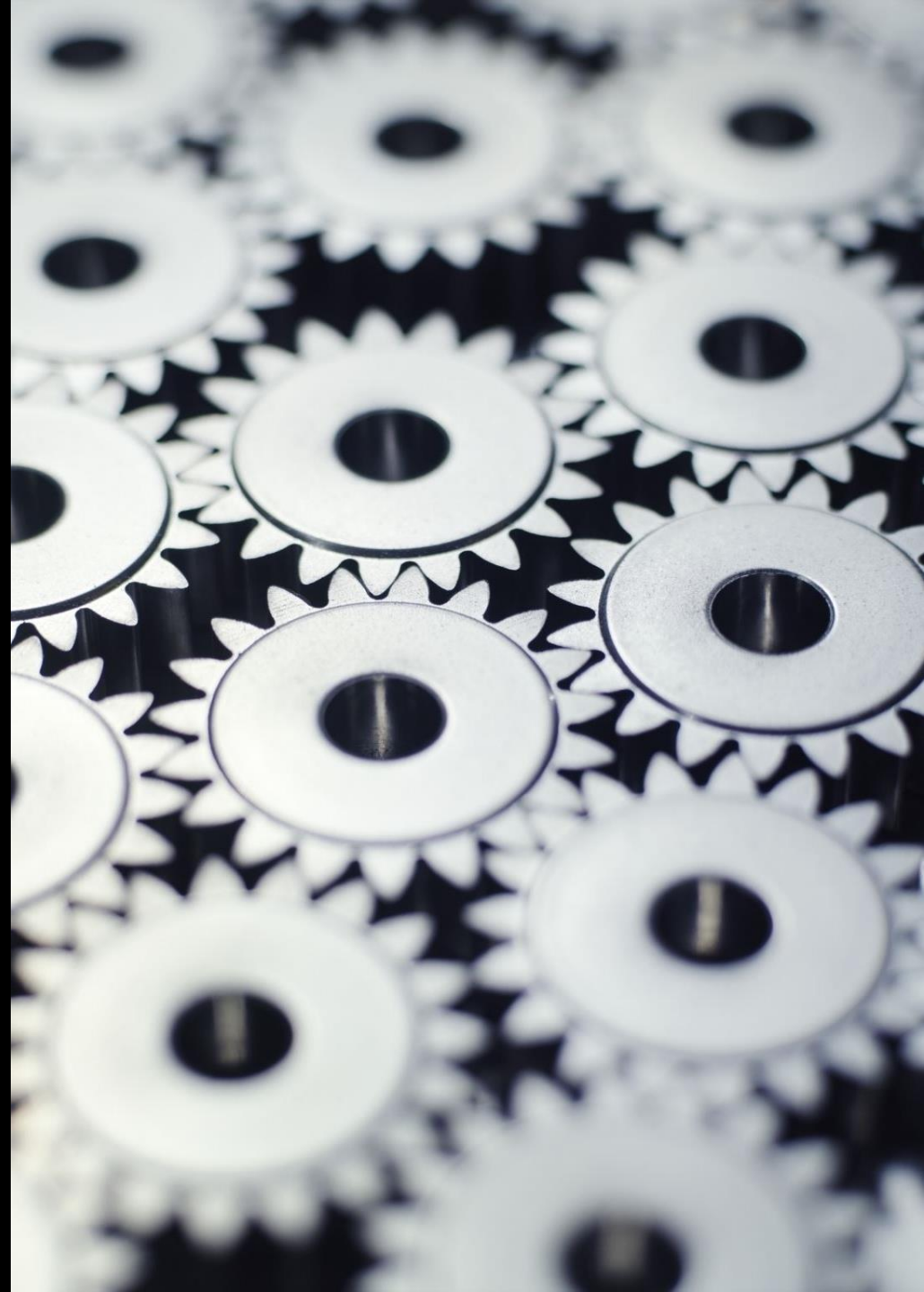


ASSEMBLY LINE OPTIMIZATION FOR BATTERY PACK PRODUCTION

Team 7

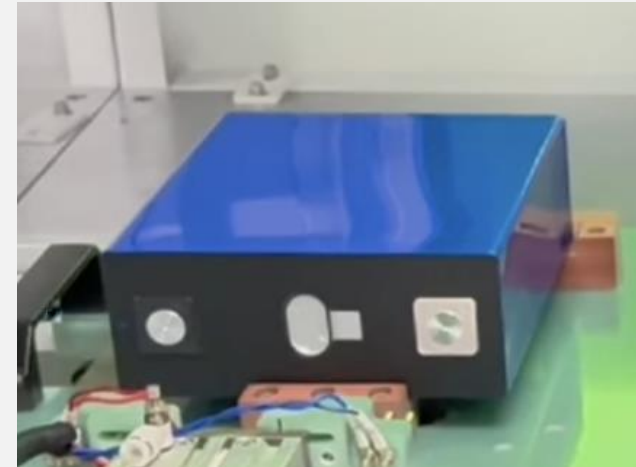
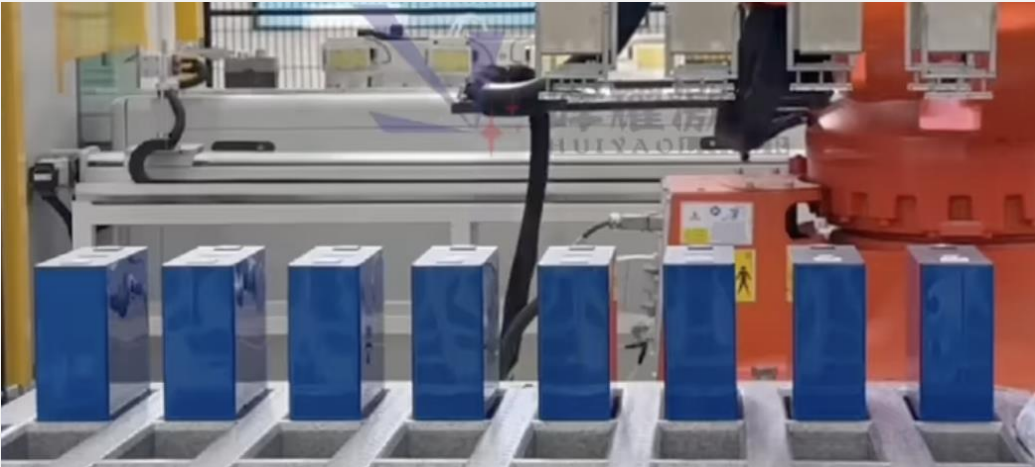
Ashutosh Kulkarni

Advait Naik



BATTERY PACK PRODUCTION

15 – station line



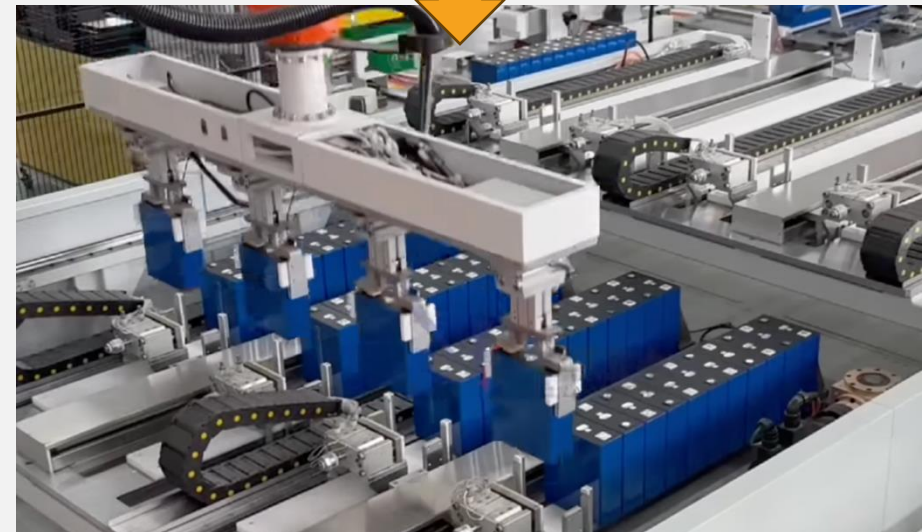
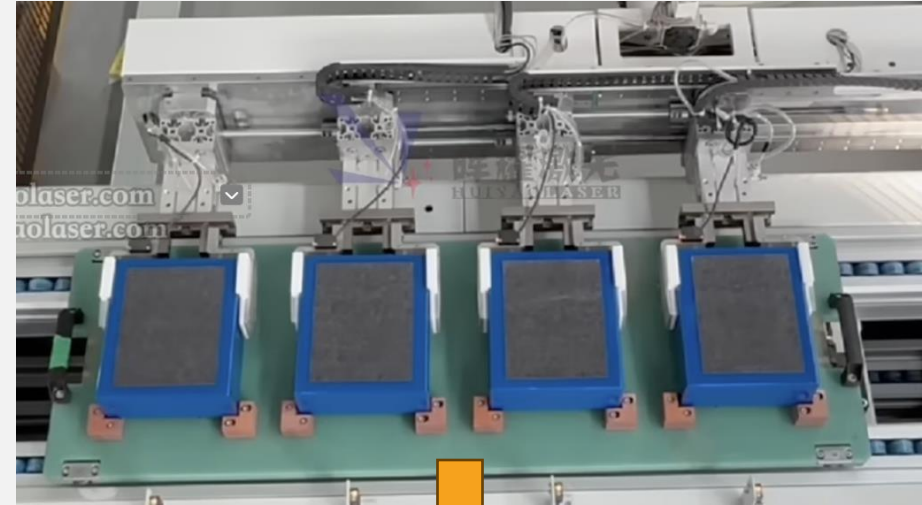
We start with a pallet of 4 cells, at Station 5 we switch to a stack of x number of cells.

Objective:
Assembly of connected Battery Module



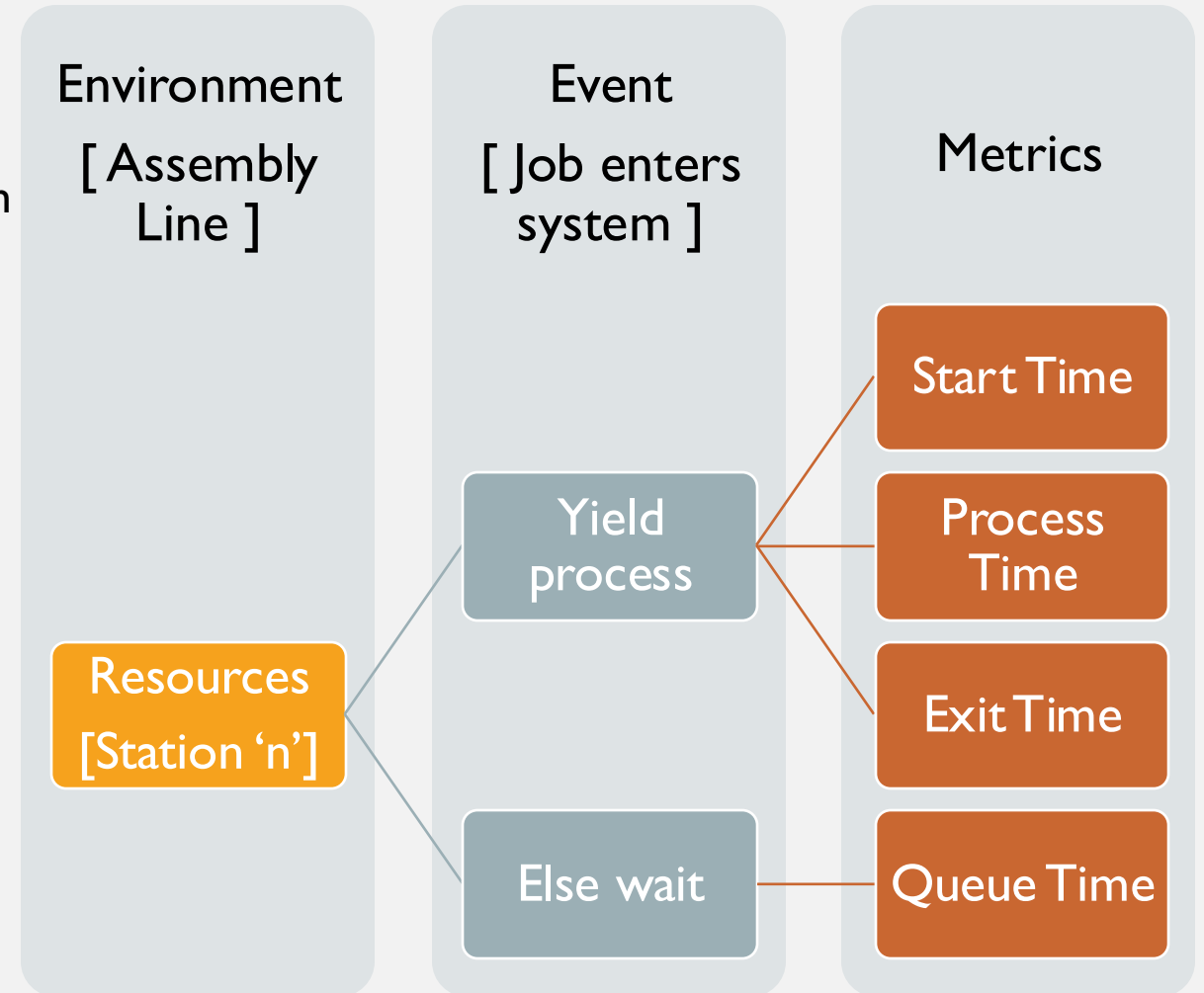
ASSEMBLY LINE

- 0: Pallet Loading
- 1: OCV Test
- 2: Cell Replacement
- 3: Orientation Correction
- 4: Adhesive Tape Application
- 5: Pallet Offload and Stack Assembly
[Acts as a buffer until x cells are stacked]
- 6: Cell Pressing
- 7: Cell code scanning and Binding
- 8: Insulation Testing
- 9: Terminal Pole scanning
- 10: Laser Cleaning
- 11: CCS Installation
- 12: Welding
- 13: Post Weld Cleaning
- 14: EOL Testing
- 15: Off Loading

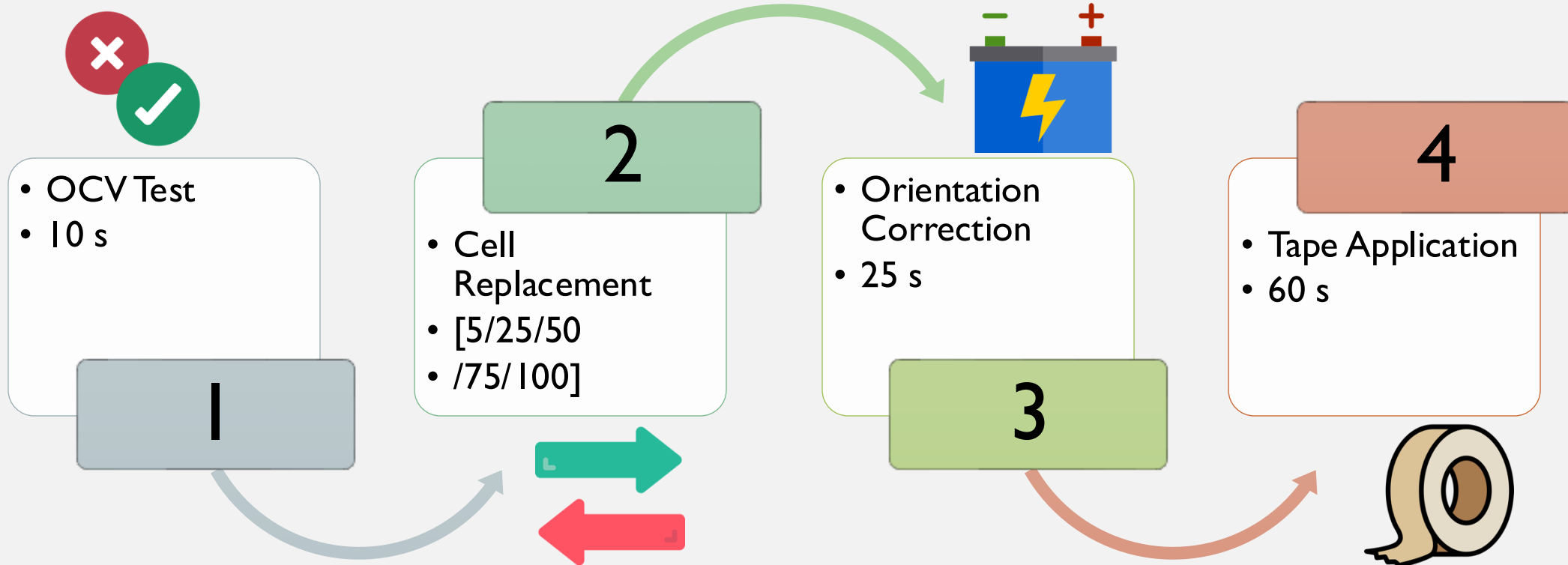


SIMULATION BASICS

- We use the **SimPy** library in Python.
- We define an **environment**, which serves as the execution space.
- Within this environment, we define **resources**, that can be requested and used by **customers**.
- For our application:
 - Environment** → **Assembly Line**
 - Resources** → **Stations**
 - Customers** → **Jobs / Work Units**
- We can control WIP limit, number of jobs to be sent and process CVs.



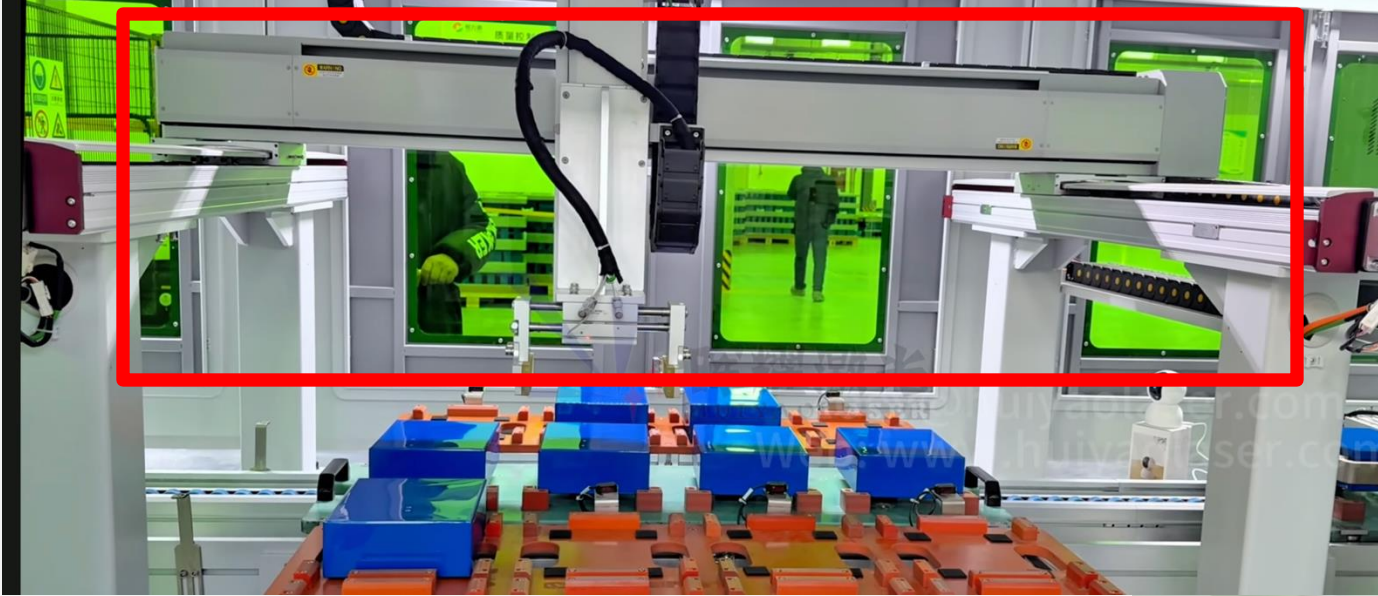
SIMULATION PART I: STATION 1 TO 4



Process Variabilities:
CV = 0.2 | Automated stations
CV = 0.5 | Manual stations

Station 2:
Process time dependent on #cells
to be replaced

STATION 2



Gantry arm with 1 gripper
Can only pickup one cell

OK : Replacement cells
NG : Area for rejected cells



OUTPUT

Job 54:

CONWIP Wait: 1720.07 seconds

Station	Arrival	Exit	Process	Queue

Station 1	3045.07	3053.86	8.79	0.00
Station 2	3053.86	3226.39	5.00	167.53
Station 3	3226.39	3273.65	32.35	14.91
Station 4	3273.65	3328.44	54.78	0.00

Queue time data in original system:

We use 'random.seed' function to get the same random pattern to compare results.

Observation: Maximum queue 167 s.

More than 5 jobs experience a queue of >100s

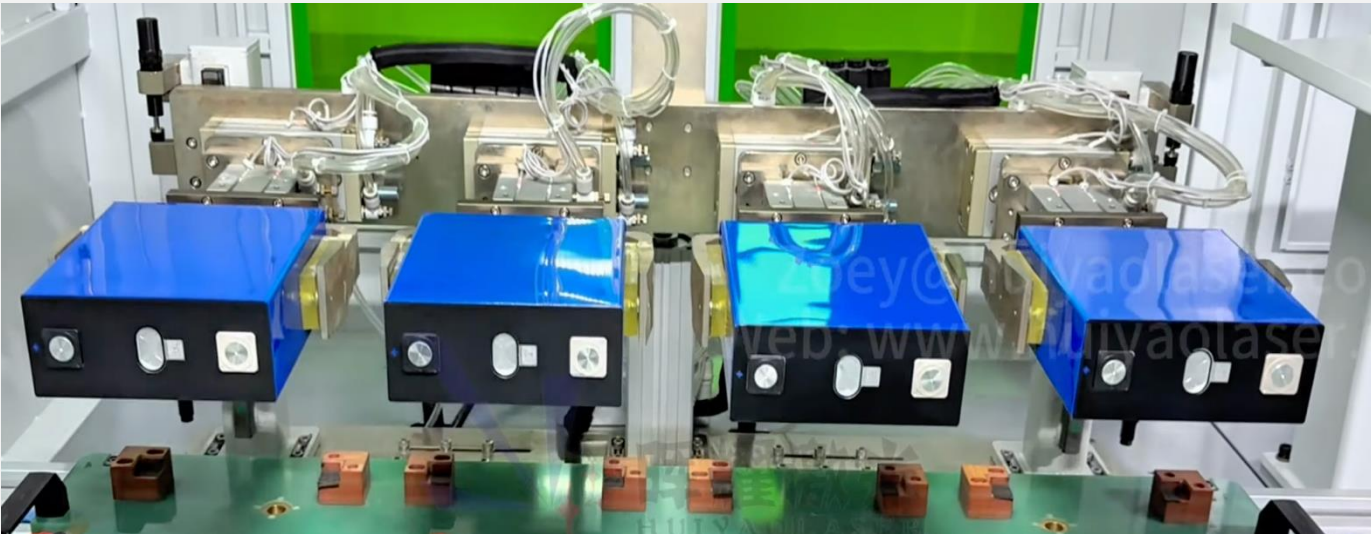
STATION 2 UPGRADE

Problem: The original station can only replace 1 cell at a time.

Solution: Replacing the gantry arm with a tool/gripper that can pickup 1 to 4 cells as required.

OR

Replace the complete station with a Kuka robot just like station 0 which is capable of replacing up 4 cells. [expensive, difficult integration]



Result: Change process times to [5 or 25], reducing variability and impact queue times.

STATION 2 UPGRADE RESULT

Result: Reducing Process time variability led to significant reduction in queues

Job 14:

CONWIP Wait: 246.47 seconds

Station	Arrival	Exit	Process	Queue
Station 1	571.47	582.80	11.33	0.00
Station 2	582.80	587.80	5.00	0.00
Station 3	587.80	608.08	20.28	0.00
Station 4	608.08	914.48	34.41	271.98

Job 15:

CONWIP Wait: 255.10 seconds

Station	Arrival	Exit	Process	Queue
Station 1	605.10	613.48	8.38	0.00
Station 2	613.48	618.48	5.00	0.00
Station 3	618.48	650.92	32.44	0.00
Station 4	650.92	933.19	18.72	263.56

Observation: Queue times have reduced significantly at station 2.

But now, we have a queue on station 4.

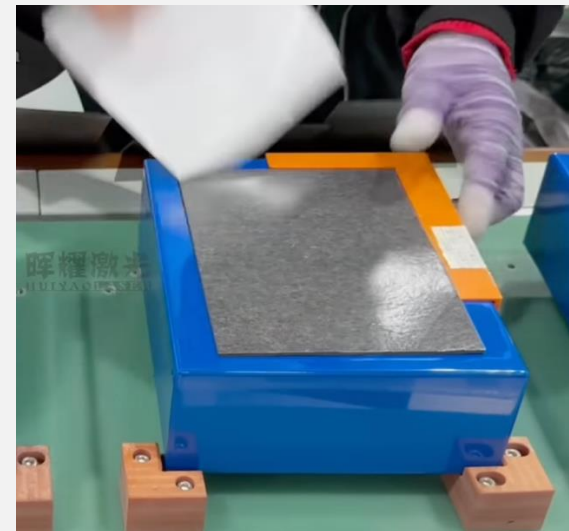
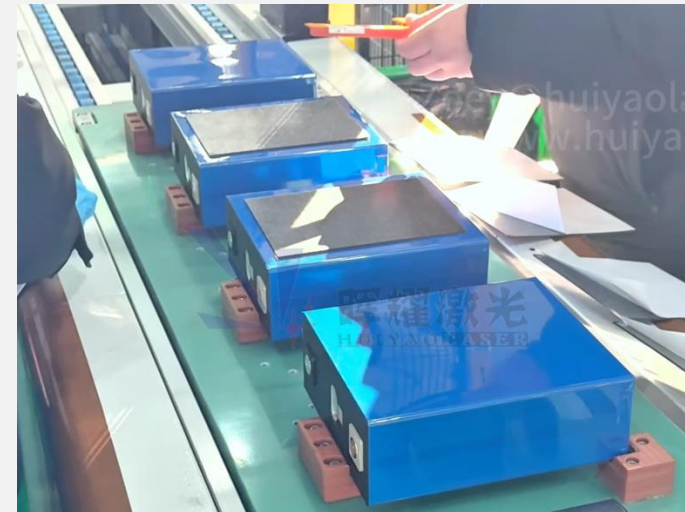
STATION 4

This is manual station with one operator [capacity = 1 pallet]
Operator places a double-sided adhesive tape with the help of a tool.

Process time has variability and chance of rework.

To reduce queue, we explore following options:

1. Improve mean cycle time by 50%, i.e. 30s we get reduction in queue times. Can be achieved by having 2 operators.
2. Two parallel station with one operator each. Cycle time for each is 60. Job waiting in queue will go to the next free station.



STATION 4 UPGRADE

50% reduction in cycle time to 30s
2 Operators at the station

Job 14:
CONWIP Wait: 29.15 seconds

Station	Arrival	Exit	Process	Queue
Station 1	354.15	366.35	12.20	0.00
Station 2	366.35	371.35	5.00	0.00
Station 3	371.35	400.20	20.24	8.61
Station 4	400.20	532.84	13.53	119.11

Max queue: 119s

Also, queue at station 2 [24 jobs, max 26s]

2 Parallel stations, mean cycle time 60s.
[capacity = 2 in code]

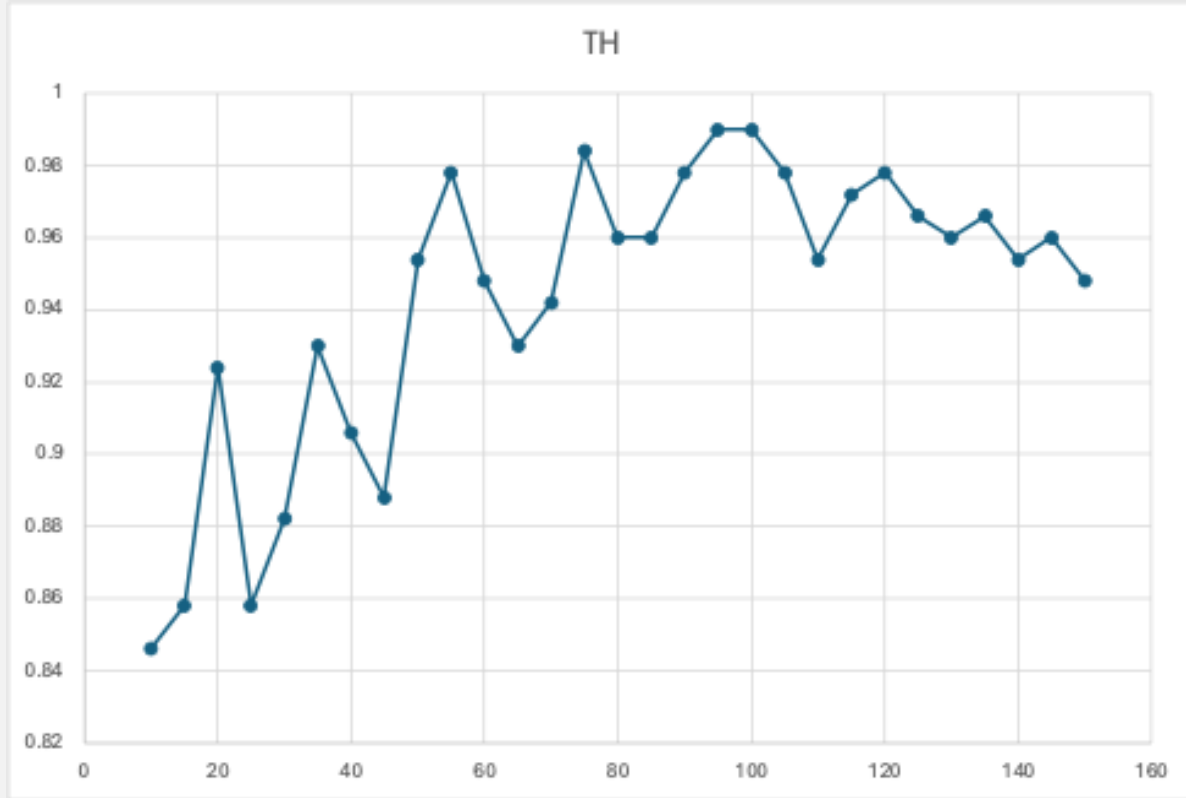
Job 37:
CONWIP Wait: 72.54 seconds

Station	Arrival	Exit	Process	Queue
Station 1	972.54	987.60	8.29	6.78
Station 2	987.60	993.41	5.00	0.81
Station 3	993.41	1047.39	20.25	33.73
Station 4	1047.39	1224.76	106.19	71.18

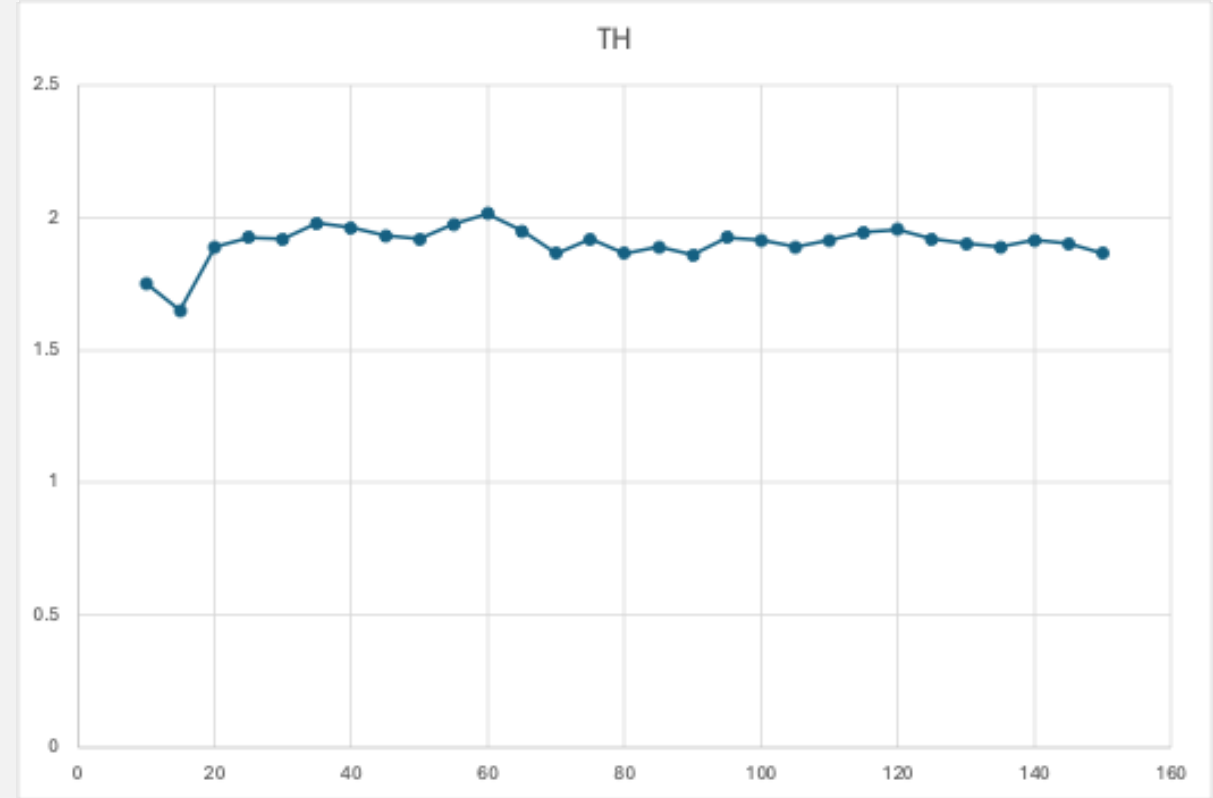
Max queue: 71s

Also, queue at station 2 [20 jobs, max 28s]

RESULTS



Before



After

OVERVIEW OF ASSEMBLY LINE PART 2

Station 6 – Cell Pressing

- Cells loaded into press fixture and compressed hydraulically.
- Operator installs two retaining rings on the compressed stack.

Station 7 – Cell Code Scanning & Module Labeling

- QR codes of individual cells scanned for traceability.
- Battery module identification sticker applied.

Station 8 – Insulation Testing

- Automated insulation resistance test.
- Ensures electrical isolation compliance before further assembly.

Station 9 – Terminal Pole Scanning

- Scans positive/negative terminal information.
- Verifies polarity and prevents mismatch errors.

Station 10 – Laser Cleaning

- Automated laser cleaning of terminal surfaces.
- Removes contaminants to prepare for welding.

Station 11 – CCS Installation

- Manual installation of Cell Connection System (CCS) parts.
- Ensures proper alignment before welding.

Station 12 – Welding

- Automated welding of CCS to cell terminals.
- Ensures strong electrical and structural connections.

Station 13 – Post-Weld Cleaning

- Cleans welded areas to remove debris.
- Prepares module for final inspection.

Station 14 – End-of-Line (EOL) Testing

- Final functional and safety testing of the module.
- Confirms compliance with quality standards.

Station 15 – Off-Loading

- Finished modules removed from the line.
- Prepared for packaging or downstream logistics.

SIMULATION PART 2, STATION 6 TO 15

- **System Structure**
- The assembly line consists of **10 sequential processing stations** (Stations 6–15).
 - Each station functions as a **single-server resource** with a capacity of one pallet, unless otherwise specified.
- **Arrivals**
- Jobs enter the system following a **fixed arrival pattern of one job every 60 seconds** (interarrival rate = $1/60$ jobs/s).
 - A total of **50 jobs** were introduced for the simulation run.
 - The **deterministic arrival pattern** enables clear identification of bottlenecks and queue formation throughout the line.

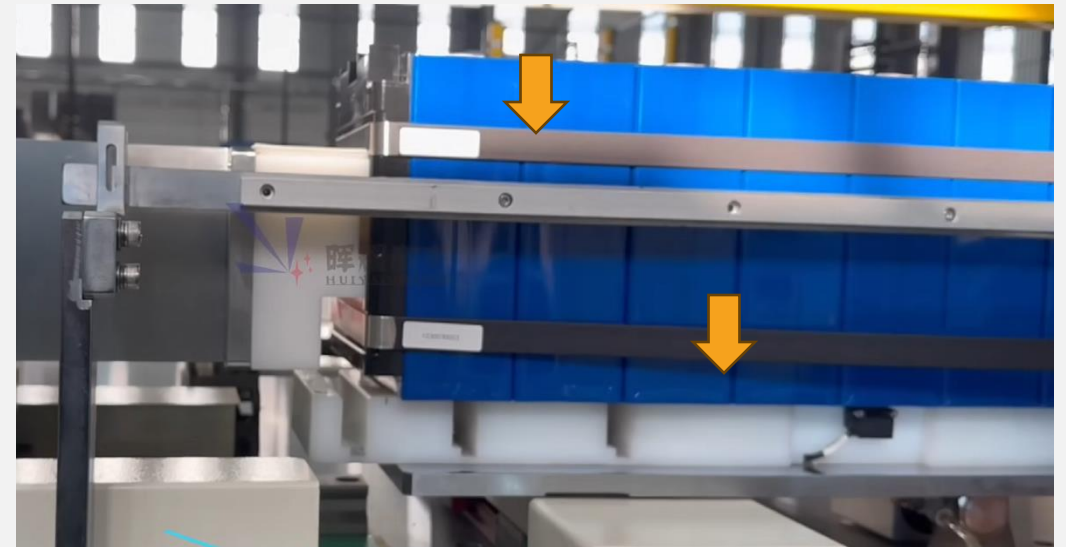
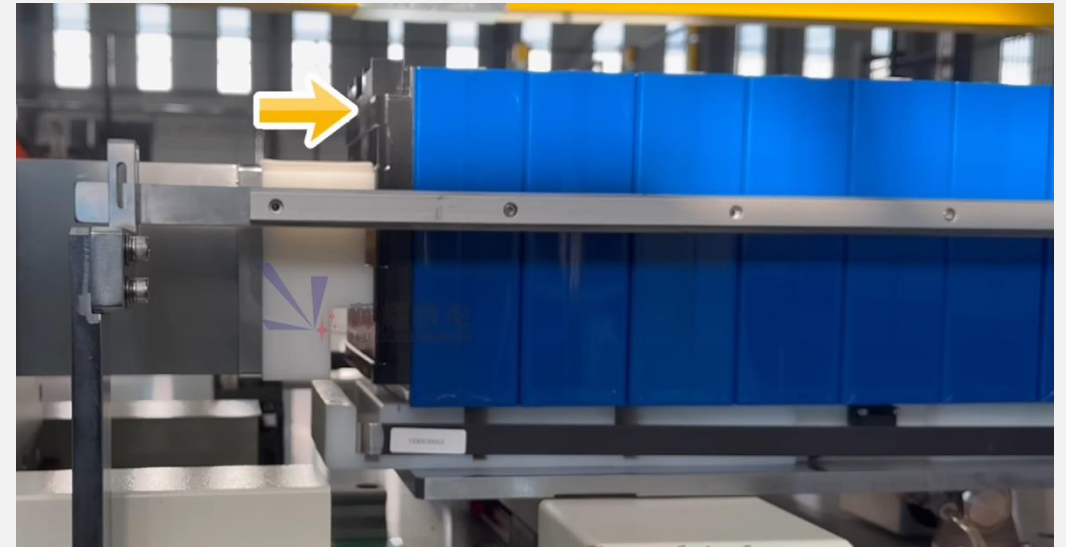
Station	Mean Time (s)
6	85
7	60
8	45
9	60
10	70
11	60
12	70
13	60
14	60
15	45

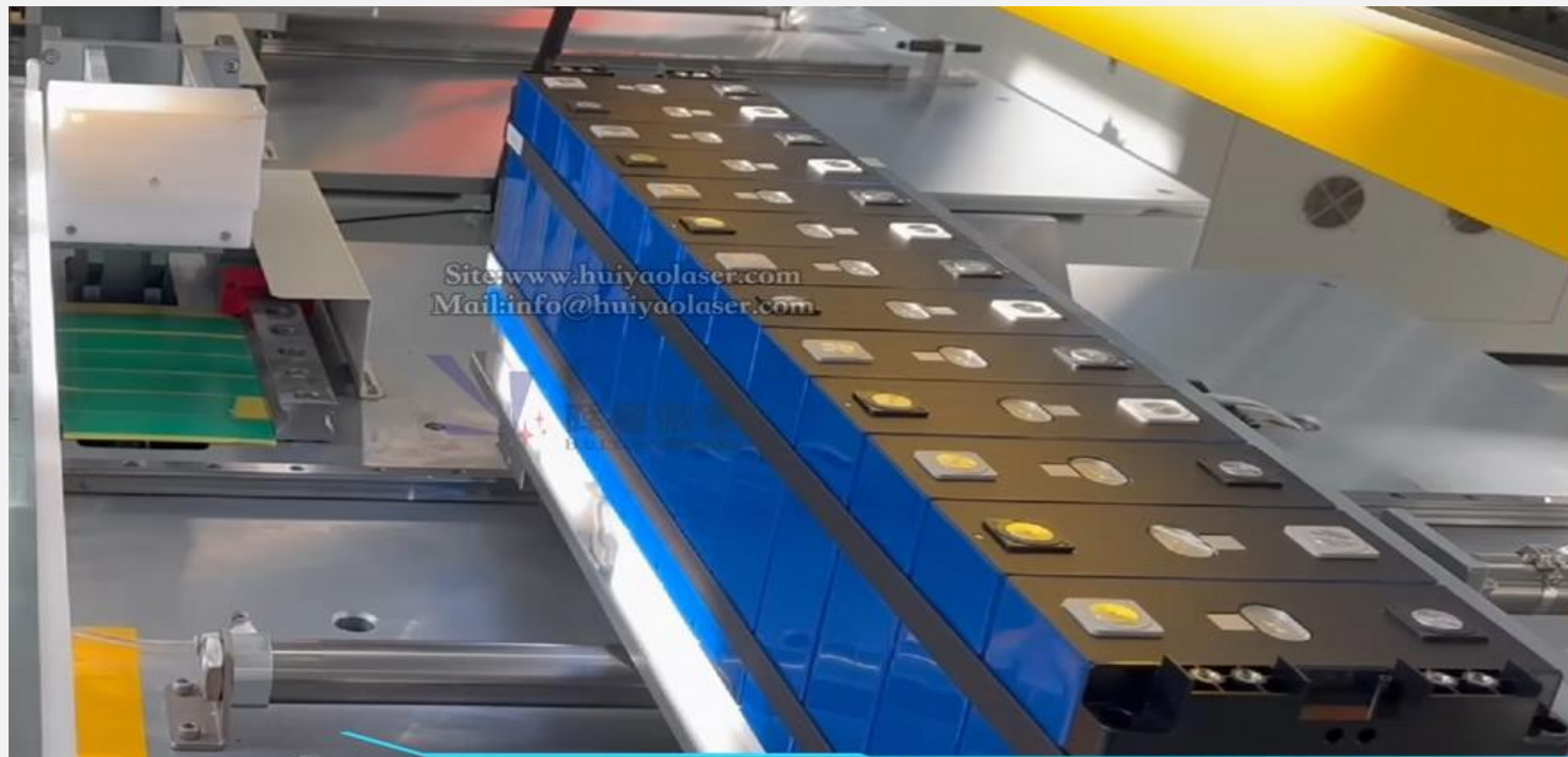
STATION 6 PROCESSING

- This is a manual station operated by one operator (capacity = 1 pallet).
At this station, all battery cells are first loaded onto the pressing fixture. A horizontal hydraulic load is then applied to compress the stacked cells. Following the press operation, the operator manually installs two rings onto the compressed cell stack.

Process Improvement Ideas

- To reduce queue buildup at Station 6, we explore the following improvement option:
- **Increase station capacity by doubling the number of parallel setups**, enabling two pallets to be processed simultaneously. This would distribute the workload, reduce waiting times, and improve overall flow through the station.





Final Battery Pack Module

Job 35:

Station	Arrival	Exit	Process	Queue	Cycle

Station 6	2862.33	3032.32	48.78	121.21	169.99
Station 7	3032.32	3091.26	44.33	14.61	58.94
Station 8	3091.26	3156.39	65.13	0.00	65.13
Station 9	3156.39	3216.84	60.45	0.00	60.45
Station 10	3216.84	3278.76	55.28	6.64	61.92
Station 11	3278.76	3340.64	61.88	0.00	61.88
Station 12	3340.64	3439.72	63.71	35.37	99.08
Station 13	3439.72	3472.90	33.18	0.00	33.18
Station 14	3472.90	3543.03	49.39	20.75	70.13
Station 15	3543.03	3582.24	39.21	0.00	39.21

Longest queue at station 6

Average value of Queue before
Station Upgrade

=====			
STATION CYCLE TIME BREAKDOWN			
=====			
Station	Avg Queue	Avg Process	Avg Cycle

Station 6	54.29	82.95	137.24
Station 7	1.36	58.95	60.30
Station 8	0.11	43.72	43.83
Station 9	4.21	58.09	62.30
Station 10	7.27	68.96	76.23
Station 11	4.68	61.38	66.06
Station 12	13.96	67.73	81.69
Station 13	6.09	60.88	66.97
Station 14	4.11	58.97	63.09
Station 15	1.09	44.42	45.51

TOTAL	97.18	606.05	703.22
=====			

DOUBLING STATION 6 CAPACITY: SIMULATION RERUN TO REMOVE BOTTLENECK

- **What We Changed**
- Increased **Station 6 capacity** from 1 → 2 servers.
- No other process times, arrival patterns, or WIP limits were changed.
- Objective: **reduce queue buildup at Station 6** and improve overall line flow.
- **Why This Change**
- Baseline simulation showed **Station 6 had the highest queue time (121 s)**.
- It acted as the **entry bottleneck**, causing long CONWIP token waits (~607 s).
- Doubling capacity targets **faster clearance of incoming jobs** and smoother downstream flow.
- **Expected Outcomes Before Rerun**
- Significant reduction in **queueing at Station 6**.
- Potential improvements in **cycle time and throughput**.
- Decreased **CONWIP wait**, since tokens should circulate faster.
- Some **load shifting**—new bottlenecks may emerge (likely Station 10 or 12).

Job 37:

Station	Arrival	Exit	Process	Queue	Cycle

Station 6	2872.37	2939.73	67.36	0.00	67.36
Station 7	2939.73	3062.08	57.42	64.92	122.35
Station 8	3062.08	3108.98	45.92	0.98	46.90
Station 9	3108.98	3219.56	54.73	55.84	110.58
Station 10	3219.56	3325.98	88.65	17.77	106.42
Station 11	3325.98	3387.00	61.02	0.00	61.02
Station 12	3387.00	3447.62	60.62	0.00	60.62
Station 13	3447.62	3503.48	37.11	18.75	55.86
Station 14	3503.48	3589.72	57.23	29.02	86.24
Station 15	3589.72	3620.18	26.25	4.21	30.46

New Bottleneck
Station 7

Significant reduction in **queueing** at
Station 6

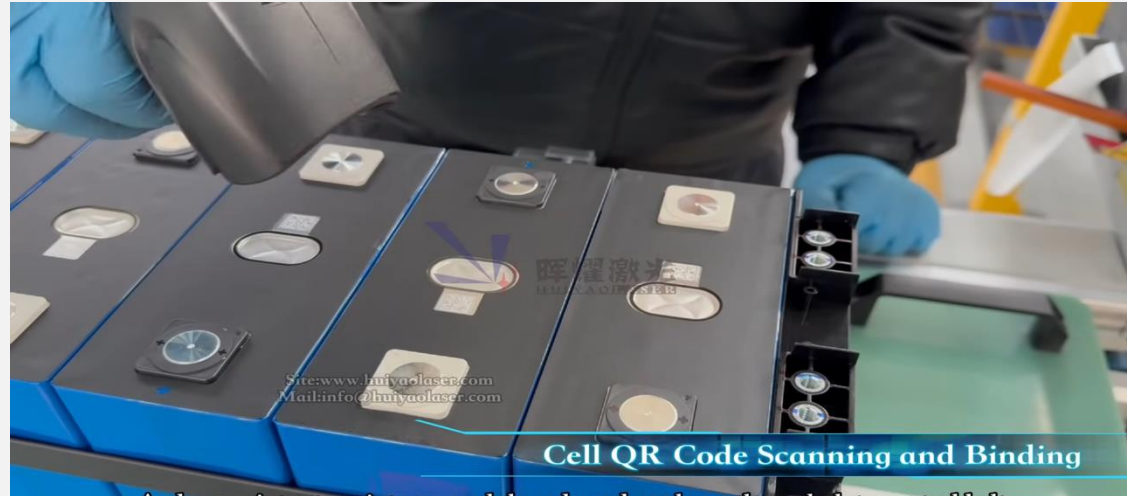
=====			
STATION CYCLE TIME BREAKDOWN			
=====			
Station	Avg Queue	Avg Process	Avg Cycle

Station 6	0.82	85.82	86.64
Station 7	17.53	62.18	79.72
Station 8	0.49	46.33	46.82
Station 9	9.57	60.42	70.00
Station 10	14.33	67.88	82.21
Station 11	6.60	57.12	63.72
Station 12	13.26	68.13	81.40
Station 13	2.59	55.99	58.58
Station 14	4.76	59.64	64.41
Station 15	0.64	41.45	42.09

TOTAL	70.60	604.97	675.57
=====			

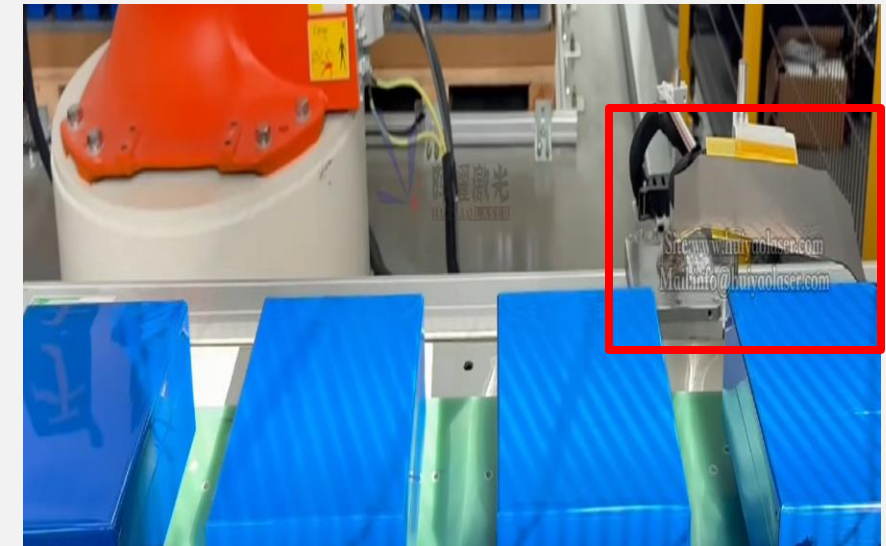
STATION 7: CELL QR CODE SCANNING AND MODULE STICKER PLACEMENT

- **This is a manual station operated by one operator (capacity = 1 pallet).** At this station, the operator begins by scanning the QR codes of each individual battery cell to verify identification, traceability, and correct sequencing. This ensures that all cells loaded onto the pallet match the required production specifications.
- After completing the scanning task, the operator applies the designated battery module sticker to the assembled cell stack.



NEW BOTTLENECK AT STATION 7: PROCESS OPTIMIZATION THROUGH SEMI-AUTOMATION

- **What We Observed After the Previous Improvement**
- Removing the Station-6 bottleneck caused **system flow to speed up at the entry point**.
- As expected, the bottleneck **shifted downstream**, with **Station 7 becoming the new constraint**.
- **Optimization Action Taken**
- Our target is to reduce the cycle time of St. 7 to 45s
- Implemented **semi-automation** to reduce manual workload at Station 7.
- **Reduced process time** by automating cell QR code scanning process.
- **Expected Impact of This Improvement**
- Shorter **processing time** → shorter queues at Station 7.
- Reduced **overall cycle time** across the line.



Job 39:

Station	Arrival	Exit	Process	Queue	Cycle

Station 6	2902.08	2970.62	68.55	0.00	68.55
Station 7	2970.62	3004.26	33.64	0.00	33.64
Station 8	3004.26	3037.63	33.36	0.00	33.36
Station 9	3037.63	3151.03	67.12	46.29	113.41
Station 10	3151.03	3292.06	59.86	81.17	141.03
Station 11	3292.06	3388.31	69.56	26.69	96.25
Station 12	3388.31	3475.08	70.87	15.89	86.76
Station 13	3475.08	3553.10	78.03	0.00	78.03
Station 14	3553.10	3622.48	69.38	0.00	69.38
Station 15	3622.48	3655.74	33.26	0.00	33.26

Job 48:

Station	Arrival	Exit	Process	Queue	Cycle

Station 6	3726.52	3823.79	97.28	0.00	97.28
Station 7	3823.79	3859.92	36.12	0.00	36.12
Station 8	3859.92	3899.99	40.07	0.00	40.07
Station 9	3899.99	3956.54	56.55	0.00	56.55
Station 10	3956.54	4006.37	49.83	0.00	49.83
Station 11	4006.37	4041.67	33.45	1.85	35.30
Station 12	4041.67	4207.13	75.25	90.21	165.46
Station 13	4207.13	4267.29	60.15	0.00	60.15
Station 14	4267.29	4313.56	46.27	0.00	46.27
Station 15	4313.56	4350.04	36.49	0.00	36.49

=====

STATION CYCLE TIME BREAKDOWN

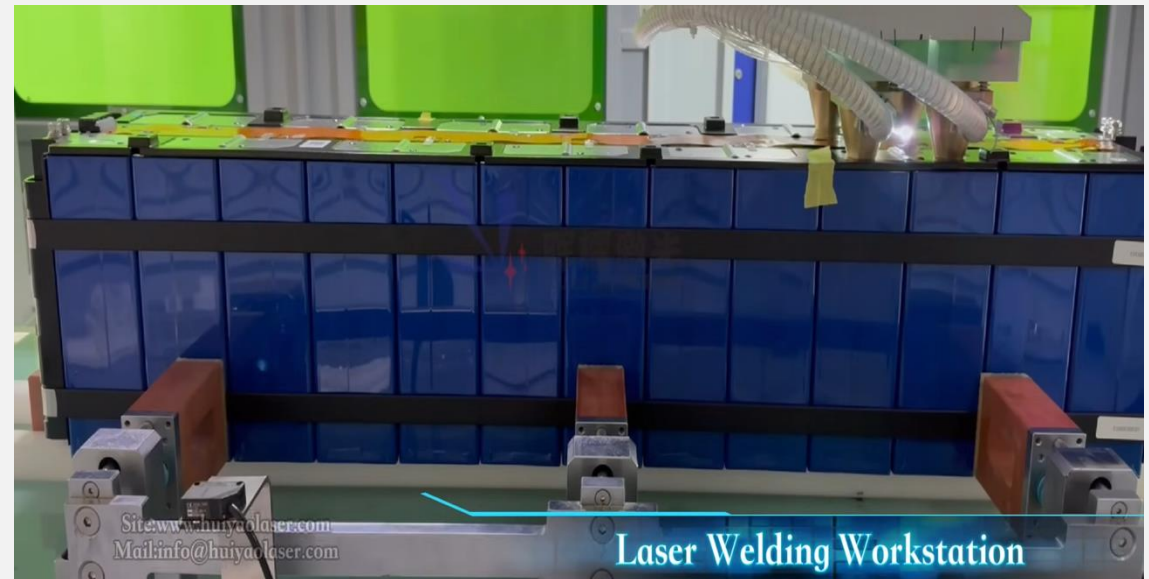
=====			
Station	Avg Queue	Avg Process	Avg Cycle

Station 6	0.44	85.02	85.46
Station 7	4.83	40.98	45.81
Station 8	2.93	43.43	46.36
Station 9	8.64	59.04	67.67
Station 10	12.68	68.07	80.75
Station 11	4.95	61.29	66.23
Station 12	10.92	67.56	78.49
Station 13	3.90	57.94	61.84
Station 14	3.86	59.39	63.26
Station 15	1.68	44.76	46.43

TOTAL	54.83	587.47	642.30
=====			

NEW BOTTLENECK IDENTIFIED AT ST10 & ST12

- After improving ST6 and ST7, the system bottleneck shifted downstream to **Station 10** and **Station 12**.
- These stations are **fully automated**, and their **cycle times cannot be reduced** with current technology. We can **use buffer** before these stations to hold the jobs in Queue
- Adding more capacity (duplicate equipment or parallel automation cells) might not be **feasible** due to:
- High capital expenditure requirements
- Space and infrastructure limitations
- As a result, traditional improvement levers like **capacity expansion** or **process-time reduction** are **difficult**.



Key summary table (Before vs After)

Metric	Before (initial sim)	After (ST6 cap ×2 + ST7 optimized)	Change
Throughput (jobs/s)	0.0103	0.0111	+7.8%
Total cycle time (CT, s)	703.22	642.30	−8.7%
Simulation time (s)	4843.34	4512.69	−6.8%
Sum of avg queue (all stations)	97.18	54.83	−43.6%

THANK YOU