Introduction to Reliability & Maintenance

https://github.com/Dr-AlaaKhamis/ISE518/tree/main/3_R&M

Lecture 4 – Wednesday 3, 2025

Outline

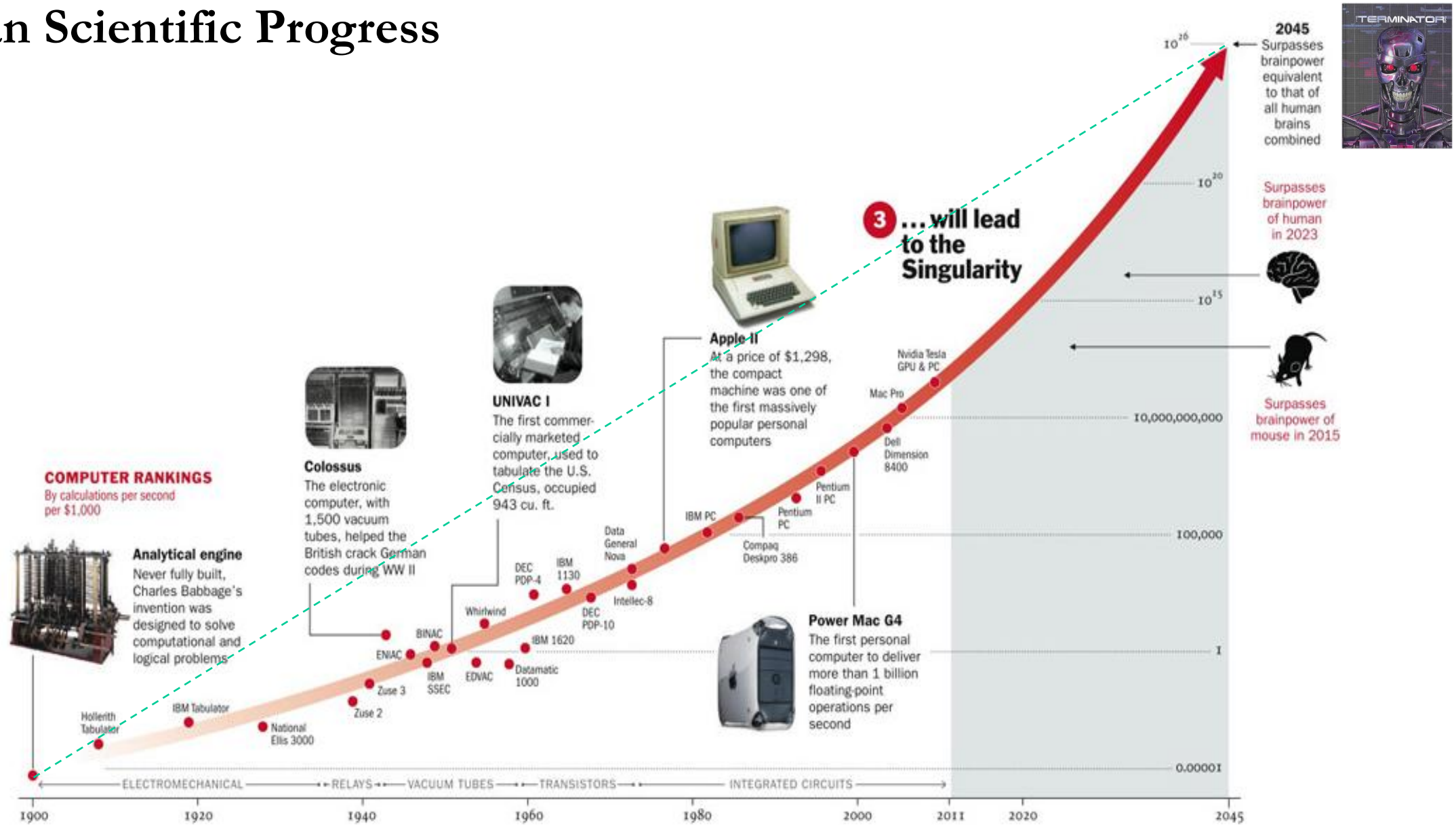
- What is Industry 4.0?
- Why Industry 4.0?
- Challenges
- Reliability Engineering
- Maintenance Engineering

Outline

- **What is Industry 4.0?**
- Why Industry 4.0?
- Challenges
- Reliability Engineering
- Maintenance Engineering

What is Industry 4.0?

- Human Scientific Progress



Source: Lev Grossman, "2045: The Year Man Becomes Immortal," TIME Magazine, February 2011.

What is Industry 4.0?

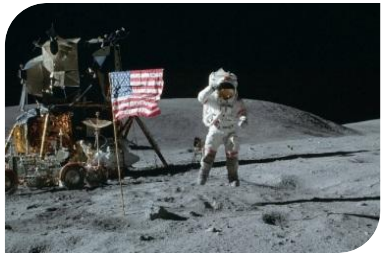
- The accelerating pace of change

Industrial revolution

120 years

Light bulb

90 years



Moon landing

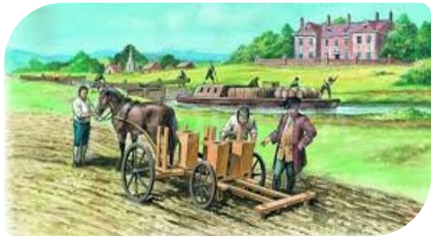
22 years

World Wide Web

9 years

Human Genome Sequenced

8,000 years

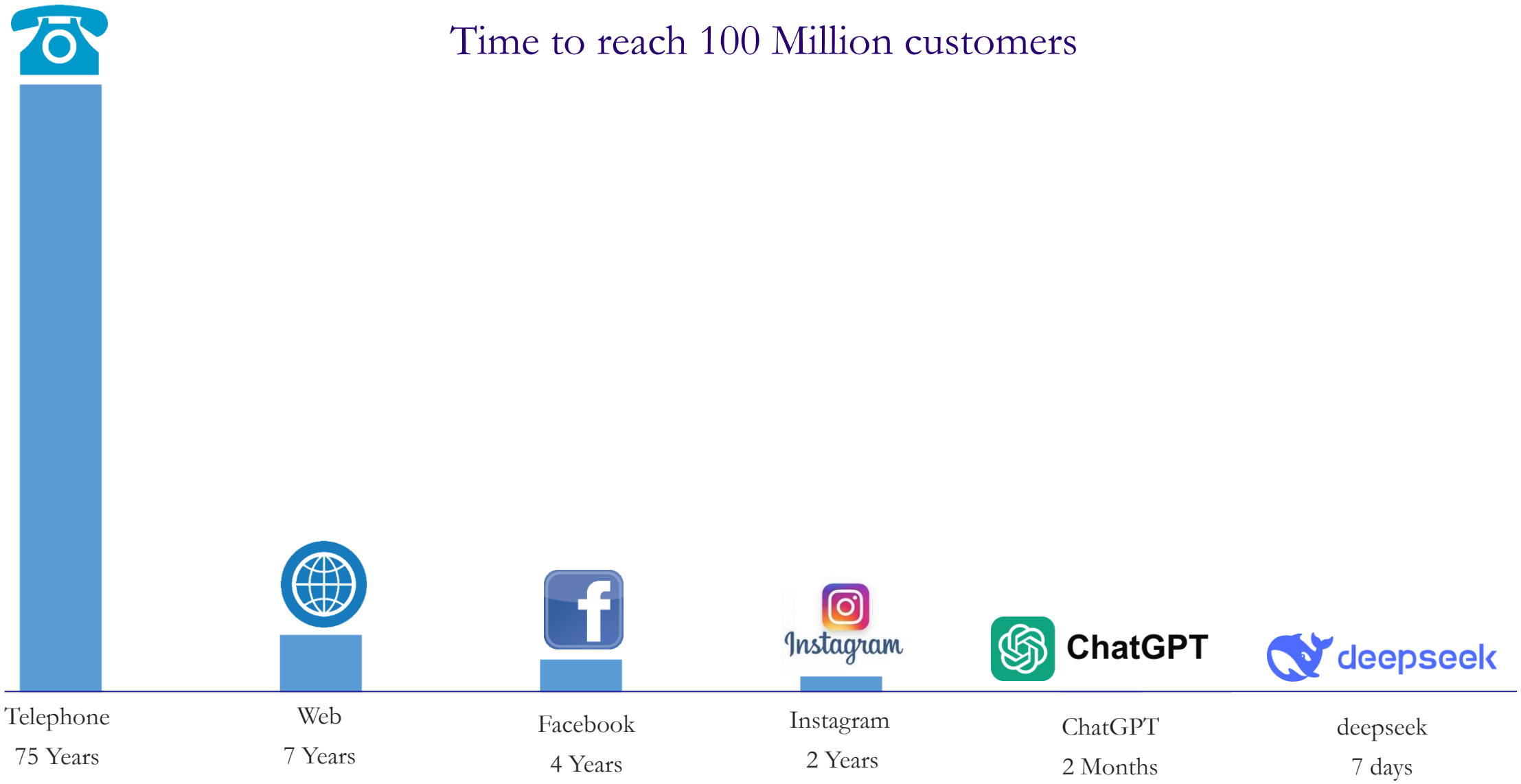


Agriculture revolution

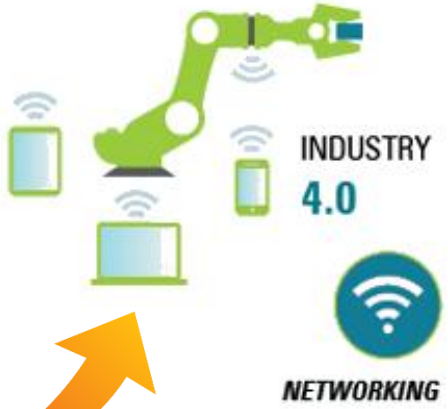
Source: Lev Grossman, "2045: The Year Man Becomes Immortal," TIME Magazine, February 2011.

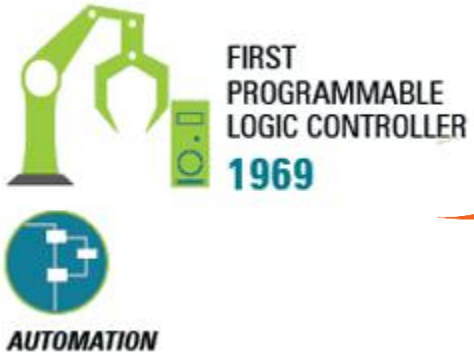
What is Industry 4.0?

- **The accelerating pace of change**



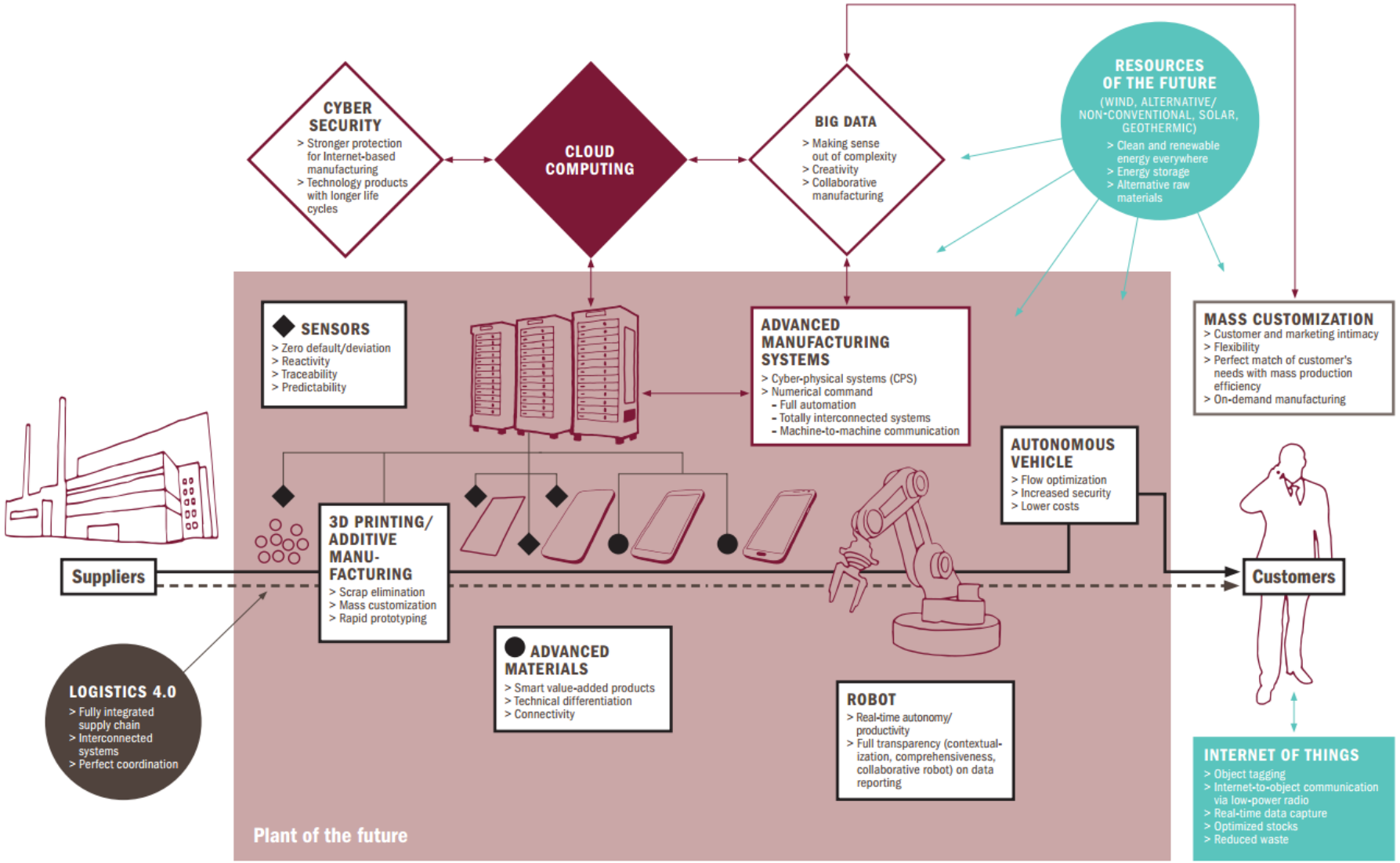
What is Industry 4.0?





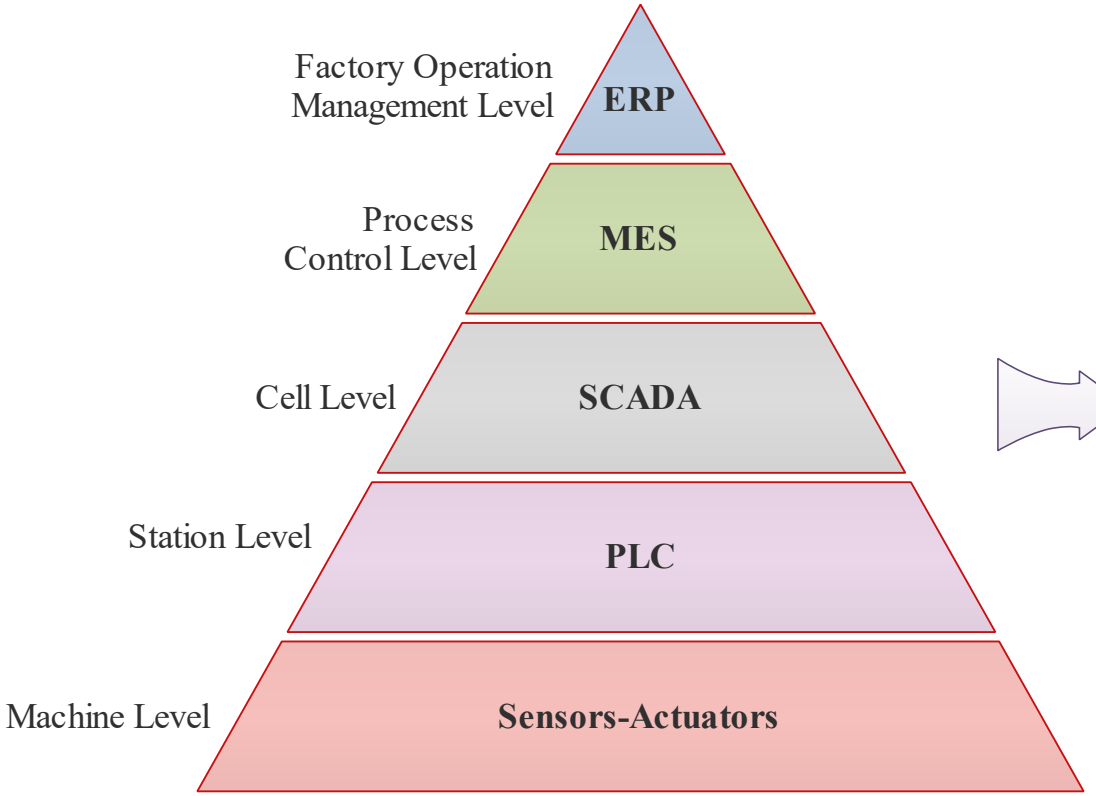
What is Industry 4.0?

Digitalization | Automation | Connectivity | Analytics

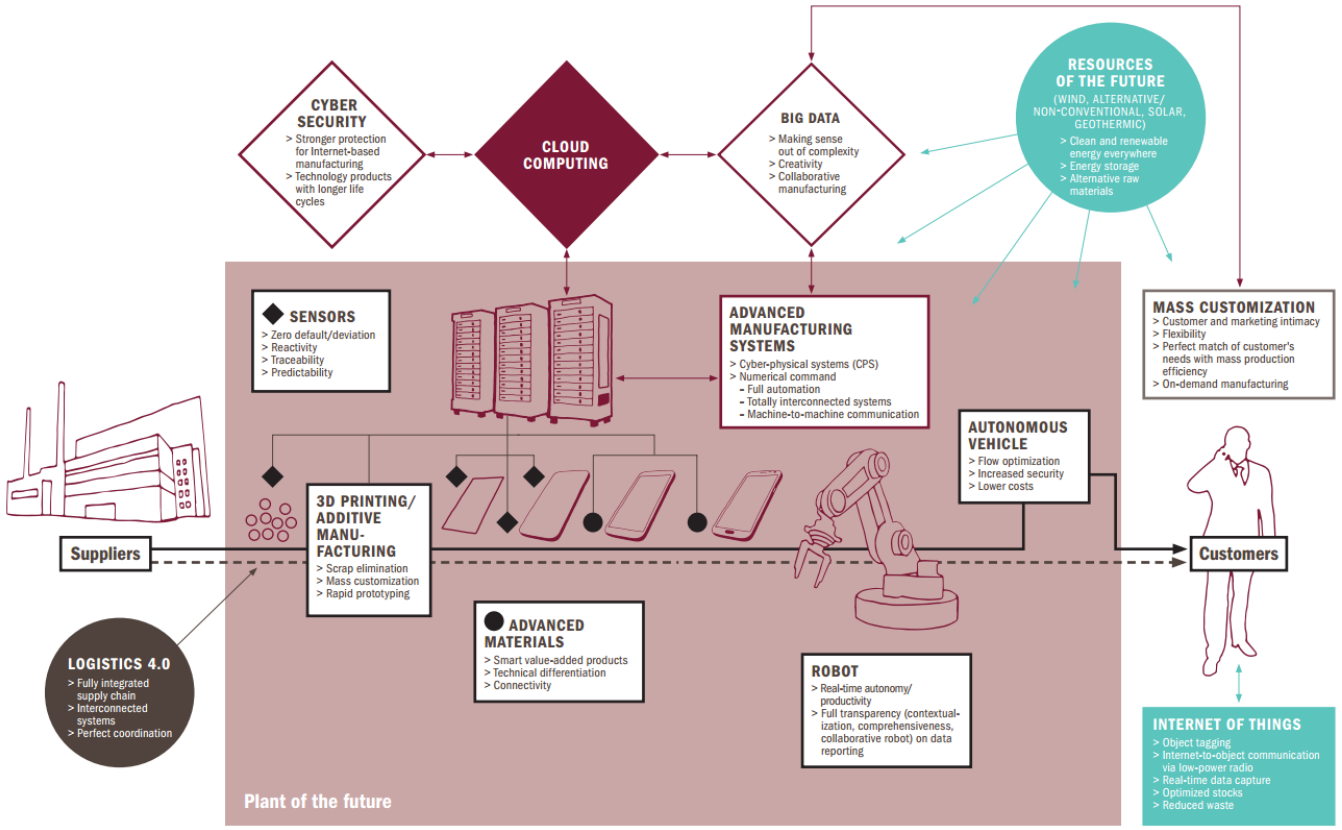


Source: B. Roland, "INDUSTRY 4.0: The new industrial revolution How Europe will succeed," Think Act, Tech. Report, 2014.

What is Industry 4.0?

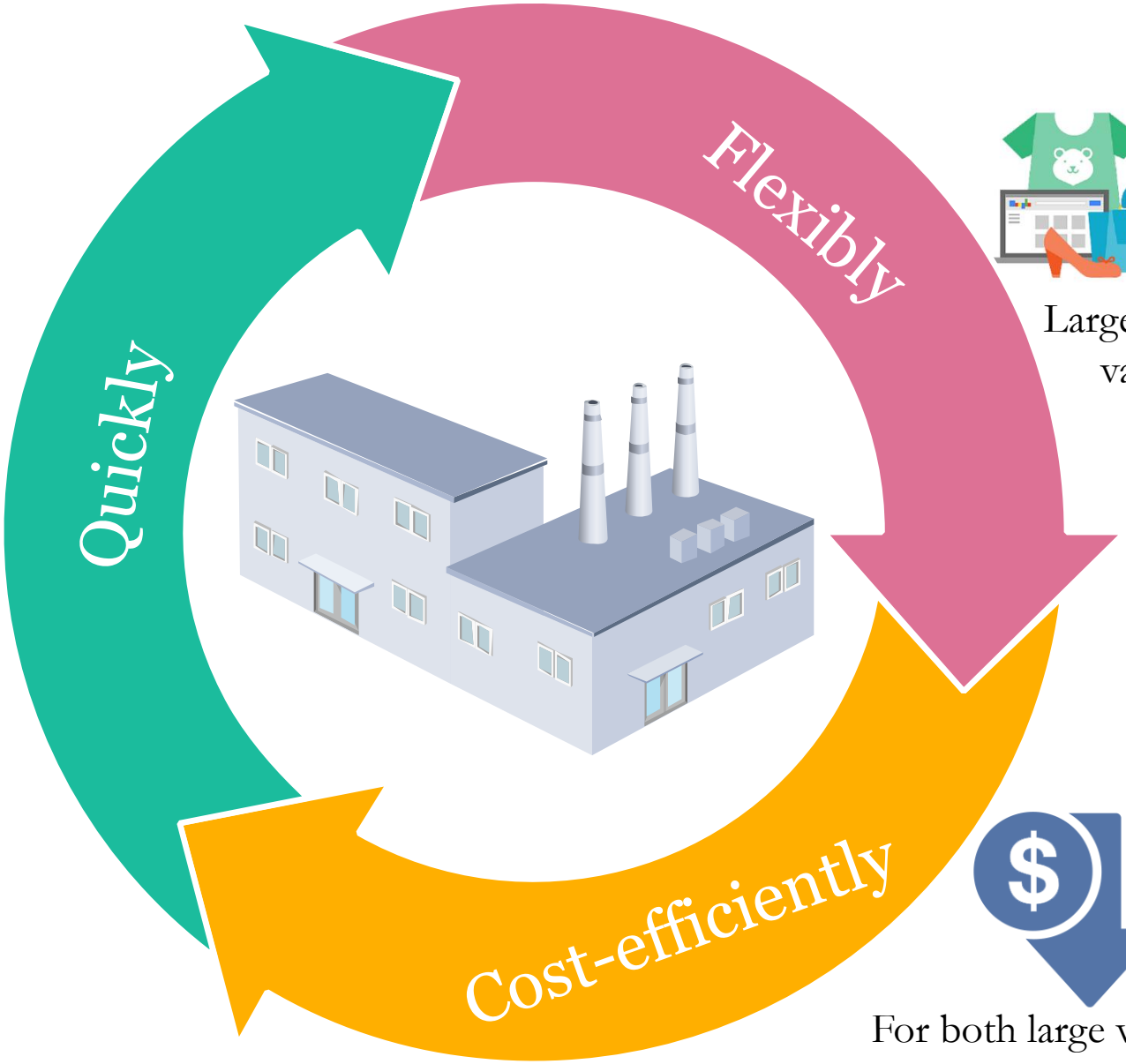


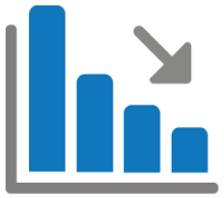
Classical 5-Layer Automation Architecture



Emerging Cyber Physical System-based Automation

What is Industry 4.0?





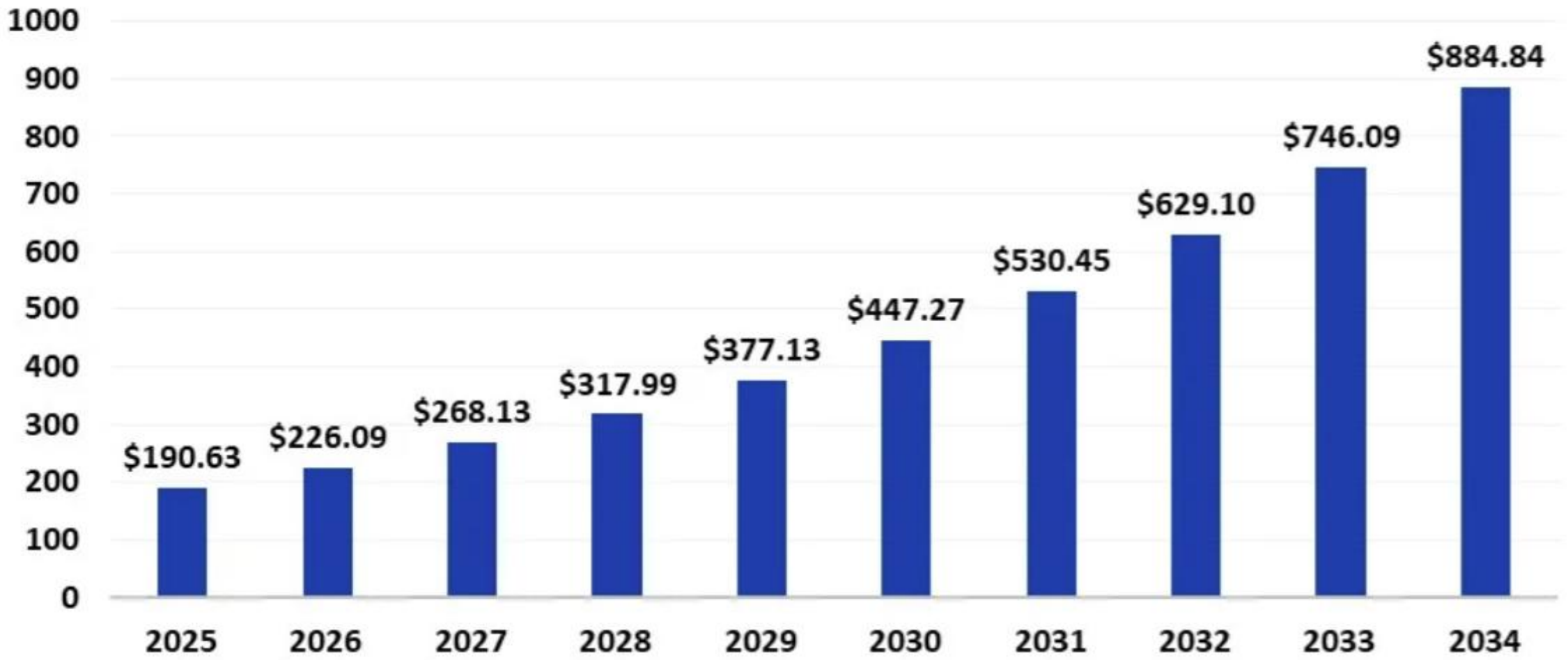
Shorter lead time/product life cycle

Larger product variance

For both large volume and small quantities

What is Industry 4.0?

The global Industry 4.0 market size was valued at USD 160.74 billion in 2024, estimated at **USD 190.87 billion in 2025** and is expected to reach around **USD 884.84 billion by 2034**, expanding at a CAGR of **18.6%** from 2025 to 2034.

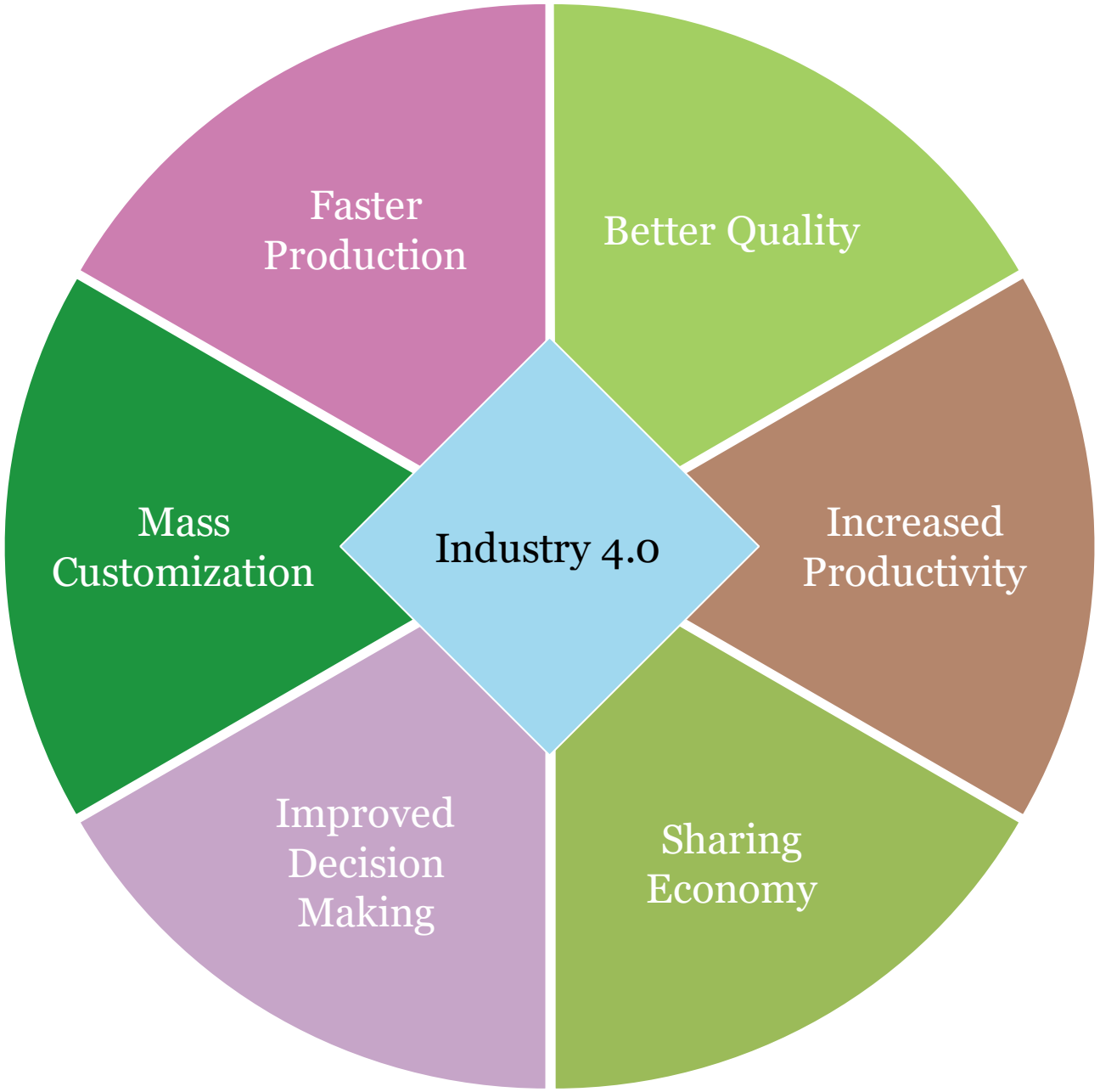


Source: https://www.precedenceresearch.com/industry-4-0-market

Outline

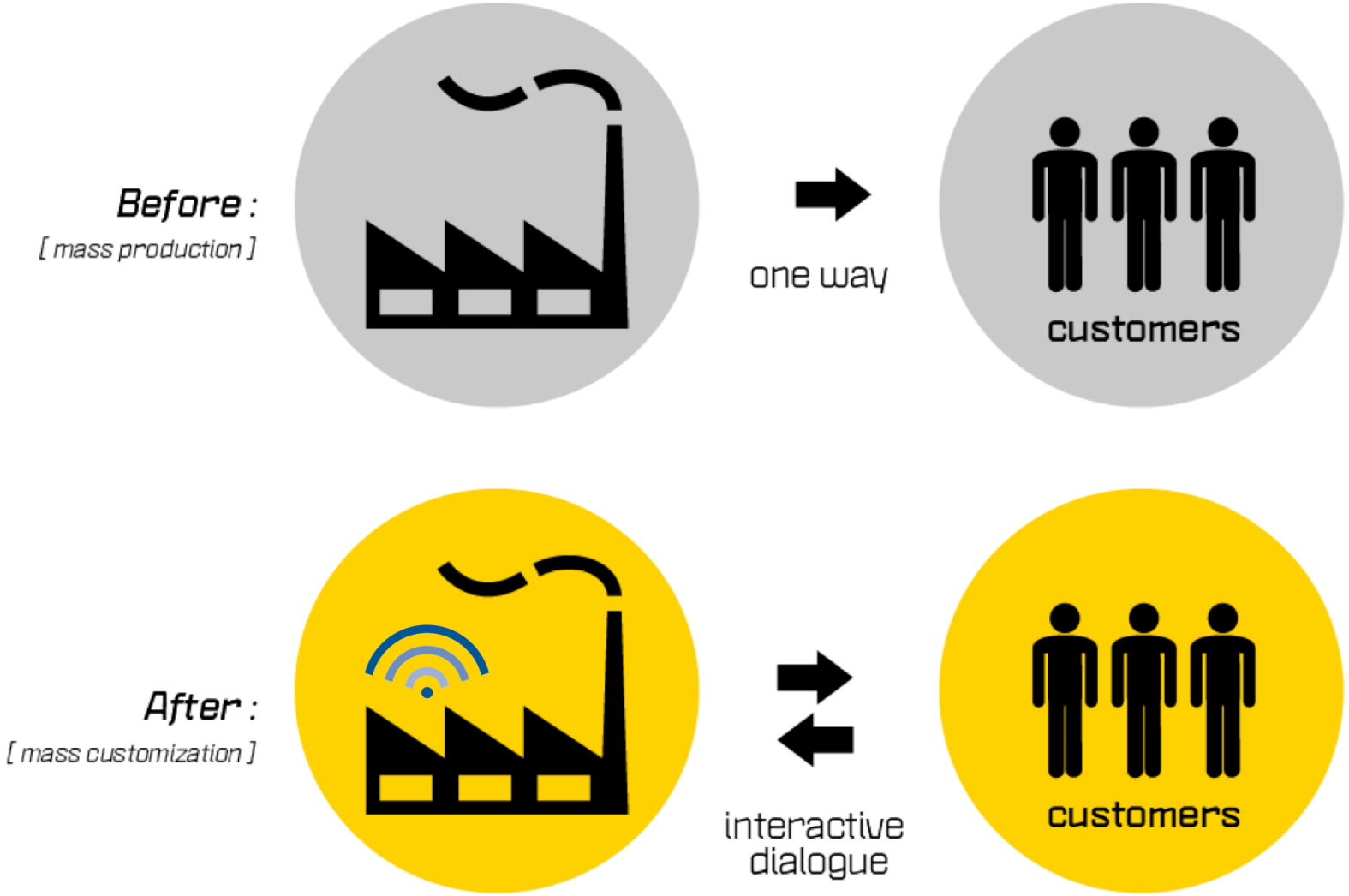
- What is Industry 4.0?
- **Why Industry 4.0?**
- Challenges
- Reliability Engineering
- Maintenance Engineering

Why Industry 4.0?



Why Industry 4.0?

- **Mass Customization**

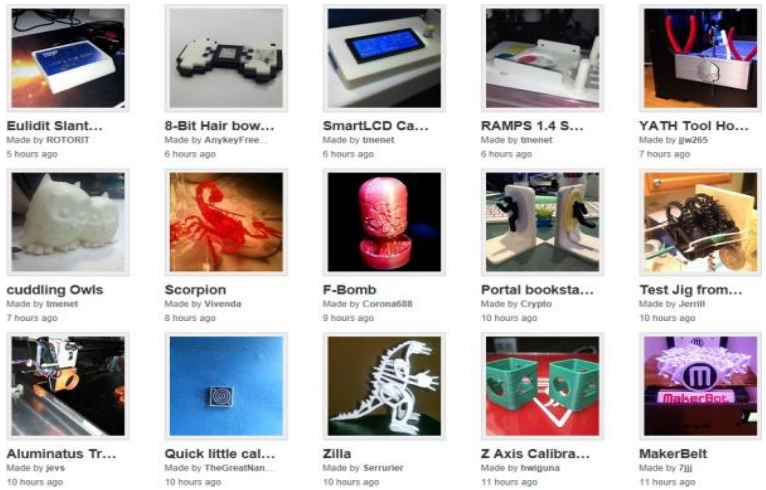


Build your own car: https://www.chevrolet.com/shopping/configurator

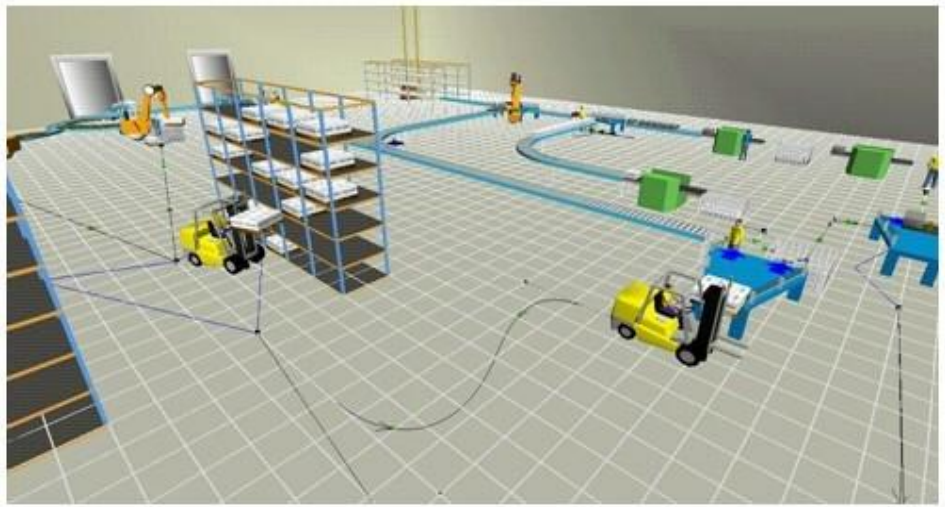
Increased flexibility in production and manufacturing on demand

Why Industry 4.0?

- **Faster Production**



Digital designs



Virtual modeling of manufacturing process

Data-driven supply chains

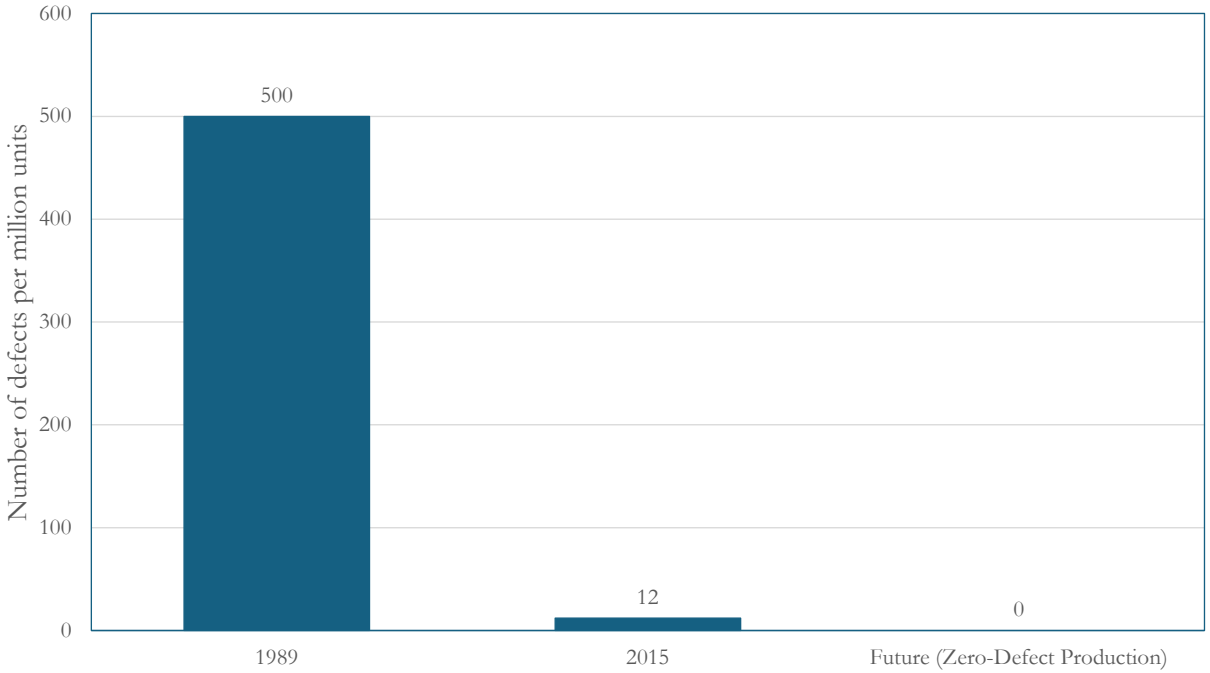
Speed up the manufacturing process :

120% in time needed to deliver orders

70% in time to get products to market

Why Industry 4.0?

- **Better Quality**

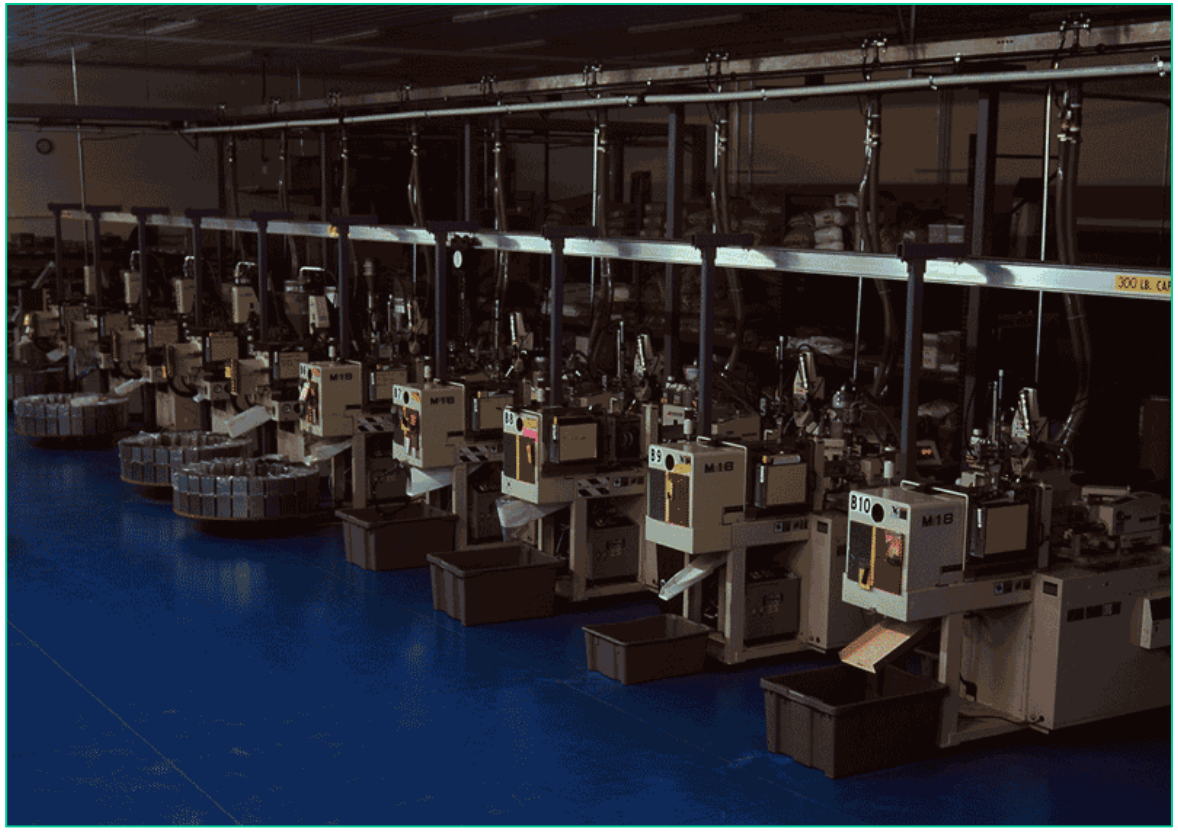


Siemens Smart factor for custom Programmable Logic Controls (PLCs)

Top 100 European manufacturers could save an estimated €160 billion in the costs of scrapping or reworking defective products if they could eliminate all defects.

Why Industry 4.0?

- **Increased Productivity**



Lights out/Dark factories work 24/7

Why Industry 4.0?

- **Increased Productivity**

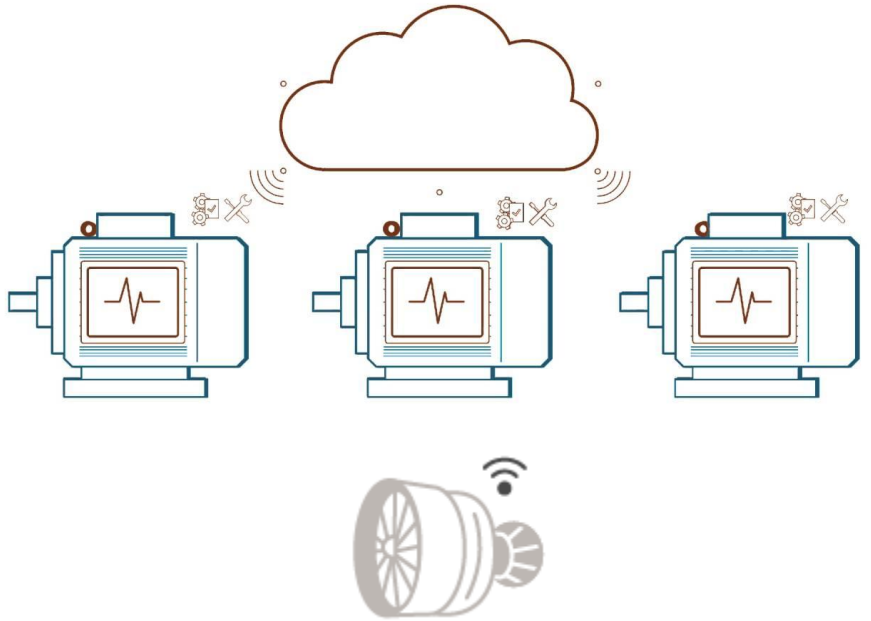
  Predictive maintenance avoids machine failures on the factory floor

50% decreased downtime

20% increased production

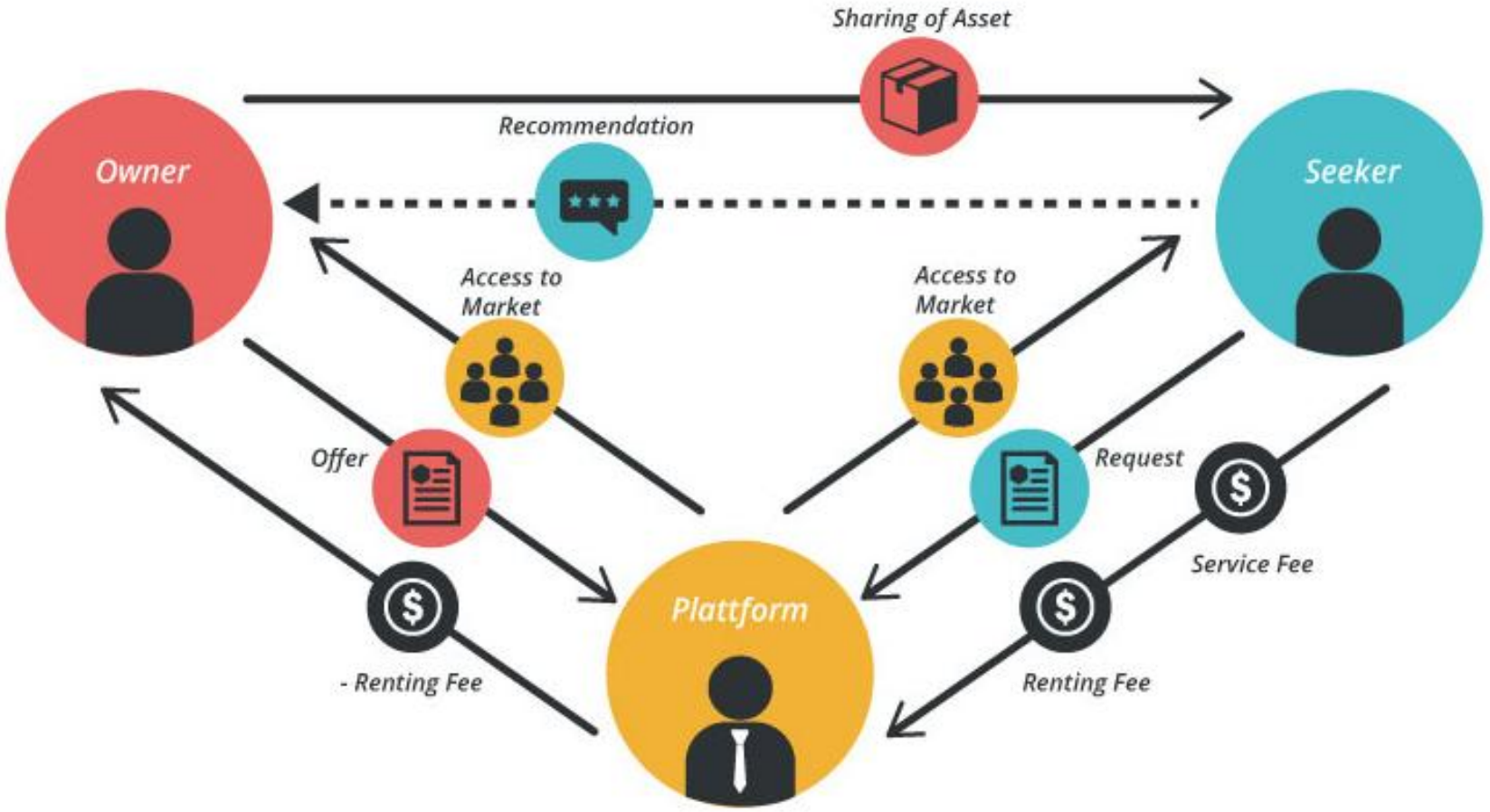
Predictive maintenance will help companies save $630 Billion by 2025 [McKinsey]

Corrective Maintenance	Planned Maintenance	Predictive Maintenance
Repair it after it breaks	Repair it before it breaks	Do not repair it, eliminate the root cause
Hight cost, overtime	Scheduled, coordinated	Life extension, labor time reduction



Why Industry 4.0?

- **Sharing Economy**

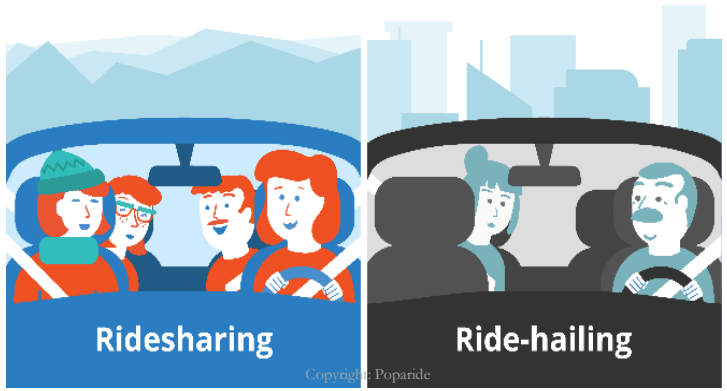


Examples:

- **3D printing:** 3DOS,Hubs, Treatstock, Xometry
- **Toots:** RentMyTool,ToolShare,Toronto Tool Library
- **On-demand labor:** TaskRabbit, Ajeer
- **Transportation:** Uber, Careem
- **Coworking spaces:** WeWork
- **Hospitality:** Airbnb

Why Industry 4.0?

- Sharing Economy: Car Sharing



We use our vehicles only 5% of the time, while for the remaining 95%, they are parked or sitting idle somewhere.

https://www.youtube.com/watch?v=sb7snDtKwJE

Why Industry 4.0?

- **Improved Decision Making**

With access to factory and cross-market data, decision makers

can predict, response, and adapt

to factory needs and market trends

Outline

- What is Industry 4.0?
- Why Industry 4.0?
- **Challenges**
- Reliability Engineering
- Maintenance Engineering

Challenges

Technical Challenges

- Communication reliability and QoS
- Cyber security
- Maturity of machine intelligence
- Handling big data
- Data-driven AI models

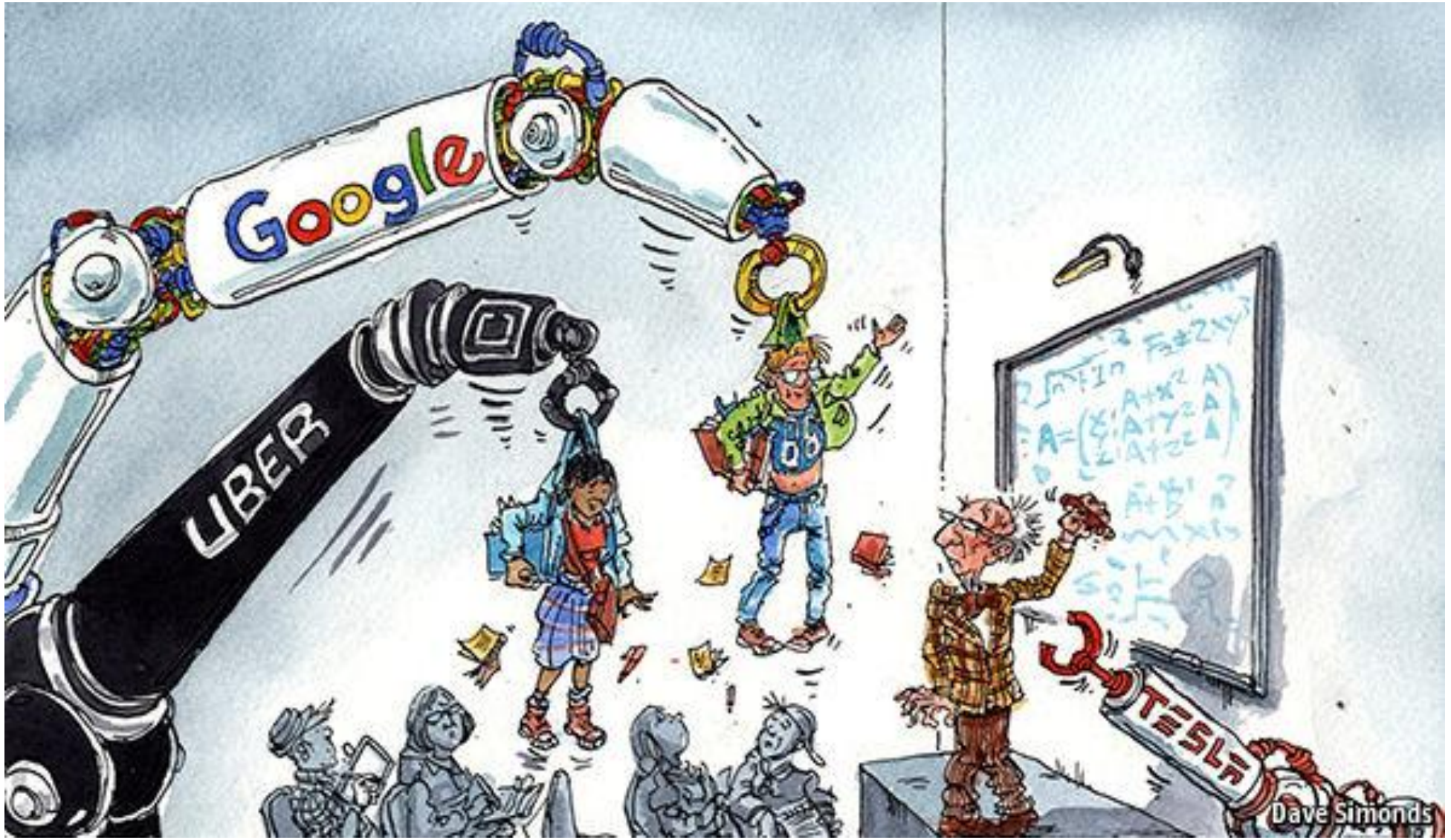
Social Impact

- General reluctance to change by stakeholders
- Lack of adequate skill-sets
- Unemployment

To be covered throughout the course…

Challenges

- Social Impact

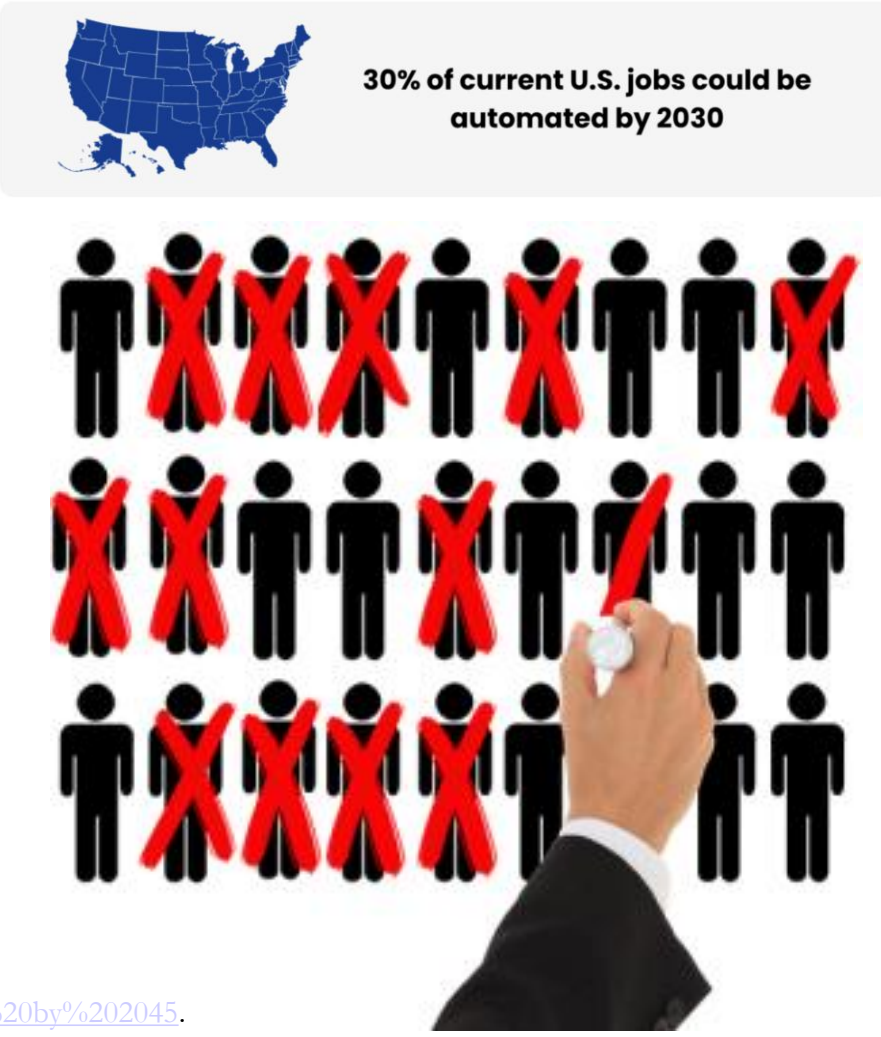


Challenges

- **Social Impact**

We can expect a wave of structural unemployment to spring from the technology in the medium term.

- 30% of current U.S. jobs could be automated by 2030; 60% will have tasks significantly modified by AI.
- 49% of companies using ChatGPT say it has replaced workers.
- By 2030, 14% of employees globally will have been forced to change their career because of AI.
- AI's impact is expected to be most disruptive in the next 10–30 years, with a possible 50% of jobs automated by 2045.



Source: https://www.nu.edu/blog/ai-job-statistics/#:~:text=AI's%20impact%20is%20expected%20to,of%20jobs%20automated%20by%202045.

Challenges

- **Social Impact**

Robots find applications in "4D tasks"

Challenges

- **Social Impact**

Machine

- Faster
- More precise
- Able to work in harsh environments
- Higher initial cost and lower running cost

Human

- Creative
- Lower initial cost and higher running cost

Challenges

- **Social Impact**

AI = Augmented Intelligence

AI will not replace you, but the person using AI will

AI is a means to an end

AI is a Good Follower, but a Dangerous Leader

Outline

- What is Industry 4.0?
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- Challenges
- **Reliability Engineering**
- Maintenance Engineering

Reliability Engineering

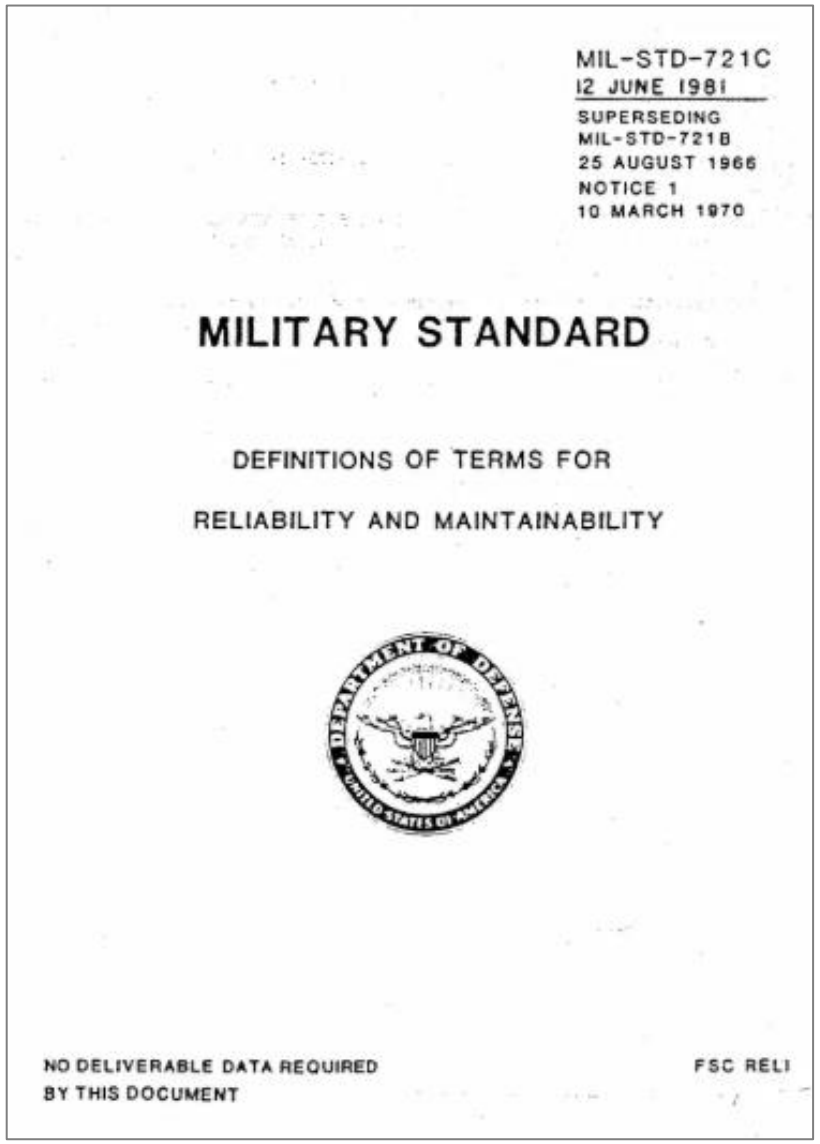
- **What is Reliability?**

Reliability is the probability that a product or system will operate as intended, under specified operating conditions for a specific period.

Reliability is consistent quality over a specified period.

Reliability Engineering

- **What is Reliability?**



MIL-STD-721C
12 JUNE 1981
SUPERSEDING
MIL-STD-721B
25 AUGUST 1966
NOTICE 1
10 MARCH 1970

MILITARY STANDARD

DEFINITIONS OF TERMS FOR

RELIABILITY AND MAINTAINABILITY

NO DELIVERABLE DATA REQUIRED
BY THIS DOCUMENT

FSC RELI

Reliability is the duration or **probability** of failure-free performance under **stated conditions**.

Reliability is the **probability** that an item can perform its intended function for a **specific interval** under **stated conditions**.

Reliability Engineering

- **What is Reliability?**

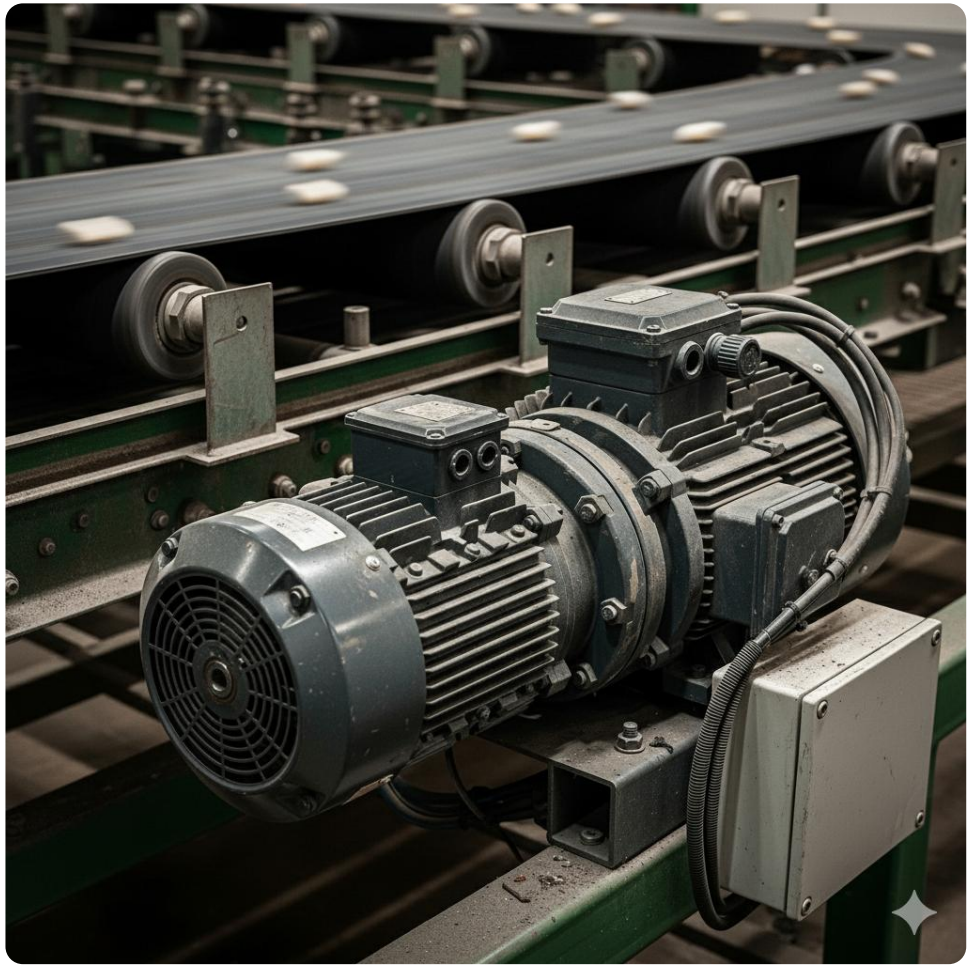
Reliability is the **probability** that an item can perform its intended function for a **specific interval** under **stated conditions**.

<u>Reliability depends on **stated conditions**.</u>

For example, a **conveyor motor** in a plant is more reliable when run under **normal load and good lubrication**, but less reliable under **overload and poor lubrication**.

<u>Reliability is also **time-bound**.</u>

The same motor under overload may run safely for **10 minutes**, but running it for **10 hours** greatly increases the chance of failure.



Reliability Engineering

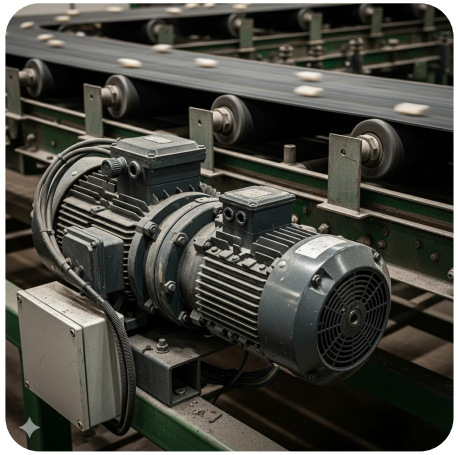
- **What is Reliability?**

Reliability is the **probability** that an item can perform its intended function for a **specific interval** under **stated conditions**.

Probability

Stated Condition

Time



- The conveyor motor has a reliability of **95%** to operate for **two 8-hour shifts** under **normal load and proper lubrication conditions**.
- The same conveyor motor has a reliability of **only 40%** to operate for **two 8-hour shifts** if run **under overload with poor lubrication**.

Reliability Engineering

- **How is reliability calculated?**

Euler's number=2.7182

$$R(t) = e^{-\lambda.t}$$

Reliability for time interval t

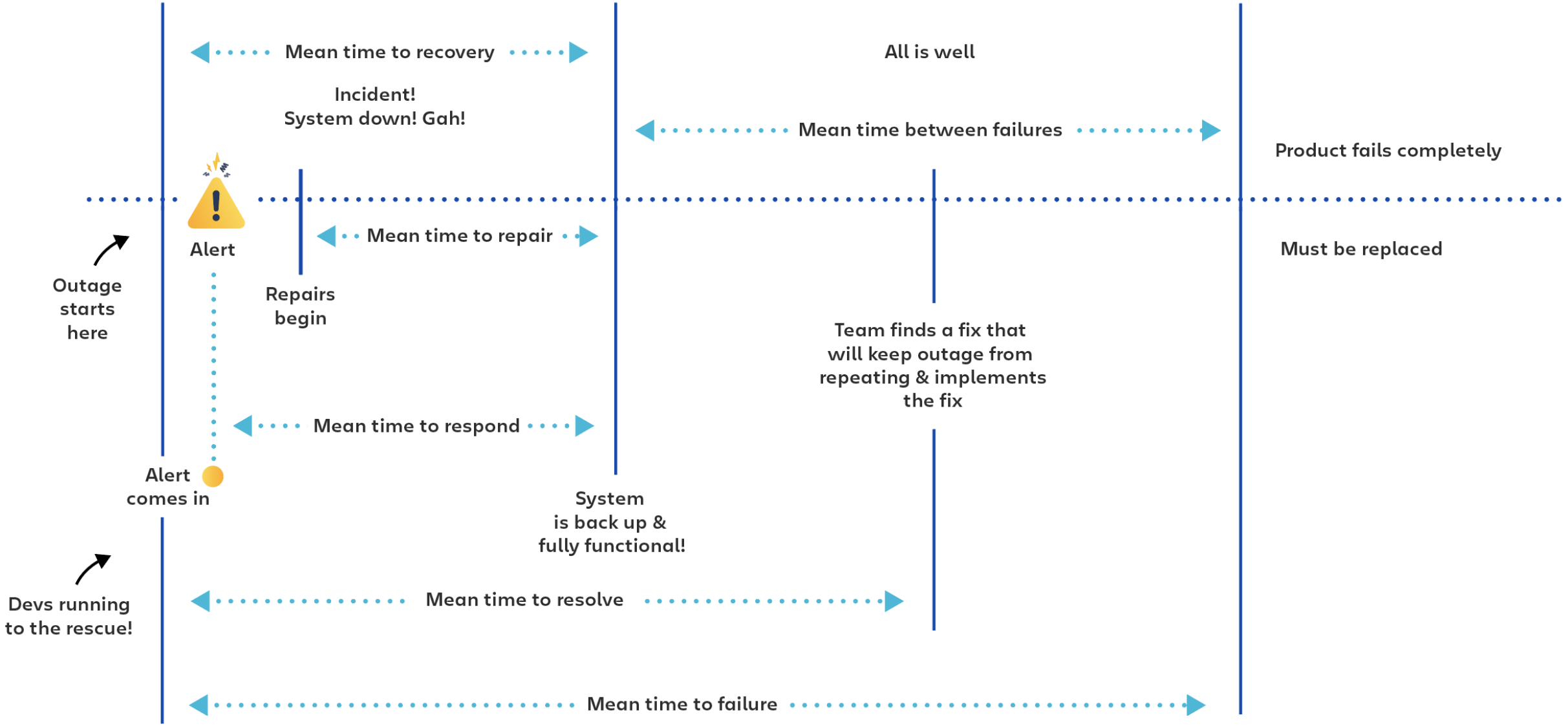
Failure rate$=\frac{No.of\ failures}{Total\ operating\ time}$

Failure rate$=\frac{50\ failures}{10{,}000\ hours} = 0.005\ failures/hour$

Q: What is the reliability of the motor to run for three 8-hour shifts?

Reliability Engineering

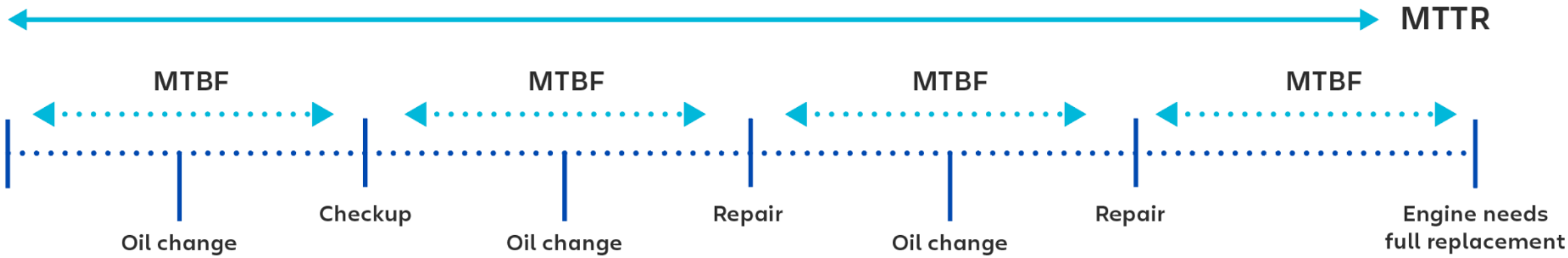
- Reliability Indices



Source: Altassian

- **Reliability Indices: Mean time between failures (MTBF)**

MTBF (mean time between failures) is the average time between repairable failures of a product. The metric is used to track both the availability and reliability of a product. The higher the time between failure, the more reliable the system.



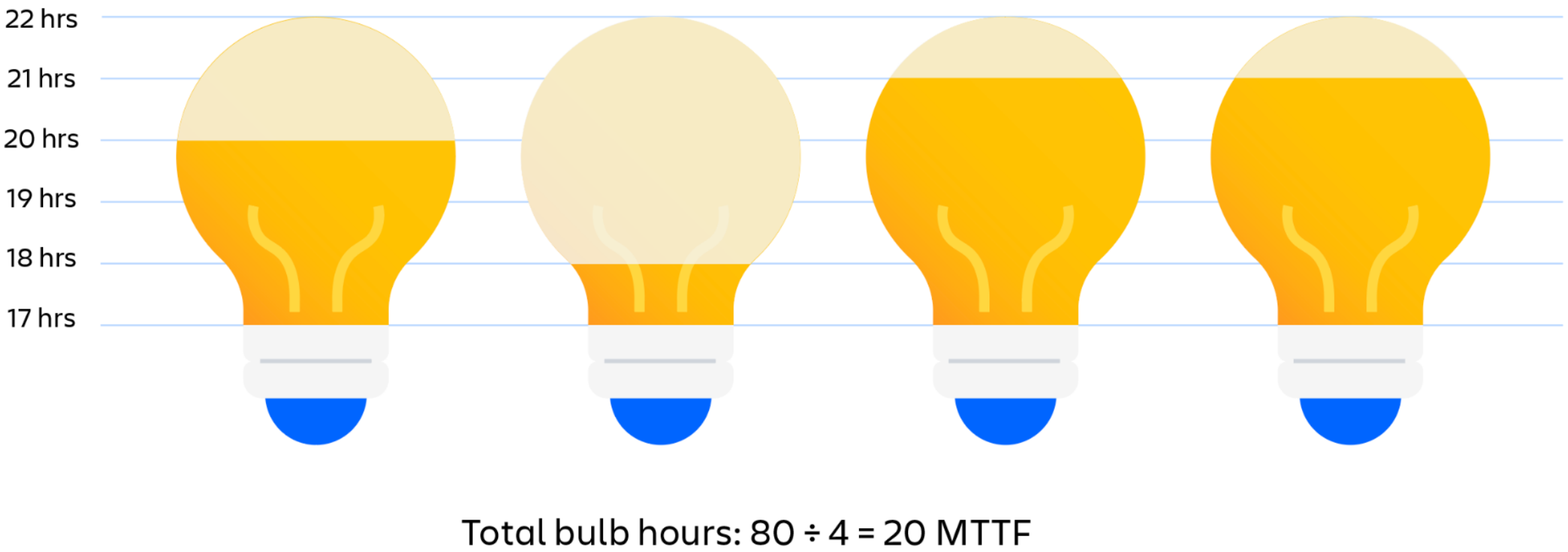
$$\text{Failure rate} = \frac{50\ failures}{10{,}000\ hours} = 0.005\ failure/hour$$

$$\text{MTBF} = \frac{1}{Failure\ rate} = \frac{total\ operating\ time}{No.of\ failures} = \frac{10{,}000}{50} = 200\ hours/failure$$

Source: Altassian

- **Reliability Indices: Mean time to failure (MTTF)**

MTTF (mean time to failure) is the average time between non-repairable failures of a product.



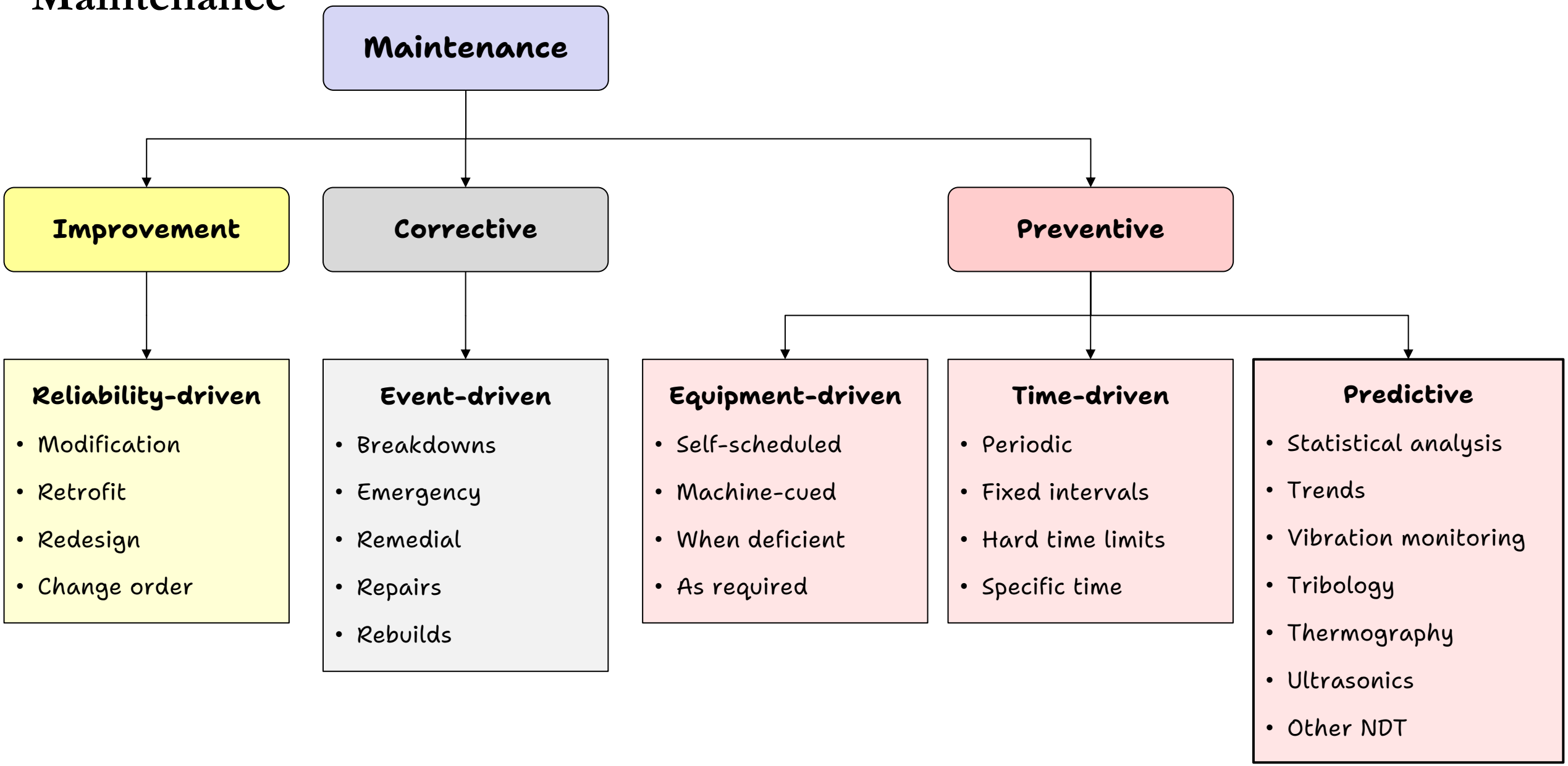
Source: Altassian

Outline

- What is Industry 4.0?
- Why Industry 4.0?
- Challenges
- Reliability Engineering
- **Maintenance Engineering**

Maintenance Engineering

- Maintenance



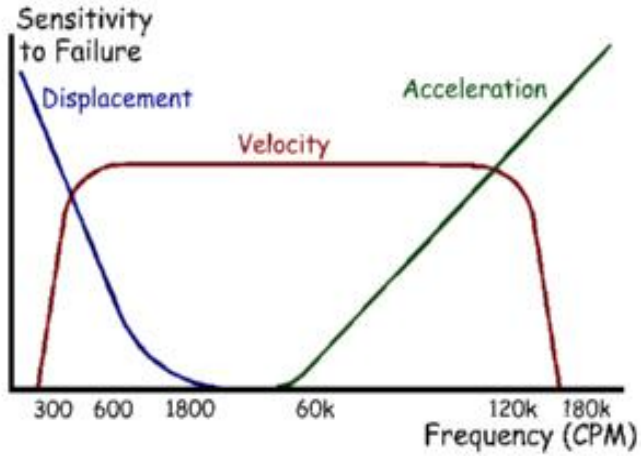
Maintenance Engineering

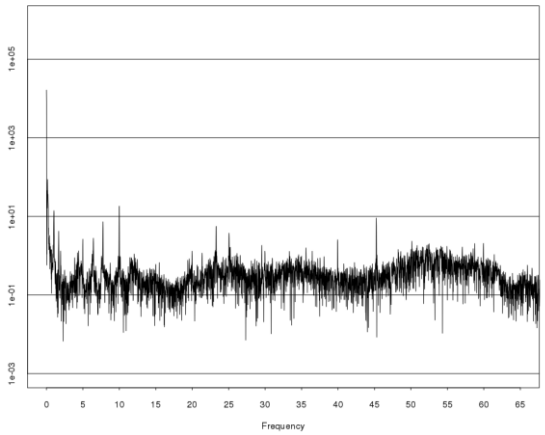
- **Predictive Maintenance**

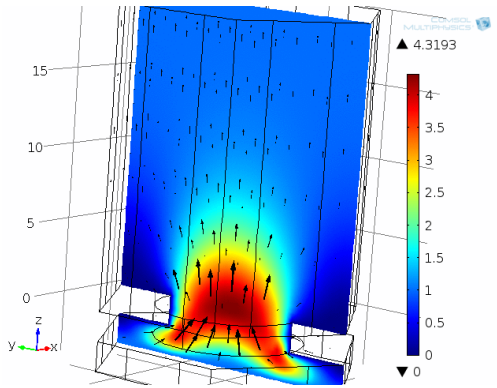
Electro-mechanical equipment does not break without warning

Minimum vibration | Apparent noise | Heating up | Smoke

Months → Weeks → Days → Minutes → Time before the faults





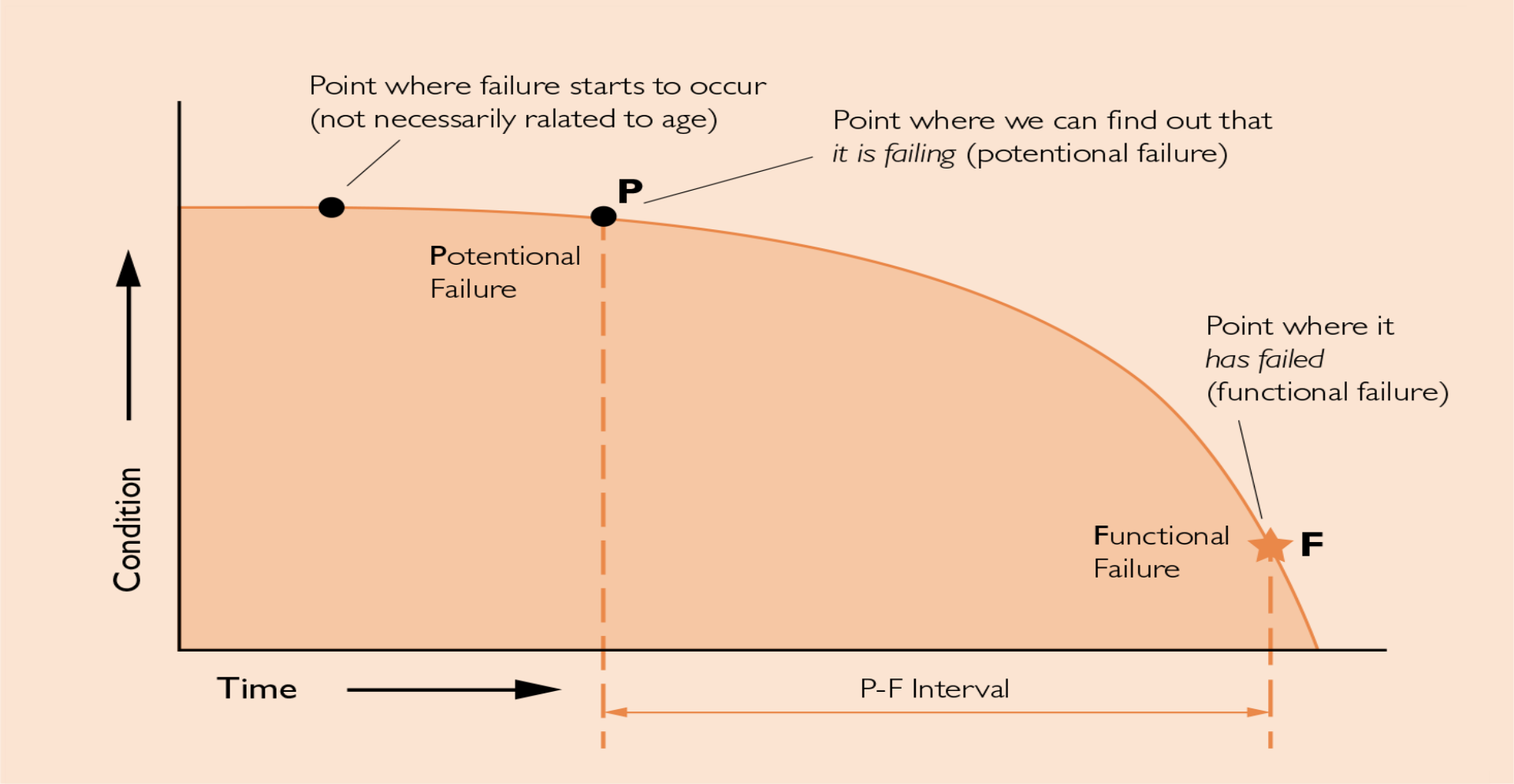


- Condition Monitoring

Diagnostics	Fault Detection	Detecting abnormal condition
	Fault Isolation	Identifying failing component
	Fault Identification	Estimating the nature and extend of the fault (Failure mode)
Prognostics	Remining Useful Life Prediction	Identifying the lead time or probability to failure
	Confidence Interval Estimation	Estimating confidence interval associated with the RUL prediction

Source: PdM Processes - Diagnostic and Prognostic. Adapted from (Sikorska, J. Z., Hodkiewicz, M., & Ma, L. (2011). Prognostic modelling options for remaining useful life estimation by industry. Mechanical Systems and Signal Processing, 25(5), 1803-1836. doi:10.1016/j.ymssp.2010.11.018)

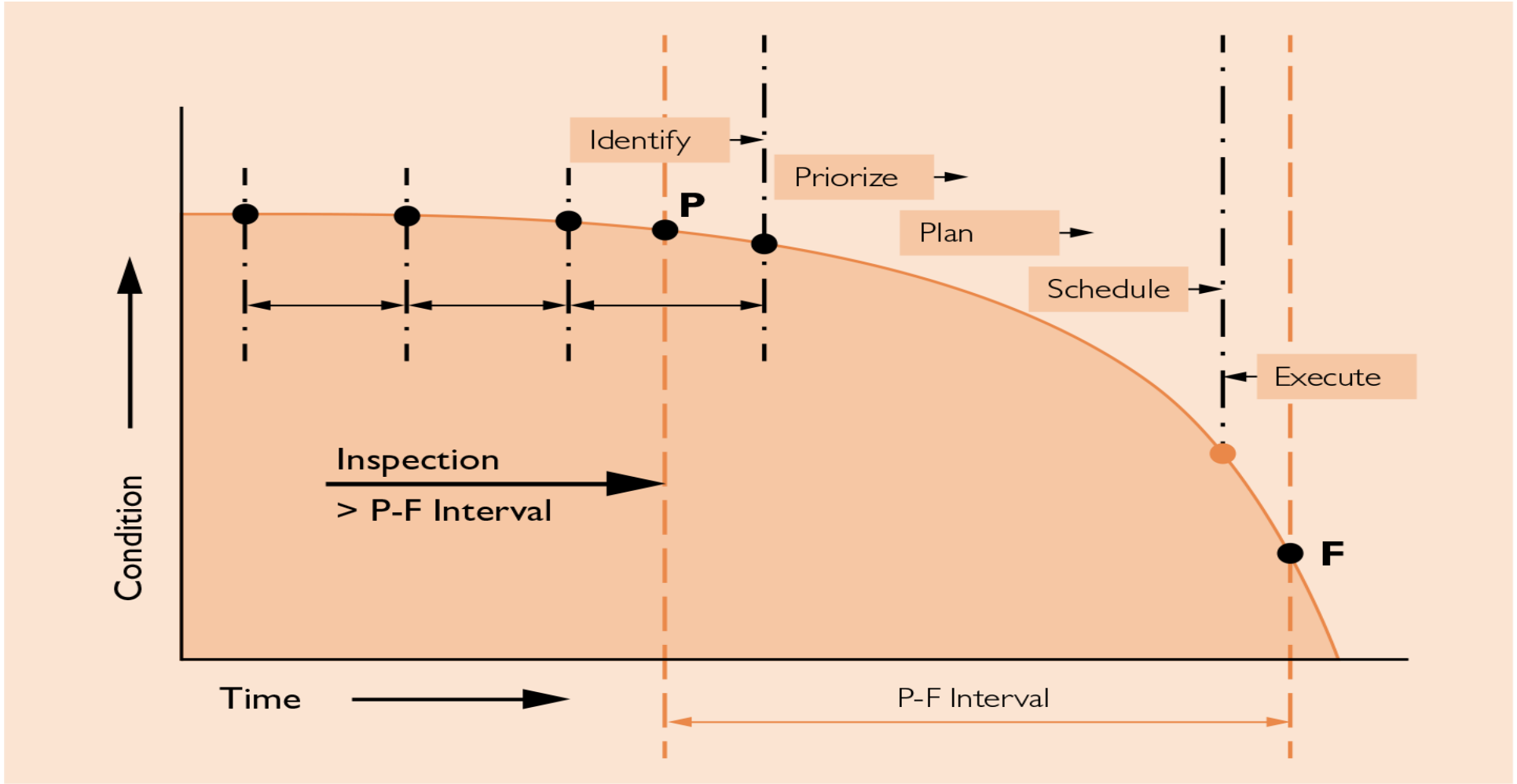
- **Condition- based Maintenance (CBM)**



Source: maintWorld

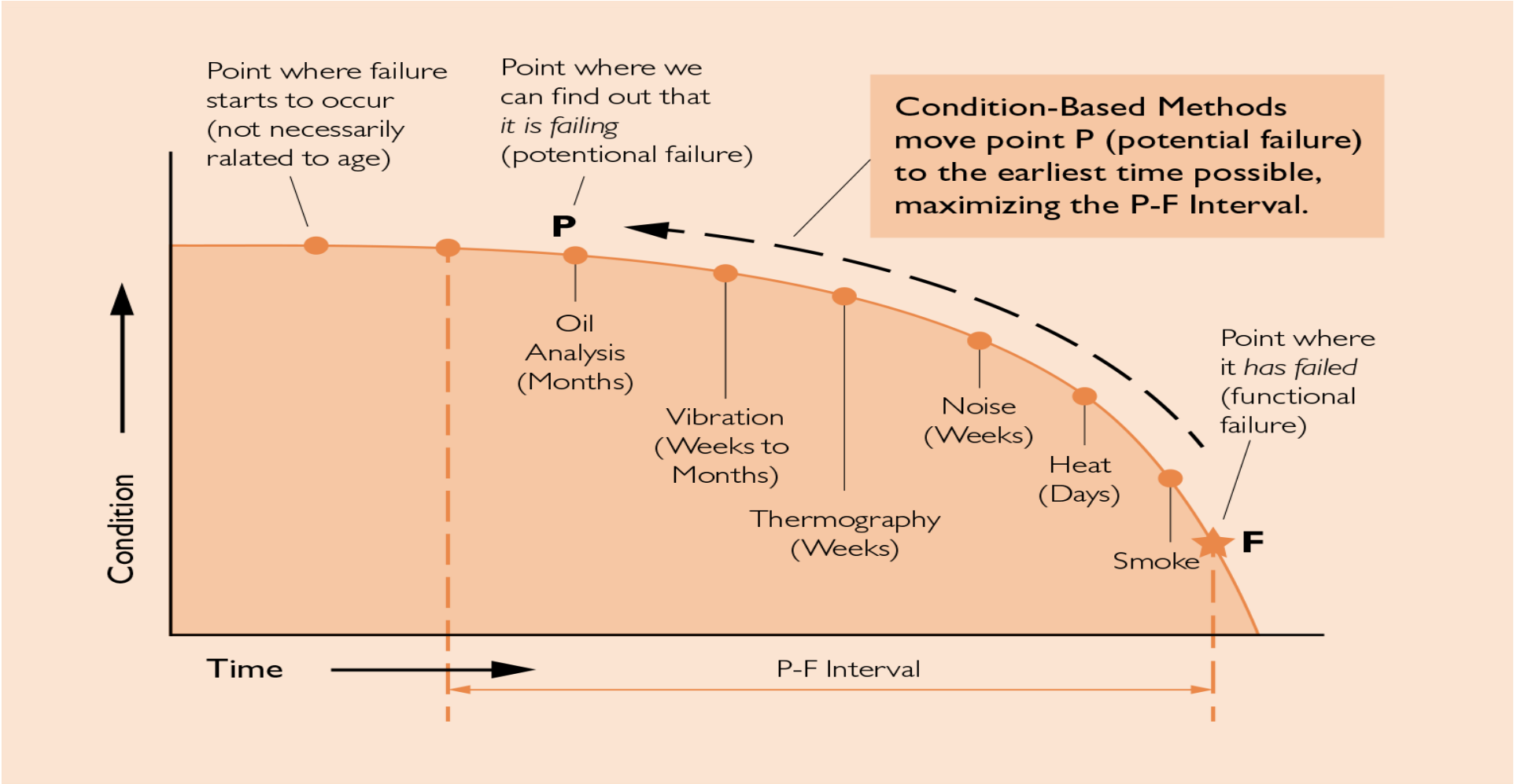
Maintenance Engineering

- **Condition- based Maintenance (CBM)**



Source: maintWorld

- Condition- based Maintenance (CBM)



Source: maintWorld

- **Condition- based Maintenance (CBM)**

When implemented properly, Condition- based Maintenance (CBM) has the ability to:

- Reduce both the time between maintenance activities (TBM) and time to repair (MTTR)
- Resultant savings in labor costs
- and reduction of downtime losses.

These benefits are achieved from predicting potential failures ahead of time,

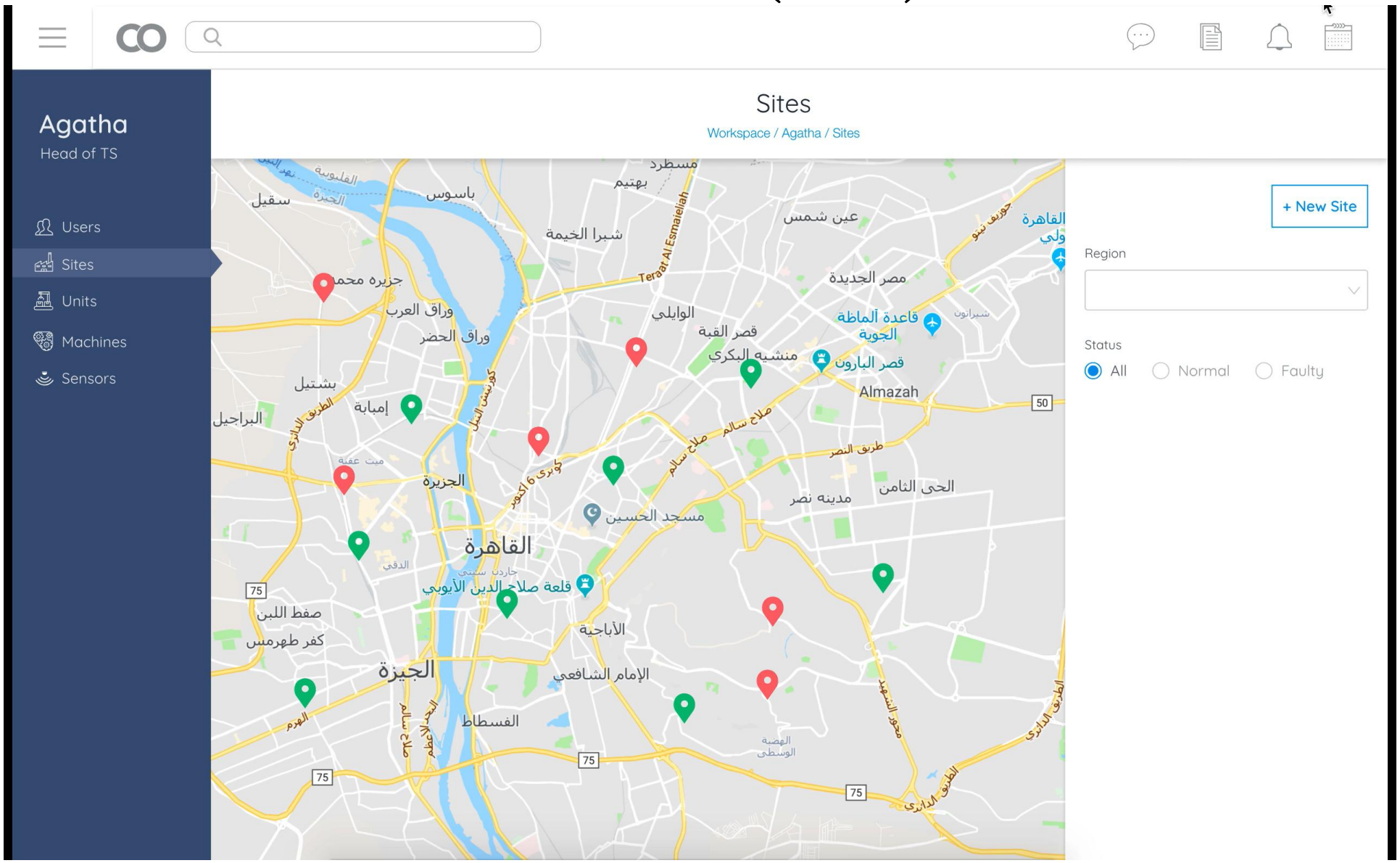
- Providing the maintenance staff with time to
- Prioritize, plan and execute the work most efficiently and economically.
- Spare parts inventories and/or expediting costs are reduced as well when there is sufficient lead-time to order parts on an "as needed" basis.

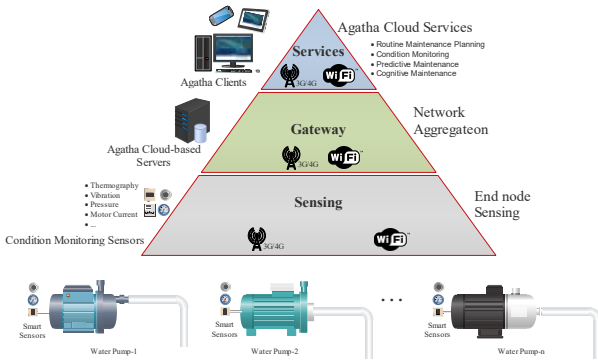
Furthermore

- Prevention of catastrophic failure eliminates excessive damage to equipment, both direct and collateral, potentially increasing the useful operating life of equipment
- Reduction in capital replacement costs.

Maintenance Engineering

- **Condition- based Maintenance (CBM)**





https://www.youtube.com/watch?v=Ewnr-lS58eE

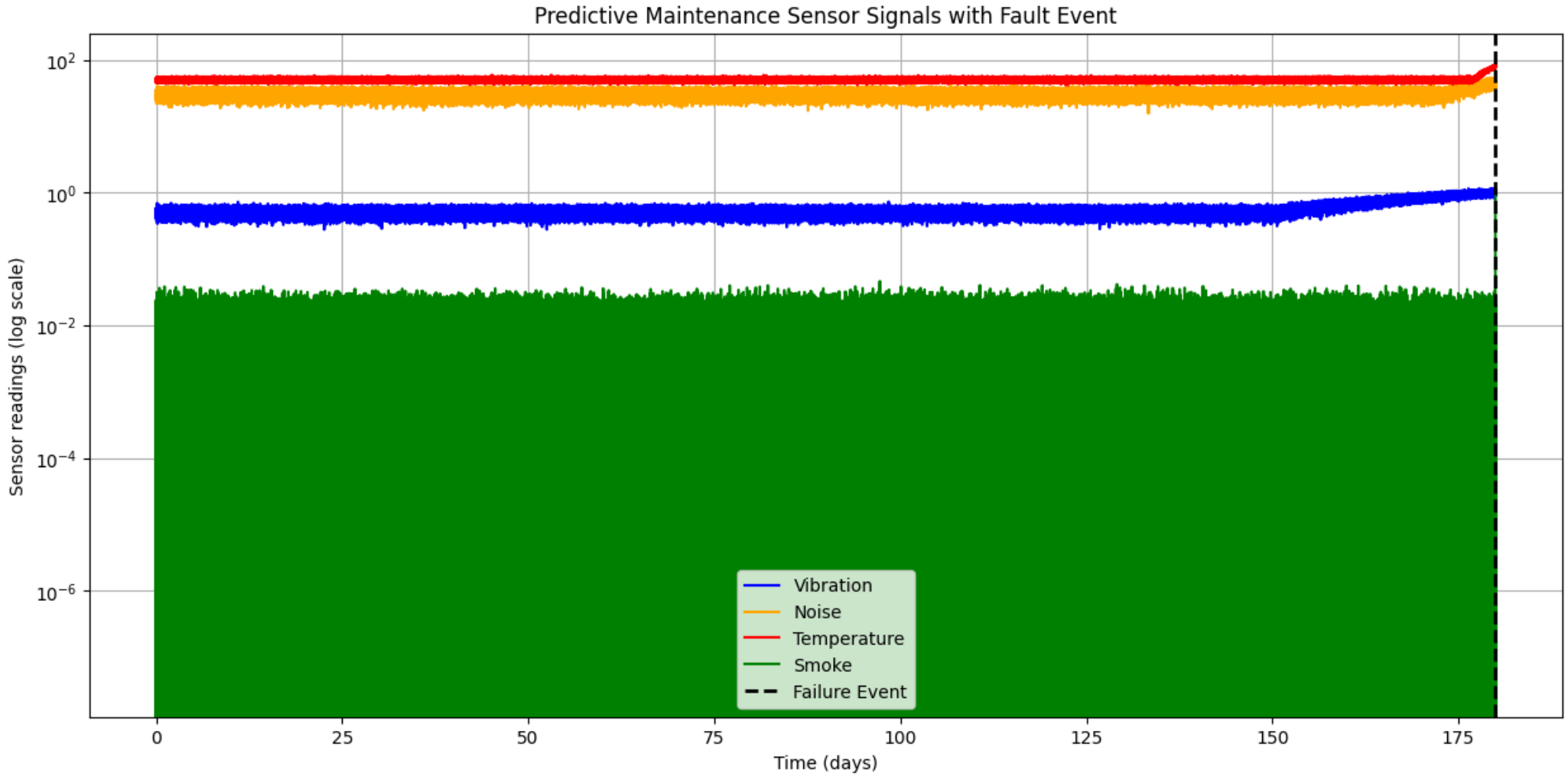
Alaa Khamis. Cognitive IoT-based Predictive Maintenance System. US, 62819700, 2019.

Maintenance Engineering

- Hands-on

Sensory data

- Vibration
- Noise
- Thermography
- Smoke



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