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Warehouse robotization with Wheel.me genius: A puzzle-based movable racks system

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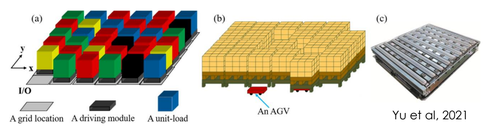
Motivation

- There is a need for **compact and responsive storage systems** (online retailing, e-commerce, micro-fulfillment centers, etc)
- Storing goods and operating a warehouse require **space and labor**
- **Automation** and **robotization** can play an important role
- Some solutions have been recently introduced, like **Robotic Mobile Fulfillment (RMF) systems** and **Puzzle-Based Storage (PBS) systems**, among the others.
- **PBSs are still not widely adopted mainly for technical reasons.** They need conveyors, driving modules or AGVs to move objects in a grid system.

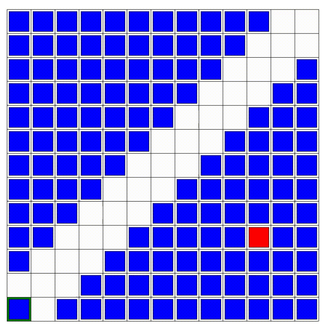


Yu et al, 2021

Sgarbossa et al, 2021

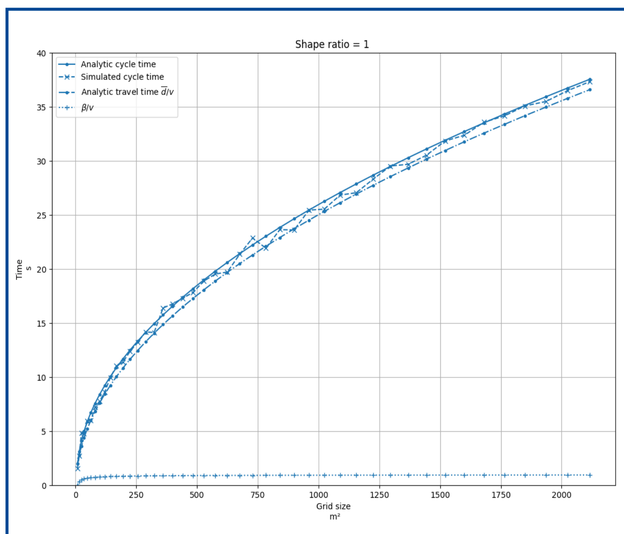
Puzzle-based movable rack system

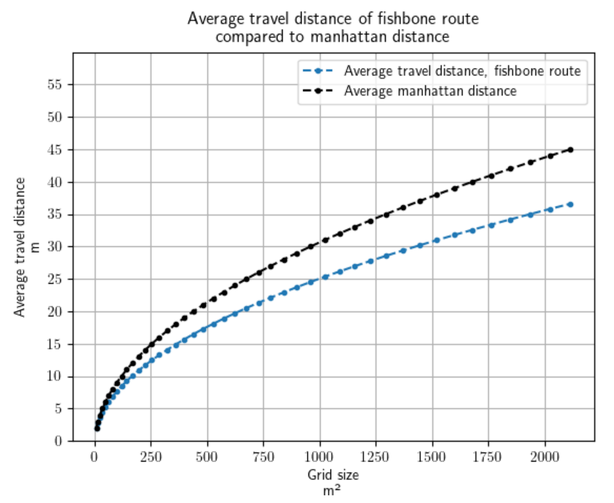
- Literature categorizes **RMF systems** and **PBS systems** in **two separate branches of automated picking systems**.
- They are **moveable rack systems** and **grid-based dynamic storage systems**, respectively.
- **RMF systems** have been **less** concerned with achieving very **high densities**, but in return, achieve **very high picking** rates and **throughput capacity**.
- Research about **PBS systems** has been aimed at reducing retrieval times while maintaining **storage density** towards the absolute upper limits.
- **No large-scale PBS system with moveable storage racks has been investigated**.

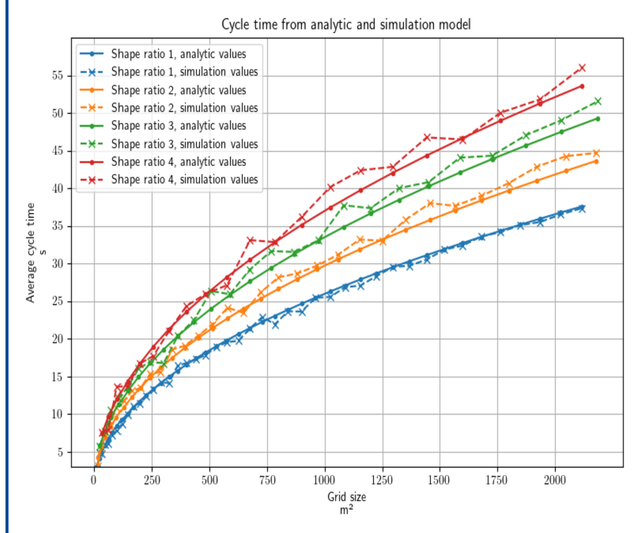


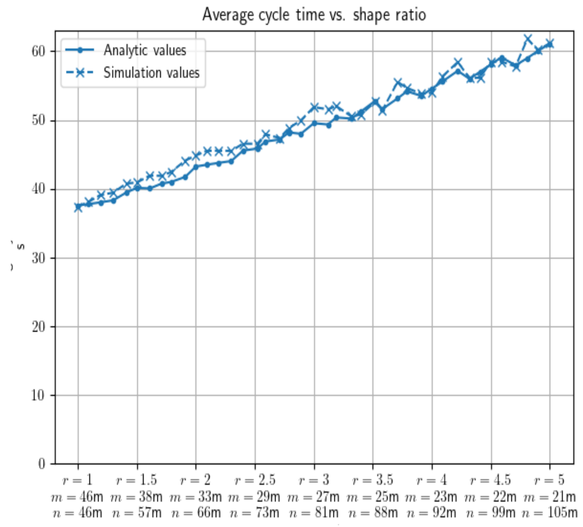
- In this research, **we will link these two branches of automated picking systems to improve the trade-off between storage density and throughput capacity**, **mounting autonomous wheels to storage racks.**
- We will assume that **racks can move autonomously and independently**, thus assuming a puzzle-based moveable rack system.
- Moreover, we include also the possibility to move **DIAGONALLY**

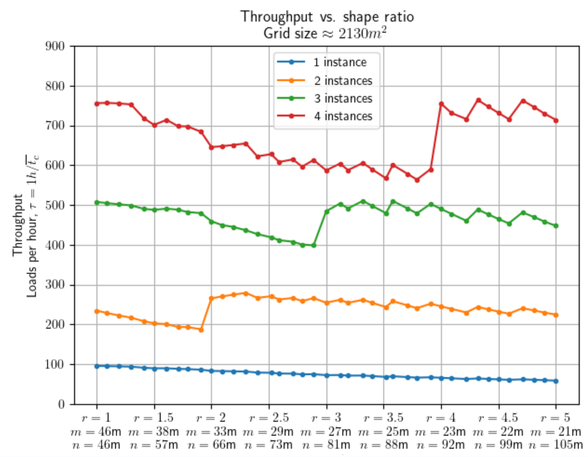
Results

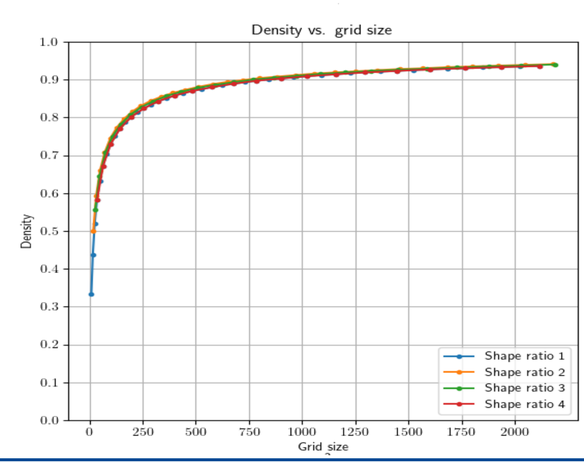












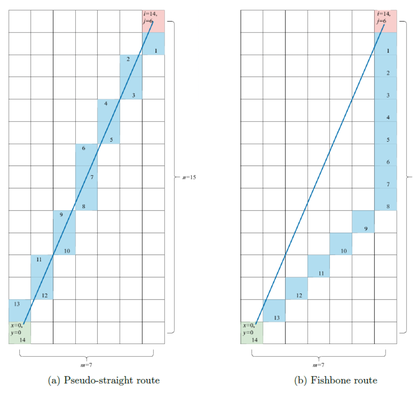
Analytical model

- Density

$$\rho(m,n) = \frac{c_f(m,n)}{mn} = \frac{(m-1)(n-2)}{mn}$$

- Average travel distance

$$\bar{d}(m,n) = \frac{1}{(m-1)(n-2)}\left(\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\max(i,j) + (\sqrt{2}-1)\min(i,j) - \frac{(m-1)m}{\sqrt{2}} - \sqrt{2}m^2 + 3\sqrt{2}m - 2m - 2\sqrt{2} + 2\right)u.$$



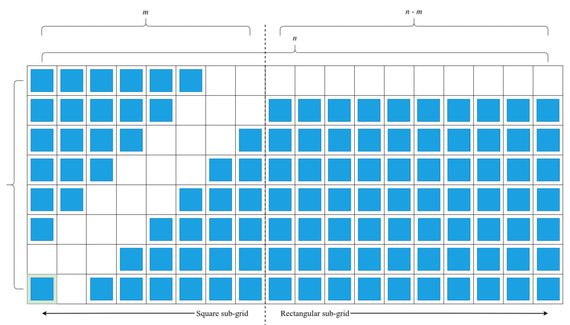
(a) Pseudo-straight route

(b) Fishbone route

- Average cycle time

$$\bar{t}_c(m,n) = \frac{(\beta(m,n) + \bar{d}(m,n))}{v}$$

$$\beta(m,n) = \frac{m^2 - 5m + 6 + (n-m)m - (n-m)}{c_f(m,n)}$$



Conclusion and future work

- **Logistics 4.0 Lab** (NTNU) started a **collaboration** with **wheel.me** on the use of **autonomous wheels**.
- By **mounting autonomous wheels to an object**, the object can **move autonomously in ANY DIRECTION.**
- We created **1st puzzle based movable rack system**, so high density and high throughput performance, even more exploiting the **diagonal movements**.
- We develop an **analytical model** for a **modular representation of the problem** (**square + rectangular sub-grids**) and validate with simulation
- We demonstrate the **high density** (around 90-95%) and **higher throughput** compared to Manhattan movements (+ about 18%).

- **Future research** will focus on:
  - Multi-objectives optimization (density vs throughput)
  - Sequencing of loads, Storage assignment policies and new operational logics (dynamic I/O location)
  - Real testing and first implementation needed to validate the results also in real operational conditions (smart logistics in library sector, e-commerce)

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