i4.0 Monitoring System for Better Utilization of Warehouse Forklift Fleet

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Agenda

1. Use Case Overview
2. Data Pipeline and Reconstruction of Forklift Routes
3. Explorative Analysis
4. As-Is and What-If Evaluation based on Discrete Event Simulation
5. Prediction of Needed Amount of Forklifts
6. Future Work with our Results

Use Case Overview

Overview of Logistics Processes in Internal Goods Receipt Area in CKY

Use Case Motivation

Goal: Get key-insights on root-causes for inefficient utilization of forklift fleet and dynamic prediction of optimal fleet size

Current Process:

- Incoming finished goods delivered via sorter from different factories
- Fleet of forklifts picks-up and puts away finished goods warehouse
- Unload diversified products, each with special requirements for forklift equipment
- Currently Calculation of the needed forklifts based on the division of total production figures

Potential for Improvement:

- Data Pipeline to match data from two separated data sources
- Key-insights on fluctuation in warehouse productivity
- Identify root-causes for inefficient forklift utilization
- Check of the current As-Is utilization of the forklift fleet
- Better estimation of the needed amount and type of forklifts

Project Plan

Overview of Data Sources

Transportation Order Data Source

Description:
- Data source containing all transportation orders

Parameters:
- ITO (Identification number of Transportation Order)
- Information about transported good
- Time point when forklift picks up the order
- Sorter (Starting point) where order gets picked up
- Destination bin where order gets unloaded
- Number of goods transported
- Identification number of forklift

Facts:
- Time stamp in Central European Time
- No reliable information about order completion time
- Data available over the periods:
  - 02.11 – 12.11 and 02.12 – 16.12

Forklift Data Source

Description:
- Data source with camera-based tracking data

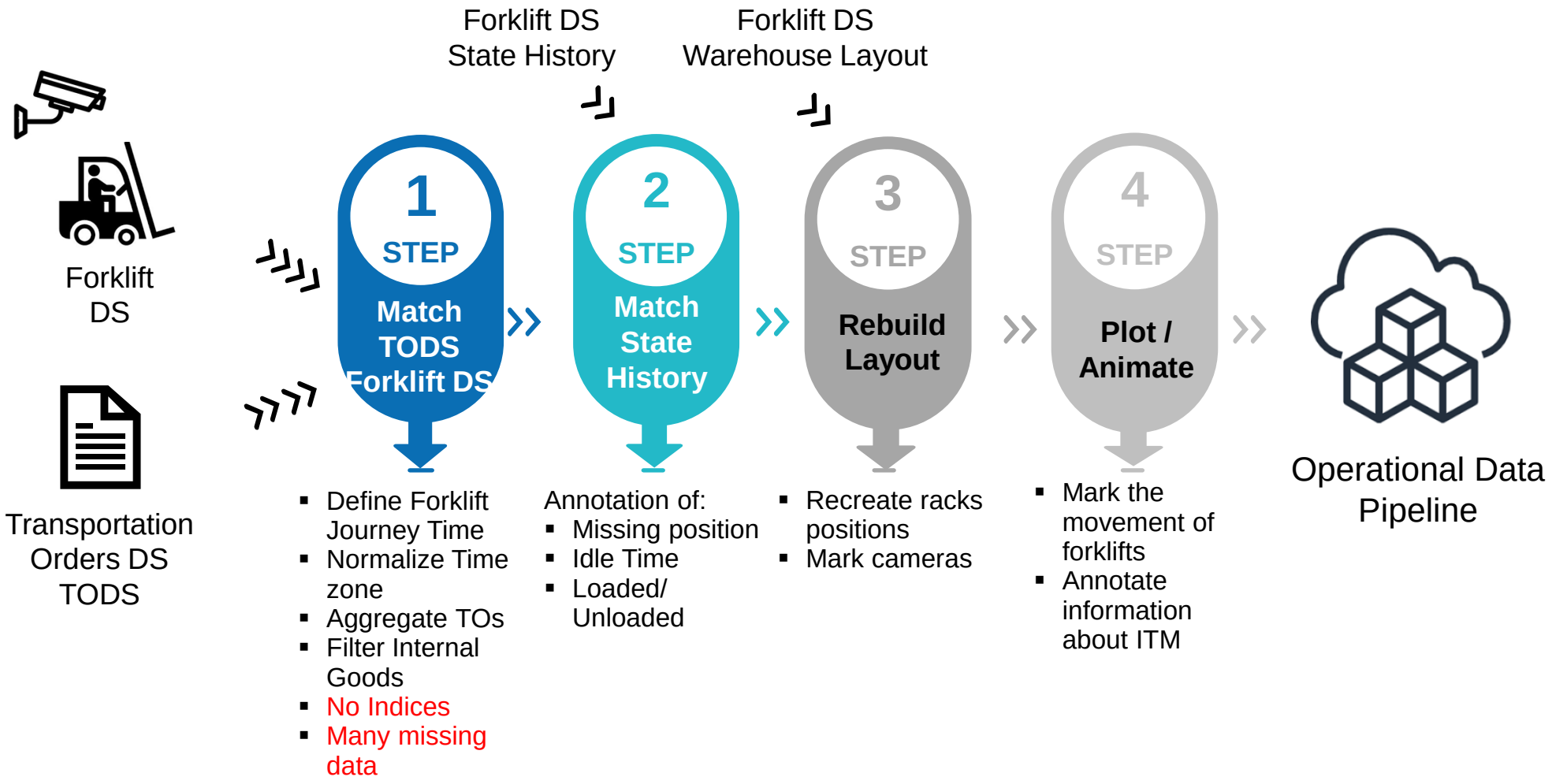
Tables:
- Dynamic object position:
  - Timestamp of forklift with its specific location
- Tracked object state:
  - State of the forklift (IDLE, Lost, Driving) with start and end time
- W2MO layout:
  - Location of storage bins and sorters

Facts:
- Timestamp in Turkey Time
- Forklifts get lost quite often
- Had to manually readjust the warehouse layout

Difficulty: no matching identifier

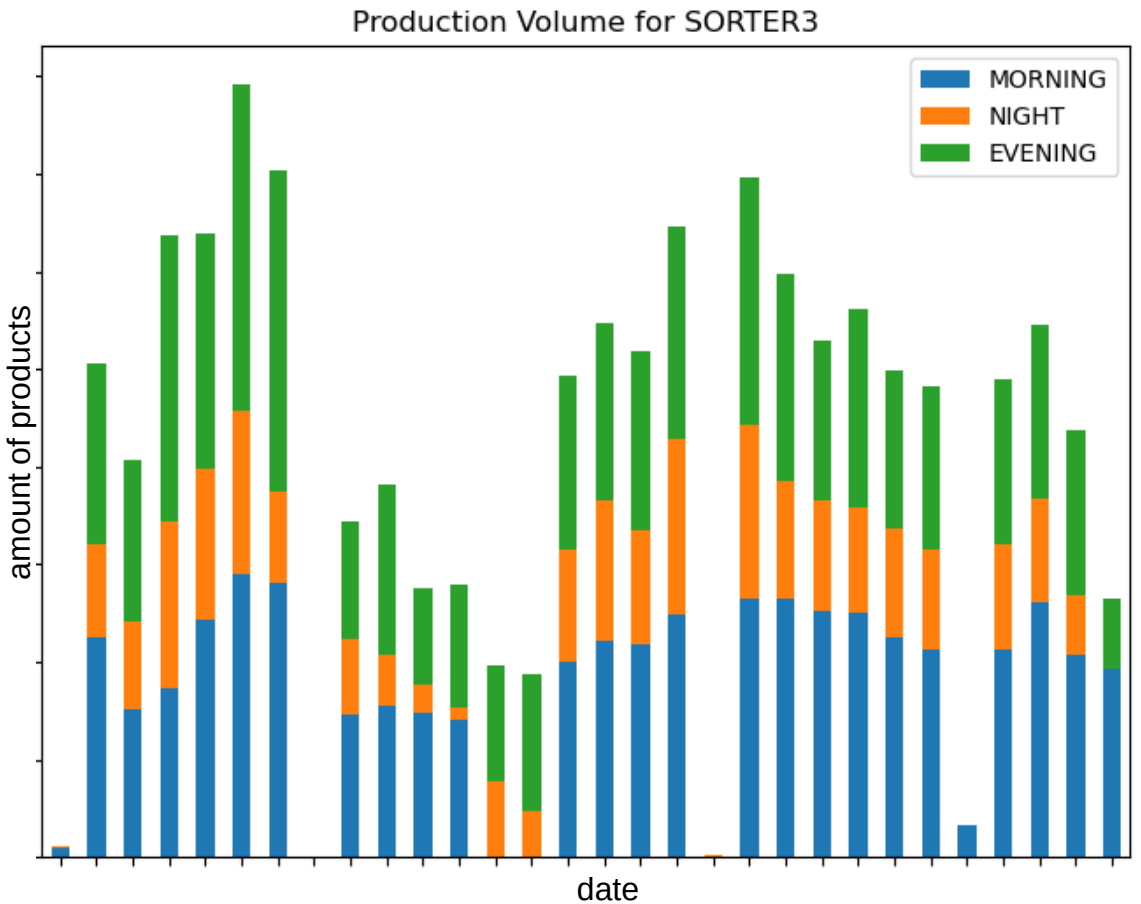
Data Pipeline and Reconstruction of Forklift Routes

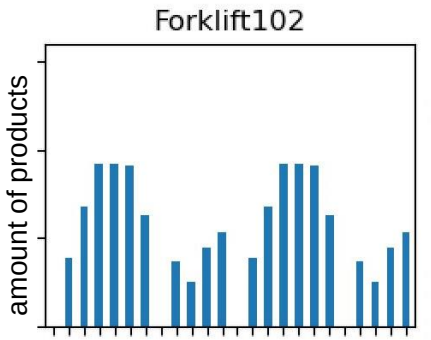
Data Pipeline

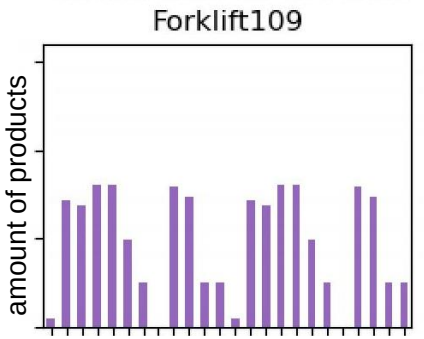


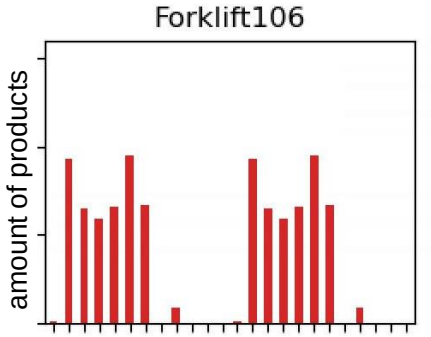
Explorative Data Analysis

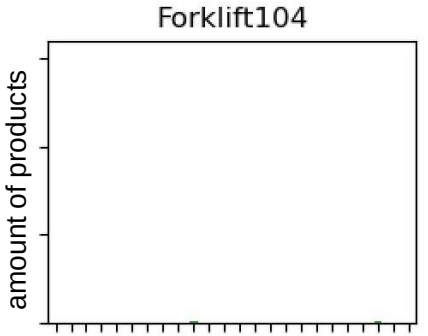
Hypothesis 1: Unused or Less Used Capacity of Forklifts

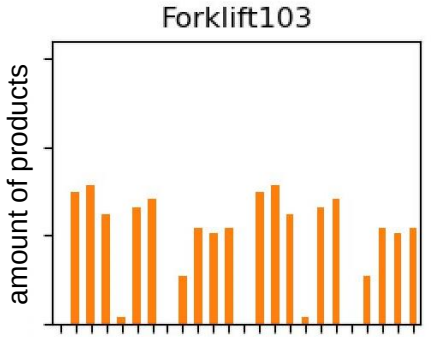


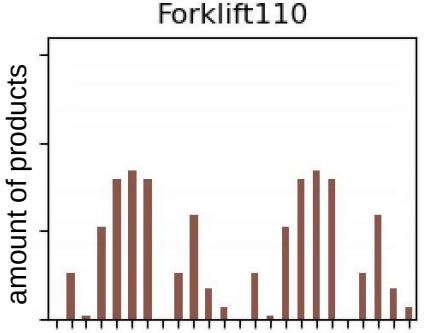




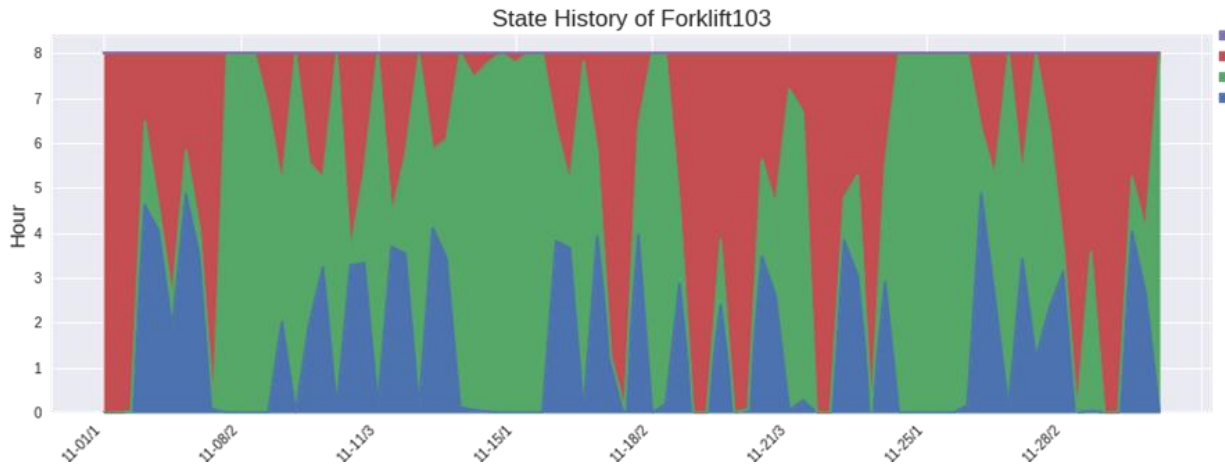


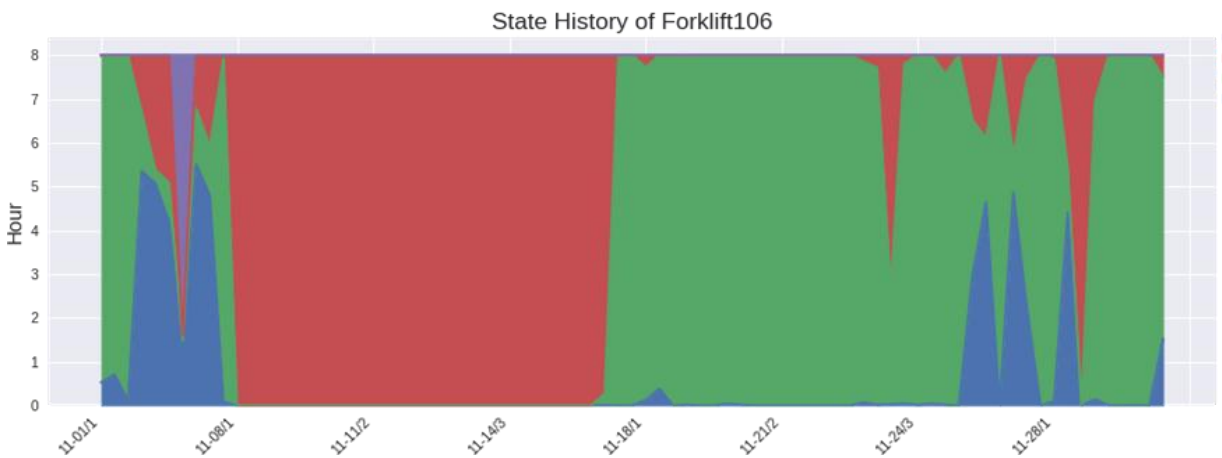


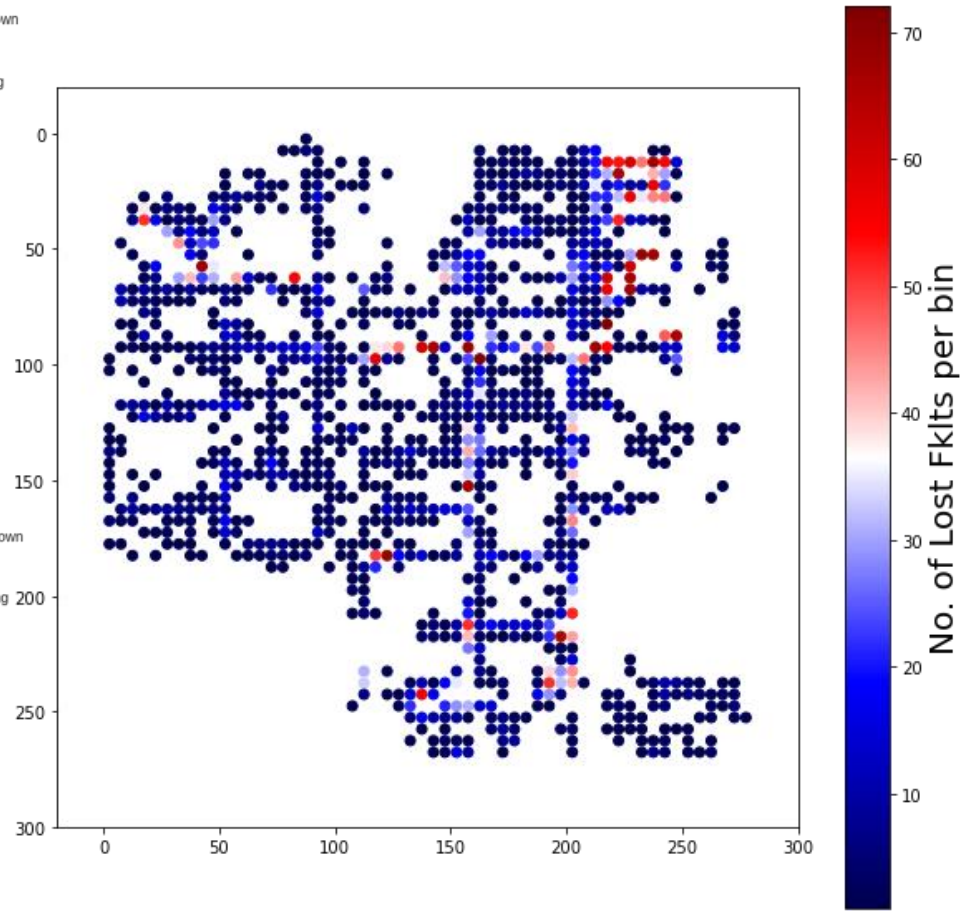




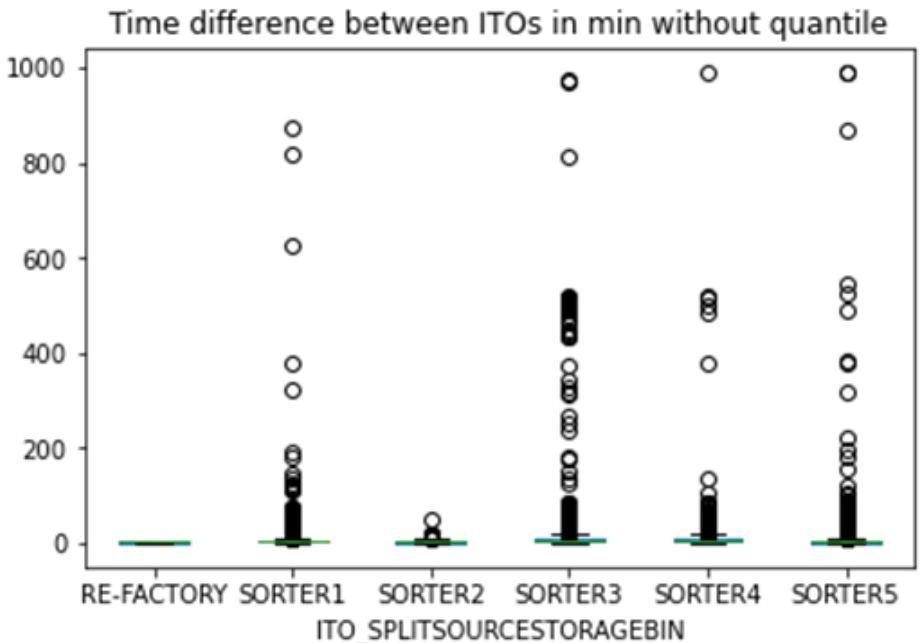
Hypothesis 2: Lost Areas and Lost Duration of Forklifts

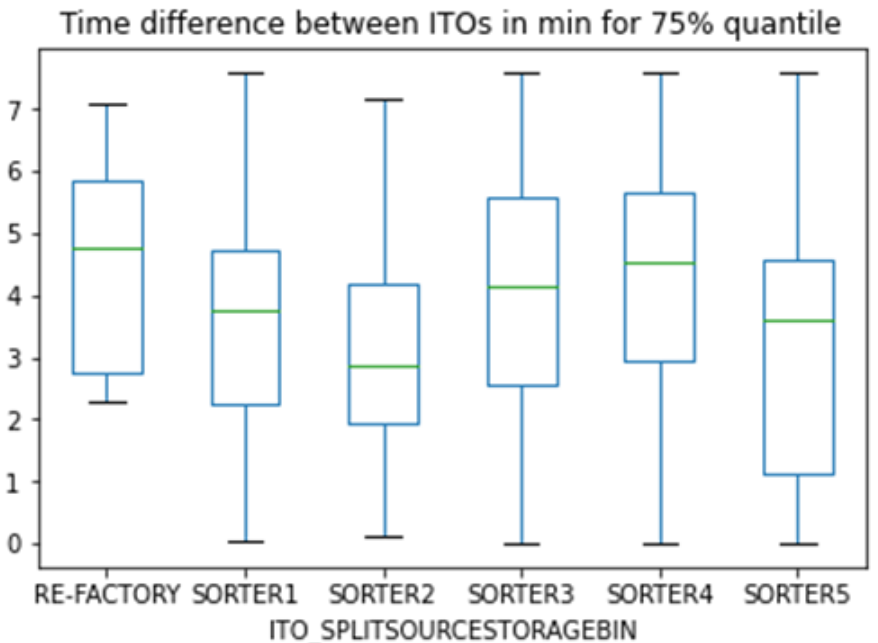




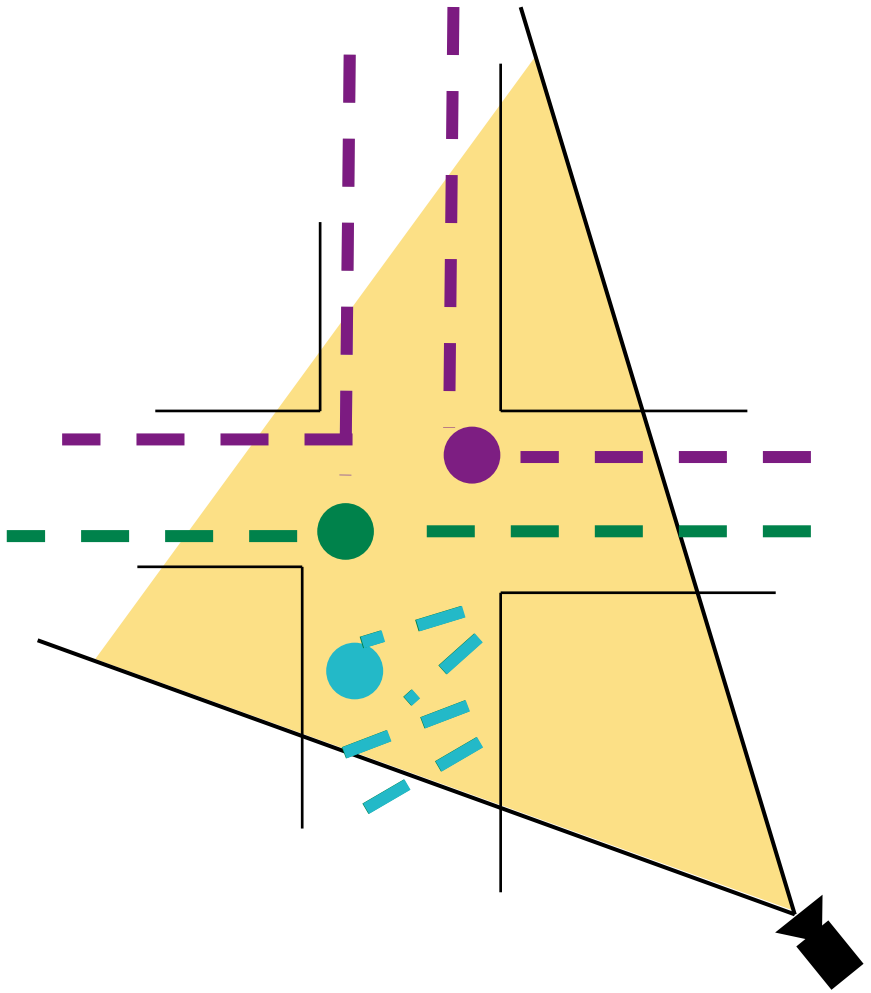


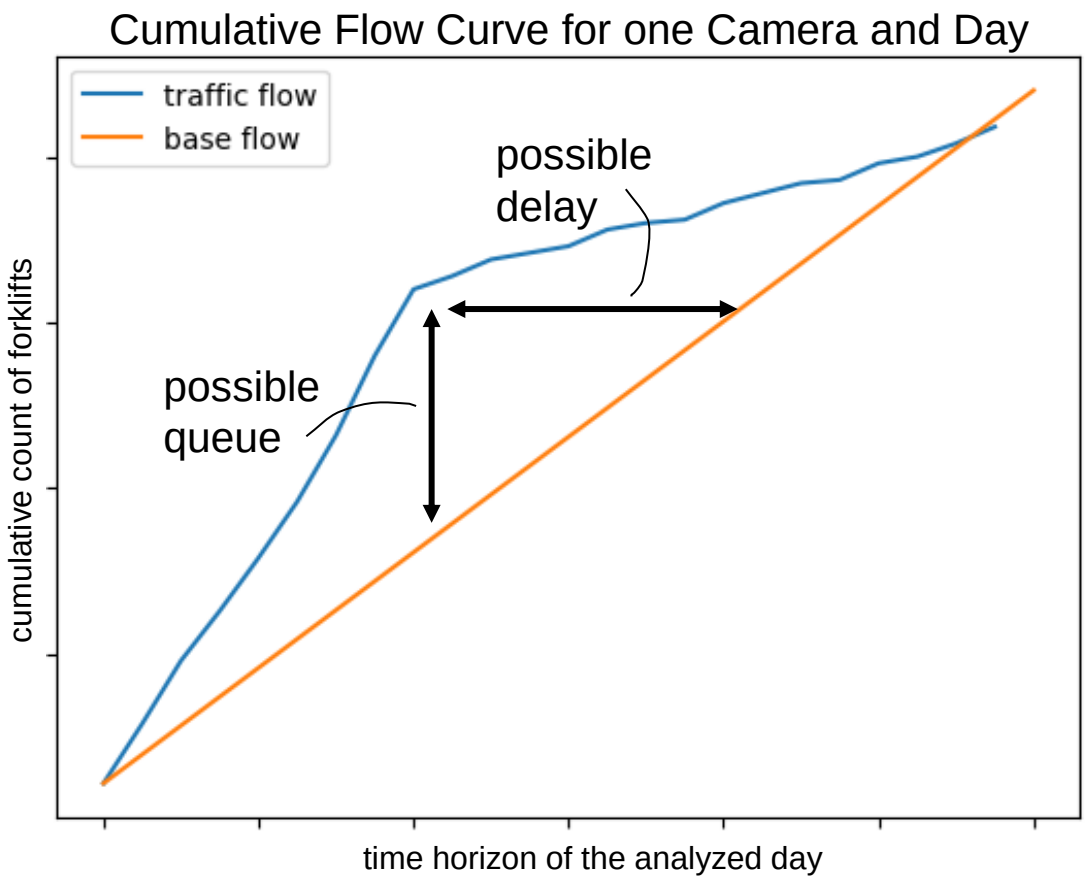
Hypothesis 3: Duration of a Single Transportation Order





Hypothesis 4: Traffic Flow Analysis for Identifying Queues/Delays



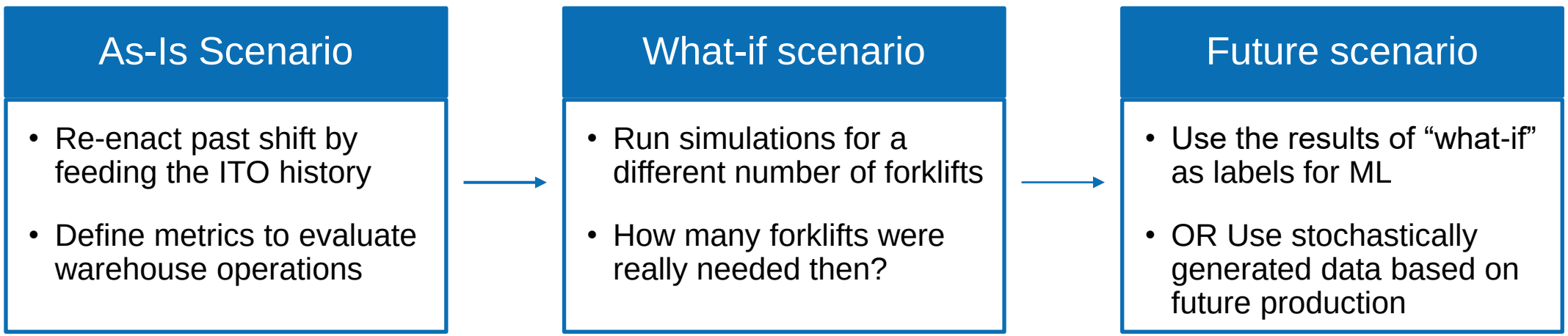


As-Is and What-If Evaluation based on Discrete Event Simulation

Discrete Event Simulation Model

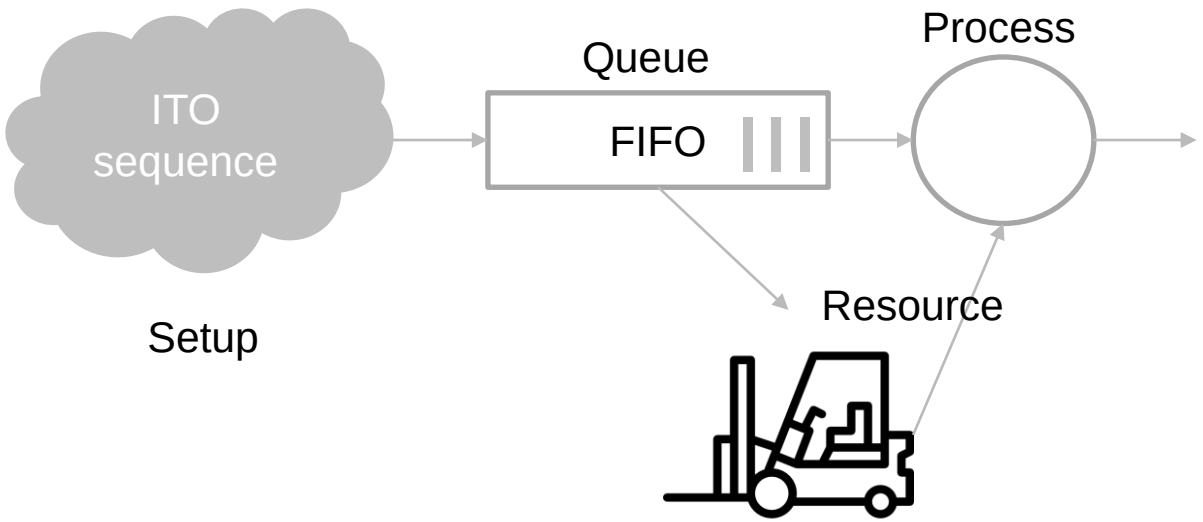
“A Discrete Event Simulation software is assuming the role of the cyber twin, executing simulation software queries on real time data produced by IoT devices embedded on the physical twin, ... facilitate the convergence of the physical and virtual warehouse, thus supporting efficient and responsive warehouse planning, management and decision making. ”

-- Discrete Event Simulation and Digital Twins



Agalianos, K., et al. "Discrete Event Simulation and Digital Twins: Review and Challenges for Logistics." *Procedia Manufacturing* 51 (2020): 1636-1641.

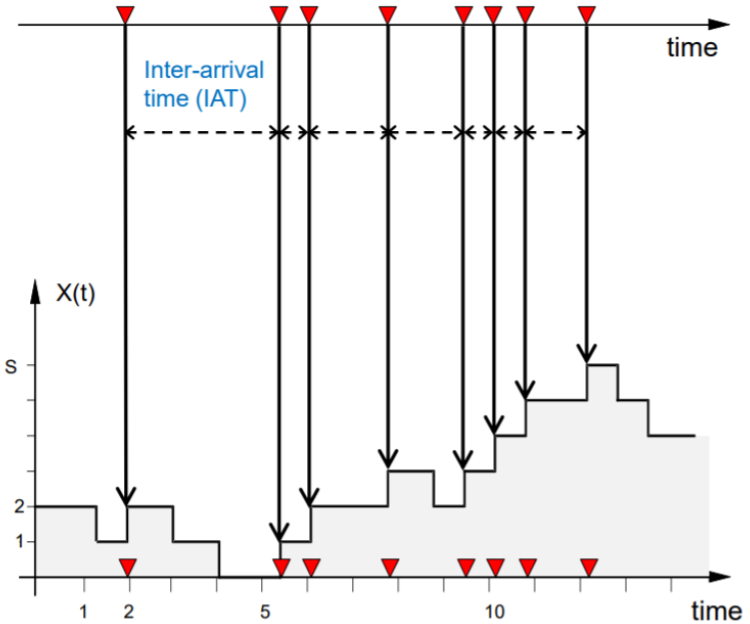
Inside the Discrete Event Simulation Model

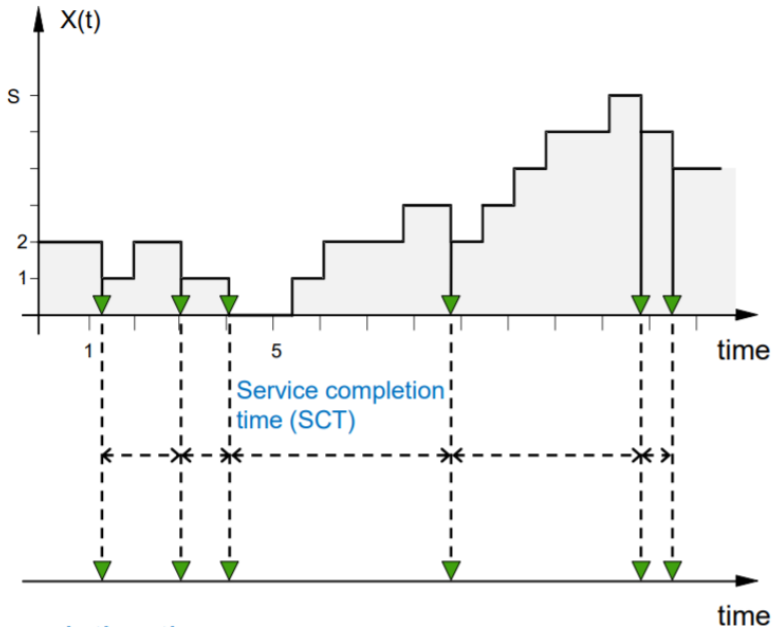


- When the simulation starts, ITO will be injected into the environment at different time steps according to **setup**
- Each new ITO will be added to the **queue** and will request for a **resource**
- If there is a free forklift, a **process** will start to execute the ITO and complete it after some specified time steps
- The simulation ends after running for the total time steps specified by the **environment**

Icon made by Creticca Creative Agency from Flaticon.

Key Inputs to the Simulation





Inter-Arrival Time (ITA):

– Look at all orders at one sorter, the time interval between two picked-up timestamps

Service Completion Time (SCT):

– Look at all orders picked up by one forklift, the time interval between two order's picked-up timestamps

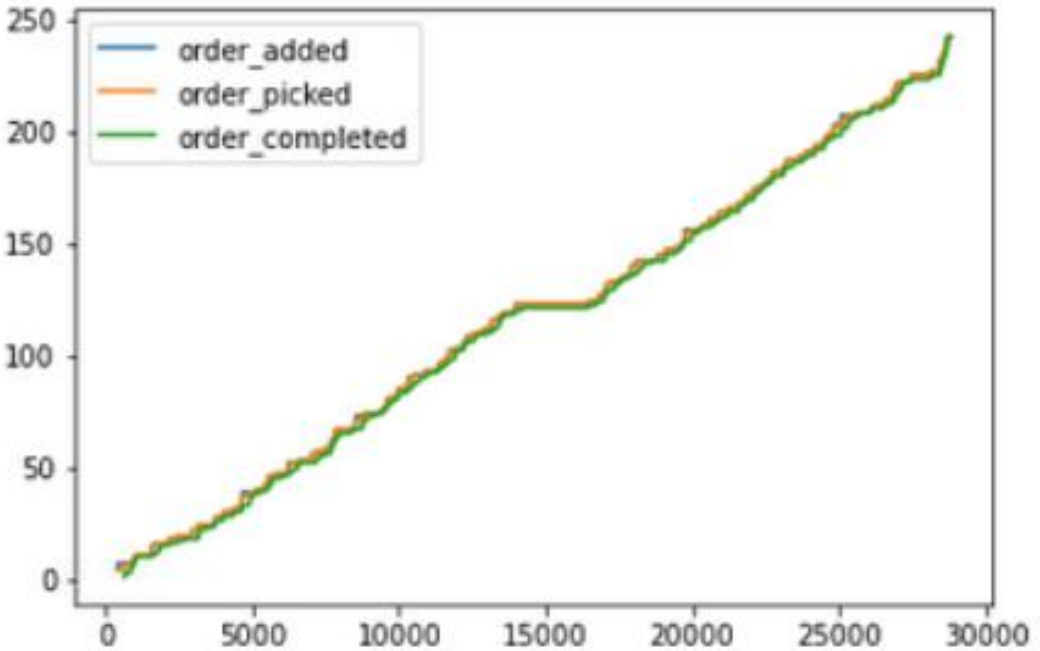
– Subtract idle time intervals using data pipeline output

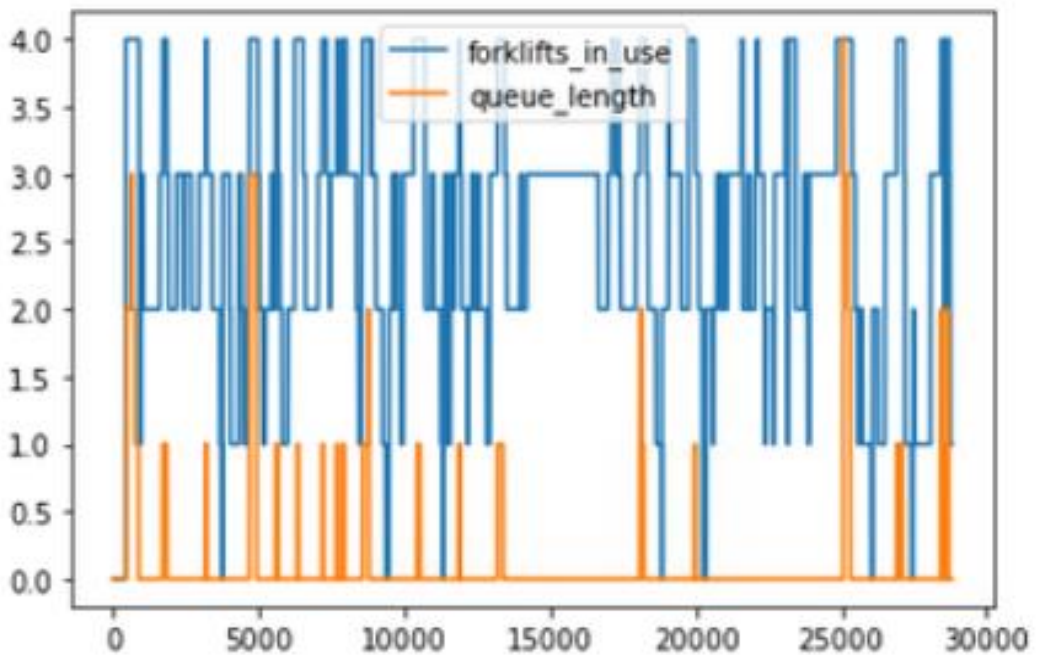
Figures borrowed from TUM WS2011/2012 IN2045 Lecture Notes.

A Simulation Run Step-by-Step

```
5 Forklifts Available.
183292464 arrives at the sorter at 1288.00. waiting for picking up ...
A forklift picks up 183292464 with 12 ovens at the sorter at 1288.00.
183292721 arrives at the sorter at 1499.00. waiting for picking up ...
A forklift picks up 183292721 with 12 ovens at the sorter at 1499.00.
183292954 arrives at the sorter at 1579.00. waiting for picking up ...
A forklift puts 183292464 with 12 ovens away at the destination bin and drove back to the sorter at 1579.00.
A forklift picks up 183292954 with 12 ovens at the sorter at 1579.00.
183292992 arrives at the sorter at 1815.00. waiting for picking up ...
A forklift picks up 183292992 with 12 ovens at the sorter at 1815.00.
A forklift puts 183292954 with 12 ovens away at the destination bin and drove back to the sorter at 1815.00.
183293046 arrives at the sorter at 2011.00. waiting for picking up ...
A forklift puts 183292721 with 12 ovens away at the destination bin and drove back to the sorter at 2011.00.
A forklift picks up 183293046 with 12 ovens at the sorter at 2011.00.
```

As-is Scenario (n=4)

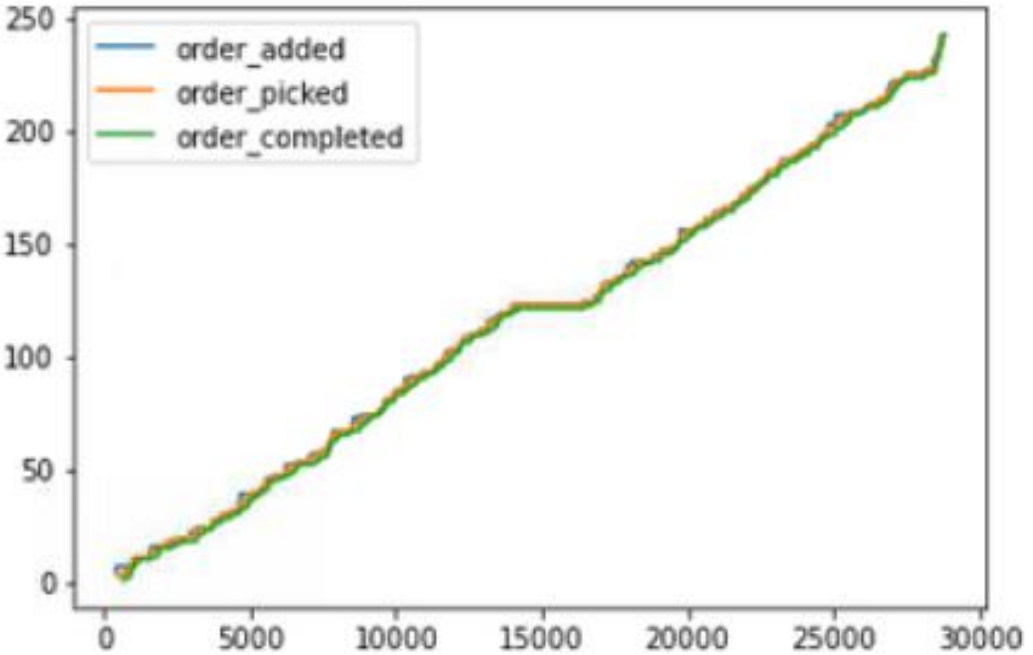


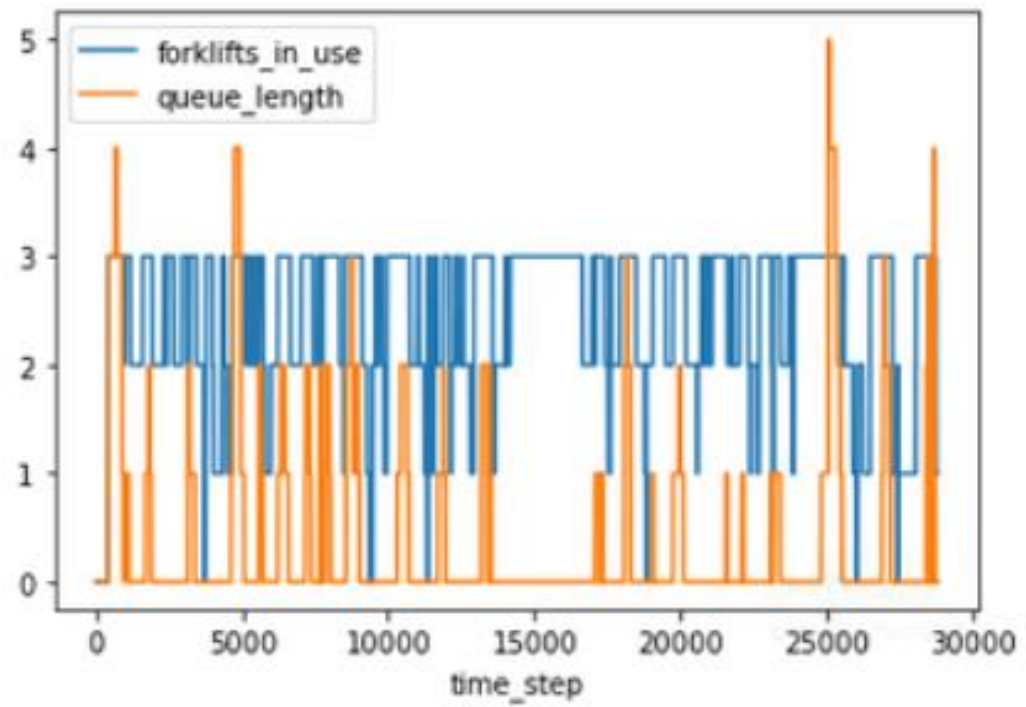


- Orders were immediately picked up and processed most of the time
- Order picked rate reached 100%

- Forklift utilization rate was at only 63.5%
- Max queue length was 4 and the average queue length is only 0.12

What-if Scenario: Reduce Fleet Size by One (n=3)

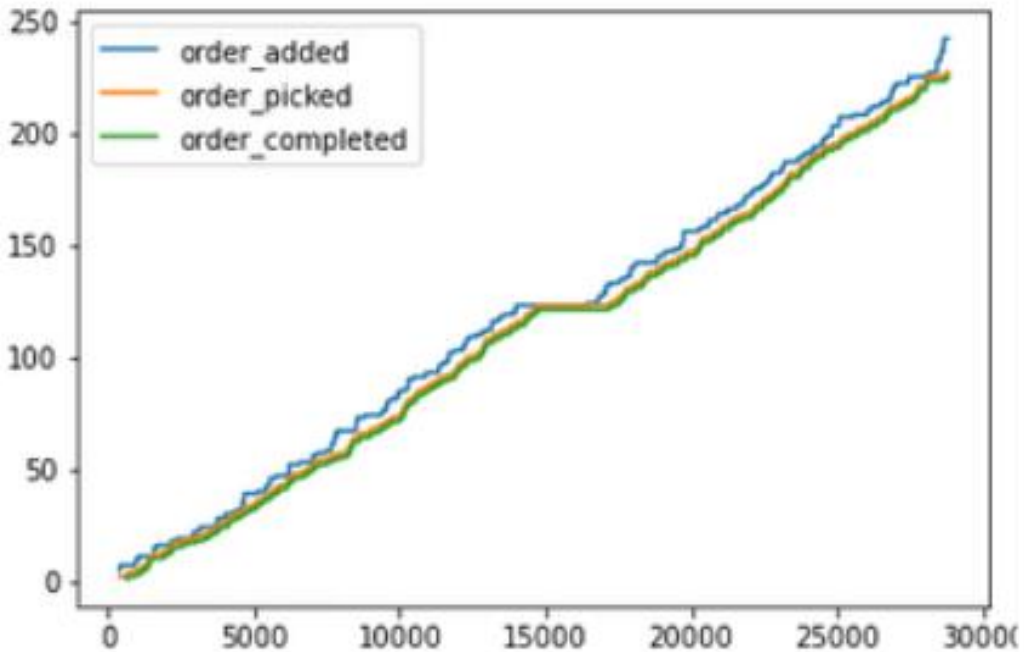


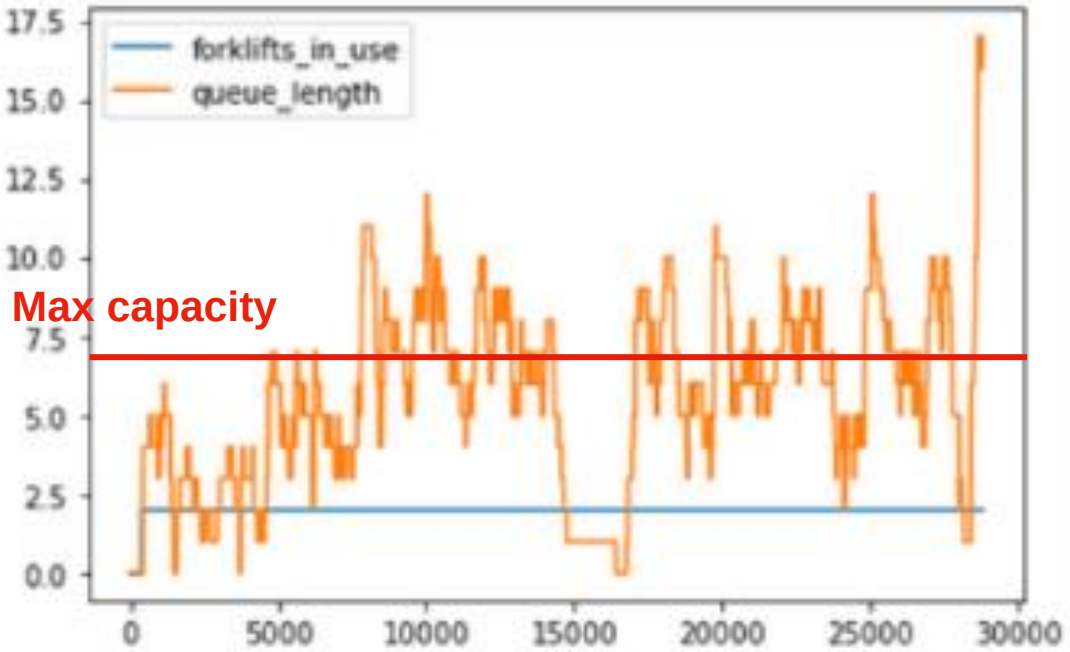


- No significant change from as-is case
- Order picked rate still at 100%

- Forklift utilization rate increased to 81.2%
- Max queue length was 5, increased only by one

What-if Scenario: Reduce Fleet Size by Two (n=2)



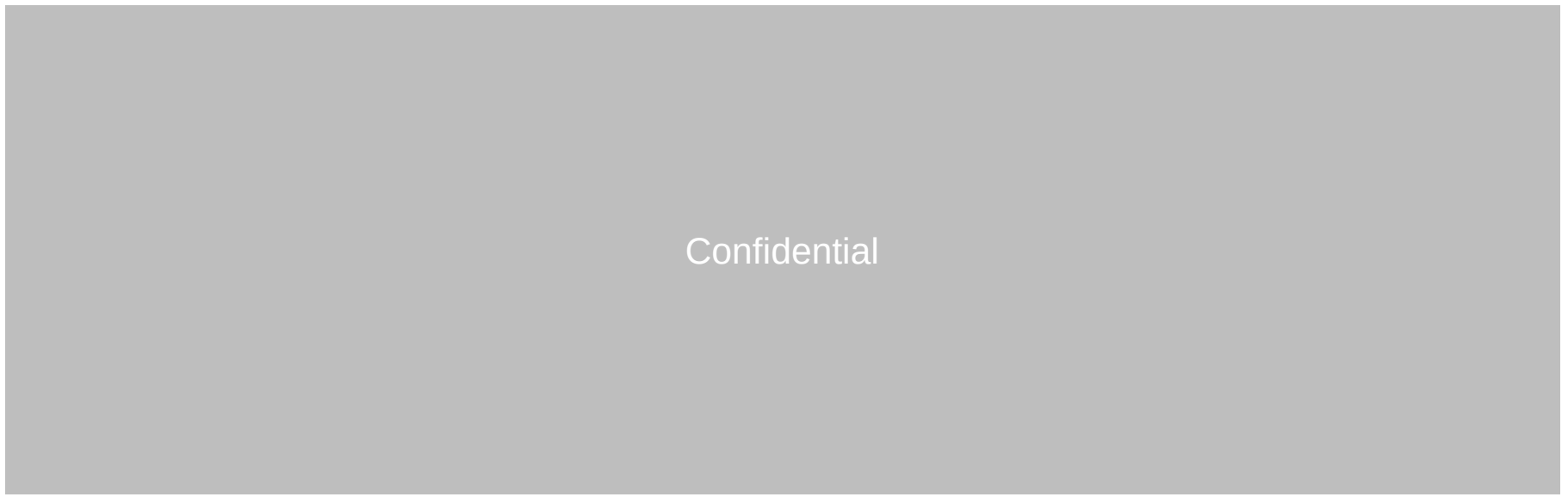


- Visible gaps between order_added and order_picked
- Order picked rate dropped to 93.8%

- Queue cumulated easily
- Max queue length reached 17, exceeding the temporary storage capacity

Large Scale What-if Scenario Analysis

- **“Grid-search” approach:** Run simulations for each shift with n=1 to n=6
- **Best number of forklifts under constraints**: Choose the minimum number of forklifts that satisfy the constraints on order picked rate, forklift utilization rate and max queue length



Prediction of Needed Amount of Forklifts

Two possible Approaches

Supervised ML Models

- Run Simulation for a longer time period on historic ITOs
- Interpret suggested number of forklifts as „true“ labels
- Train a supervised ML model based on the daily production data and other features using the „true“ labels

Generate ITOs from Production Data

- Break down daily production data into realistic ITOs
- Use generated ITOs as input for the simulation
- Simulation gives amount of needed forklifts on a daily/weekly basis

Daily Production Data given

	12.02.2021	13.02.2021	14.02.2021
Sorter 1	564[1]	672	323
Sorter 2	854	785	520
Sorter 3	200	194	102
Sorter 4	403	504	200

1 No real production data; random numbers

Sample Quantity of Transported Products from Historic KLA Distribution to Identify Number of needed ITOs per Sorter and Day

Column of interest

ID	Shift	Arrival Time	Source Bin	Quantity	Distance	Speed	Duration
1			Sorter 3	12			
2			Sorter 3	4			
3			Sorter 3	12			
4			Sorter 3	1			
5			Sorter 3	12			
6			Sorter 3	12			

Distribute Number of ITOs over Different Shifts according to Shift Distribution

Column of interest

ID	Shift	Arrival Time	Source Bin	Quantity	Distance	Speed	Duration
1	1		Sorter 3	12			
2	1		Sorter 3	4			
3	2		Sorter 3	12			
4	2		Sorter 3	1			
5	3		Sorter 3	12			
6	3		Sorter 3	12			

Sample Distance per ITO according to Historic Distance Distribution

Column of interest

ID	Shift	Arrival Time	Source Bin	Quantity	Distance	Speed	Duration
1	1		Sorter 3	12	150m		
2	1		Sorter 3	4	195m		
3	2		Sorter 3	12	85m		
4	2		Sorter 3	1	120m		
5	3		Sorter 3	12	345m		
6	3		Sorter 3	12	450m		

Sample Speed per ITO according to Historic Speed Distribution and Calculate Duration of each ITO

Column of interest

ID	Shift	Arrival Time	Source Bin	Quantity	Distance	Speed	Duration
1	1		Sorter 3	12	150m	2.2 m/s	68.2 s
2	1		Sorter 3	4	195m	2.7 m/s	72.2 s
3	2		Sorter 3	12	85m	1.6 m/s	53.1 s
4	2		Sorter 3	1	120m	2.0 m/s	60 s
5	3		Sorter 3	12	345m	2.4 m/s	143.7 s
6	3		Sorter 3	12	450m	2.9 m/s	155.2 s

Distribute ITOs Uniformly over Different Shifts

Column of interest

ID	Shift	Arrival Time[1]	Source Bin	Quantity	Distance	Speed	Duration
1	1	2304	Sorter 3	12	150m	2.2 m/s	68.2 s
2	1	4608	Sorter 3	4	195m	2.7 m/s	72.2 s
3	2	6301	Sorter 3	12	85m	1.6 m/s	53.1 s
4	2	12602	Sorter 3	1	120m	2.0 m/s	60 s
5	3	1300	Sorter 3	12	345m	2.4 m/s	143.7 s
6	3	2600	Sorter 3	12	450m	2.9 m/s	155.2 s

1 sec/shift

Remarks on Production Breakdown Approach

- Possible to adjust all the different distributions
- Allows BSH to predict amount of forklifts on a daily basis
- First test runs done with promising results
- Further improvements possible in distribution of arrival time

Future Work with Our Results

Future Work

Business Side:

- Validation of the right number of allocated forklifts per shift
- Forecast of the right amount of needed forklift drivers

Model Owner:

- Analysis of efficiency and transportation orders
- Evaluation of idle and driving time
- Identifying queues and delays by traffic flow analysis

Thank you!