SMART FACTORY DATA ANALYTICS

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BY TEAM OPTIMUS | 17 JUN 2022

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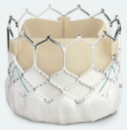
OUTLINE

COMPANY OVERVIEW

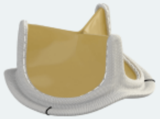
Edwards

Edwards Lifesciences, a global leader in patient-focused medical innovations for structural heart disease, critical care and surgical monitoring.



Transcatheter heart valves

Critical care technologies



Surgical valve technologies

Global presence, products are being manufactured in several global locations including the United States, Puerto Rico, the Dominican Republic and Singapore.

Edwards Singapore manufactures Transcatheter and Surgical heart valves products. Most of the steps are performed by human and every product has a unique serial number.

Manufacturing Execution System (MES) implementation to achieve electronic Device History Records (eDHR)

Helping patients is our life's work, and *life is now*

PROBLEM STATEMENT (1)

- Benefits that your organization has realized through its analytics use? (*)

64%	56%	51%
Improved efficiency and productivity	Faster, more effective decision making	Better financial performance

- When employees need to make a data-driven solution?

(*) https://www3.microstrategy.com/getmedia/db67a6c7-0bc5-41fa-82a9-bb14ec6868d6/2020-Global-State-of-Enterprise-Analytics.pdf

PROBLEM STATEMENT (2)

- Transformation from hardcopy DHR to eDHR through MES implementation

  MES system is used to manage the process workflow and record **where/when/by whom the tasks were performed**

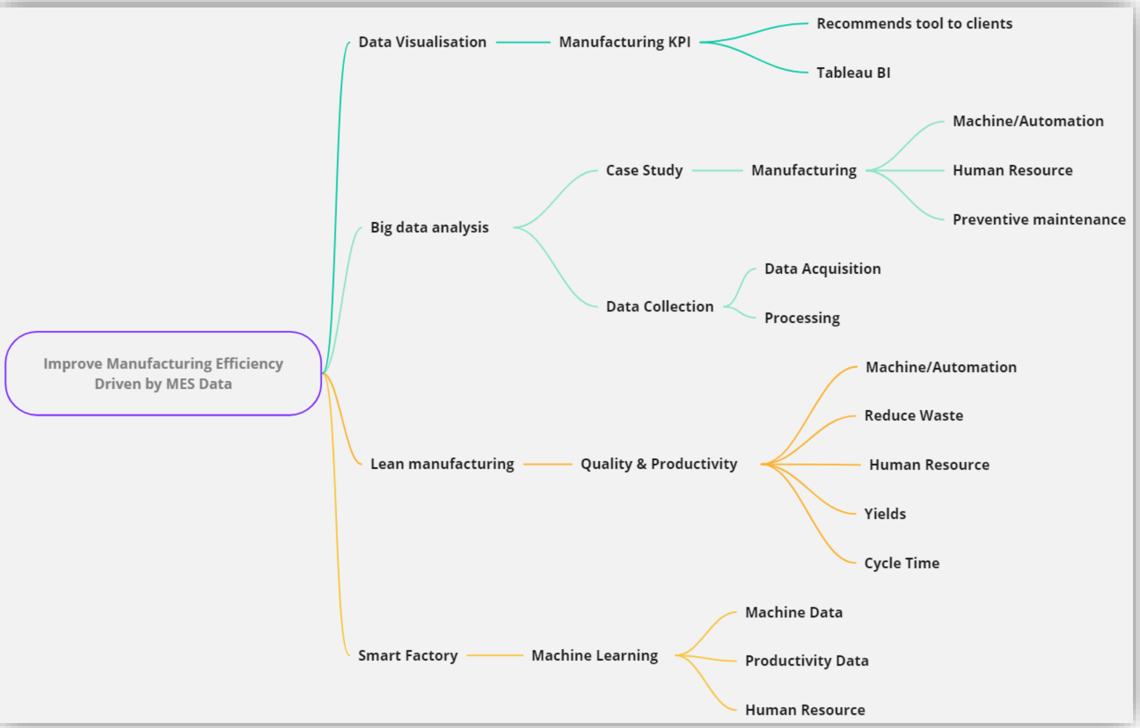
- Next step in digital transformation initiatives, to leverage data for **data-driven decision making** to improve operational productivity and efficiency.

PROJECT SCOPE

- **Knowledge discovery** based on operation dataset from MES that consists of product, operation transactions, defects (rework and scrap), operator information, etc.
- **Develop data analytics pipeline/framework** encompassing data preprocessing, data mining, pattern & knowledge discovery, data visualization to support decision making.
- **Recommendation analytics** on how to improve production productivity in terms of cycle time and quality.

LITERATURE REVIEW

STRATEGY TO FIND A METHODOLOGY FOR MES DATA ANALYTICS



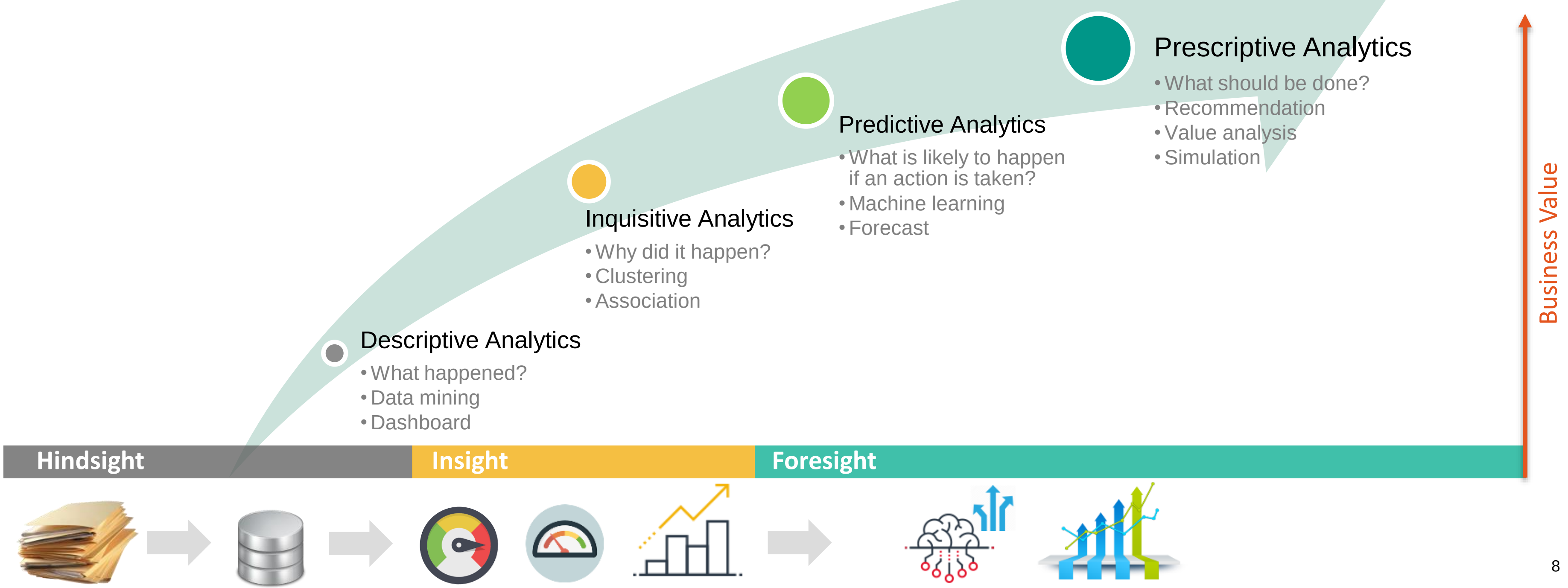
Brainstorm:

- What are the needs of the manufacturing line?
  - Improve productivity
  - Important KPIs: Cycle Time CT, Yield, Rework
- How to improve current status?
  - Throughput calculated from the ERP.
- What kind of processes?
  - Human-based processes, no machine involves.
- What are the main factors?
  - Operator. Product Type & Size. Environment.
- How to make use of the available data to achieve goals?
  - Sufficient: product id tracking, operation steps, employees id, time stamps, defects.

METHODOLOGY OVERVIEW

A COMPREHENSIVE SOLUTION IN ALL DIMENSIONS

The project shall cover the 4 main areas of data analytics and solutions



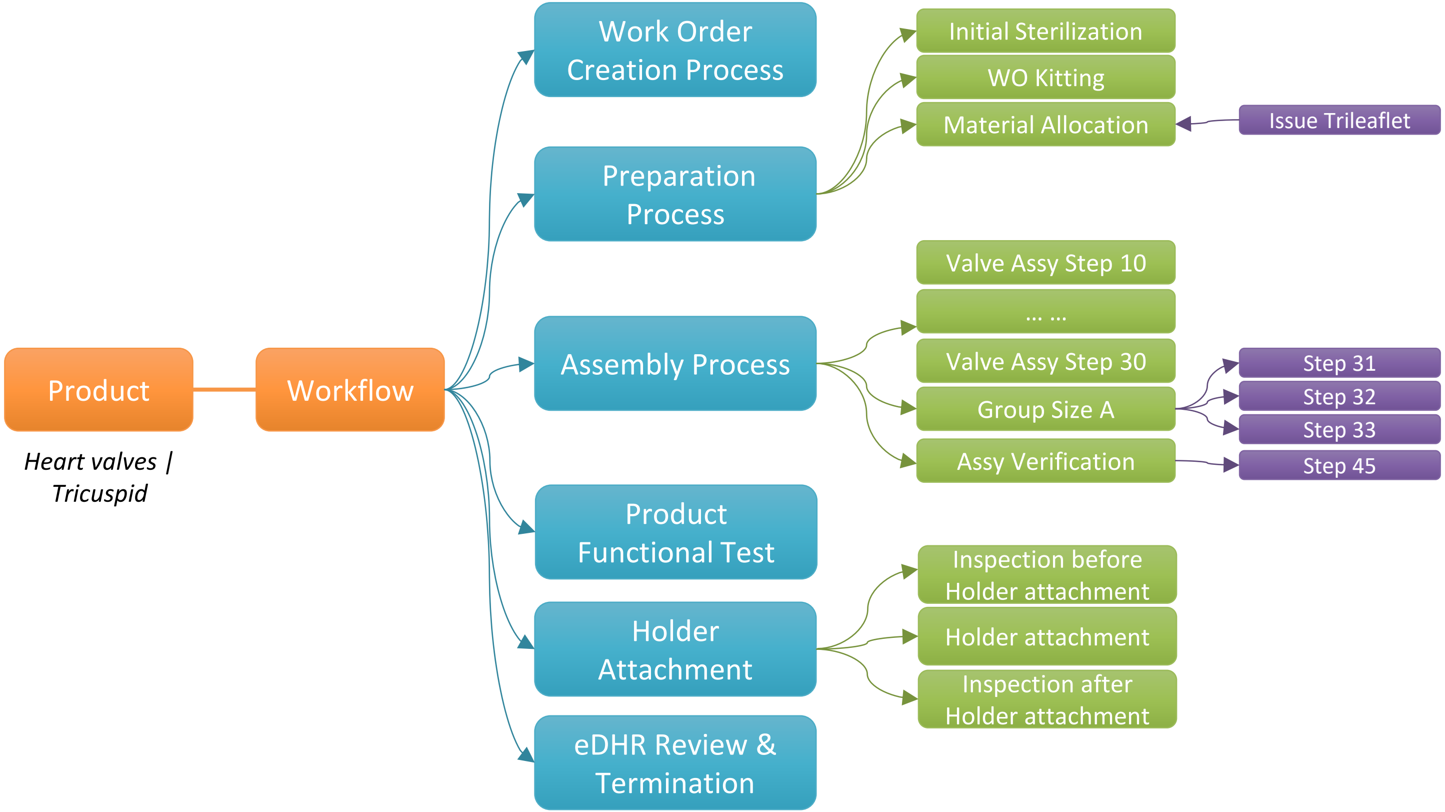
UNDERSTANDING MES DATA

- **Myriad of data**, > 7 mil records and close to 50 data attributes
- Understand **business needs**
- How do we relate to and understand what is happening in the production?
  - Starts with ***manufacturing process flow***
    - What are the products? How is each of them manufactured?
  - ***Dissect*** MES data and ***link*** it to the manufacturing process

PHASE 1

UNDERSTANDING MES DATA

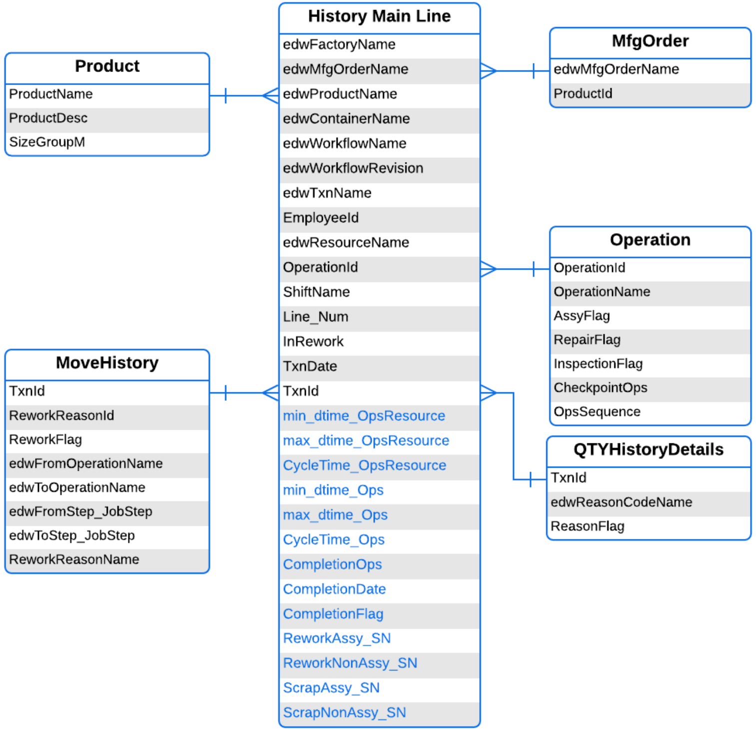
LOOKING AT MANUFACTURING PROCESS FLOW

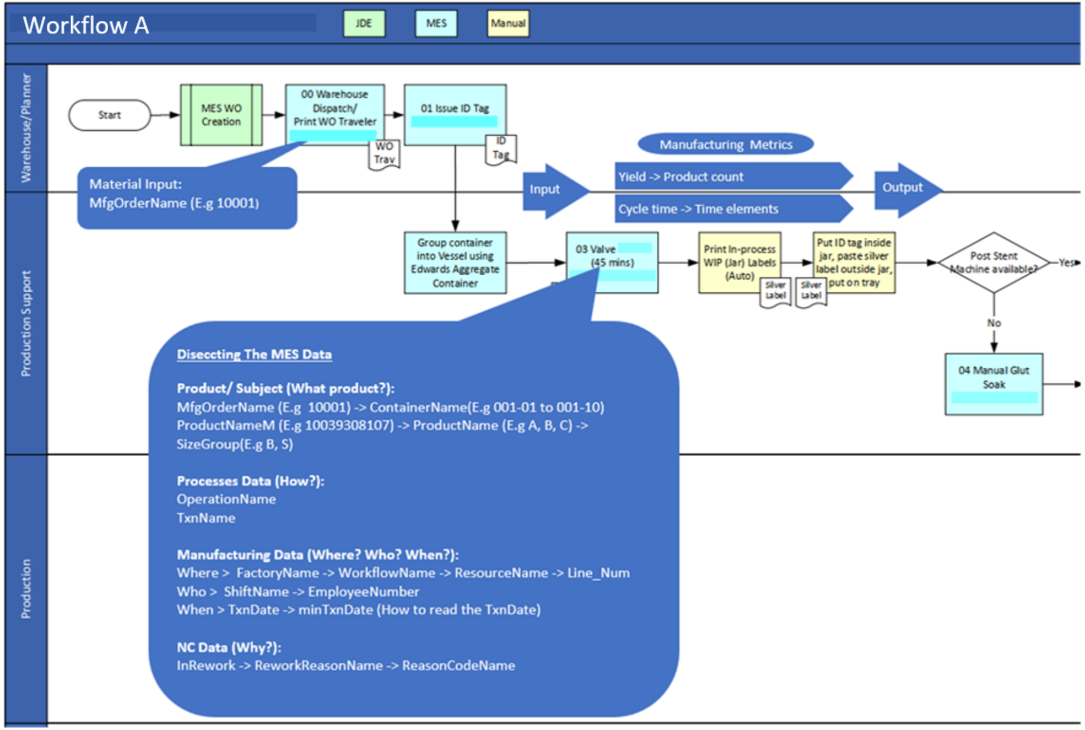


PHASE 1

UNDERSTANDING MES DATA

RELATING MES DATA TO MANUFACTURING





DATA SET PREPARATION

Data Extraction & Merging

- Product information
- Work order data
- Tasks execution records
- Ops ID to Ops data mapping
- Detailed part movement history
- Scrap & Rework data
- Employee master data

Data Pre-processing

- Sanitize & mask sensitive data
- Clean up irrelevant transactions
- Handling of Null features
- Timestamp conversion
- Text clean-up

Define Measurable KPIs

- Cycle Time (CT)
- Yield and First-Pass Yield
- Rework count
- Scrap count

Feature Engineering & Data Aggregation

- Derive Ops cycle time from transaction timestamps
- Rework/scrap flags
- Derive yield & first-pass yield

High-level Exploratory Data Analysis

- To understand overall data trend
- Understand business needs

DATA VISUALIZATION

PRODUCTION PERFORMANCE MONITORING

Productivity Overview

- YTD / MTD Cycle Time statistics
- Month-over-month cycle time trend
- Aggregated by product family / line / shift
- Cycle Time heatmap for bottleneck visualization

Overall Quality Monitoring

- Total output
- Yield & first-pass yield
- Rework & scrap rate
- Aggregated by product family / line / shift
- Long-term quality trend
- Defects heatmap for ops excellence improvement opportunities

Non-Conformance (NC) Analysis

- NC statistics by type
- Rework time by product / operation / shift
- Defect count by product / operation / shift

Employee Performance Monitoring

- Employee profile
- Number of units handled
- Number of associated non-conformance
- Individual yield & first-pass yield
- Daily cycle time statistics

Productivity Deep-Dive

- Avg. & Median cycle time break-down by operation
- Week-averaged operation cycle time vs. all-time average
- Top-*N* worst performing employee listing for user-specified operations
- Month-over-month cycle time trend for worst performing employees
- Dynamic fetching of raw transaction records
- Avg. cycle time break-down by individual shifts & lines

PHASE 2

DATA VISUALIZATION

DEMO VIDEO: PRODUCTIVITY DASHBOARD

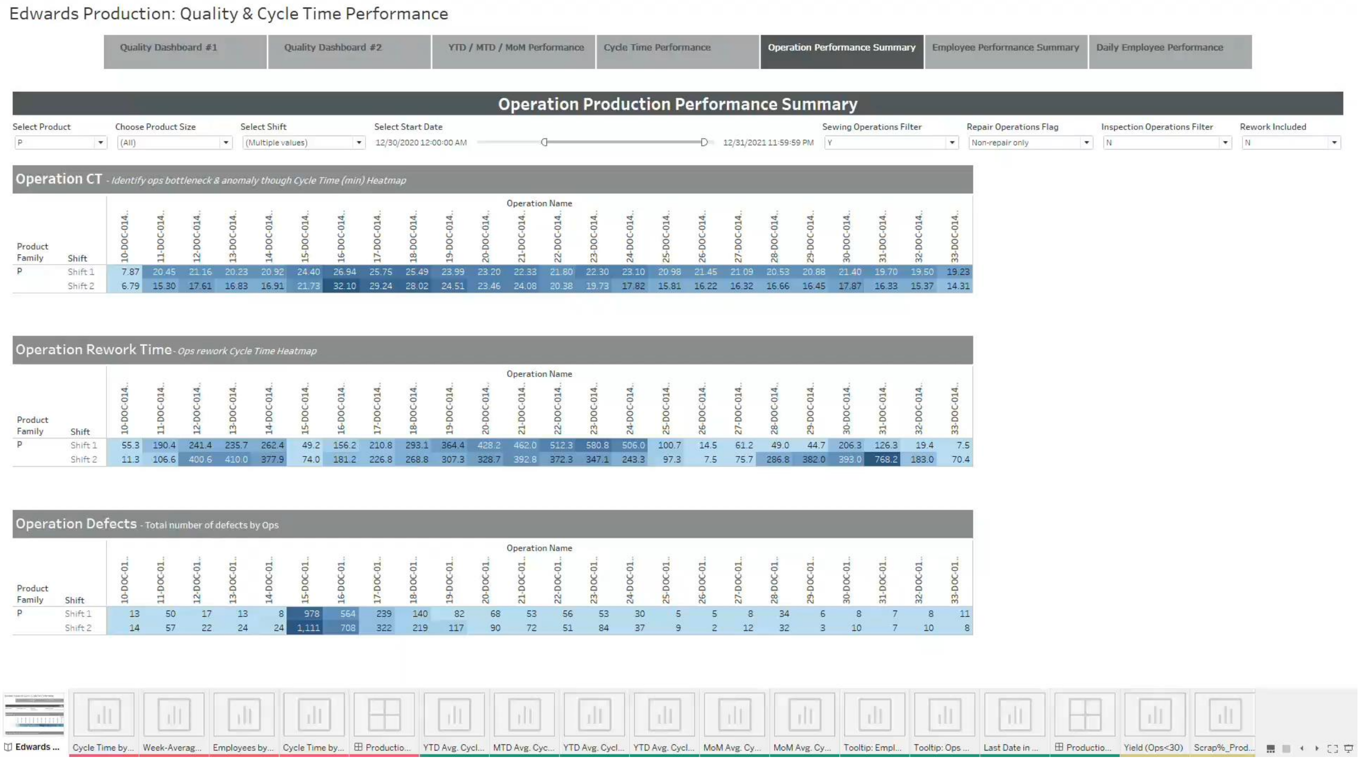
PHASE 2

DATA VISUALIZATION

DEMO VIDEO: QUALITY MONITORING DASHBOARD

DATA VISUALIZATION

DEMO VIDEO: OPERATION PERFORMANCE DASHBOARD



Operation CT - *Identify ops bottleneck & anomaly though Cycle Time (min) Heatmap*

Operation Name

Product Family	Shift	10-DOC-014..	11-DOC-014..	12-DOC-014..	13-DOC-014..	14-DOC-014..	15-DOC-014..	16-DOC-014..	17-DOC-014..	18-DOC-014..	19-DOC-014..	20-DOC-014..	21-DOC-014..	22-DOC-014..	23-DOC-014..	24-DOC-014..	25-DOC-014..	26-DOC-014..	27-DOC-014..	28-DOC-014..	29-DOC-014..	30-DOC-014..	31-DOC-014..	32-DOC-014..	33-DOC-014..
P	Shift 1	7.87	20.45	21.16	20.23	20.92	24.40	26.94	25.75	25.49	23.99	23.20	22.33	21.80	22.30	23.10	20.98	21.45	21.09	20.53	20.88	21.40	19.70	19.50	19.23
	Shift 2	6.79	15.30	17.61	16.83	16.91	21.73	32.10	29.24	28.02	24.51	23.46	24.08	20.38	19.73	17.82	15.81	16.22	16.32	16.66	16.45	17.87	16.33	15.37	14.31

Operation Rework Time - *Ops rework Cycle Time Heatmap*

Operation Name

Product Family	Shift	10-DOC-014..	11-DOC-014..	12-DOC-014..	13-DOC-014..	14-DOC-014..	15-DOC-014..	16-DOC-014..	17-DOC-014..	18-DOC-014..	19-DOC-014..	20-DOC-014..	21-DOC-014..	22-DOC-014..	23-DOC-014..	24-DOC-014..	25-DOC-014..	26-DOC-014..	27-DOC-014..	28-DOC-014..	29-DOC-014..	30-DOC-014..	31-DOC-014..	32-DOC-014..	33-DOC-014..
P	Shift 1	55.3	190.4	241.4	235.7	262.4	49.2	156.2	210.8	293.1	364.4	428.2	462.0	512.3	580.8	506.0	100.7	14.5	61.2	49.0	44.7	206.3	126.3	19.4	7.5
	Shift 2	11.3	106.6	400.6	410.0	377.9	74.0	181.2	226.8	268.8	307.3	328.7	392.8	372.3	347.1	243.3	97.3	7.5	75.7	286.8	382.0	393.0	768.2	183.0	70.4

Operation Defects - Total number of defects by Ops

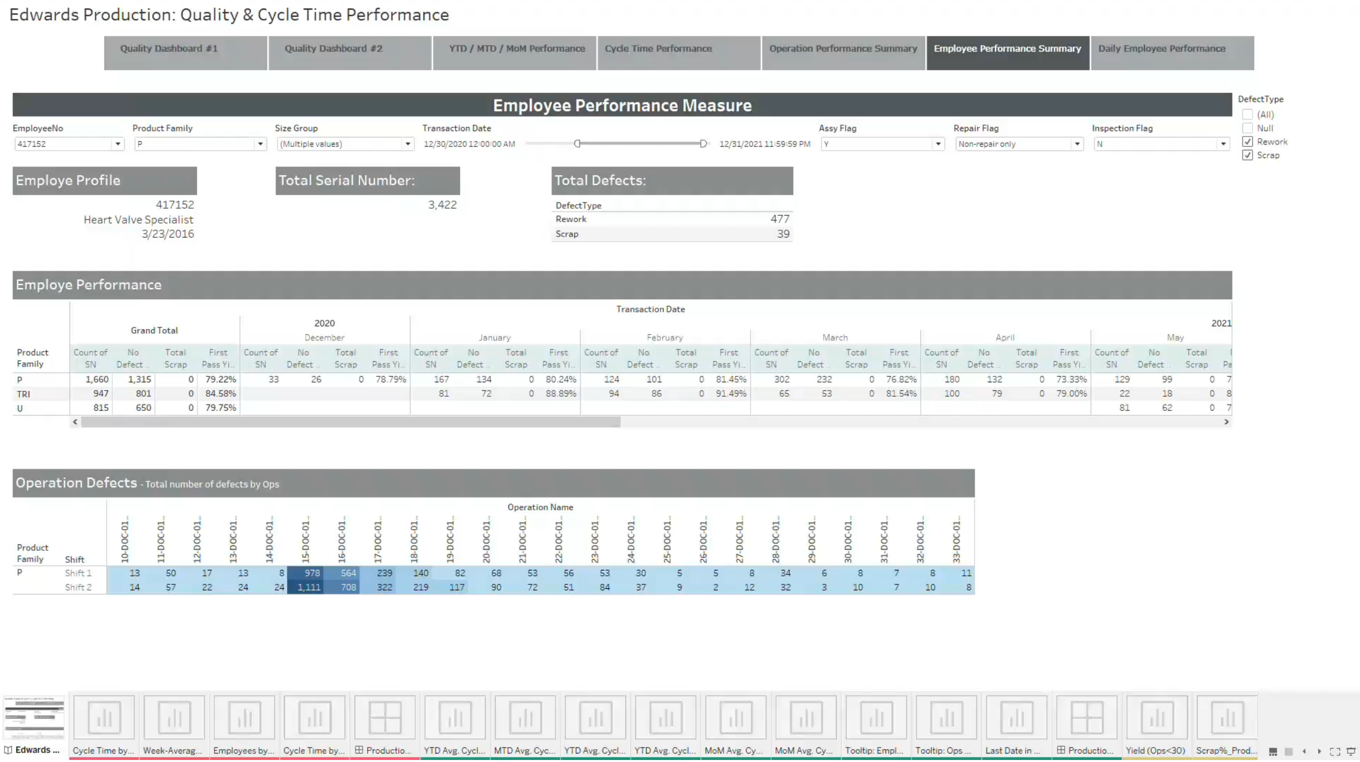
Operation Name

Product Family	Shift	10-DOC-01..	11-DOC-01..	12-DOC-01..	13-DOC-01..	14-DOC-01..	15-DOC-01..	16-DOC-01..	17-DOC-01..	18-DOC-01..	19-DOC-01..	20-DOC-01..	21-DOC-01..	22-DOC-01..	23-DOC-01..	24-DOC-01..	25-DOC-01..	26-DOC-01..	27-DOC-01..	28-DOC-01..	29-DOC-01..	30-DOC-01..	31-DOC-01..	32-DOC-01..	33-DOC-01..
P	Shift 1	13	50	17	13	8	978	564	239	140	82	68	53	56	53	30	5	5	8	34	6	8	7	8	11
	Shift 2	14	57	22	24	24	1,111	708	322	219	117	90	72	51	84	37	9	2	12	32	3	10	7	10	8

PHASE 2

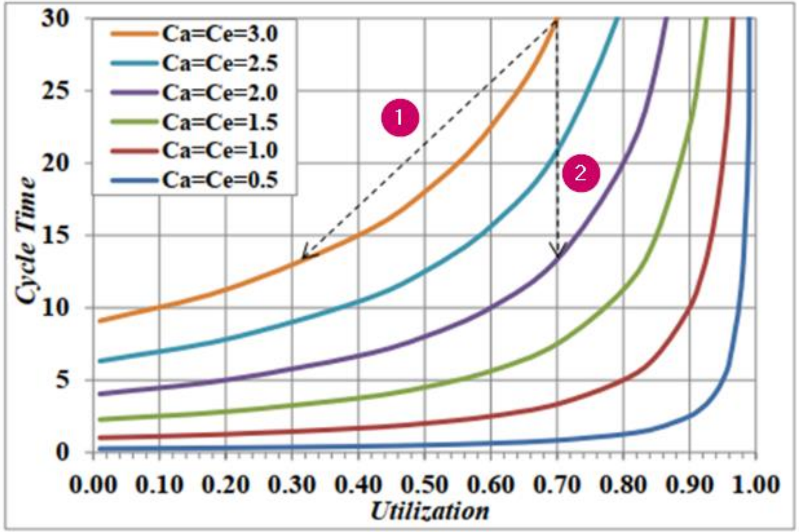
DATA VISUALIZATION

DEMO VIDEO: EMPLOYEE PERFORMANCE DASHBOARD



CYCLE TIME IMPROVEMENT BY VARIABILITY REDUCTION

METHOD TO REDUCE CYCLE TIME



1. Reducing utilization by either
   a) decreasing throughput
   b) increasing capacity.

2. Reducing the variability of either
   a) service time
   b) availability time
   c) repair time

- Efficiency improvement
- No investment in capacity

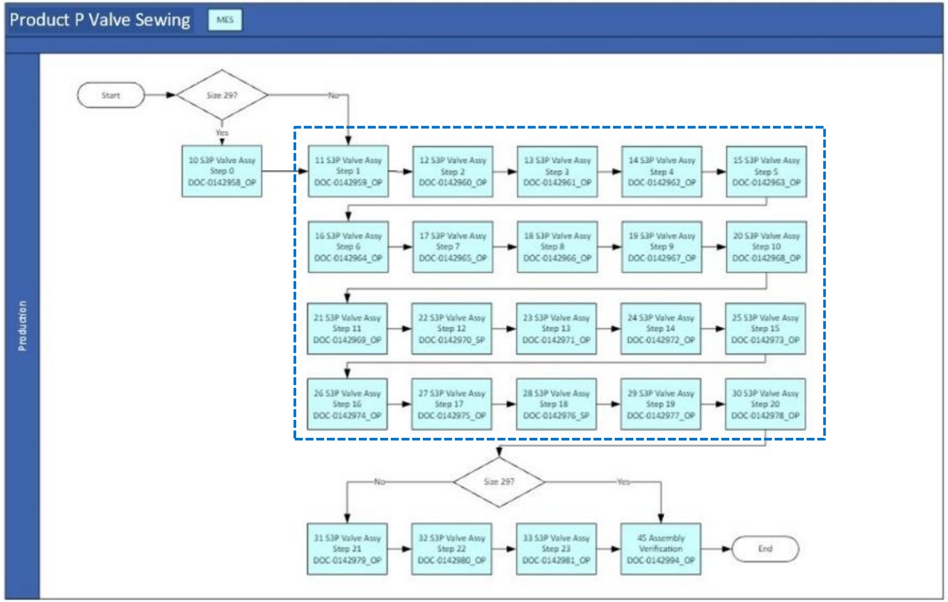
Preferred Method

R. Israel Tirkel, "The effectiveness of variability reduction in decreasing wafer fabrication cycle time"

PHASE 3

CASE STUDY ON PRODUCT P VALVE SEWING OPERATION

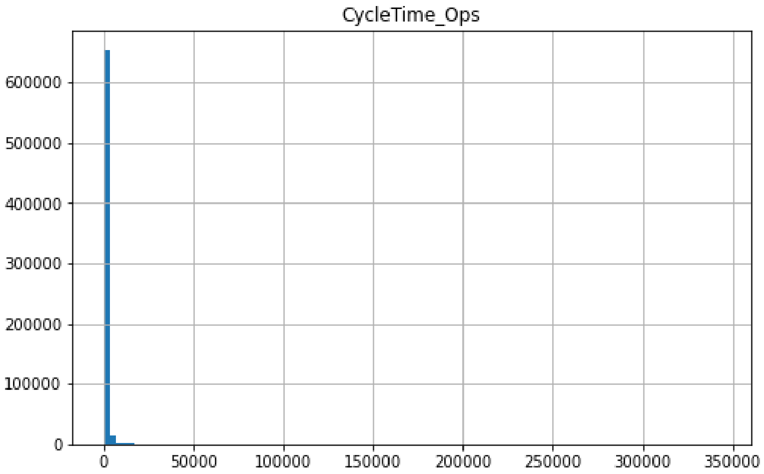
PRODUCT P: THE HIGHEST VOLUME PRODUCT

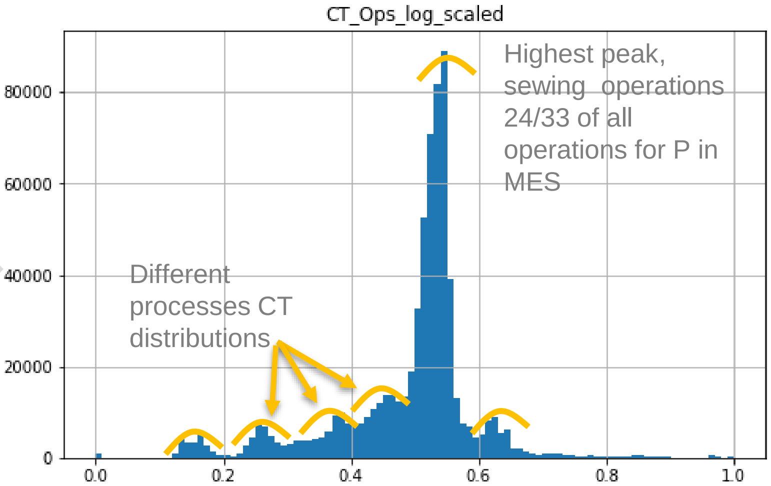


- Sewing process with operations flow in series.
- Each operation must index in tandem with well balance task.
- Each operation with similar nature of processes.

CYCLE TIME IMPROVEMENT BY VARIABILITY REDUCTION

CT EXPLORATION FOR INSIGHTS





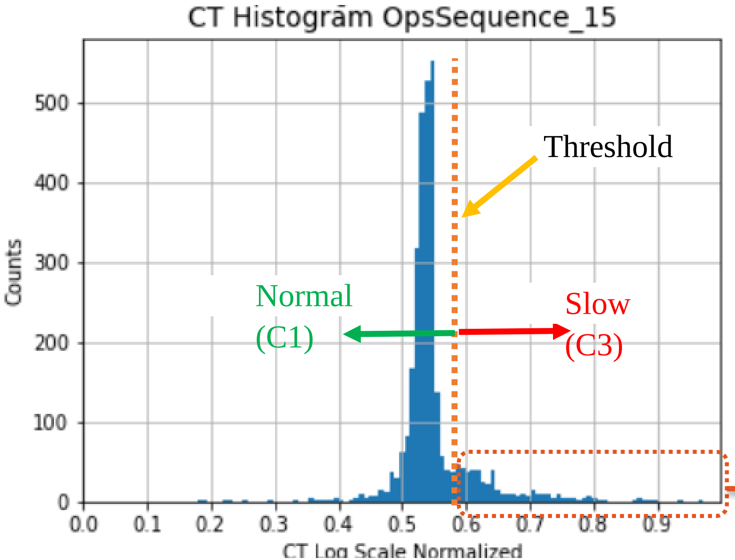
- CT in linear scale for Product P on all operations and transaction types.
- Highly skewed. Unable to see hindsight.

- CT in normalized log scale
- The distribution nearer to normal distribution is optimized for machine learning processing.
- Observed there are multiple different categories of processes with different CT.

PHASE 3

CYCLE TIME IMPROVEMENT BY VARIABILITY REDUCTION

METHOD OF REMOVING THE VARIABILITY

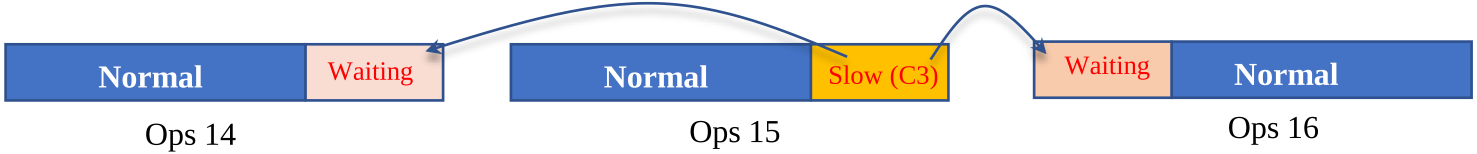


- Based on the employees' MES CT data, separate the employee into 2 groups by threshold and classify them into:

  C1, the normal group of employees

  C3, the slower group of employees

Who performed these jobs? → C3 group

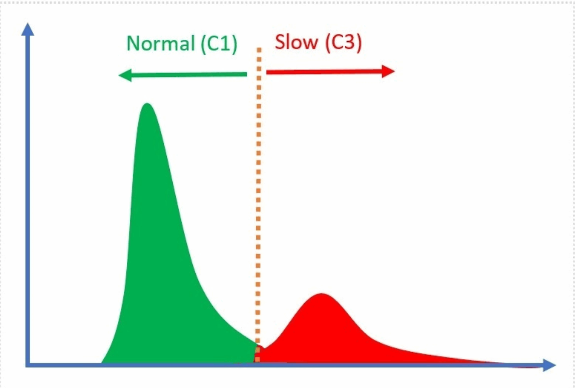


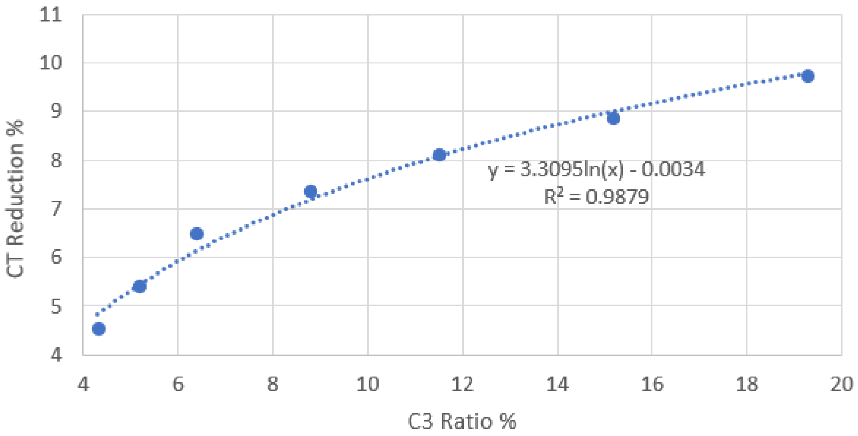
Chain disruption

CYCLE TIME IMPROVEMENT BY VARIABILITY REDUCTION

SIMULATION OF CT AND C3 RATIO

- Varied the threshold left and right, and remove the C3 employee from Current MES data.
  - Too much to the left, less C3 group include more variability, not effective reduce CT
  - Too much to the right, diminishing CT reduction due to false classification of the normal employee as a slow employee and reducing the available pool of C1 group of employees.





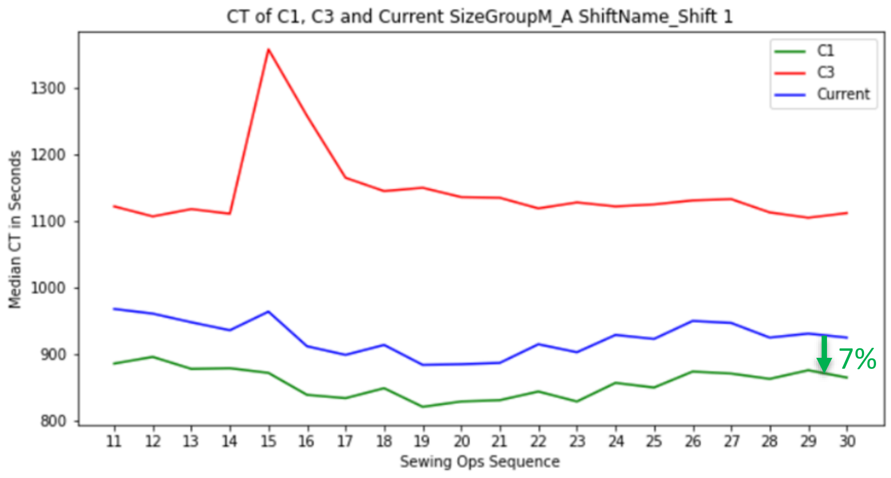
Simulation of various C3 ratios to CT Reduction

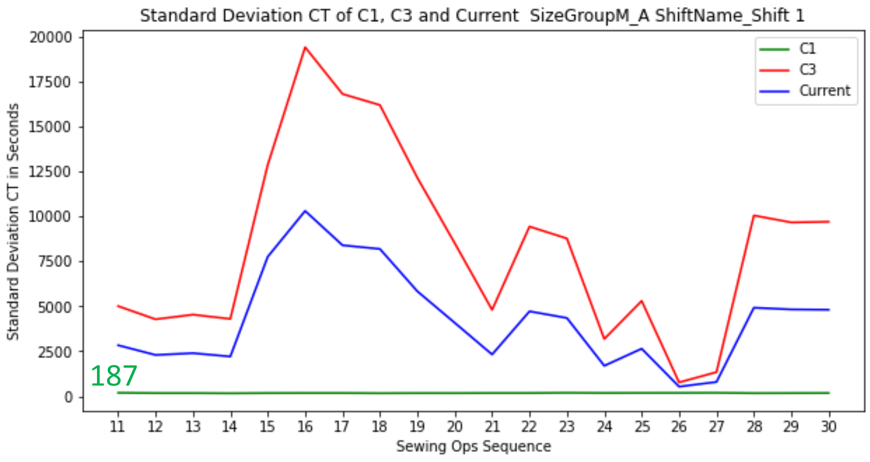
PHASE 3

CYCLE TIME IMPROVEMENT BY VARIABILITY REDUCTION

EXAMPLE OF SIMULATION

- Remove the C3 group from Current MES data and calculate the Median CT.
- C3 ratio at 8%, CT reduction 7% on average to Median CT.
- The standard deviation of CT greatly stabilized at 187seconds. Reduce disruption greatly.
- Coefficient of variability (CV) reduced from 4.6 (high variability) to 0.21 (low variability) stable process (Hopp & Spearman 2001).





CV= standard deviation / mean

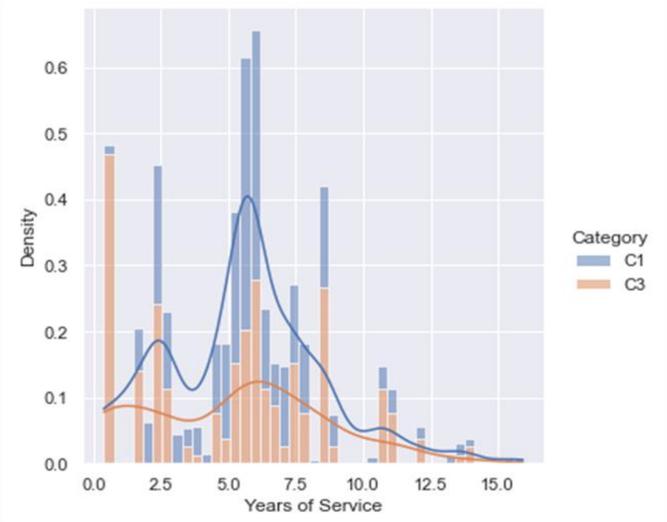
Hopp W.J., Spearman M.L. 2001. Factory physics. McGraw-Hill, Boston.

CYCLE TIME IMPROVEMENT BY VARIABILITY REDUCTION

SEARCHING FOR CORRELATION BETW. EMPLOYEE PROFILE AND CT

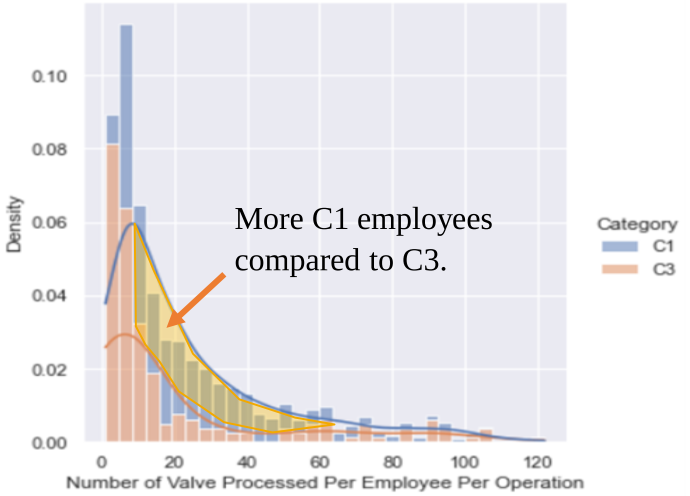
Year of Service

- Both ends did not show significant differences for C1 or C3.
- No correlation to Year of Service



Number of valves processed per Employee per Operation

- Shown a moderate more C1 when the individual employee does more valves in one operation.
- Employee CT performance better when more valves processed in an operation.



PHASE 3

CYCLE TIME IMPROVEMENT BY VARIABILITY REDUCTION

PROPOSED IMPLEMENTATION

a) Not to mix C1 and C3 classified employees in a production line. Use all the C1 or C3 employees for all operations in the same production line. This will reduce the waiting time.

b) Do less swapping of employees to various operations. Letting an employee stay longer in an operation to do more of the same task repeatedly may help improve the employee performance in CT.

c) Study the C1 group’s technique and compare it with the C3 group to identify the gaps that can be improved.

- To aid manpower arrangement by the supervisor, the Python code outputs a spreadsheet with the list of the employee in C1 and C3 categories for each operation

Category	C1
Ops_Sequence	18

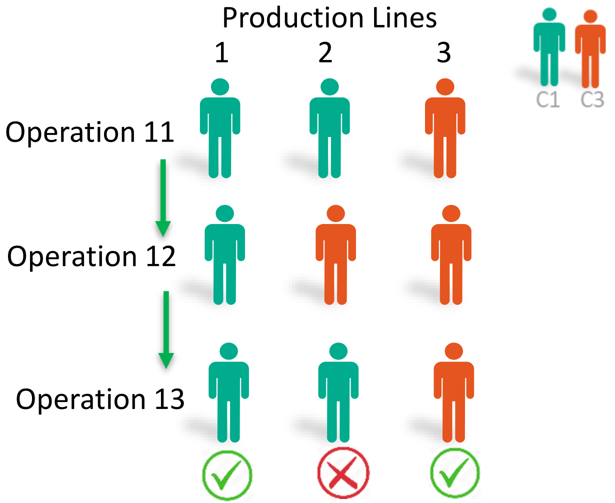
Category C1 employee for Operation : 18

Row Labels
Employee_405284_Sr Heart Valve Specialist_13.93
Employee_405637_Sr Heart Valve Specialist_13.65
Employee_405967_Assoc Heart Valve Specialist_4.93
Employee_406490_Assoc Heart Valve Specialist_5.32
Employee_407099_Assoc Heart Valve Specialist_5.57
Employee_407208_Sr Heart Valve Specialist_12.09
Employee_408600_Heart Valve Specialist_10.92
Employee_409070_Assoc Heart Valve Specialist_10.67
Employee_409222_Sr Heart Valve Specialist_7.45
Employee_411715_Assoc Heart Valve Specialist_8.72
Employee_411811_Heart Valve Specialist_8.64
Employee_411900_Assoc Heart Valve Specialist_0.39

Category	C3
Ops_Sequence	18

Category C3 employee for Operation : 18

Row Labels
Employee_408418_Sr Heart Valve Specialist_10.99
Employee_408939_Sr Heart Valve Specialist_10.71
Employee_413845_Sr Heart Valve Specialist_7.45
Employee_417509_Heart Valve Specialist_5.8
Employee_419407_Assoc Heart Valve Specialist_5.16
Employee_420349_Assoc Heart Valve Specialist_4.82
Employee_427276_Assoc Heart Valve Specialist_2.54
Employee_430489_Assoc Heart Valve Specialist_1.54
Employee_433322_Assoc Heart Valve Specialist_0.43
Employee_433478_Assoc Heart Valve Specialist_0.38
Employee_433479_Assoc Heart Valve Specialist_0.39
Grand Total



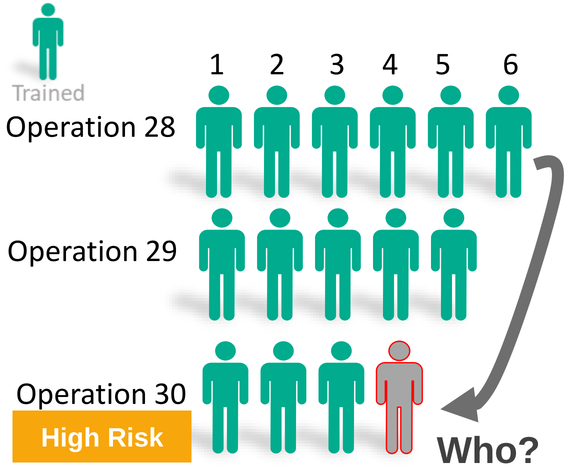
PHASE 3

CYCLE TIME IMPROVEMENT BY VARIABILITY REDUCTION

PREDICTION OF EMPLOYEE PROFILE

Problem:

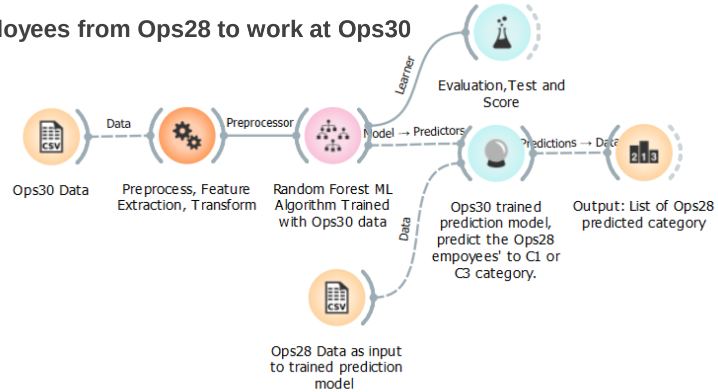
- In case of risk management of trained employees' availability on each operation. Cross-training of employees that can work in multiple operations is important to ensure production operation continuity.
- **Who is better candidate from other operations is to be deployed for cross-training?**



Solution:

- Establish prediction model using machine learning on the high-risk operation data.
- Use the trained model to predict the cross-train candidate from other operations

Example:
Predict suitable employees from Ops28 to work at Ops30



	Employee_Ops28 to 30	Predicted Category
0	Employee_402961_Heart Valve Specialist_15.93	C1
1	Employee_403672_Assoc Heart Valve Specialist_1...	C1
2	Employee_406190_Sr Heart Valve Specialist_13.26	C1
3	Employee_407208_Sr Heart Valve Specialist_12.09	C1
4	Employee_408418_Sr Heart Valve Specialist_10.99	C1
...	...	...
106	Employee_427662_Assoc Heart Valve Specialist_2.44	C3
107	Employee_427801_Assoc Heart Valve Specialist_2.38	C3
108	Employee_427807_Assoc Heart Valve Specialist_2.38	C3
109	Employee_427813_Assoc Heart Valve Specialist_2.38	C3
110	Employee_428962_Assoc Heart Valve Specialist_2.06	C3

PHASE 4

OPTIMIZING EMPLOYEE ALLOCATION

DATA-DRIVEN AUTOMATIC EMPLOYEE ALLOCATION

Motivations:

- Many operations (>20) per product family.
- Hundreds of employees to allocate.
- Difficult to achieve optimal allocation manually.

1 **Framing Optimization Problem**

- How to optimally allocate employees in a production line to improve overall productivity?
- Naïve way: By minimizing overall cycle time.

2 **Formulate Cost Function**

- How to define the cost of each employee as a resource.
- How to account for quality and cycle time inconsistency?

3 **Formulate Objective Function**

- Must encompass the cost of each employee assigned to every station of the production line.

4 **Define Constraints**

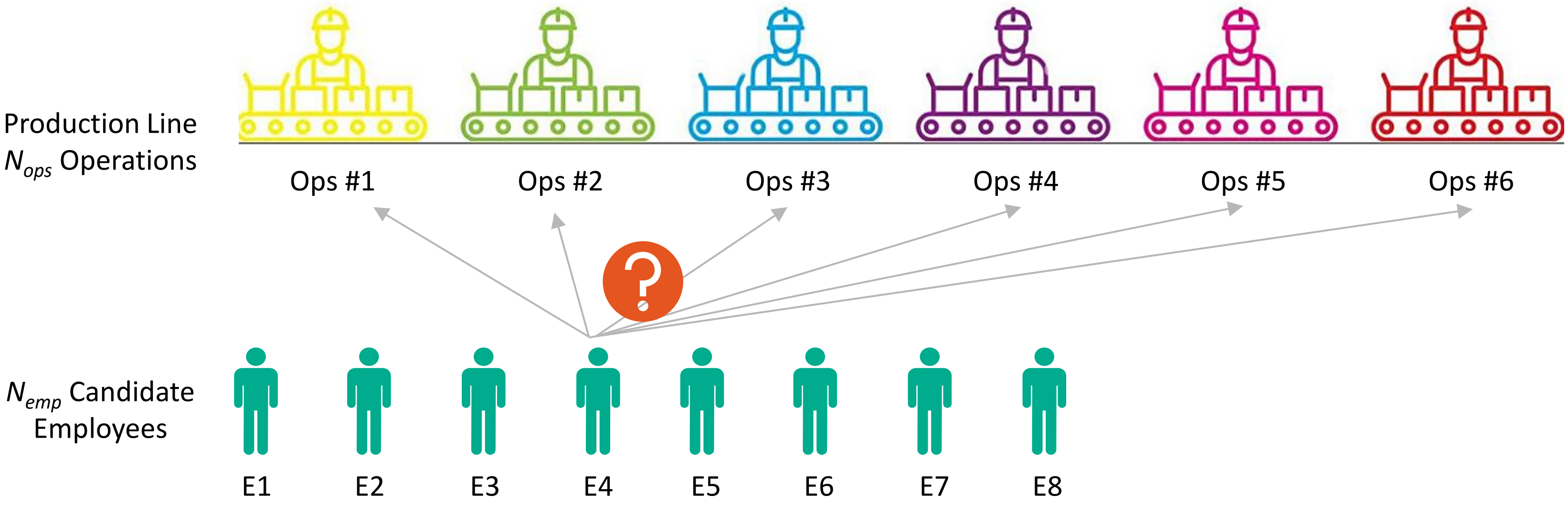
- At most how many employees can be allocated to a station or an operation?
- How many operation can an employee handle at any time?

OPTIMIZING EMPLOYEE ALLOCATION

EMPLOYEE ALLOCATION PROBLEM

Problem:

Given a production line with N_{ops} number of operations in series, how do we allocate employees to maximize productivity?



OPTIMIZING EMPLOYEE ALLOCATION

COST FUNCTION

How to quantify the performance of each employee?

- Each employee is associated with a fixed cost.
- And the goal is to find a combination of employees that minimizes the overall cost.

Average Cycle Time

Cycle Time Variation

Rework Rate

Experience (parts processed)

Employee

Performance Indicators

Employee Cost Function

$$C = \text{Avg. CT} \times \left[1 + w_1(\text{CT std. dev.}) + w_2(\%\text{Rework}) + w_3\left(\log \frac{1}{\text{Parts Processed}}\right) \right]$$

Cost Matrix

OperationName	11-DOC-0142959_OP	12-DOC-0142960_OP	13-DOC-0142961_OP	14-D 014296
EmployeeNumber				
402961	1664.012915	2334.181543	2115.522690	2327.29
403203	2823.830061	1000000.000000	3358.213982	1000000.000
403672	1729.902091	2353.530632	1811.283569	2084.603
404933	1000000.000000	1000000.000000	1000000.000000	1000000.000
405167	3852.641122	4139.931669	3352.252326	3155.32
...	...	...	...	...

OPTIMIZING EMPLOYEE ALLOCATION

OBJECTIVE FUNCTION & CONSTRAINTS

- The objective function is a linear sum of the costs (*C*) associated with all the employees chosen.

$$Obj = \sum_{i=1}^{N_{emp}} \sum_{j=1}^{N_{ops}} \left[D_{i,j} \times C_{Emp\ i,\ Ops\ j} \right]$$

- We want to find D_{ij}'s that minimize the value of the objective function.

Assignment Matrix

Emp \ Ops	Ops #1	Ops #2	Ops #3
Employee 1	D_{11}	D_{12}	D_{13}
Employee 2	D_{21}	D_{22}	D_{23}
Employee 3	...	...	...
Employee 4			

Constraint 1: Sum of each row ≤ 1

Constraint 2: Sum of each column = 1

PHASE 4

OPTIMIZING EMPLOYEE ALLOCATION

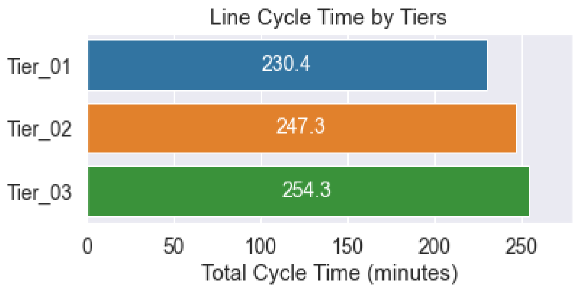
MULTI-TIERED EMPLOYEE ALLOCATION RESULTS

Case Study #1: Naïve approach

- Product family P, size group A
- Set w_1, w_2, w_3 to zero → Naïve optimization based purely on how fast each employee is.
- Set number of tiers = 3

Allocated Employees

	Tier_01	Tier_02	Tier_03
Ops #1	417312, Assoc Heart Valve Specialist	415270, Assoc Heart Valve Specialist	417430, Assoc Heart Valve Specialist
Ops #2	427081, Assoc Heart Valve Specialist	420186, Assoc Heart Valve Specialist	413056, Assoc Heart Valve Specialist
Ops #3	419100, Assoc Heart Valve Specialist	427090, Assoc Heart Valve Specialist	419095, Assoc Heart Valve Specialist
Ops #4	412955, Assoc Heart Valve Specialist	413741, Assoc Heart Valve Specialist	426989, Assoc Heart Valve Specialist
Ops #5	427141, Assoc Heart Valve Specialist	419343, Assoc Heart Valve Specialist	421233, Assoc Heart Valve Specialist
Ops #6	419337, Assoc Heart Valve Specialist	419522, Assoc Heart Valve Specialist	418166, Assoc Heart Valve Specialist
Ops #7	424262, Assoc Heart Valve Specialist	418425, Assoc Heart Valve Specialist	418085, Assoc Heart Valve Specialist
Ops #8	411976, Assoc Heart Valve Specialist	417237, Assoc Heart Valve Specialist	415107, Heart Valve Specialist
Ops #9	419151, Assoc Heart Valve Specialist	428119, Assoc Heart Valve Specialist	416283, Assoc Heart Valve Specialist
Ops #10	426342, Assoc Heart Valve Specialist	417667, Assoc Heart Valve Specialist	418456, Assoc Heart Valve Specialist
Ops #11	416488, Assoc Heart Valve Specialist	417080, Assoc Heart Valve Specialist	418766, Assoc Heart Valve Specialist
Ops #12	417345, Assoc Heart Valve Specialist	420594, Assoc Heart Valve Specialist	[illegible]



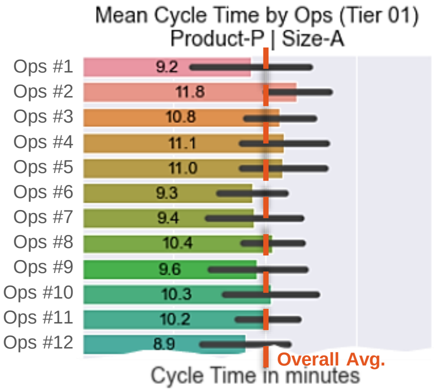
OPTIMIZING EMPLOYEE ALLOCATION

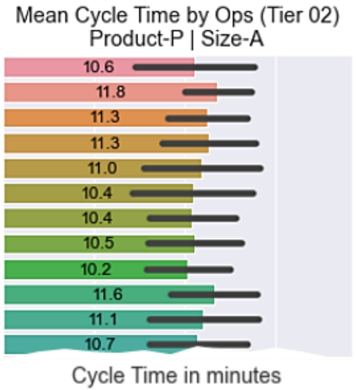
MULTI-TIERED EMPLOYEE ALLOCATION RESULTS

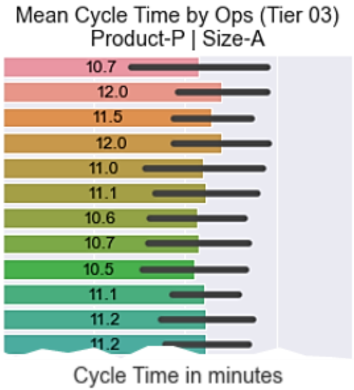
Case Study #1: Naïve approach

- Product family P, size group A
- Set w_1, w_2, w_3 to zero → Naïve optimization based purely on how fast each employee is.
- Set number of tiers = 3

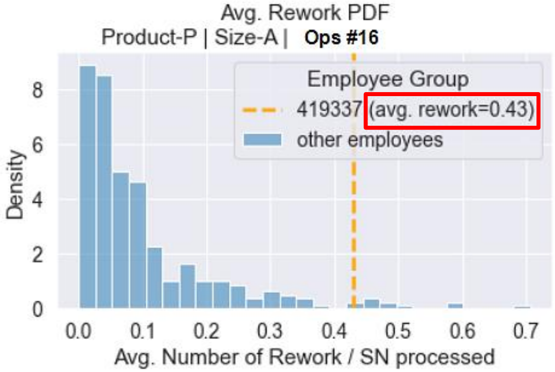
High variability in cycle time







Employee with high rework rate is chosen → not good



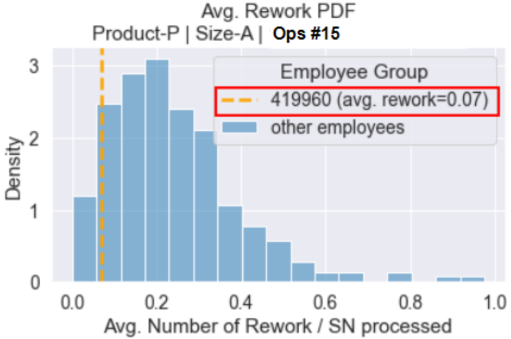
OPTIMIZING EMPLOYEE ALLOCATION

MULTI-TIERED EMPLOYEE ALLOCATION RESULTS

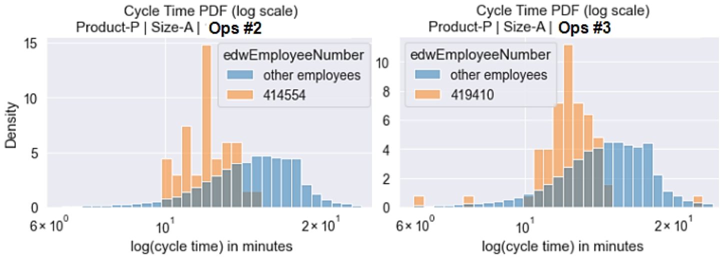
Case Study #2:

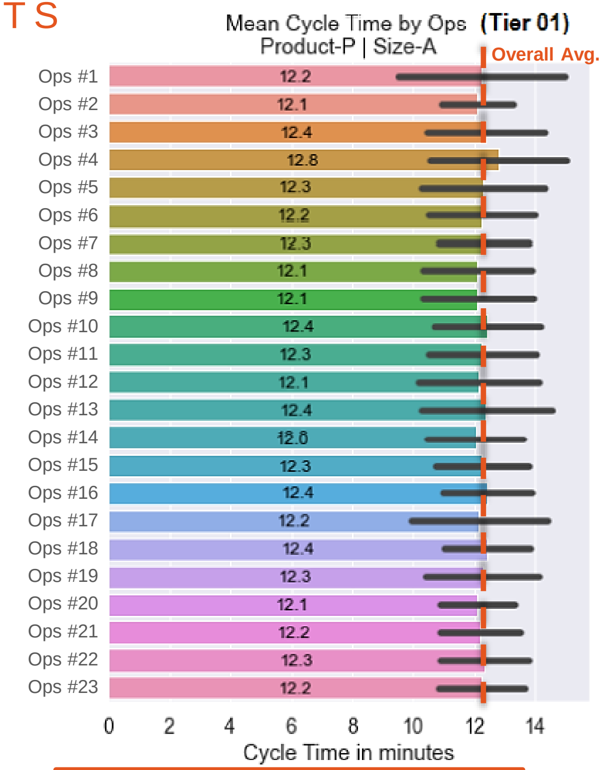
- Product family P, size group A
- Set weights as follows:
  - Weighting factor for within-ops **cycle time variability**: $w_1 = 3$
  - Weighting factor for **rework rate**: $w_2 = 4$
  - Weighting factor for **number of parts processed**: $w_3 = 1$

Highest rework rate is reduced to 7%



Algorithm manages to identify employee with relatively short cycle time!





Lower variability in cycle time

OPTIMIZING EMPLOYEE ALLOCATION

IMPROVEMENT OPPORTUNITIES

The current model does not consider additional factors such as

- Employees’ availability
- Shift preference
- Planned rotation

CHALLENGES

- Lack of manufacturing data warehouse
- Highly regulated industry
- Majority of data comes from human transactions
- Traditional decision-making mindset

RECOMMENDATION AND CONCLUSION

- Implement on enterprise data warehouse and BI platform
- Secure sensitive employee related performance KPIs
- Think Big, Start Small, Learn Fast
- Develop data-driven decision culture
- Organizational Change Management for successful adoption

COMMENTS / QUESTIONS / FEEDBACK ?

END

SMART FACTORY DATA ANALYTICS

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