Politecnico di Torino
Corso di Laurea Magistrale in Engineering and Management
Tesi di Laurea Magistrale

Design of Innovative Transport Systems for automated warehouses

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Objective of the study

Performance evaluation of an **innovative technology** under different scenarios through **Discrete Event Simulation**

- Best Storage Policy

- Best Outcomes (Throughput, Cycle time and Energy Consumption)

Automated Vehicle Storage and Retrieval System

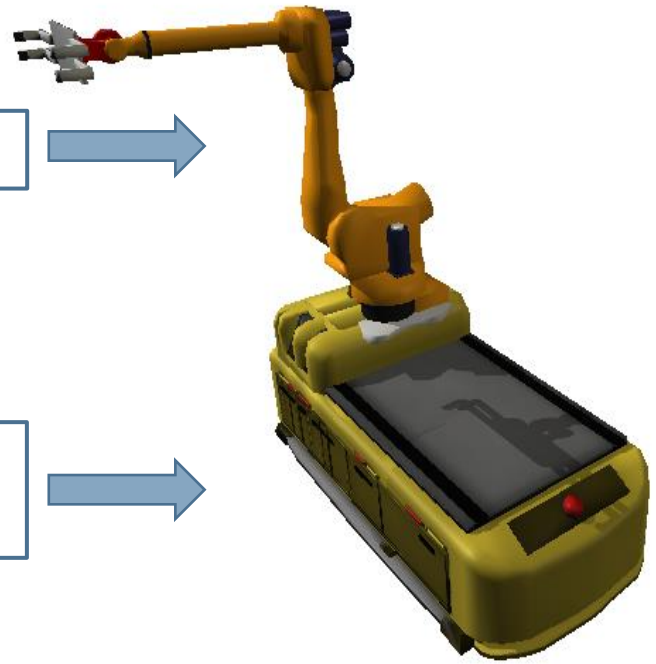
Already commercialized Autonomous vehicle in AVS/RS

Innovative Technology for Autonomous vehicle in AVS/RS

Satellite

Shuttle

Robotic Arm



Shuttle and Satellite

Simulation Design

Varying Parameters

Parameter name (factors)	Parameter values (levels)
Number of corridors	2
	4
Number of levels	3
	6
Number of vehicles	3
	6
Number of SKUs	5
	9
Inter-arrival time of piking orders [s]	50
	100

Storage Policies
Random Storage
Dedicated slots storage
Class Based storage
Storage by weight
Storage by association rules

Full Factorial design Approach

$$levels^{factors} = 2^5$$

Every simulation is the result of 5 simulations

↓

800 Simulation runs (10 h each)

Simulation Runs for each Storage Policy

		factors				
N° Simulations	N° Runs	N° Corridors	N° Levels	N° Vehicles	N° SKUs	Orders Inter-arrival time
1	5	2	3	3	5	50
2	5	2	3	3	5	100
3	5	2	3	3	9	50
4	5	2	3	3	9	100
5	5	2	3	6	5	50
6	5	2	3	6	5	100
7	5	2	3	6	9	50
8	5	2	3	6	9	100
9	5	2	6	3	5	50
10	5	2	6	3	5	100
11	5	2	6	3	9	50
12	5	2	6	3	9	100
13	5	2	6	6	5	50
14	5	2	6	6	5	100
15	5	2	6	6	9	50
16	5	2	6	6	9	100
17	5	4	3	3	5	50
18	5	4	3	3	5	100
19	5	4	3	3	9	50
20	5	4	3	3	9	100
21	5	4	3	6	5	50
22	5	4	3	6	5	100
23	5	4	3	6	9	50
24	5	4	3	6	9	100
25	5	4	6	3	5	50
26	5	4	6	3	5	100
27	5	4	6	3	9	50
28	5	4	6	3	9	100
29	5	4	6	6	5	50
30	5	4	6	6	5	100
31	5	4	6	6	9	50
32	5	4	6	6	9	100

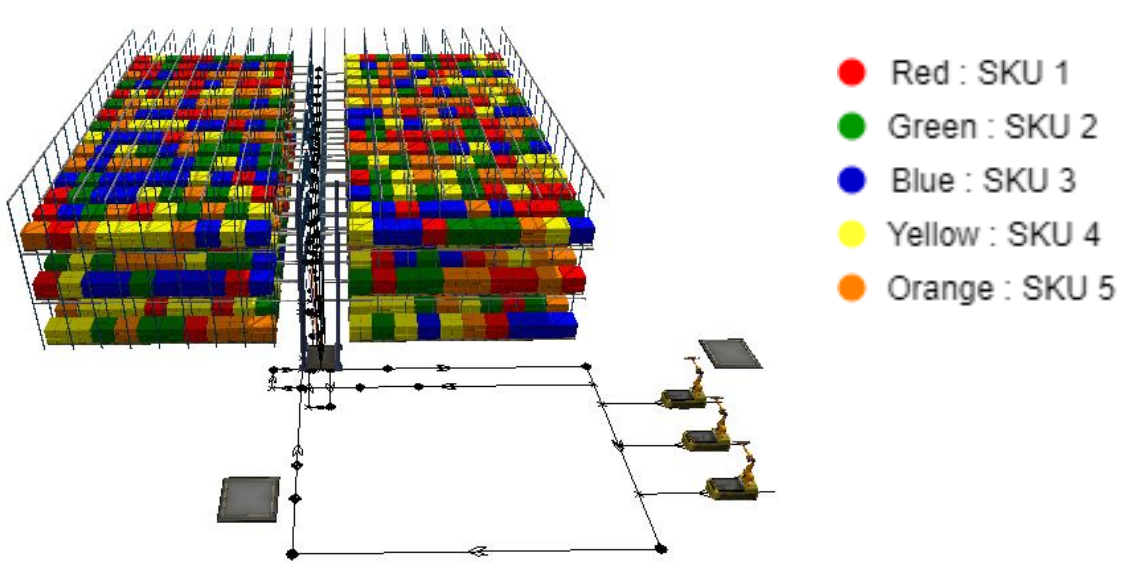
- Random Storage Policy
- Class Based Storage Policy
- Dedicated Slots Storage Policy
- Storage Policy by weight
- Storage Policy by Association rules

Written algorithms to let the model implement the desired storage policy

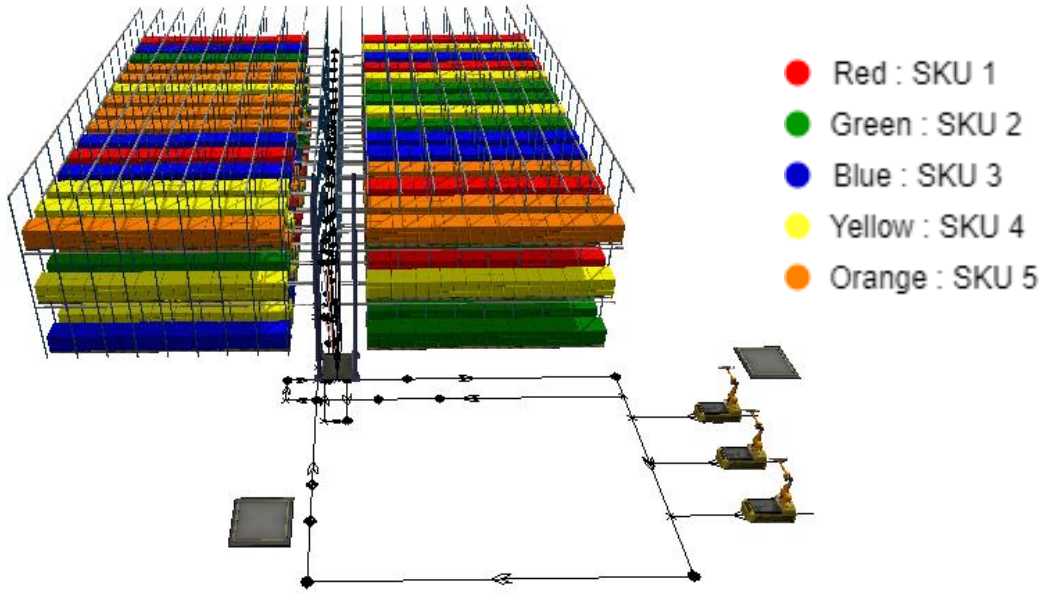
Analysis of past orders to generate new orders

Storage Policies implemented in Flexsim

Random Storage Policy

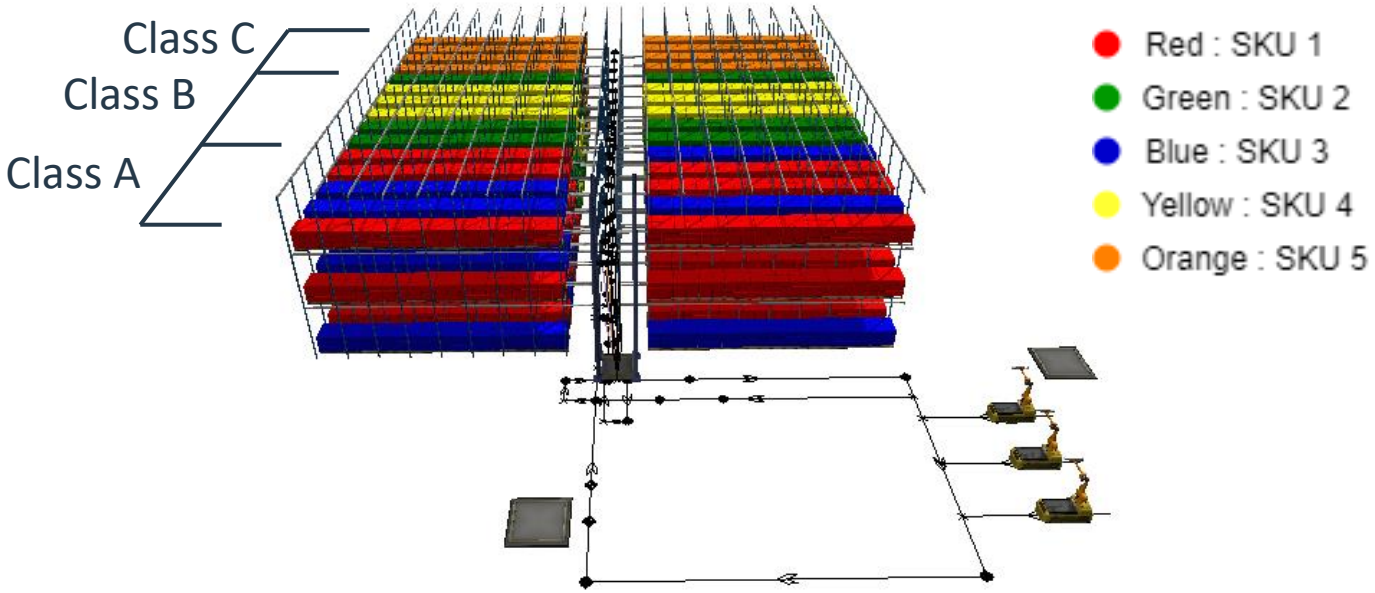


Dedicated Slots Storage Policy



Storage Policies implemented in Flexsim

Class Based Storage Policy



Class A: SKU1 and SKU3

Class B: SKU2 and SKU4

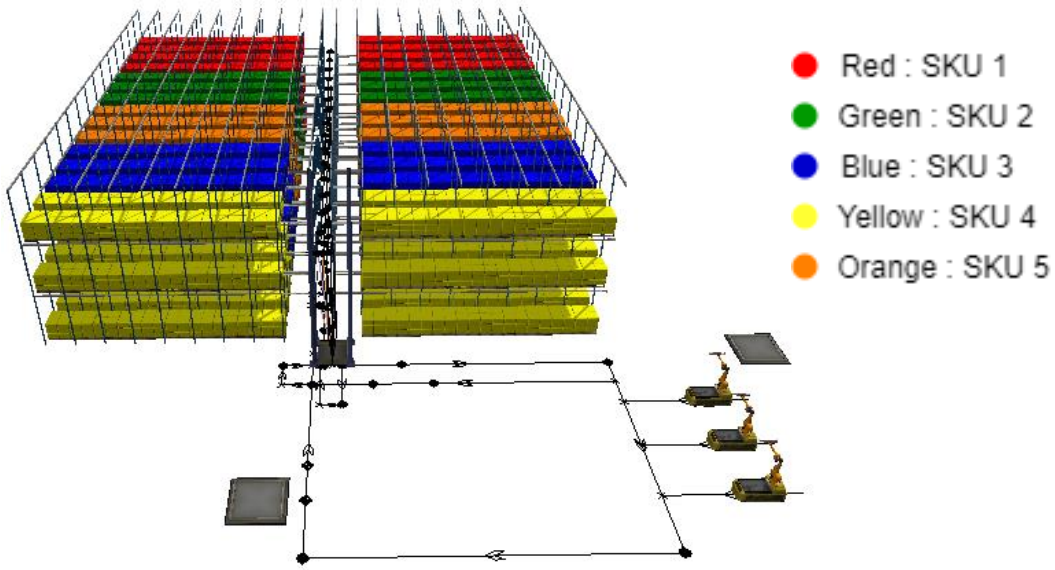
Class C: SKU5

Prioritization during Picking:

Vehicle fouses first on items from Class A

Storage Policies implemented in Flexsim

Storage by Weight

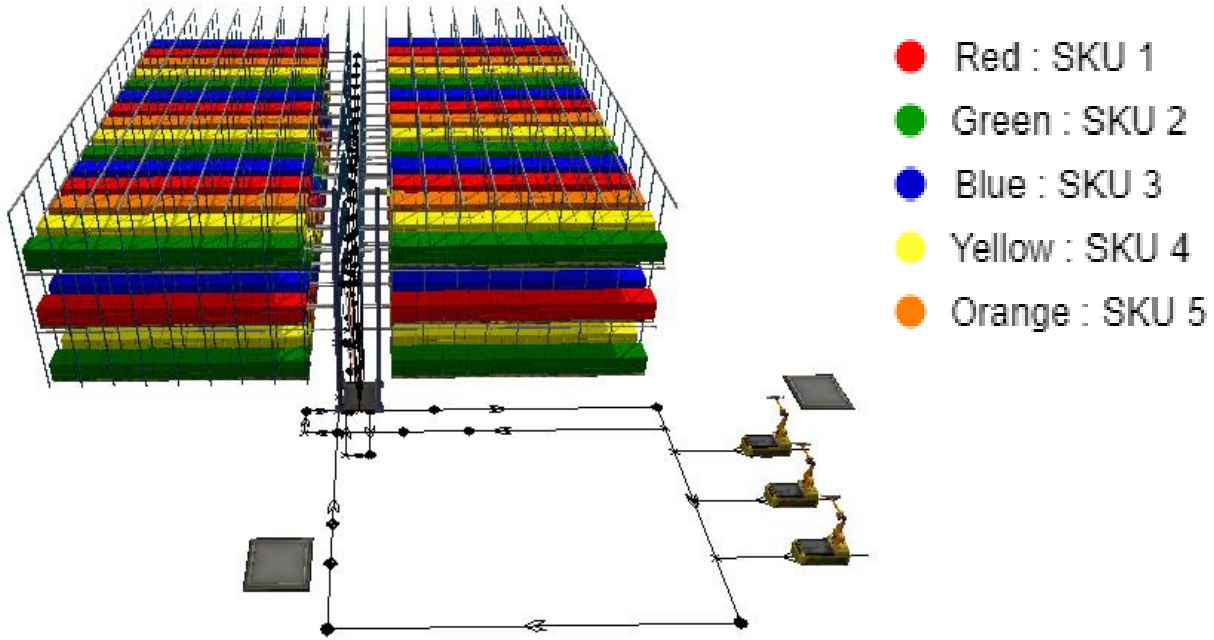


Prioritization during Picking:

The vehicle gives priority to the items that weight less

Storage Policies implemented in Flexsim

Storage by Association Rules



Apriori Algorithm:

SKU1 and SKU3 are often required in the same customer order

Prioritization during Picking:

The vehicle gives priority to the items that are often required together

Performance Variables

- **Throughput [orders/h]**
- Receptivity [units]
- Selectivity [%]
- Shelf Occupation [%]
- Unoccupied Space [%]
- Vehicle Utilization [%]
- **Average Order Cycle Time [min/order]**
- Average Order Task Time (Picking) [min/order]
- Average Order Task time (Retrieval) [min/order]
- Average Order Waiting time [min/order]
- Average meters run by vehicles [m/vehicles]
- Average Energy consumption per vehicle [KWh/vehicles]
- **Overall Energy Consumption [KWh]**

Analysis of Results

1

Warehouse performance for a single storage policy

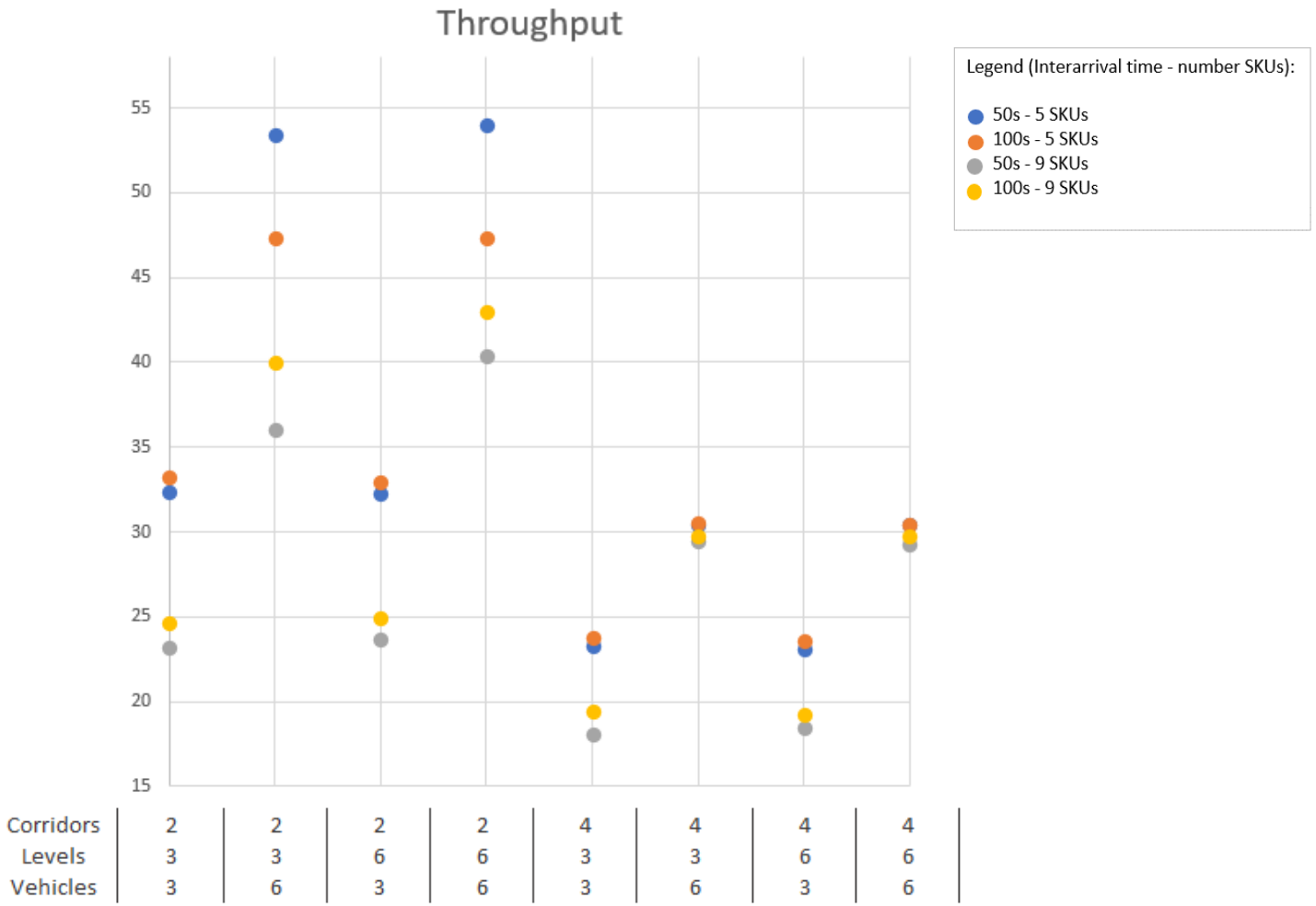
Throughput
Cycle time
Energy Consumption

2

Comparison of all 5 storage policies

Throughput
Cycle time
Energy Consumption

1 Results on Throughput

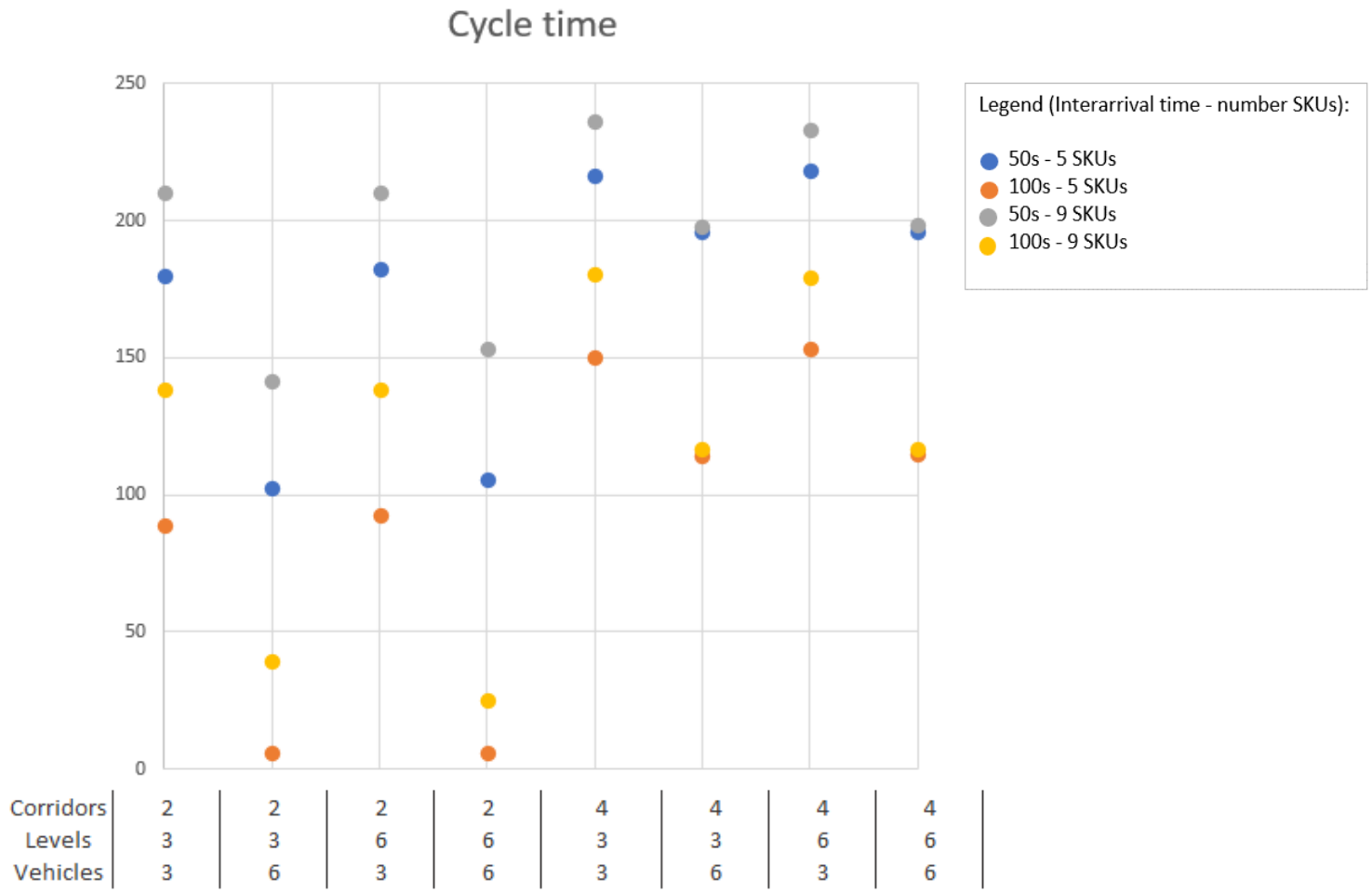


- Throughput increases as the number of vehicles increases

- No great variations when the number of levels changes

- Throughput decreases as the number of SKUs increases
- Throughput decreases as the number of corridors increases

1 Results on Cycle Time

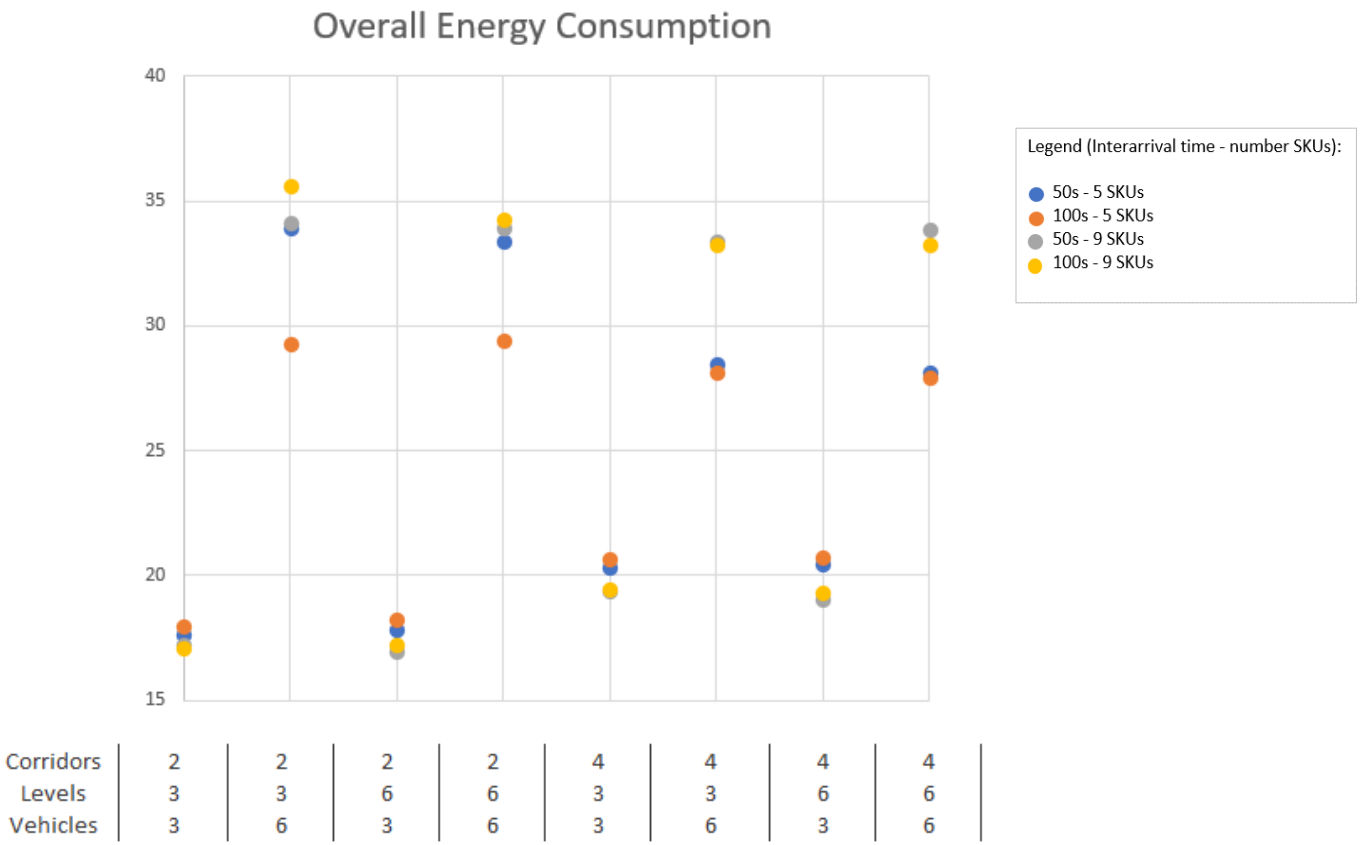


- Cycle time increases as the number of corridors increases
- Cycle time increases as the order interarrival time decreases

- No great variations when the number of levels changes

- Cycle time decreases as the number of vehicles increases
- Cycle time decreases as the number of corridors increases

1 Results on Energy Consumption



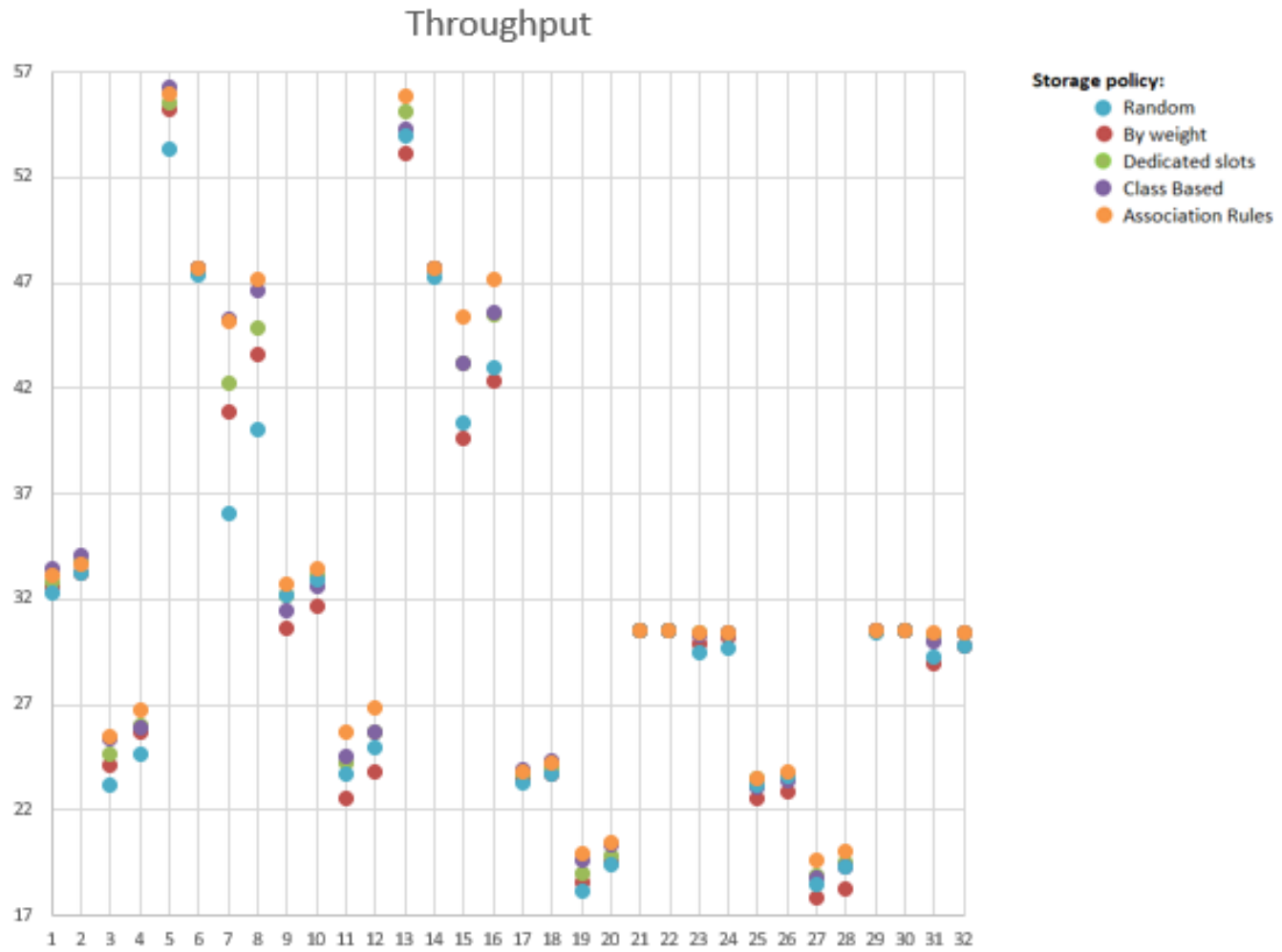
- Energy Consumption increases as the number of corridors increases
- Energy consumption increases as SKUs and vehicles increase

- No great variations when the number of levels changes

- Energy consumption decreases as the number of vehicles decreases

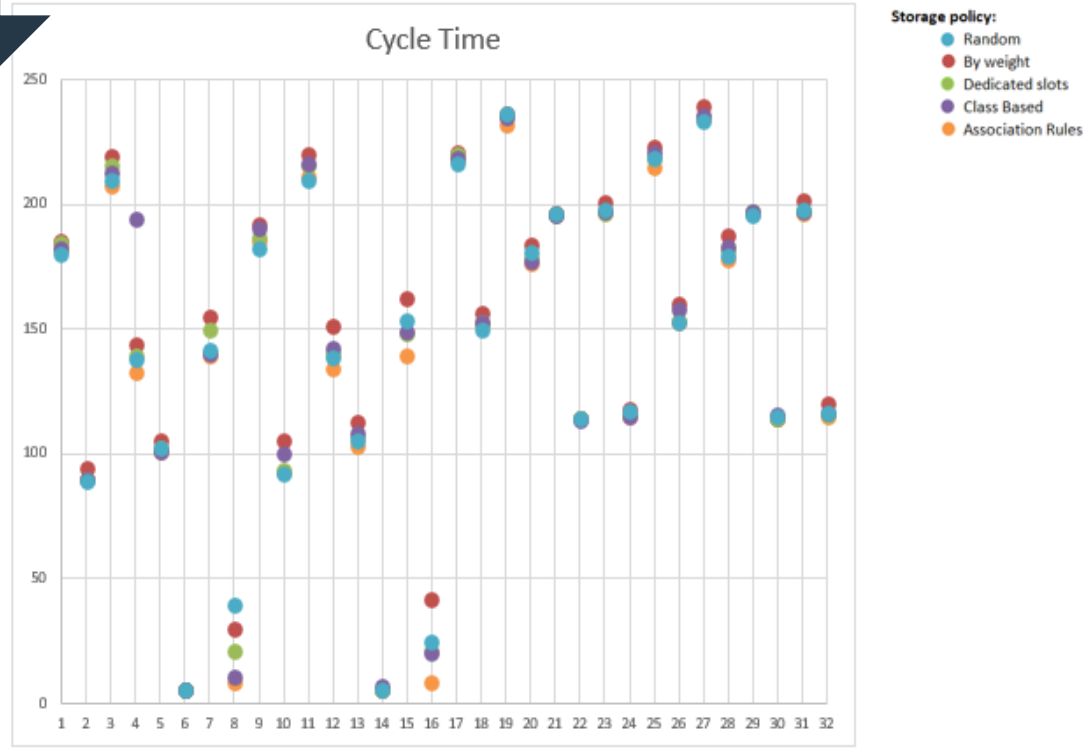
2 Comparison of Storage Policies

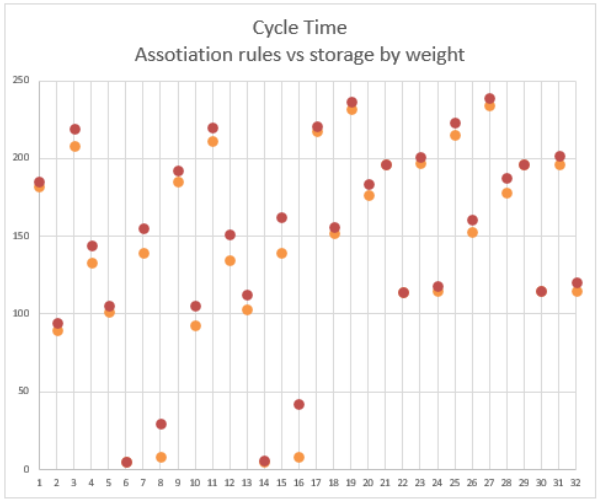
Best Storage Policies: the ones with the highest Throughput

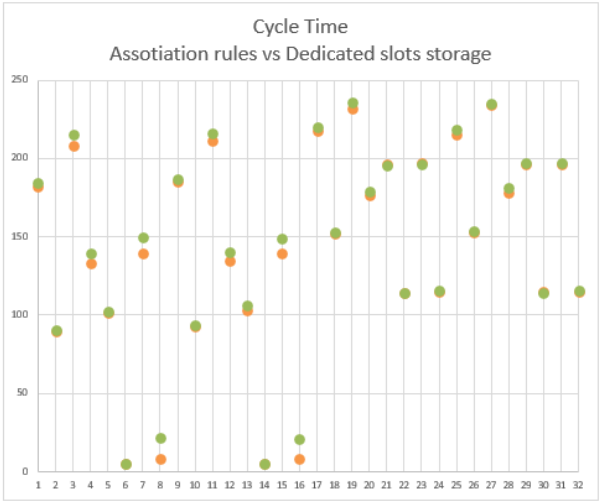


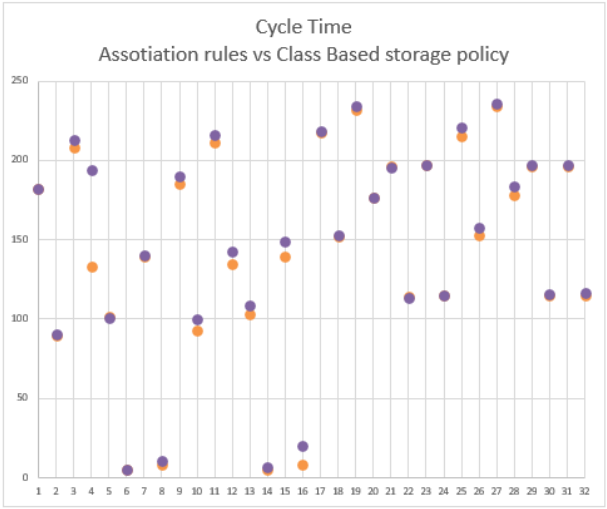
2 Comparison of Storage Policies

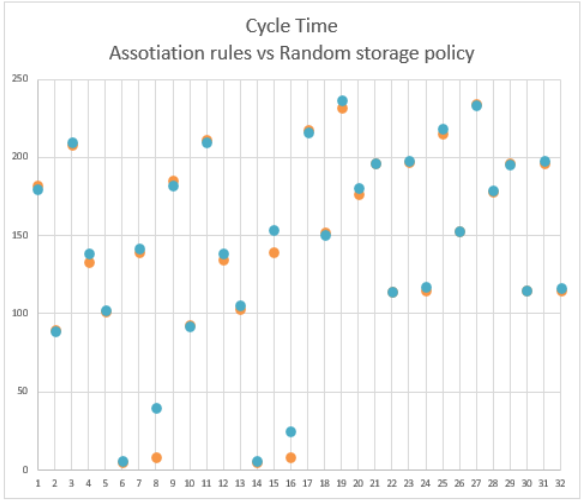
Best Storage Policies: the ones with the lowest Cycle Time





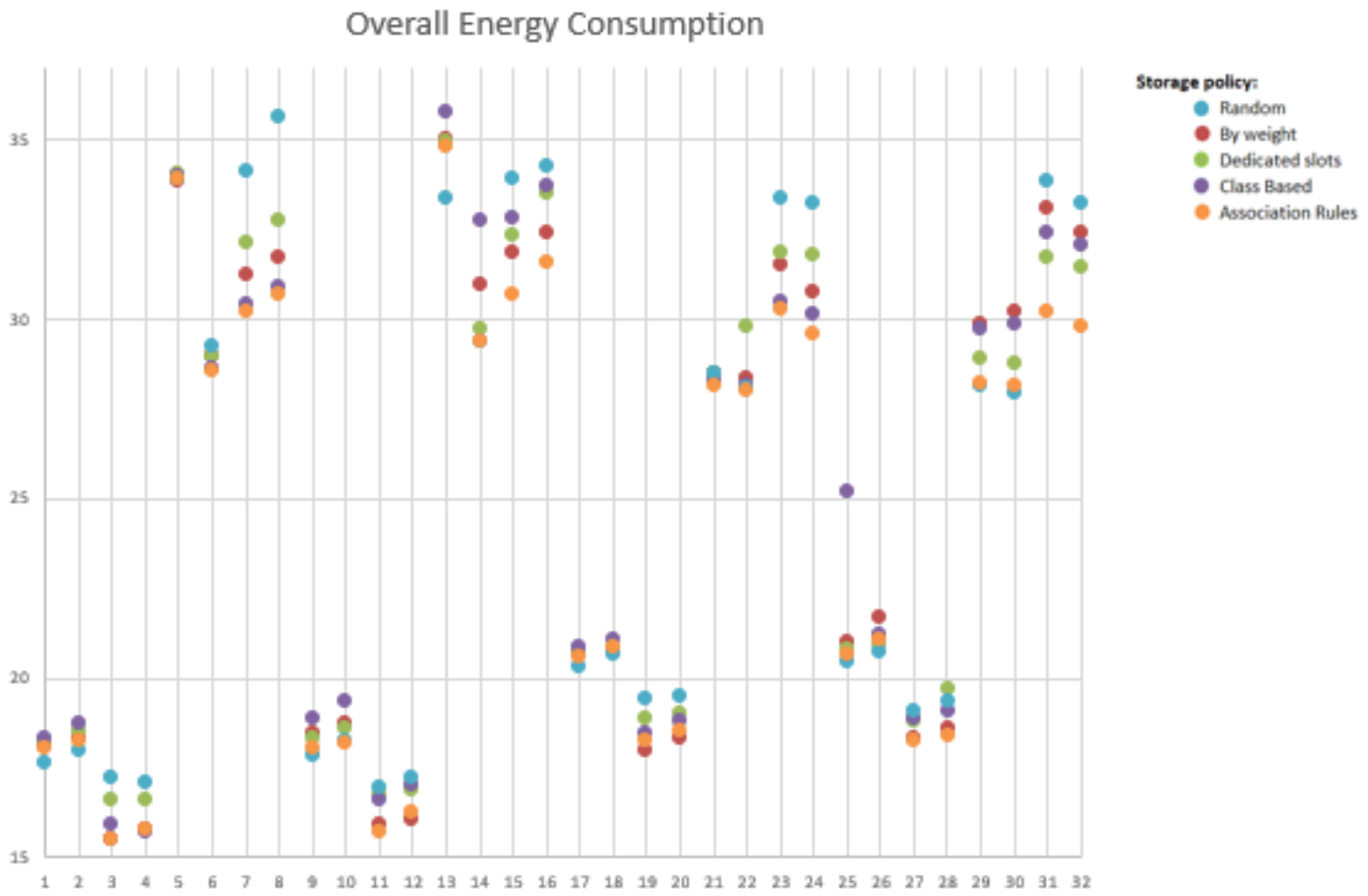






2 Comparison of Storage Policies

Best Storage Policies: the ones with the lowest Energy Consumption



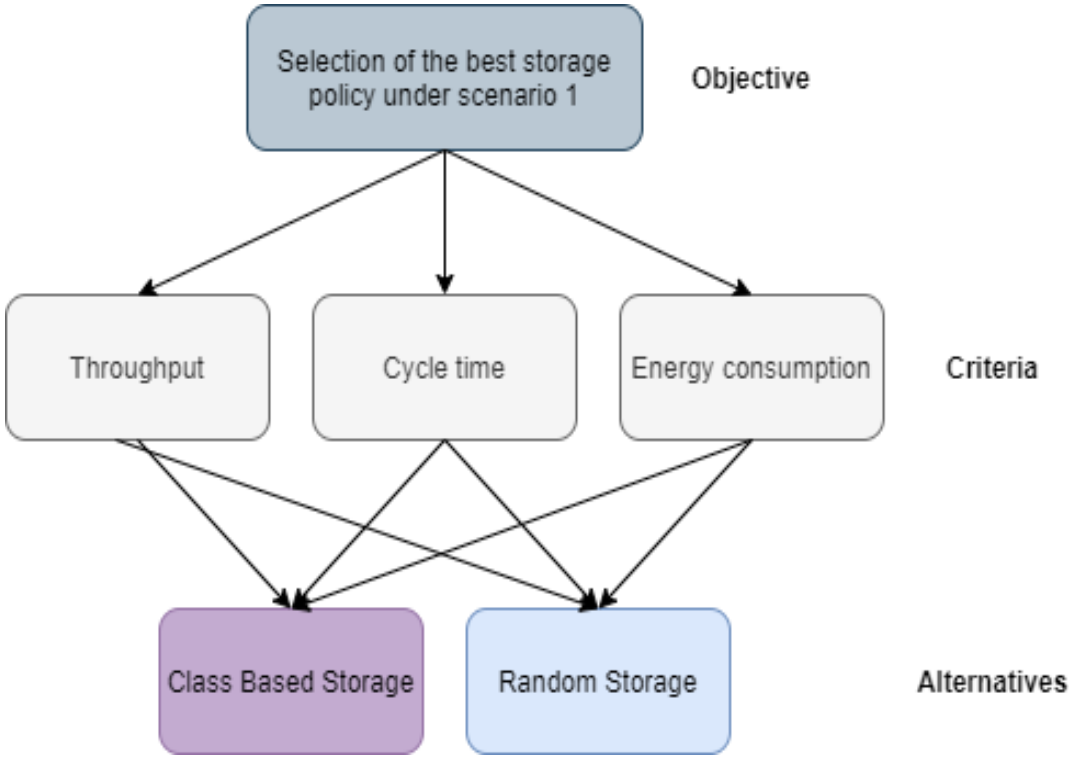
Summary of Results

The best storage polices under different warehouse structures for every performance variable

Storage policy:
- Random
- By weight
- Dedicated slots
- Class Based
- Association Rules

	5skus- 50time								5skus- 100time								9skus- 50time								9skus- 100time							
	1	5	9	13	17	21	25	29	2	6	10	14	18	22	26	30	3	7	11	15	19	23	27	31	4	8	12	16	20	24	28	32
Throughput																																
Cycle time																																
Energy																																
Corridors	2	2	2	2	4	4	4	4	2	2	2	2	4	4	4	4	2	2	2	2	4	4	4	4	2	2	2	2	4	4	4	4
Levels	3	3	6	6	3	3	6	6	3	3	6	6	3	3	6	6	3	3	6	6	3	3	6	6	3	3	6	6	3	3	6	6
Vehicles	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6
SKUs	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Interarrival time	50	50	50	50	50	50	50	50	100	100	100	100	100	100	100	100	50	50	50	50	50	50	50	50	100	100	100	100	100	100	100	100

AHP Analysis



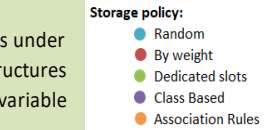
Intensity of importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or Slight	
3	Moderate Importance	Experience and judgment slightly favor one activity over another
4	Moderate Plus	
5	Strong Importance	Experience and judgment strongly favor one activity over another
6	Strong Plus	
7	Very Strong	An activity is favored very strongly over another
8	Very, very Strong	
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation

Comparison matrix of 3 criteria

	Throughput	Cycle time	Energy consumption
Throughput	1	6	5
Cycle time	0.166666667	1	2
Energy consumption	0.2	0.5	1

AHP Analysis: Outcomes and Conclusions

The best storage polices under different warehouse structures for every performance variable



	5skus- 50time								5skus- 100time								9skus- 50time								9skus- 100time							
	1	5	9	13	17	21	25	29	2	6	10	14	18	22	26	30	3	7	11	15	19	23	27	31	4	8	12	16	20	24	28	32
Throughput																																
Cycle time																																
Energy																																
Corridors	2	2	2	2	4	4	4	4	2	2	2	2	4	4	4	4	2	2	2	2	4	4	4	4	2	2	2	2	4	4	4	4
Levels	3	3	6	6	3	3	6	6	3	3	6	6	3	3	6	6	3	3	6	6	3	3	6	6	3	3	6	6	3	3	6	6
Vehicles	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6
SKUs	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Interarrival time	50	50	50	50	50	50	50	50	100	100	100	100	100	100	100	100	50	50	50	50	50	50	50	50	100	100	100	100	100	100	100	100

The best storage polices under different warehouse structure - results of AHP

	5skus- 50time								5skus- 100time								9skus- 50time								9skus- 100time							
	1	5	9	13	17	21	25	29	2	6	10	14	18	22	26	30	3	7	11	15	19	23	27	31	4	8	12	16	20	24	28	32
Best Policy																																
Corridors	2	2	2	2	4	4	4	4	2	2	2	2	4	4	4	4	2	2	2	2	4	4	4	4	2	2	2	2	4	4	4	4
Levels	3	3	6	6	3	3	6	6	3	3	6	6	3	3	6	6	3	3	6	6	3	3	6	6	3	3	6	6	3	3	6	6
Vehicles	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6	3	6
SKUs	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Interarrival time	50	50	50	50	50	50	50	50	100	100	100	100	100	100	100	100	50	50	50	50	50	50	50	50	100	100	100	100	100	100	100	100

Low Complexity warehouse:
Class Based Storage

High Complexity Warehouse:
Storage Policy by Association rules

THANK YOU
for your attention