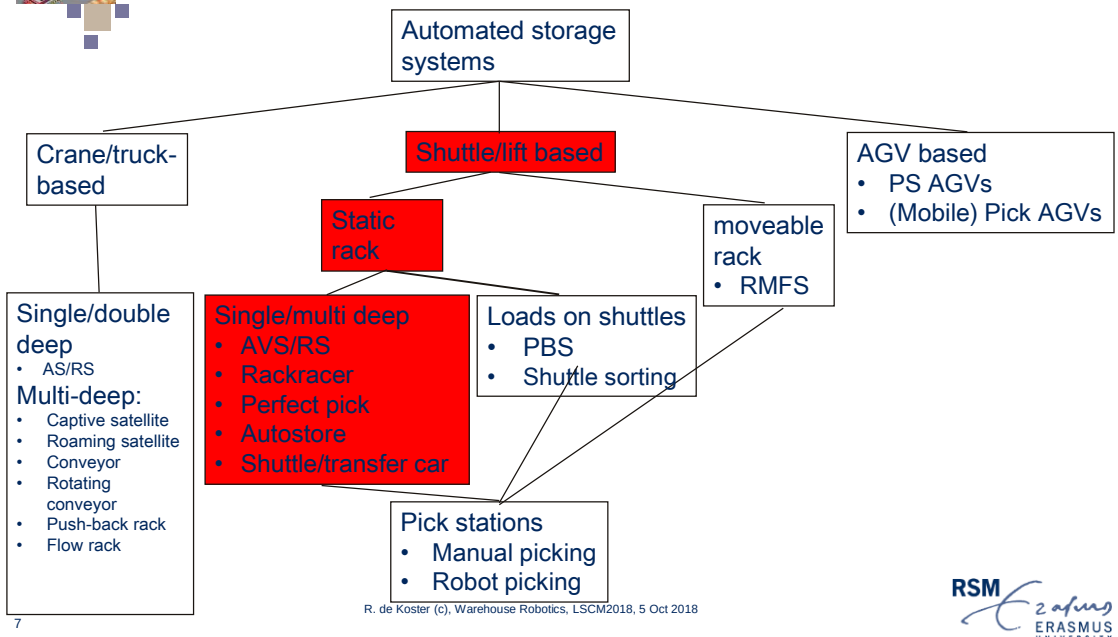

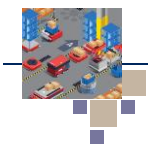

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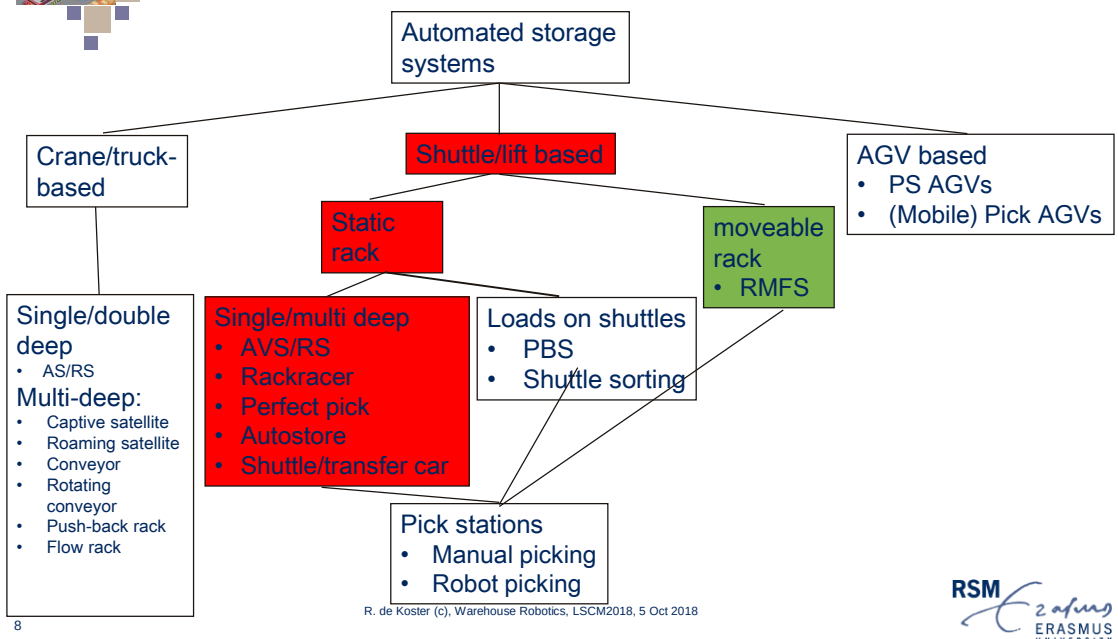

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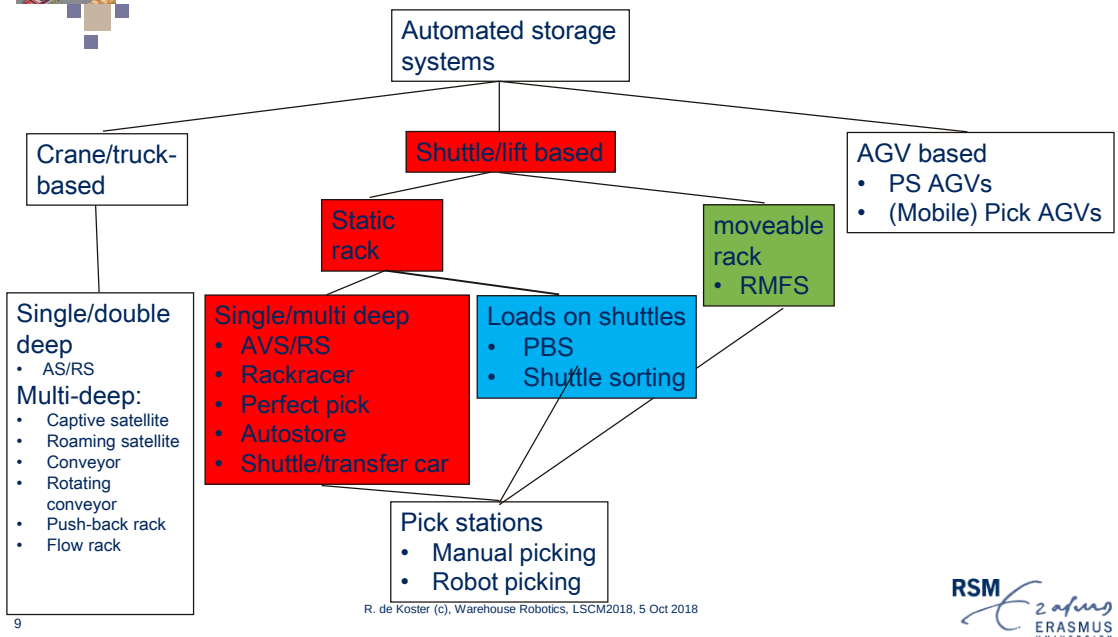

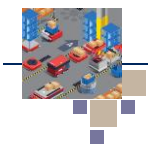

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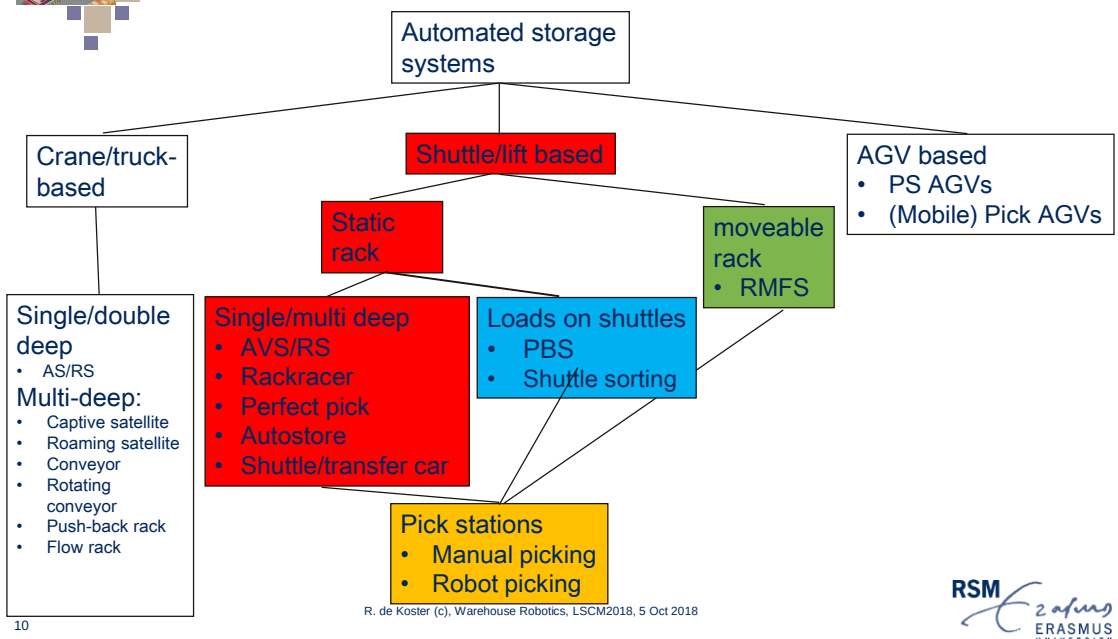

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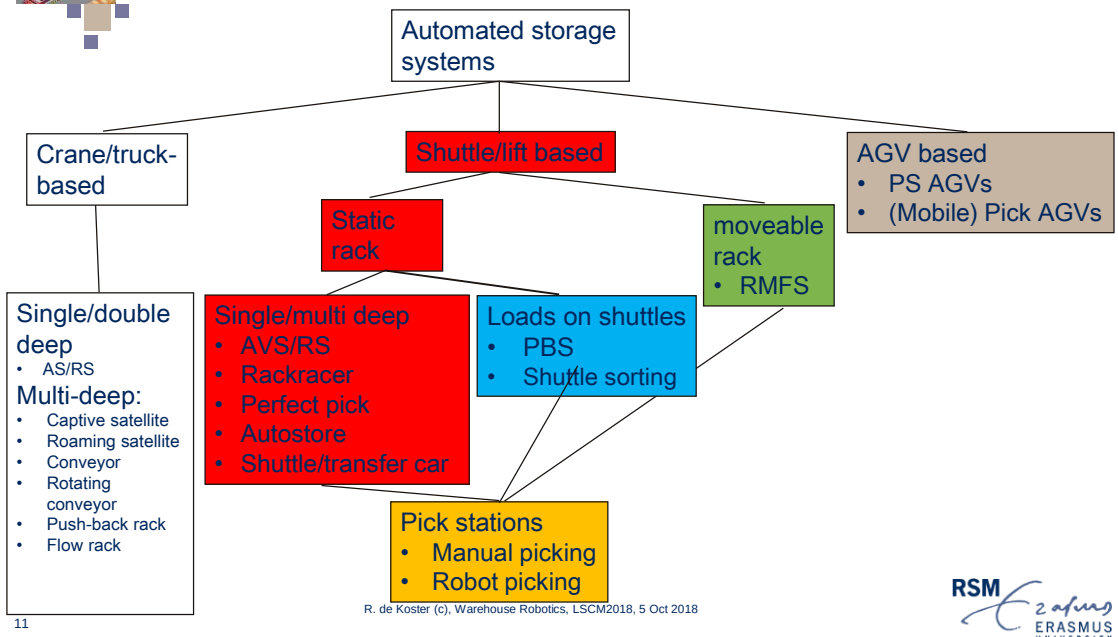

R. de Koster (c), Warehouse Robotics, LSCM2018, 5 Oct 2018

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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

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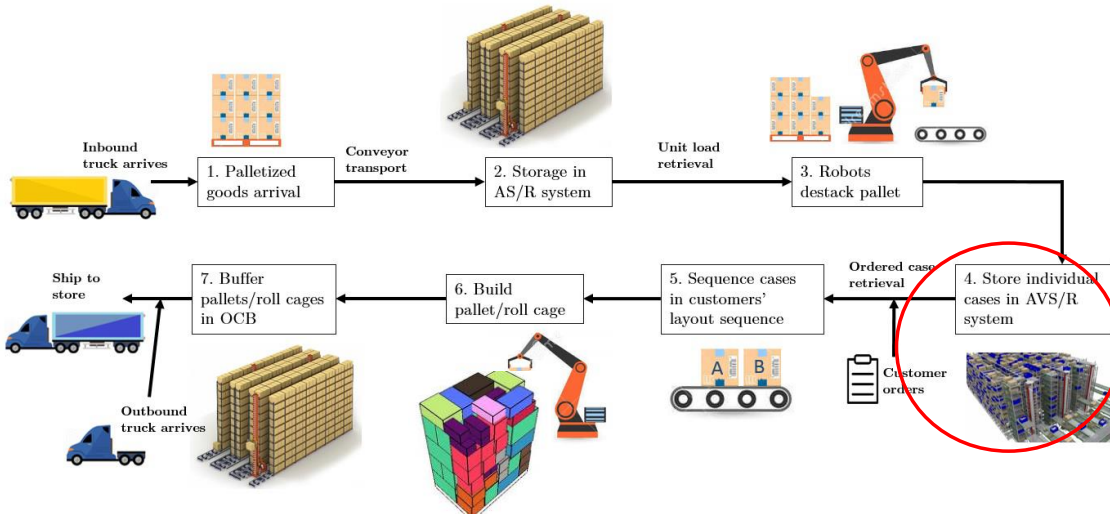
FULLY ROBOTIC WAREHOUSES EXIST



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

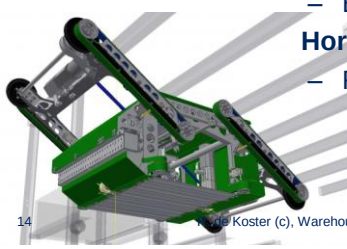
A.

-Malmborg, 2002
-Fukanari, Malmborg, 2008
-Roy et al., 2012, 2014, 2015
-Marchet et al., 2012
-…….

Horizontal movement only:
- Savoye
- Symbotic
- 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)



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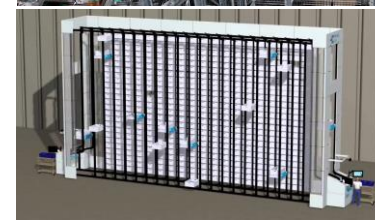
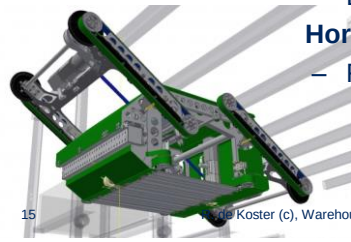
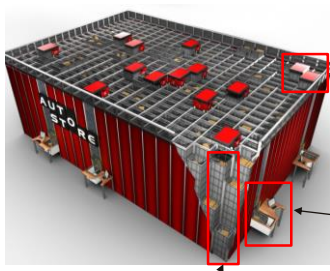


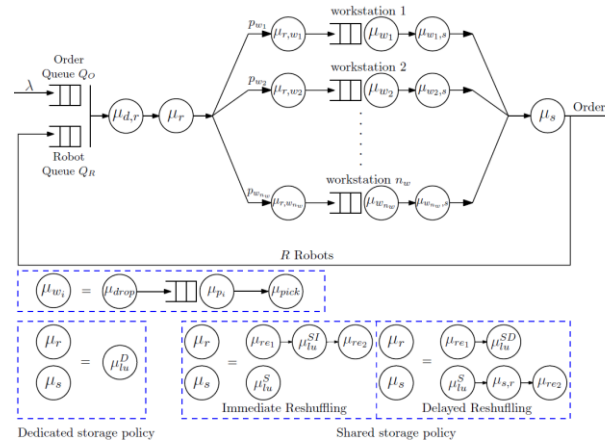


RESEARCH ON AUTOSTORE

Zou, De Koster, Xu, Transportation Science, 2018

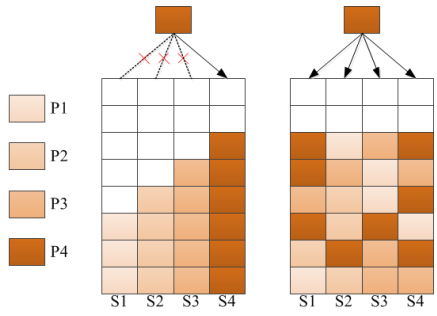
Research questions
- Dedicated storage, or shared storage?
- Zoned storage or not?
- …

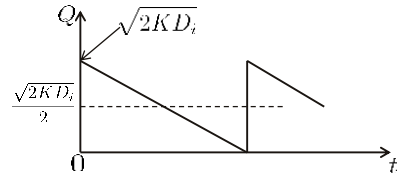




Semi-Open Queueing Network model
Aggregation + CTMC analysis

Autostore: Dedicated or Shared storage?





Yu et al. (POM, 2015)

$a_i(N_i) = 0.5(1 + N_i^{-\varepsilon})\sqrt{2KD_i} + SS_i,$

$\varepsilon = 0.23$

Dedicated $N_i = 1$ Shared $N_i = 4$

$$a_i^D > a_i^S \longrightarrow THT_D \; ? \; THT_S$$

Autostore—System cost optimization
Given: throughput, storage capacity, #products

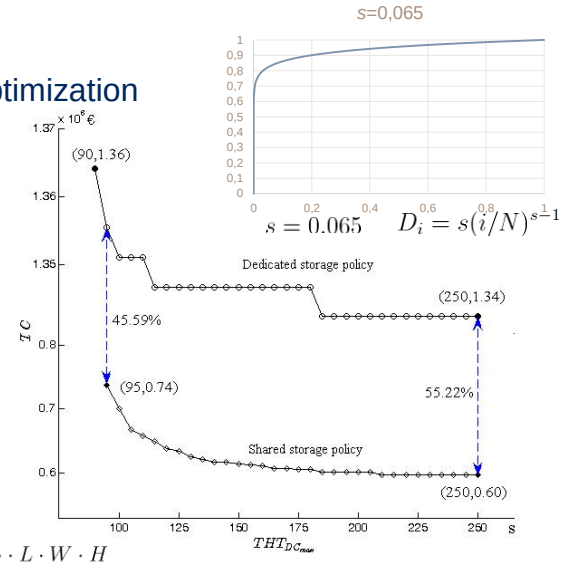
$N = 10{,}000$
$C_R =$ € 30,000 amortized in 7 years
$C_{FS} =$ € 40 amortized in 10 years
$C_S =$ € 500/m² amortized in 30 years
4 pick stations
λ = 300 picks/hour, 10 sec/pick

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

$$s.t. \begin{cases} N_{st} \le L \cdot W \\ THT_{DC}(L, W, H, R) \le THT_{DC_{max}} \\ L \le \hat{L}, W \le \hat{W}, H \le \hat{H} \\ D_i = s(i/N)^{(s-1)}, i = 1, 2, \cdots, N \\ r = \frac{W}{L} \\ P_A + P_B + P_C = 1, 0 < P_A < 1, 0 < P_B < 1, 0 < P_C < 1 \\ N, \lambda, n_w, K, \tau \text{ are given} \end{cases} \quad (M.2)$$

Autostore—System cost optimization

$N = 10{,}000$
$C_R = €\ 30{,}000$ amortized in 7 years
$C_{SP} = €\ 40$ amortized in 10 years
$C_{FS} = €\ 500/m^2$ amortized in 30 years
4 pick stations
λ = 300 picks/hour, 10 sec/pick



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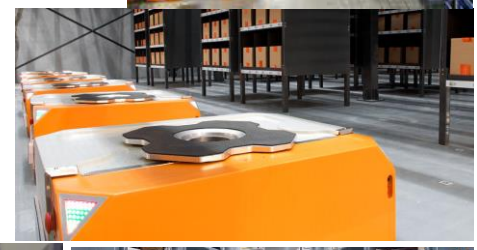
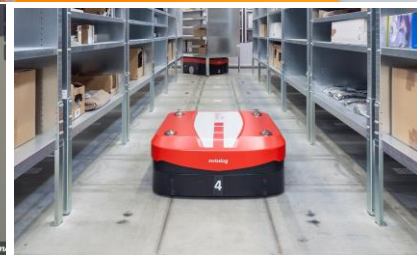
B. ROBOTIC MOBILE FULFILMENT SYSTEMS MOVABLE ROBOTS (AGV)

B.

AGVs transporting racks

- Kiva (Amazon Robotics)
- Grey Orange
- Swisslog/Grenzebach
- Scallog
- Suning
- Etc.

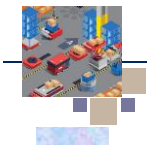




RECENT RESEARCH ON RMF SYSTEMS

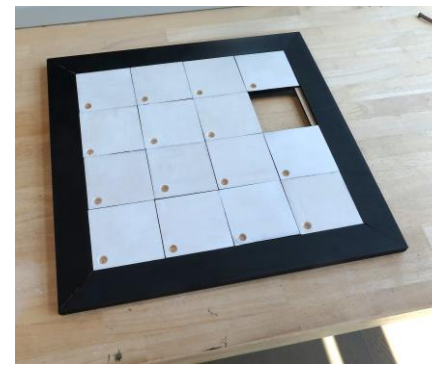
- Lamballais et al. (EJOR, 2017)
  Objective: minimizing order throughput time.
- Zou et al. (EJOR, 2017)
  Objective: impact of battery charging policies
- Boysen et al.(EJOR, 2017)
  Objective: determine slotting strategy for pods

- …



C. LOADS ON SHUTTLES: PUZZLE-BASED STORAGE

C.



LOADS ON SHUTTLES - SORTING

0			127			124			130			124			5
121	7	8	130	10	118	12	13	14	124	16	17	127	130	20	127
127	23	24	127	26	27	118	29	30	31	118	118	124	35	118	37
121	39	118	41	42	130	124	45	46	133	48	127	50	121	52	130
130	133	133	57	118	59	60	61	62	63	64	65	121	67	68	69
121	71	133	124	74	133	76	127	78	79	80	124	82	133	130	85
86	87	88	89	121	91	121	93	127	95	96	97	130	99	100	101
130	103	104	121	106	107	124	121	110	127	112	133	114	115	116	133
118	119	118	121	122	123	124	124	126	127	121	129	130	131	132	133

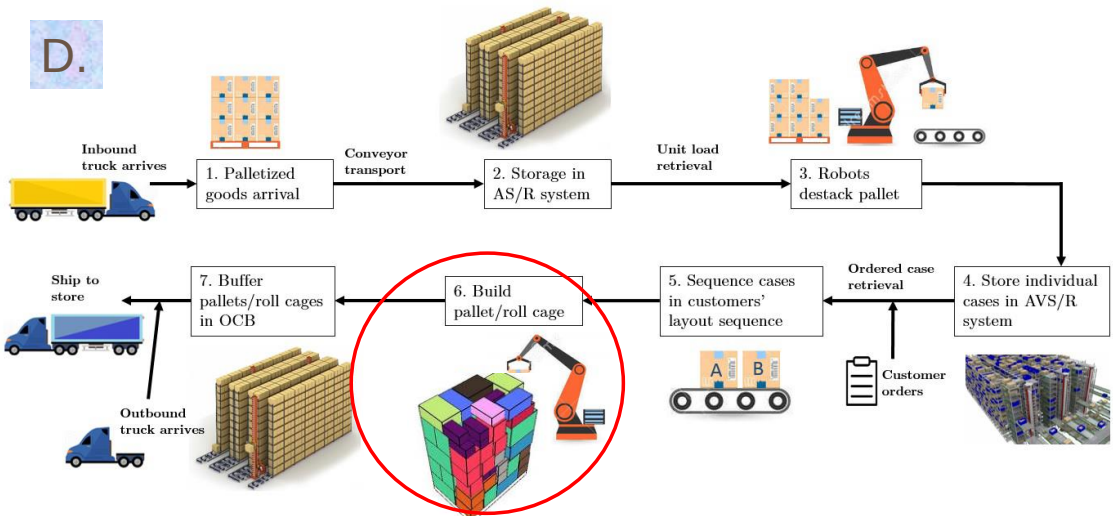
GridStore/GridSort – Gue/Furmans

PUZZLE-BASED STORAGE/SORTING

Little literature yet

- Gue, Kim, *NRL*, 2007: optimal movement patterns
- Gue, Furmans, Seibold, Uludag, *IEEE T on Automation Science*, 2014: deadlock free gridlock control algorithm
- Zaerpour, Yu, De Koster, *Transportation Science*, 2017: optimal design

D. ADVANCED PICK STATIONS



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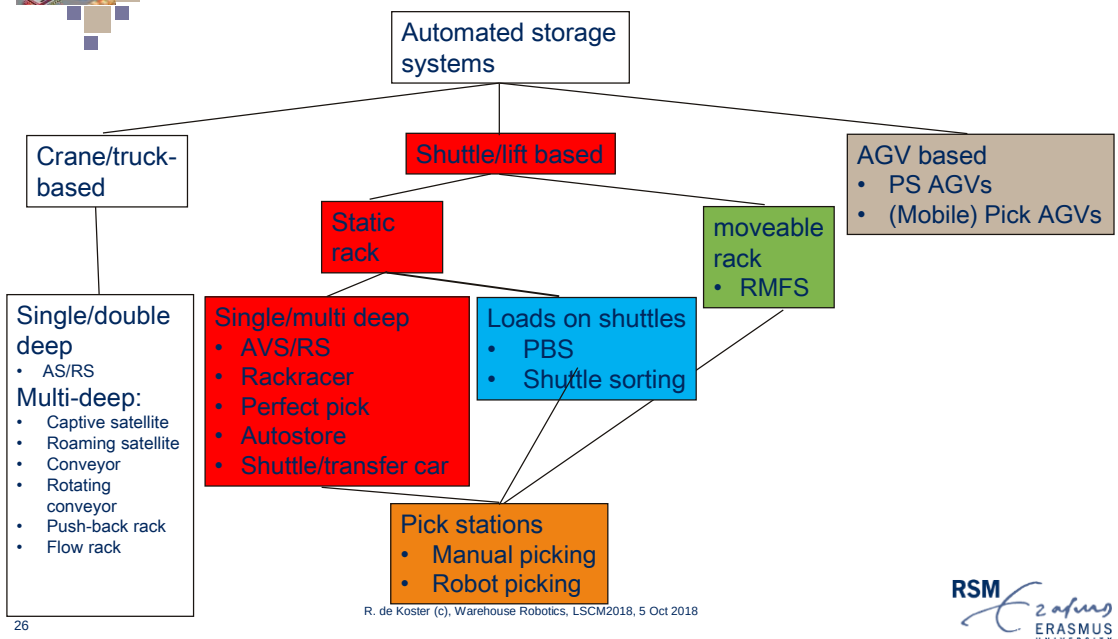
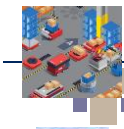
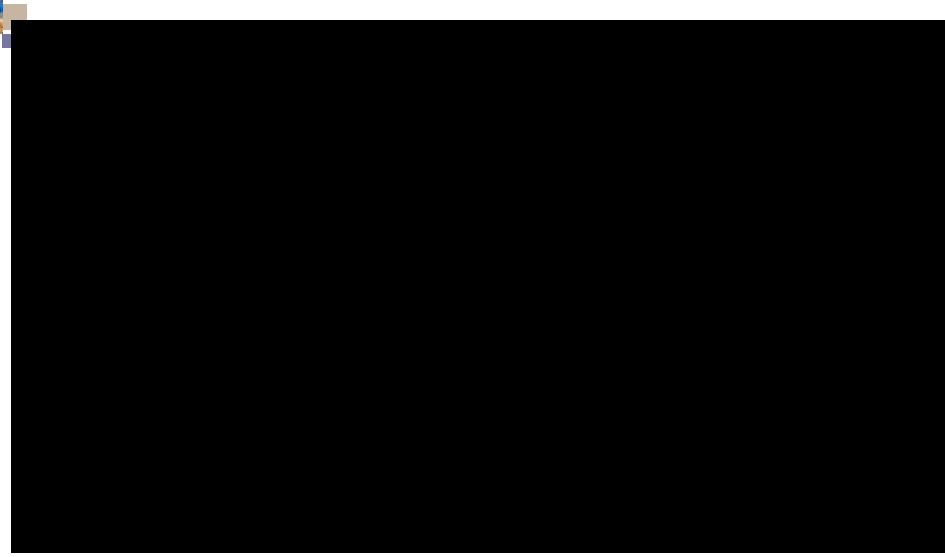




E. PICKING WITH AGVS
MANUAL WORKING WITH THE ROBOT/AGV

E.



Fetch Robotics

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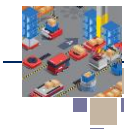

MODELING PS-AGVS

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ROBOTIZED: FULLY AUTOMATED PICKING?

TORU - Magazino

RESEARCH OPPORTUNITIES

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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

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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!

LOGISTIC INFRASTRUCTURE

Automated and Robotic Warehouses: Developments and Research Opportunities

René B.M. de Koster[1]
Erasmus University Rotterdam

1. SYSTEMS FOR UNIT LOADS

1.1. Automated unit load warehouses with aisle-captive cranes.1

Interested in Review Paper?
Mail René de Koster: rkoster@rsm.nl