Discrete Event Simulation of Warehouse Operations

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May 2025

Problem Statement

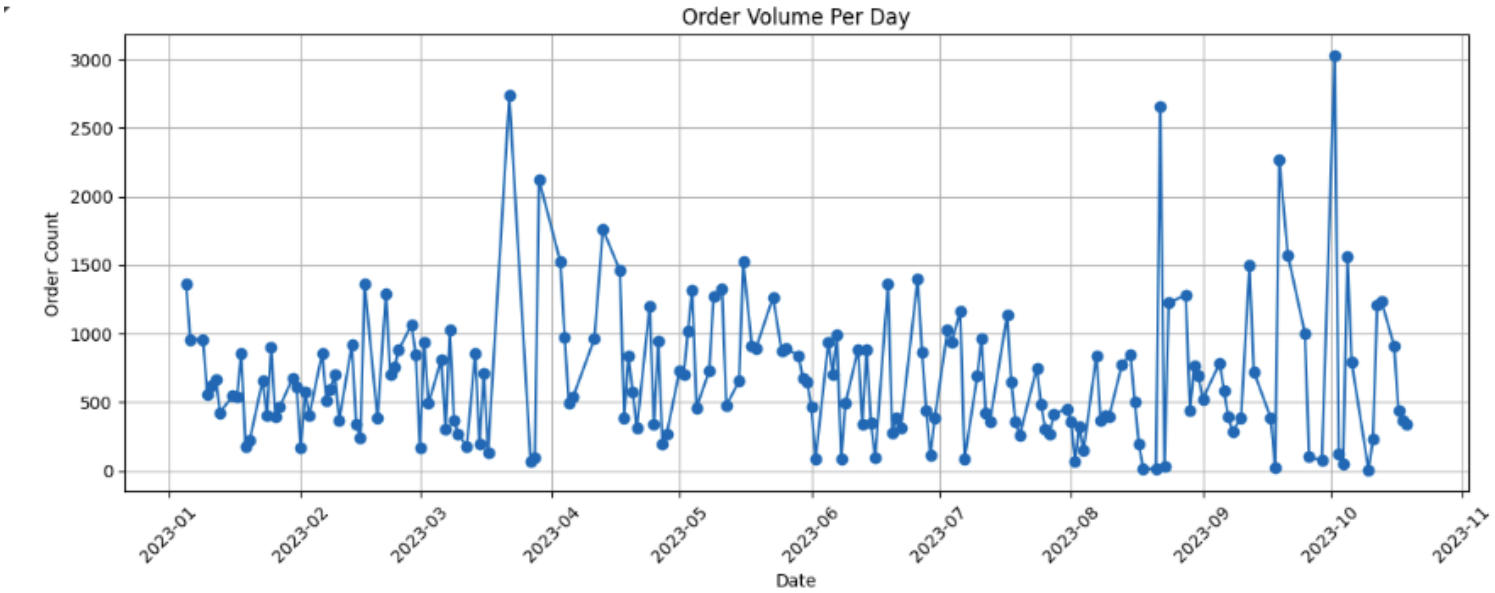
- Simulate warehouse order picking operations using Discrete Event Simulation (AnyLogic).
- Analyze picker utilization, order cycle time, throughput.
- Identify bottlenecks and recommend operational improvements.

Input Data Analysis

- Loaded Customer Order data: Order ID, SKU, Quantity, Timestamp.
- Parsed datetime, extracted day, hour, weekday features.
- Attempted fitting Exponential, Normal, Weibull distributions using KS and AD tests.
- Final assumption: **Poisson process** for order arrivals [1].
- Inter-arrival times modeled as **Exponential** distribution.

[1] Bartholdi & Hackman, 2014

Order Volume Over the Year



Order Arrival Rates (Top 3 Products)

Product	Order Count	Estimated Arrival Rate (orders/time)
PY5UPB	1144	2265.73
8N10W9	925	2802.16
WRRW1W	551	4704.17

Modeling Overview

- Order generation using Poisson process.
- Dynamic assignment of orders to pickers.
- Picking, traveling, and placement activities simulated.
- Batching logic incorporated for batch and zone picking.

Modeling Components

- **Source Block:** Creates orders based on arrival rate.
- **Seize-Delay-Release:** Picker seized, pick delayed, picker released.
- **Java Functions:** createOutputTable() for performance logging, Travel Time calculations.
- **Experiment Parameterization:** Number of pickers and batch sizes.

Key Modeling Diagram

Output Data Analysis: Key Output Metrics

- **Average Cycle Time:** Average time from order release to placement for the three products.
- **Picker Utilization:** Proportion of time picker is busy.
- **Order Per Labour Hour**: Number of orders processed per active labour hour.
- **Throughput:** Number of orders processed per hour.

Output Data Analysis: Output Metrics Plots

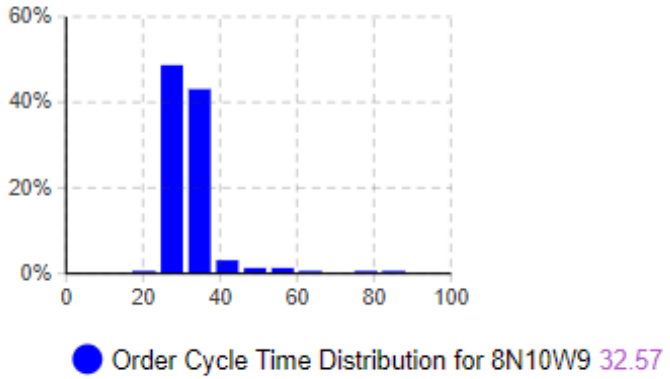


Figure: Cycle Time

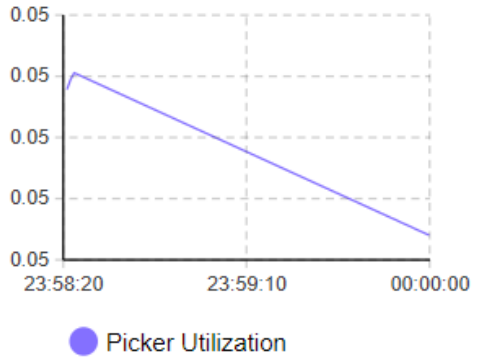


Figure: Picker Utilization

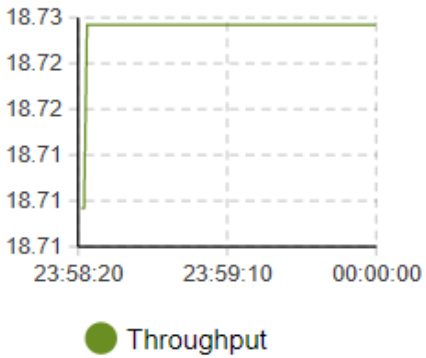


Figure: Warehouse Throughput

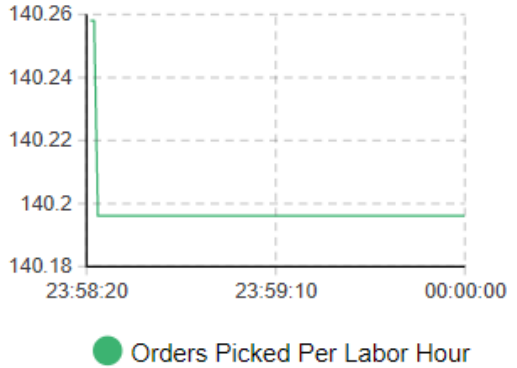


Figure: Orders per Labour Hour

Output Data Analysis: Replications Needed

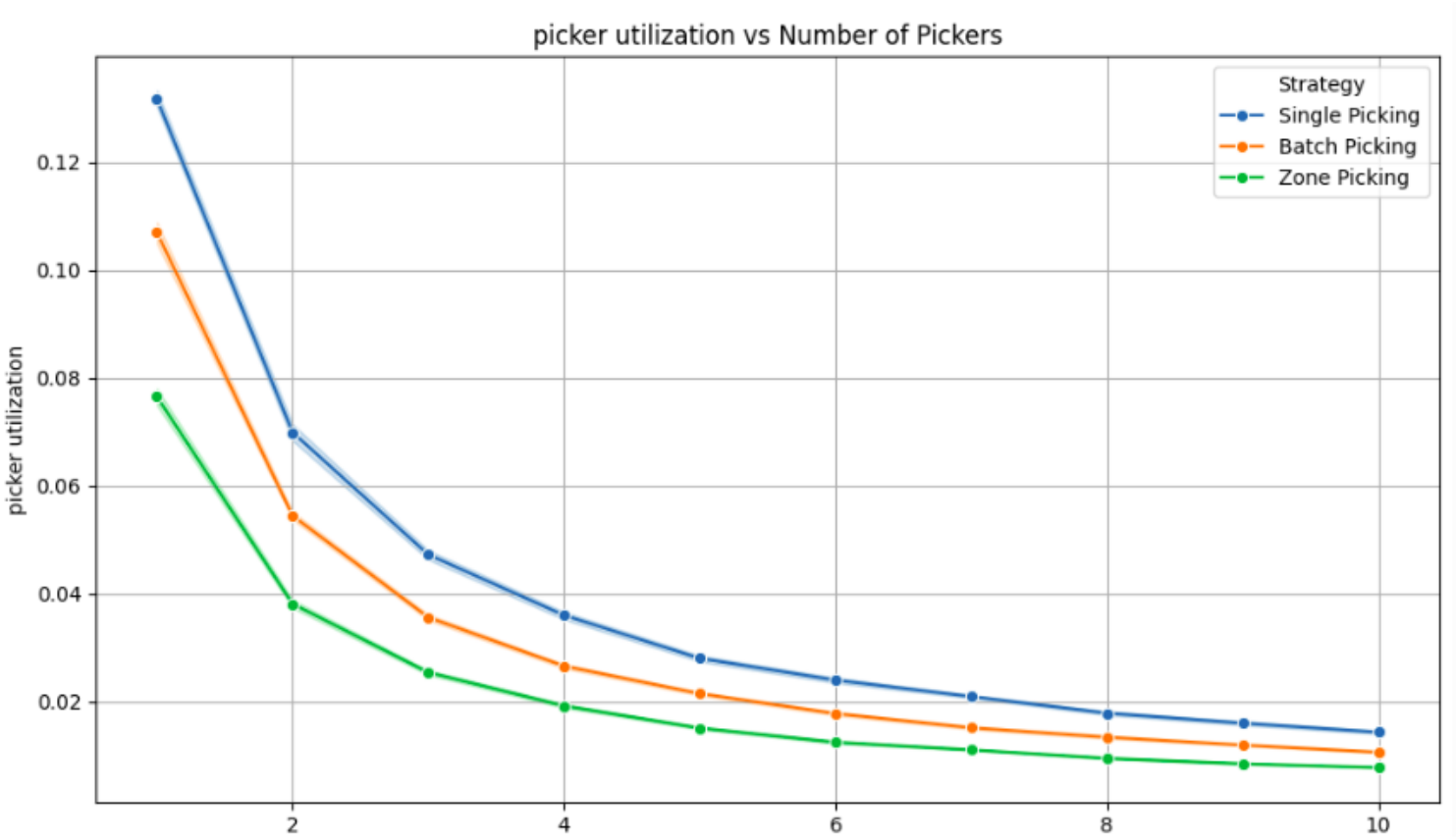
- Replications calculated using the formula:

$$n = \left(\frac{Z_{1-\alpha/2} \times S}{H} \right)^2$$

- Where:
  - $n_0 = 10$ (initial pilot replications)
  - $S = 0.273$ (pilot sample standard deviation)
  - $H = 0.1$ (desired half-width for 95% CI)
  - $Z_{0.975} = 1.96$ (z-critical value for 95% confidence)
- Required number of replications: **28**.

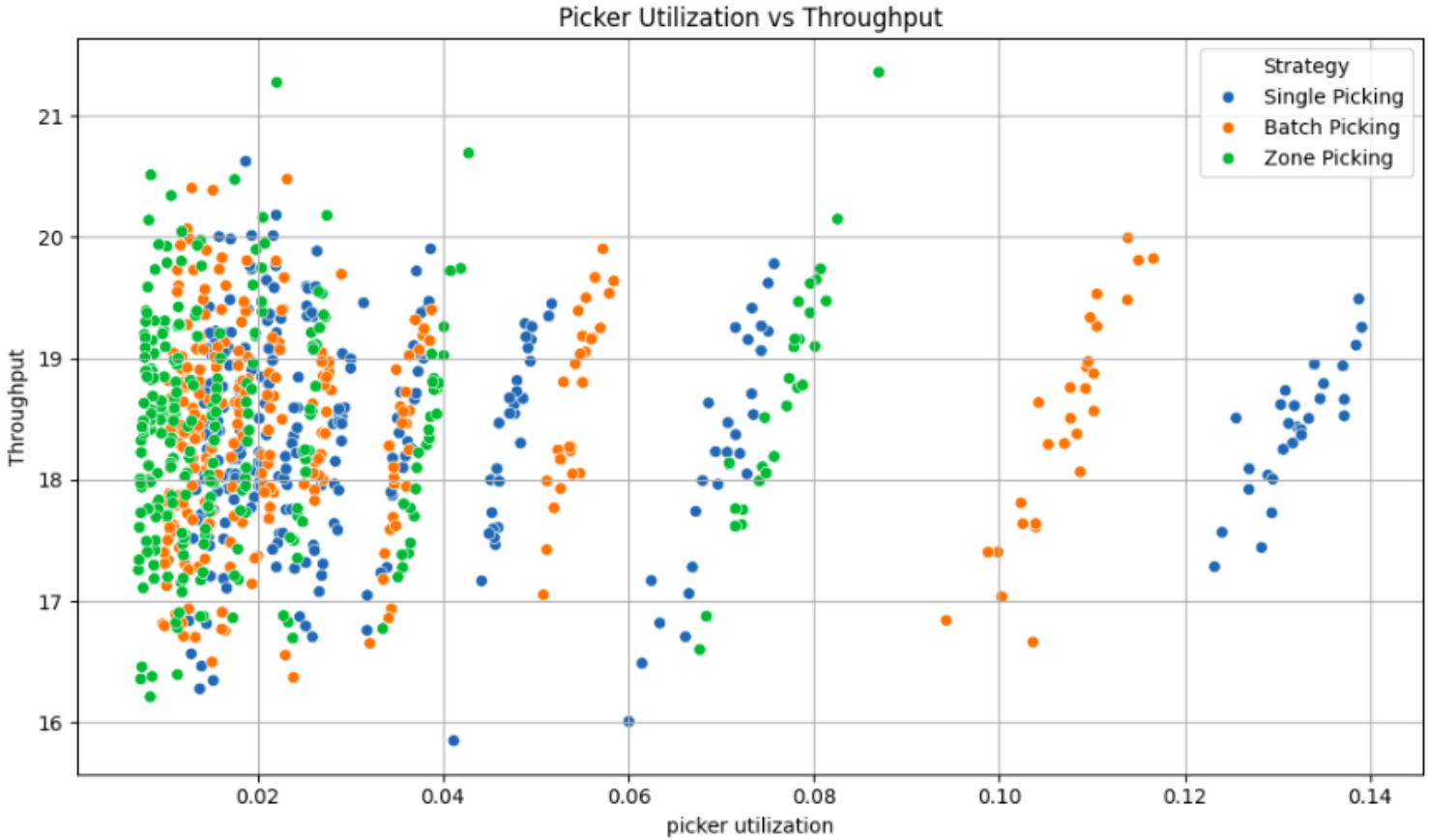
Output Data Analysis: Picking Strategy Comparison

- Comparing Single, Batch, Zone Picking strategies.



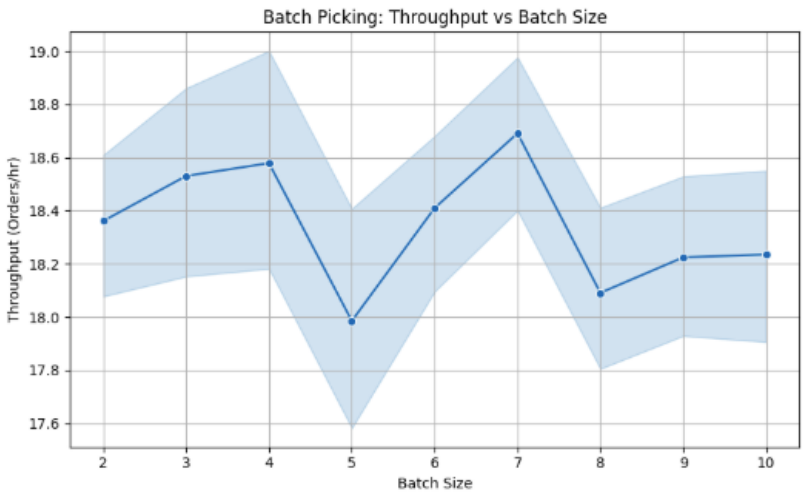
Output Data Analysis: Optimal Number of Pickers

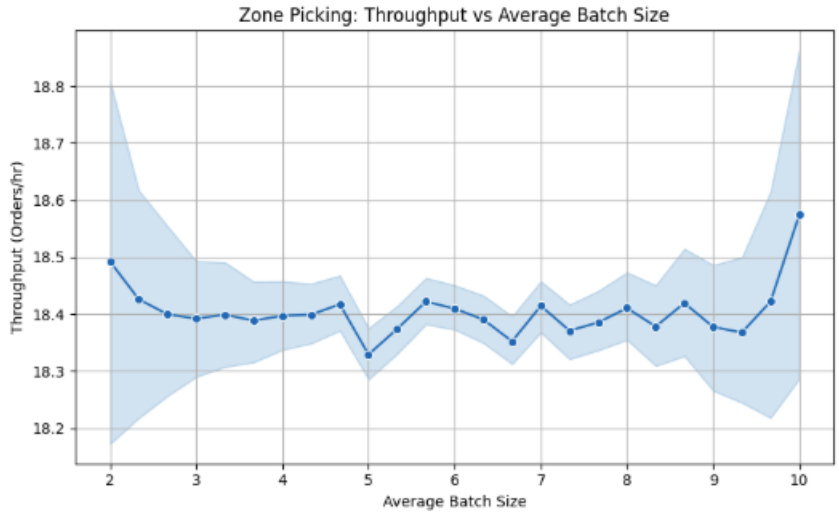
- Varying number of pickers to optimize throughput and cycle time.



Output Data Analysis: Optimal Batch Size Selection

- Analyzing batch sizes to maximize throughput while controlling cycle time for both Batch Picking and Zone Picking strategies.





Key Results: Best Configurations

Strategy	Best Configuration
Single Picking	7 Pickers
Batch Picking	2 Pickers
Zone Picking	1 Picker
Batch Picking	4 (Batch Size)
Zone Picking	2 (Batch Size)

Output Data Analysis - Confidence Interval Estimation

Picking Strategy	Average Cycle Time	Picker Utilization	Orders per Labour Hour	Throughput
Single Picking	30.32 $\pm$0.15	0.02	139.14 $\pm$0.8	18.78 $\pm$0.27
Batch Picking	258.57 $\pm$4.78	0.05	171.43 $\pm$1.24	18.69 $\pm$0.29
Zone Picking	681.26 $\pm$19.98	0.08	242 $\pm$1.22	18.70 $\pm$0.4

Recommendations

- Use **7 Pickers** for Single Picking to minimize cycle time.
- Use **2 Pickers** for Batch Picking balancing throughput and time.
- Use **1 Picker** for Zone Picking considering warehouse constraints.
- Batch Picking: **Batch Size 4**; Zone Picking: **Batch Size 2**.

Future Scope

- Model real warehouse layout for accurate travel time.
- Include 3D animation for better representation.
- Include handling equipment and aisle congestion.
- Extend to agent-based modeling of picker behavior.

References

- Bartholdi, J. J., & Hackman, S. T. (2014). Warehouse & Distribution Science.
- Law, A. M., & Kelton, W. D. (2000). Simulation Modeling and Analysis.
- AnyLogic Simulation Software Documentation.
- Footwear Order Dataset Analysis.

Thank You!