

Staying Profitable with AI

Virtual Test and Process Redesign

Tarapong Sreenuch

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克明峻德，格物致知

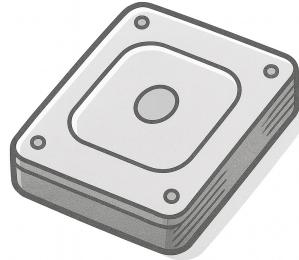
Seminar Outline

- Context of Data Storage Industry
- Framing AI
- Use Case & Pain Points
- Replacing Job Task with Machine Learning
- Handling Uncertainty
- Process Redesign & ROI

Composite Teaching Case; Synthetic Figures; No Confidential Info.

Setting the Context: Data Storage

Market: Hard Disk Drive (HDD)

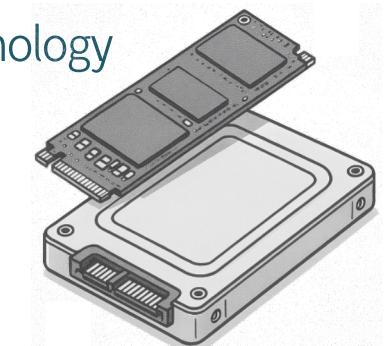


Key Players: Highly Concentrated. Seagate, Toshiba & Western Digital are only the three makers today.

Hard Disk Drive (HDD): Low Cost, Low Performance, (Very Very) Complicated Technology



Threat: Solid State Drive (SSD), High Performance, Expensive (but getting cheaper), Simple Technology



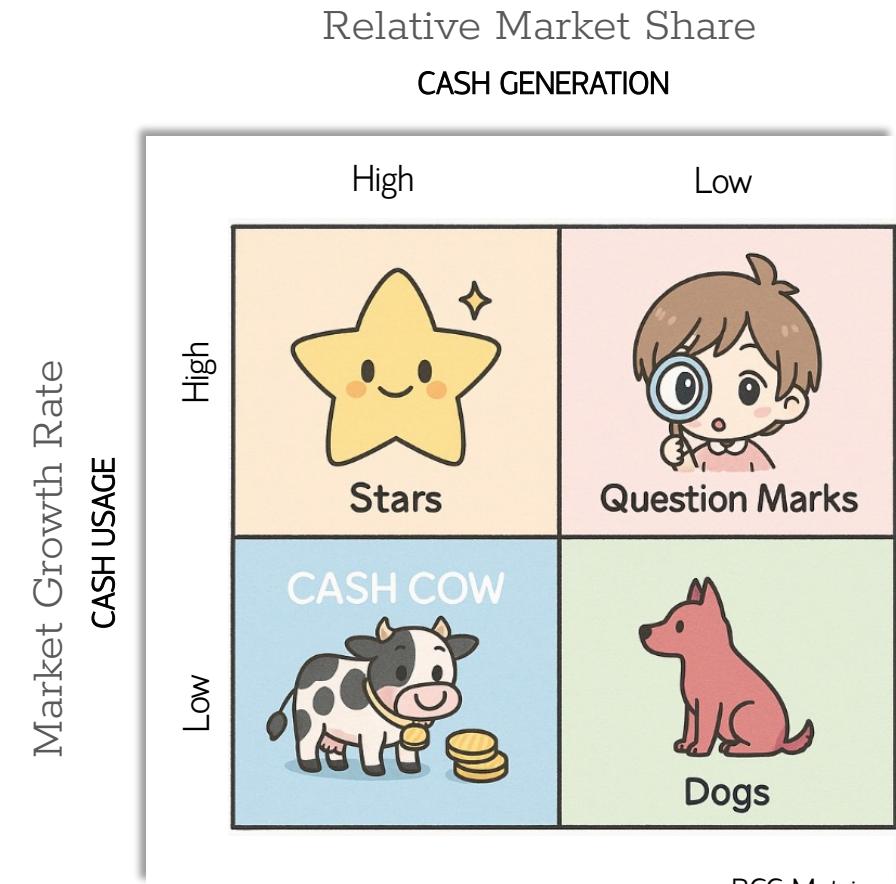
Composite Teaching Case; Synthetic Figures; No Confidential Info.

Sunsetting Technology

Near Term: Cloud Expansion → High Demand in Data Storage

Outlook: Sunsetting Technology (being replaced by SSD)

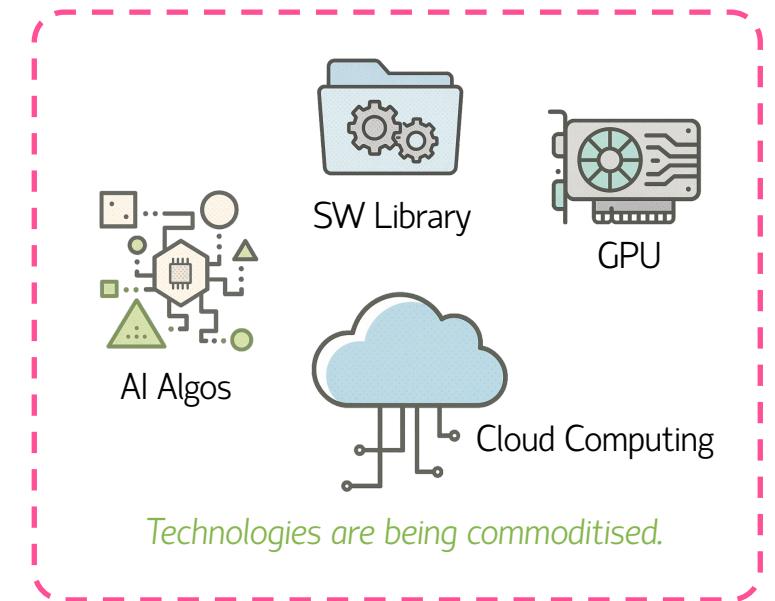
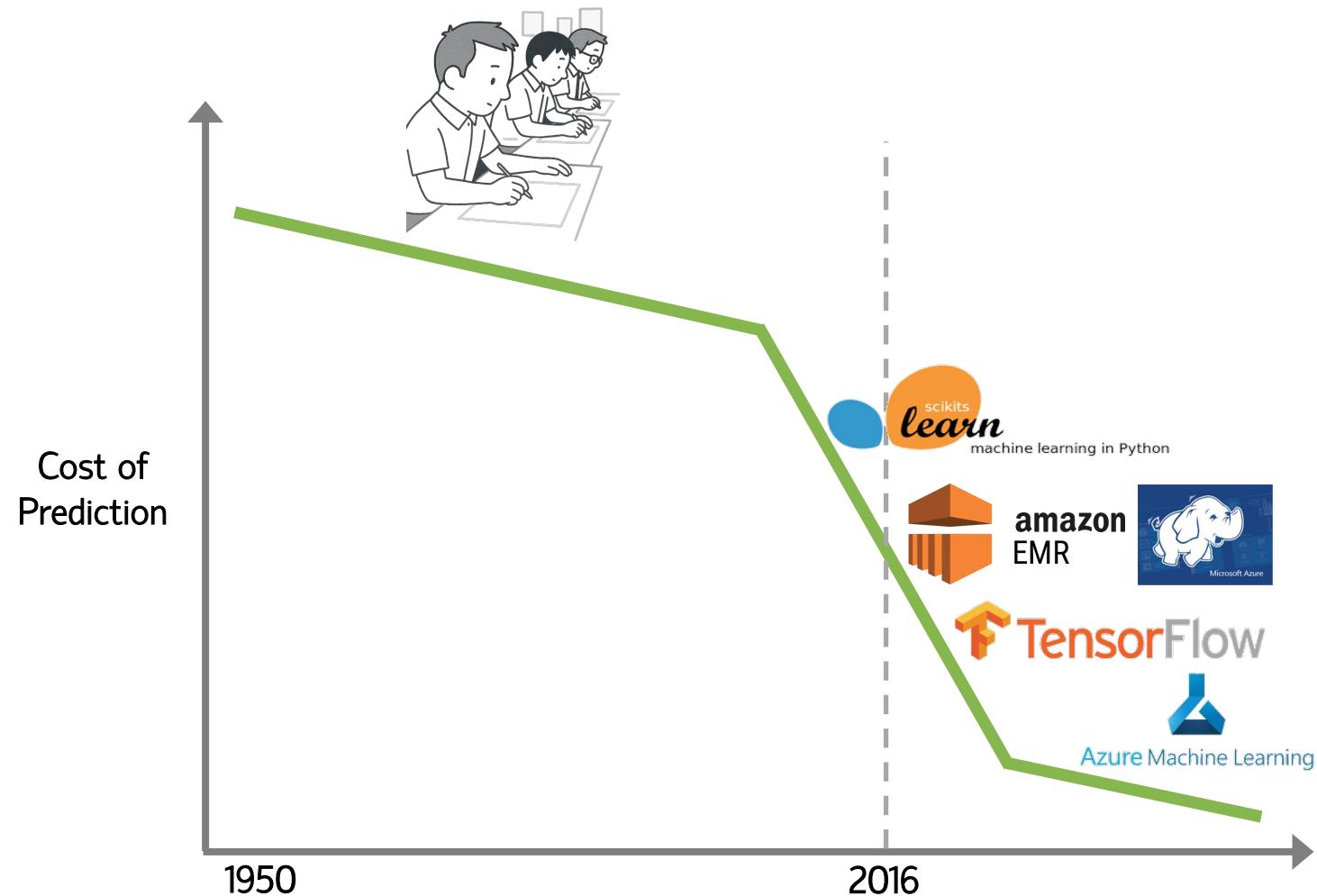
Firms often hesitate to invest heavily in sunsetting tech even amid short-term demand.



Context: We have orders. → We are struggling to fulfill the orders. → But yet, we don't want to invest.

Composite Teaching Case; Synthetic Figures; No Confidential Info.

Artificial Intelligence (AI)



'Perhaps, we can even get rid of our data scientists.'

What Is AI?

AI lowers cost of prediction. It's a cheap prediction.

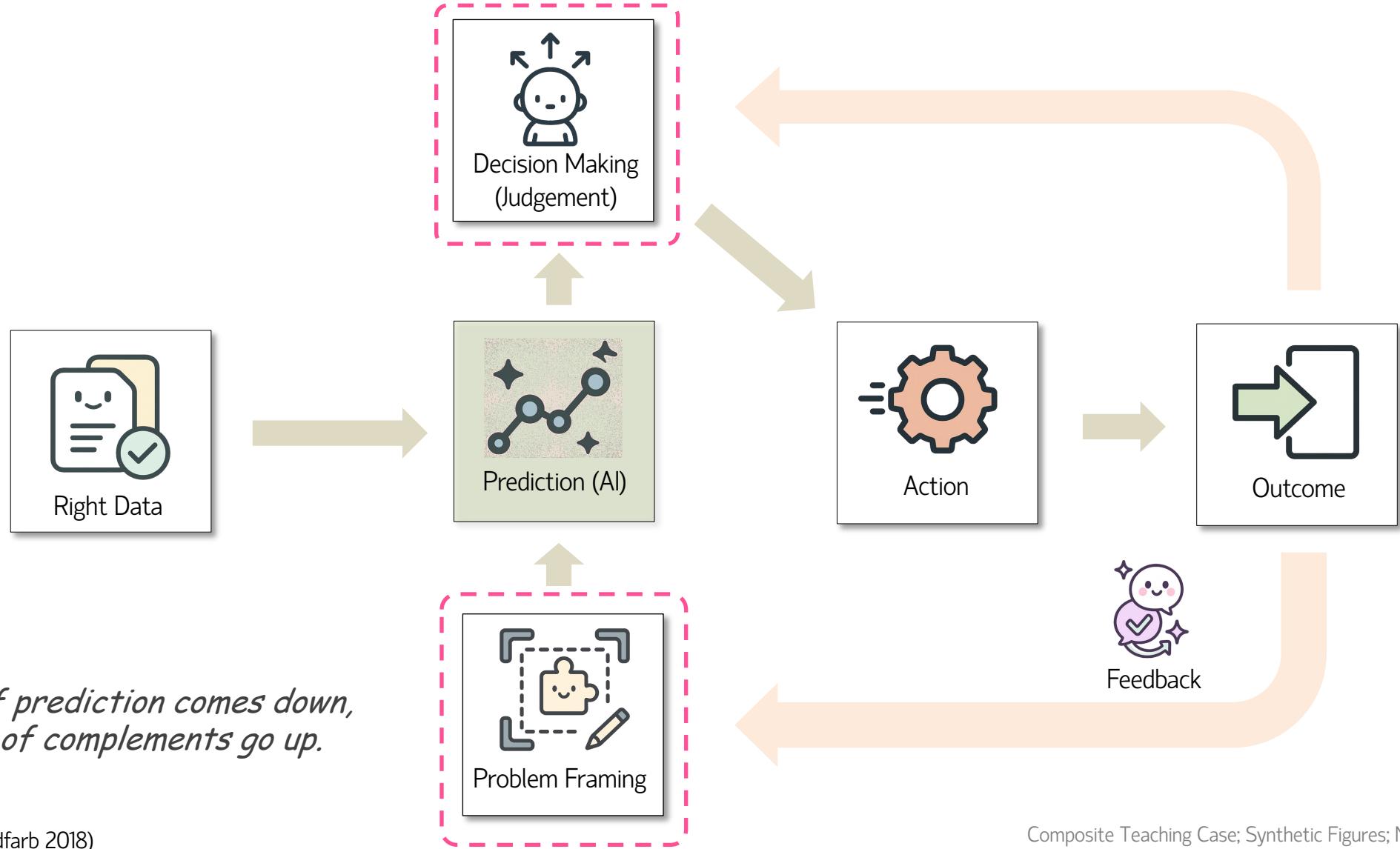
Business Meaning of AI

Think of It This Way: Things will become less magical.

What will happen when prediction becomes cheap?

Surely, we will use more of it.

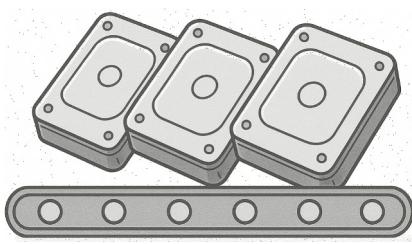
AI's Complements



(Agrawal, Gans and Goldfarb 2018)

Composite Teaching Case; Synthetic Figures; No Confidential Info.

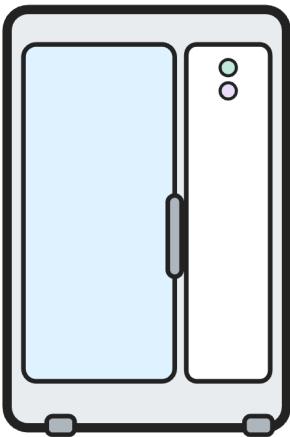
HDD Test Process: Operation Bottleneck



Assembled HDD Drives

Assembled Hard Disk Drives

Every hard disk drive is quality tested.



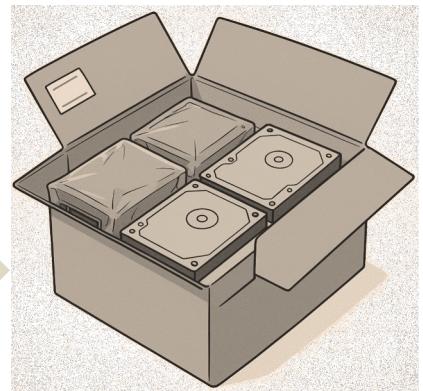
HDD Electrical Tester

Every hard disk drive is quality tested.

It takes 1-4 weeks to test a hard disk drive.

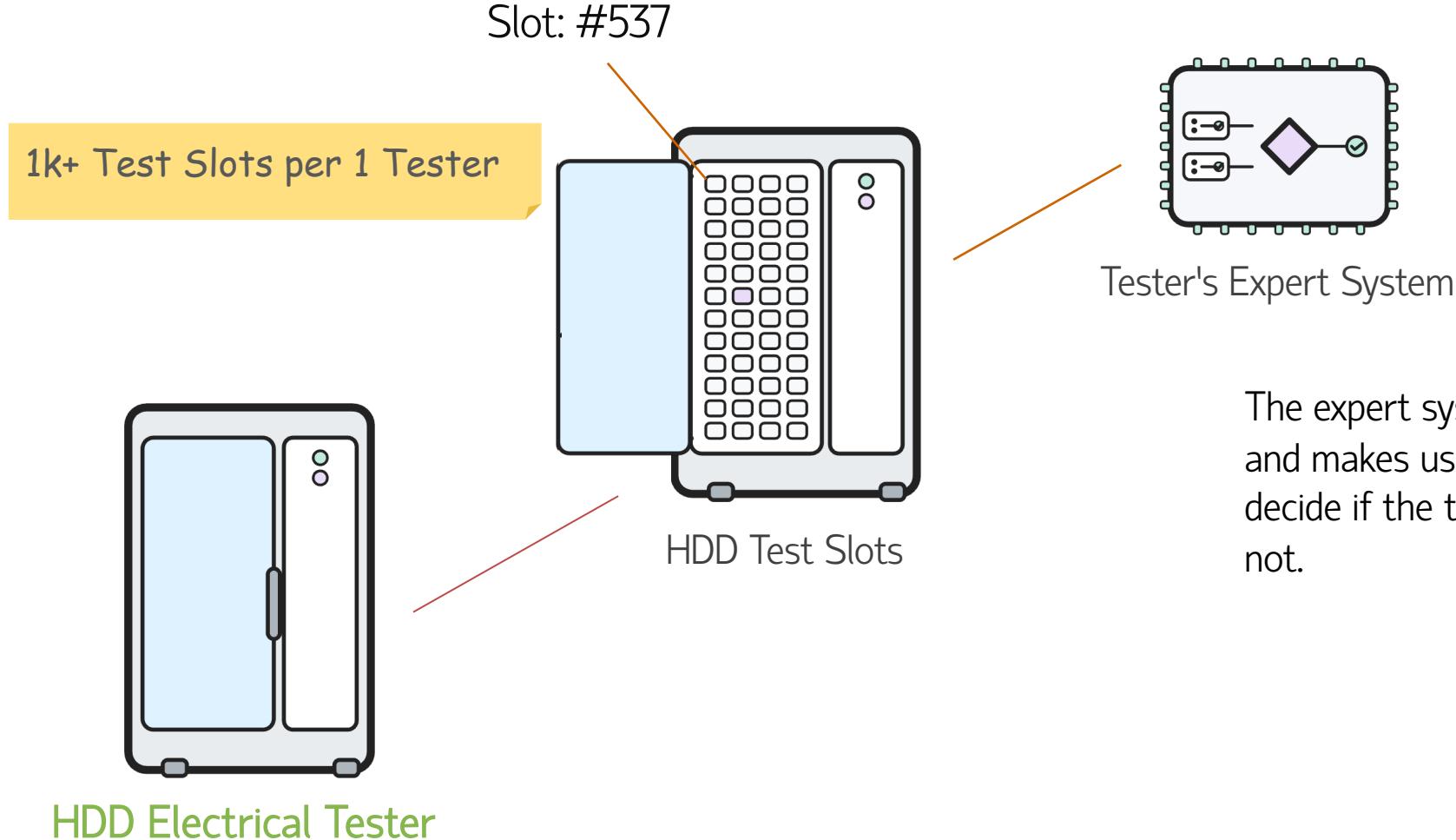
- 1k+ Test Slots per 1 Tester
- 1k+ Testers per Large Site
- 1M+ hard disk drives (HDDs) are being tested at one time.

Passed HDDs



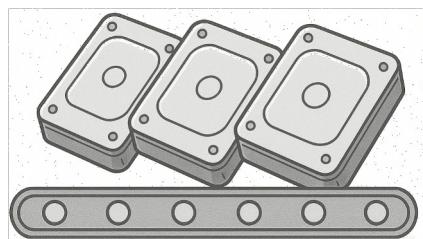
Package & Ship

Who Test the The Tester?



Composite Teaching Case; Synthetic Figures; No Confidential Info.

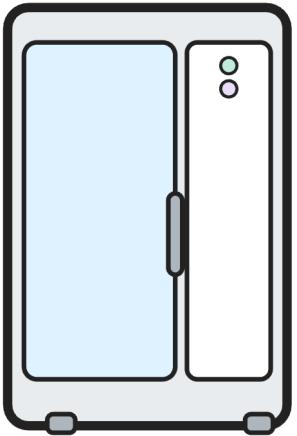
Test Slots Do Fail



Assembled HDD Drives

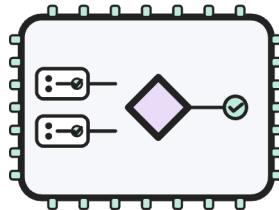
Assembled Hard Disk Drives

Every hard disk drive is quality tested.



HDD Electrical Tester

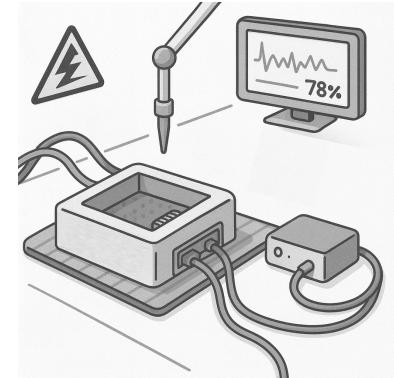
It takes 1-4 weeks to test a hard disk drive.



Tester's Expert System

Test Slot Failed by BIT

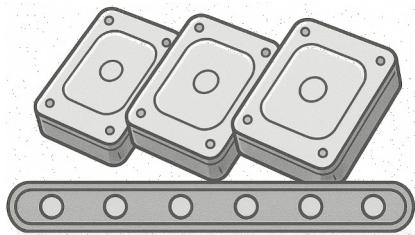
Test slots are removed and then replaced. 4-6 hours of lead time.



Lab Test

Test slots are sent for further Lab tests. 3-5 days of lead time. If OK, then put it back to operation. If not, then we send it for a repair.

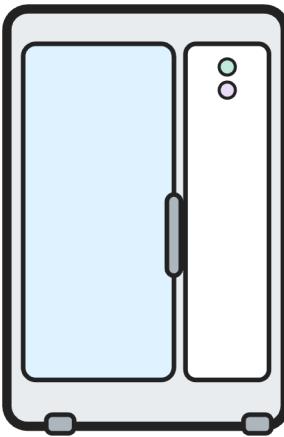
Pain Point



Assembled HDD Drives

Assembled Hard Disk Drives

Every hard disk drive is quality tested.

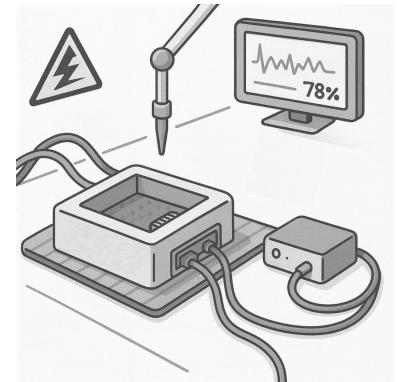


HDD Electrical Tester

It takes 1-4 weeks to test a hard disk drive.

Test Slot Failed by BIT

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Lab Test

Test slots are sent for further Lab tests. 3-5 days of lead time. If OK, then put it back to operation. If not, then we send it for a repair.

80% of '**FAULT**' are in fact '**OK**' → ~1% loss in OEE.

A high false-positive rate in legacy screening can materially reduce OEE.

OEE: Overall Equipment Effectiveness

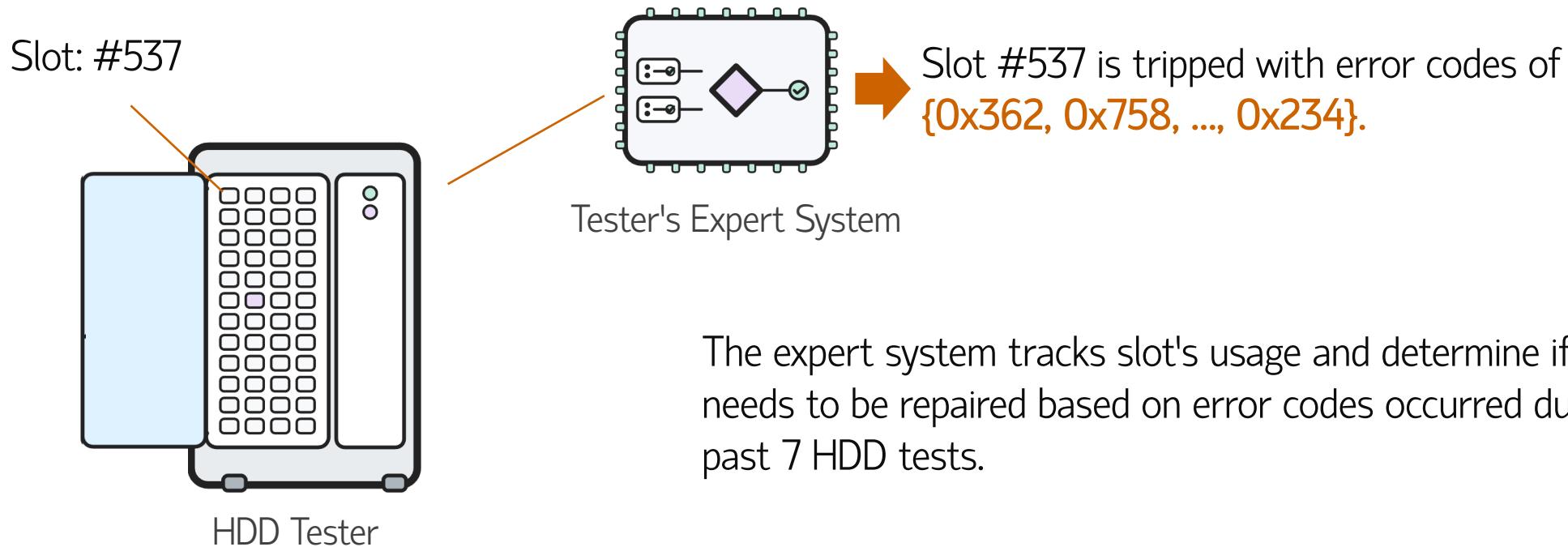
Composite Teaching Case; Synthetic Figures; No Confidential Info.

WHAT-IF Seconds vs Days

WHAT-IF: We can do the test verification in seconds, instead of 3-5 days.

THEN: 1% OEE can be re-gained, which is an additional test capacity of ~5 more testers.

Measurements



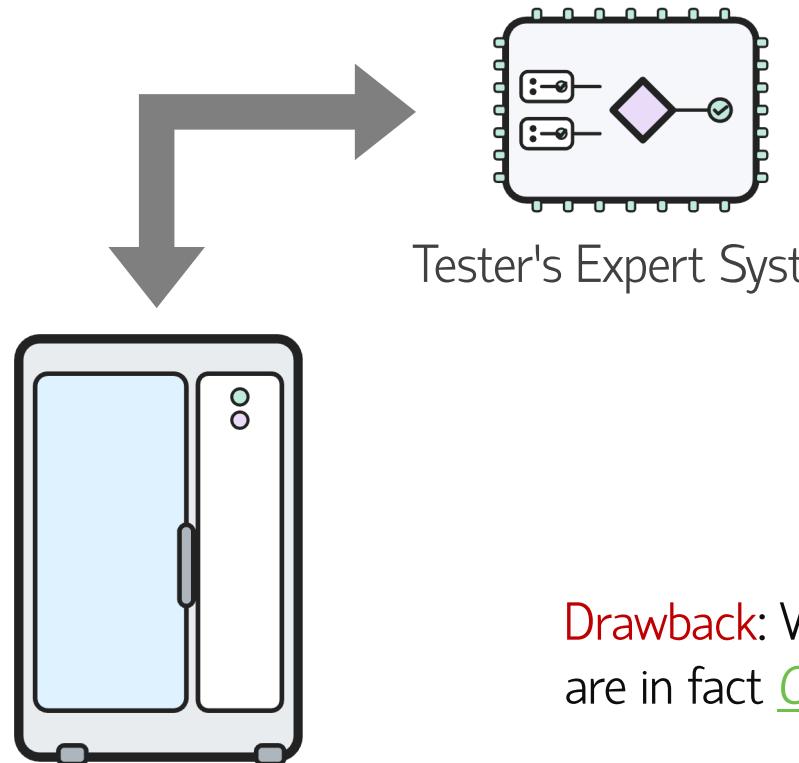
>1k Test Slots per 1 Tester

80% of slots identified as faults are *in fact 'OK'* after lab re-verifications and put back online.

Isn't that a definition of 'Recall'?

Our expert system has a very High Recall (and hence very Low Precision).

Recap: Who Is Testing the Testers?



Tester's Expert System

A diagram illustrating a branching process or probability model. It shows a single node at the top connected by three arrows to three separate nodes below. The top-most branch is labeled $e \cdot w(1-e)$. The middle branch is labeled $u \cdot B$. The bottom-most branch is labeled $u \cdot w(1-e)$.

$$E[w] = \sum_{i=0}^{\infty} (1-e)^i (1-u)^{1-i} e \cdot w(1-e)$$
$$= \sum_{i=0}^{\infty} (1-e)^{i+1} (1-u)^i \cdot u \cdot B$$

Mathematical Model of Complex Physics

Drawback: We cannot model everything. 80% of what it said to be Fault end up are in fact OK.

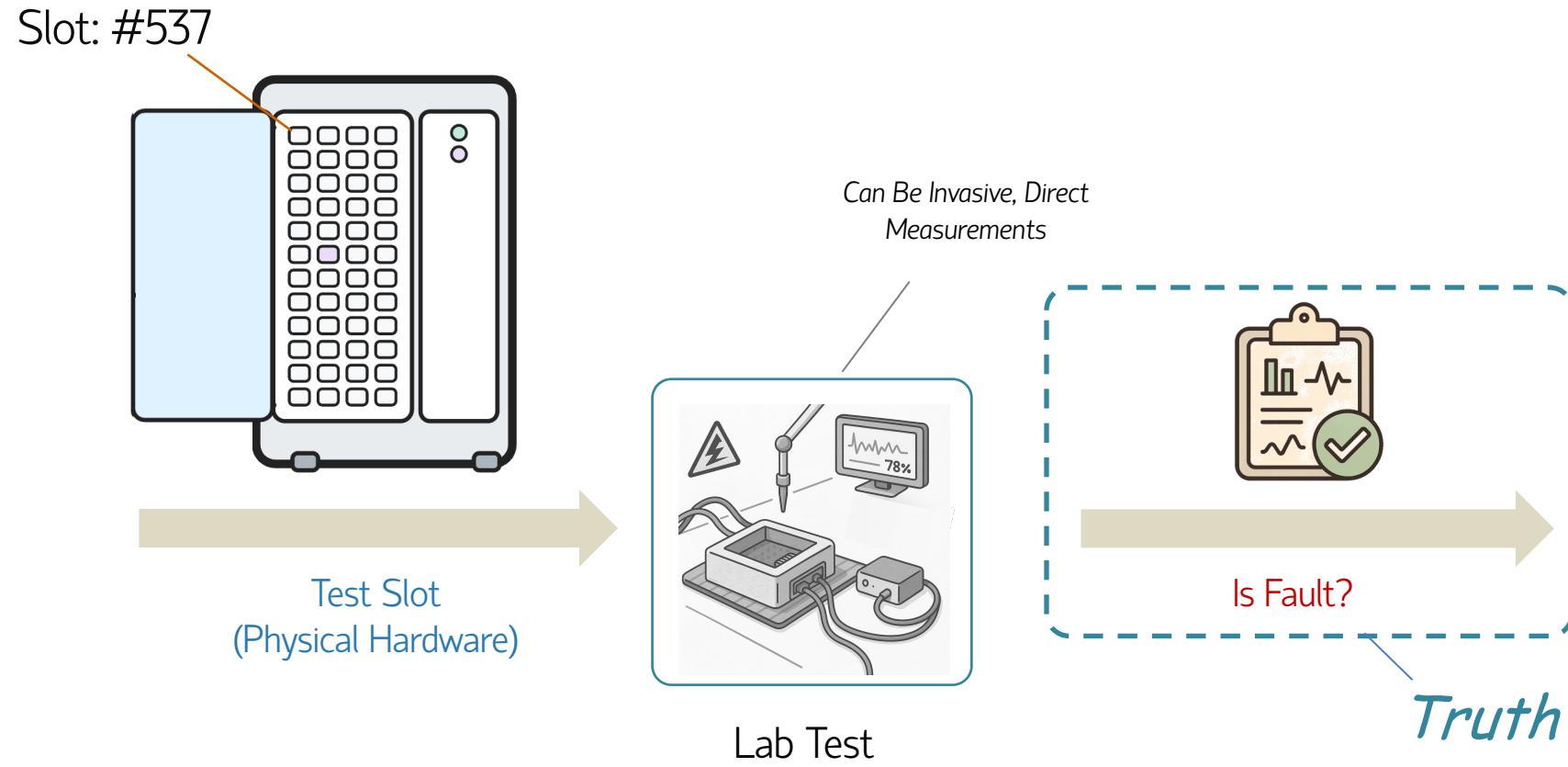
Q: Is there an alternative?
A: Data-Driven

What Is Prediction?

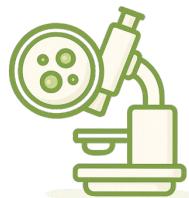
PREDICTION is the process of filling in missing information.

Prediction takes **information you have**, often called 'data', and uses it to generate **information you don't have**.

Lab Test



Analogy:



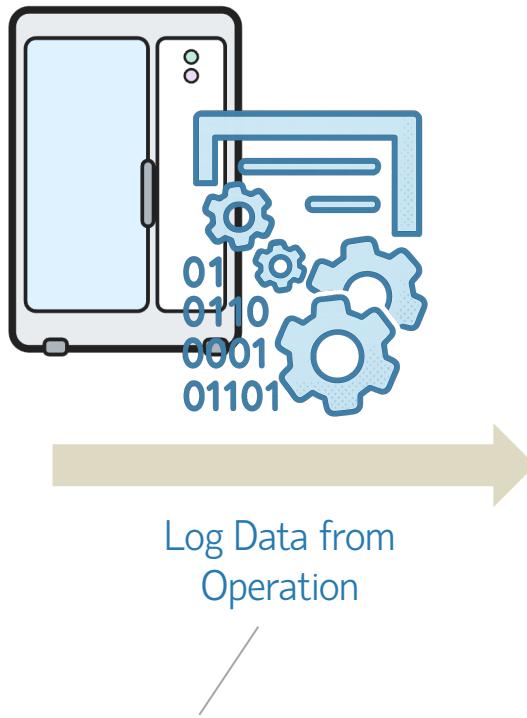
Biopsy in Medicine



GCSE/A-Level Exam

Composite Teaching Case; Synthetic Figures; No Confidential Info.

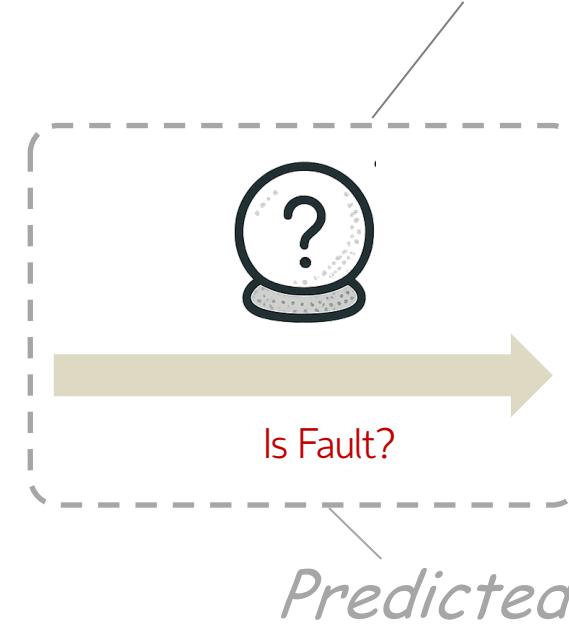
(AI-Enabled) Virtual Test



Failure Re-Verifier

Cheap, non-invasive virtual test triages cases before expensive steps.

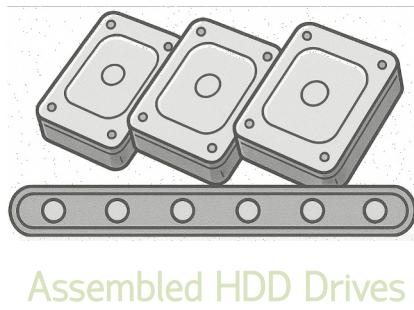
However, we will always have uncertainty in the predictions with the virtual test.



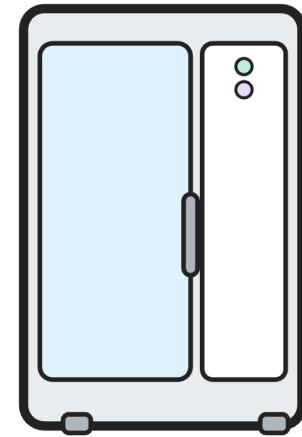
We don't know the physical conditions of the electronic components inside the test slots.

Composite Teaching Case; Synthetic Figures; No Confidential Info.

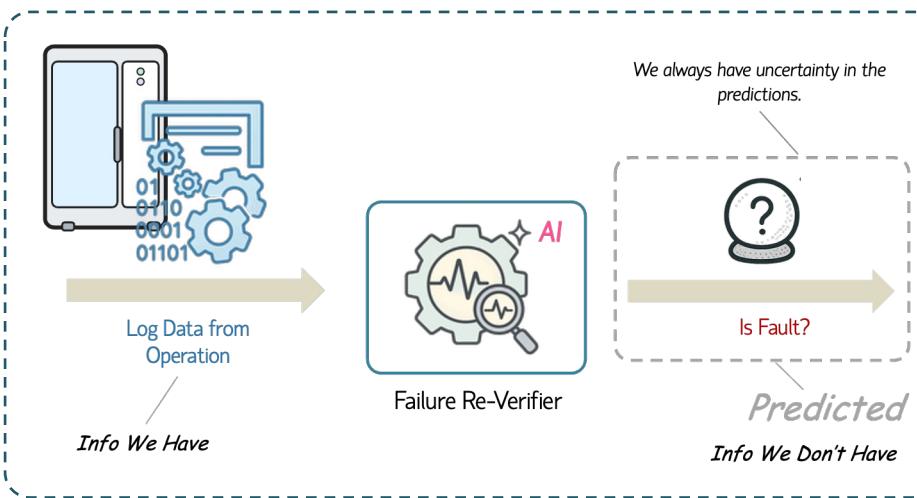
Expensive Job Task



Assembled Hard Disk Drives
Every hard disk drive is quality tested.

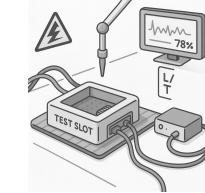


It takes 1-4 weeks to test a hard disk drive.



Cheap Virtual Test

Test Slot Failed by BIT
Test slots are removed and the replaced.
4-6 hours of lead time.

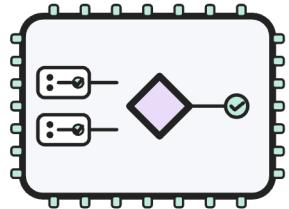


Lab Test

Test slots are sent for further Lab tests. 3-5 days of lead time. If OK, then put it back to operation. If not, then we send it for a repair.

Composite Teaching Case; Synthetic Figures; No Confidential Info.

Problem Formulation



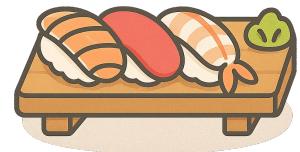
Slot #537 is tripped with error codes of {0x362, 0x758, ..., 0x234}.

Tester's Expert System

It's sound a bit like...



My friend tried their ramen, and it was pretty forgettable.

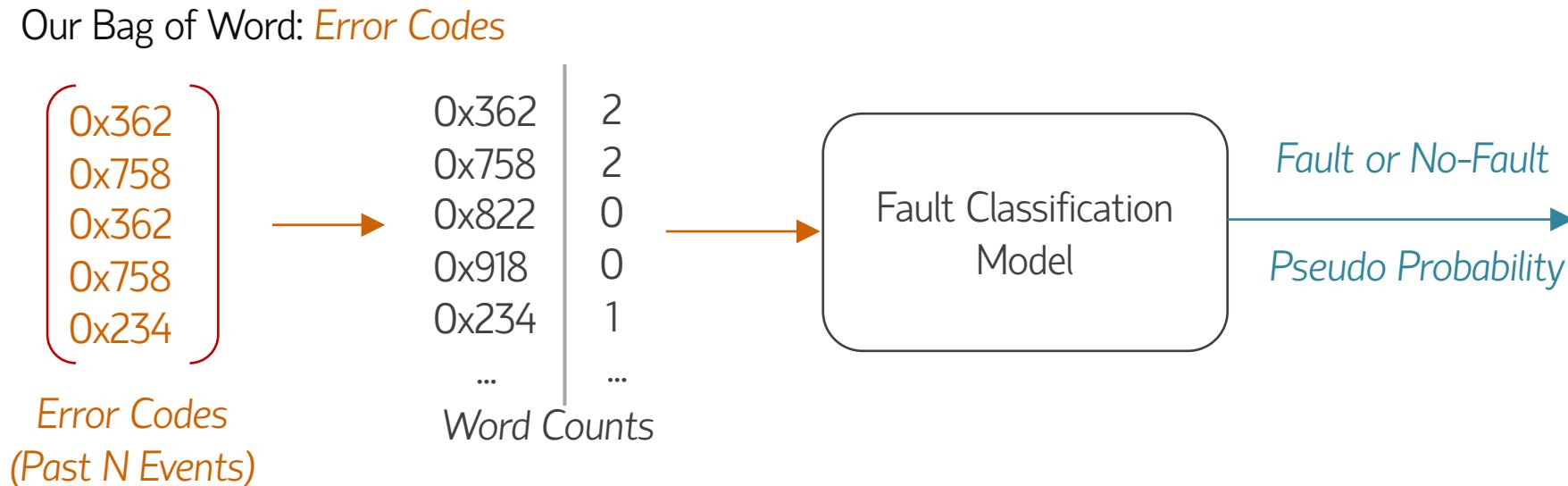


All the sushi was delicious. Easily best sushi in Bangkok.



You know what, how about we do Sentiment Analysis?

Machine Learning Model



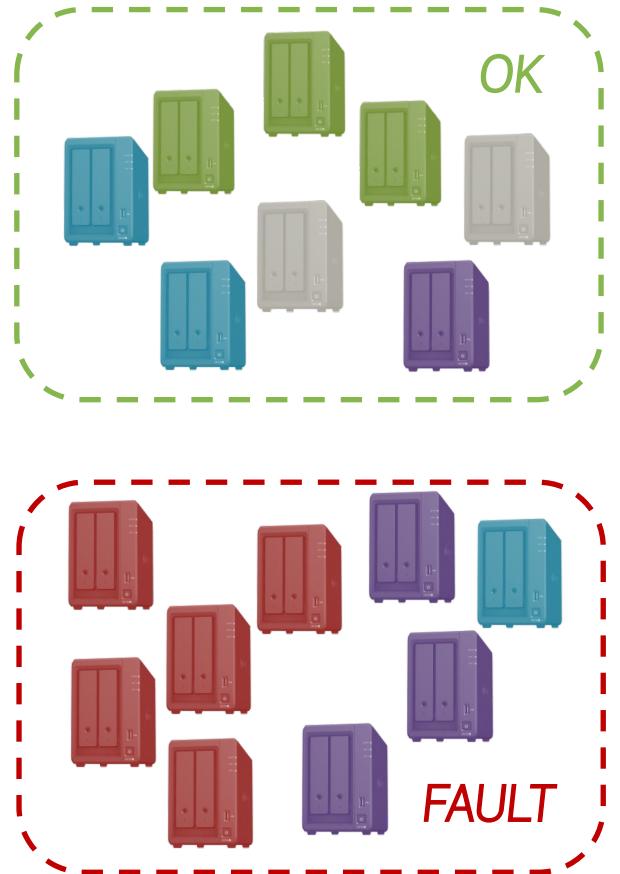
There are 7 words in a (review) sentence.

Q: What's Temporal?

A: Which word comes first matters.

- + Deep Learning GRN model, if temporal events are to be captured.
- + Logistic Regression, Naïve models, if we are to ignore possible temporal effects.

Imperfect Predictions



Known Knowns:



Known Unknowns:



D. Rumsfeld's Known & Unknown



Composite Teaching Case; Synthetic Figures; No Confidential Info.

Where Can We Know For Sure?

Classification Performance: 82% (says) Accuracy on the Balanced Classes



**Operation
Manager**

There'll be too many re-work with 82% accuracy. >98% would be ideal.

Not really. We can focus on those cases that we're sure if they're fault or no fault.

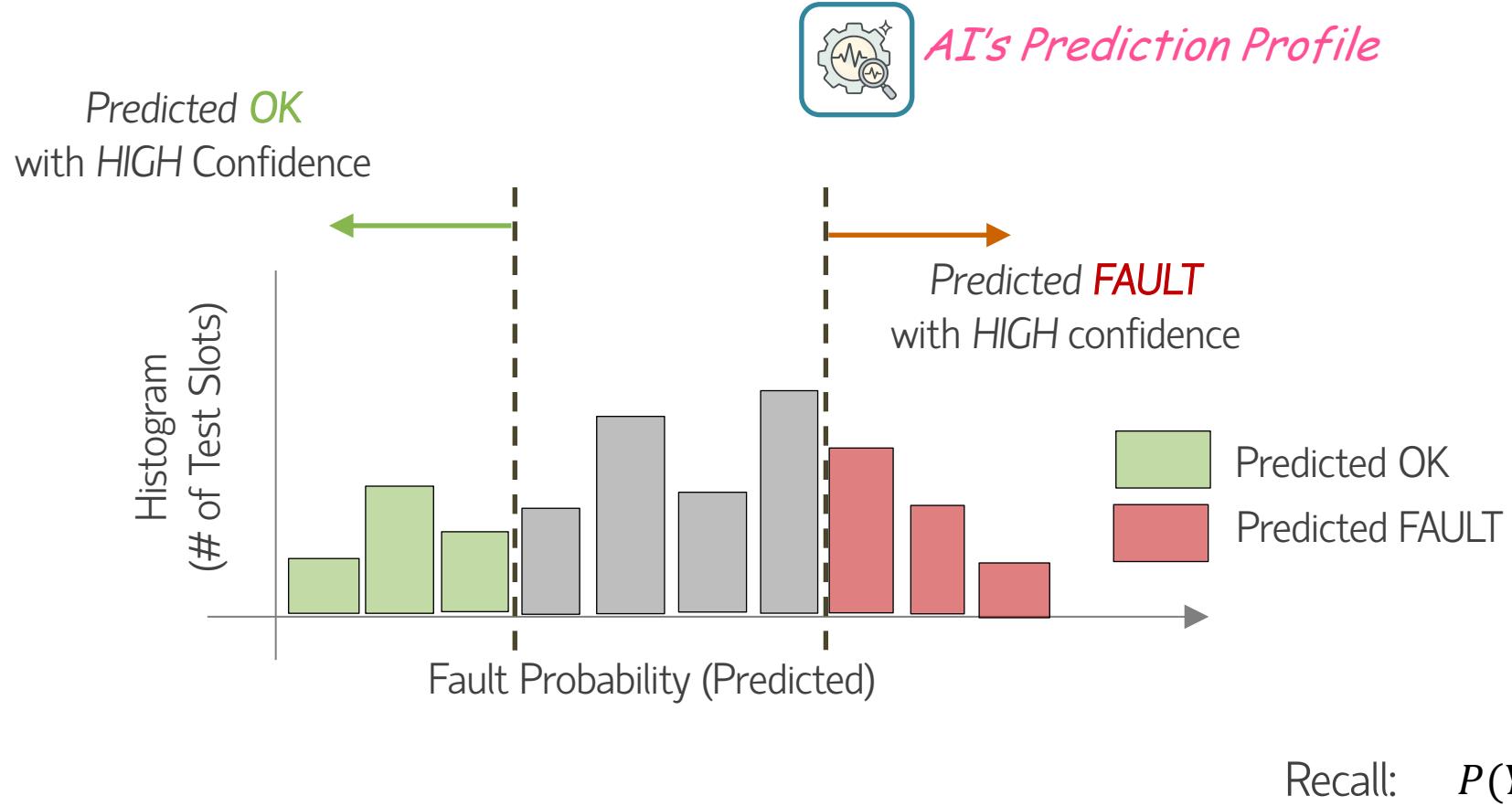


**Equipment
Engineering Manager**

... focus on 'Known Knowns' ...

Composite Teaching Case; Synthetic Figures; No Confidential Info.

Imperfect Predictions



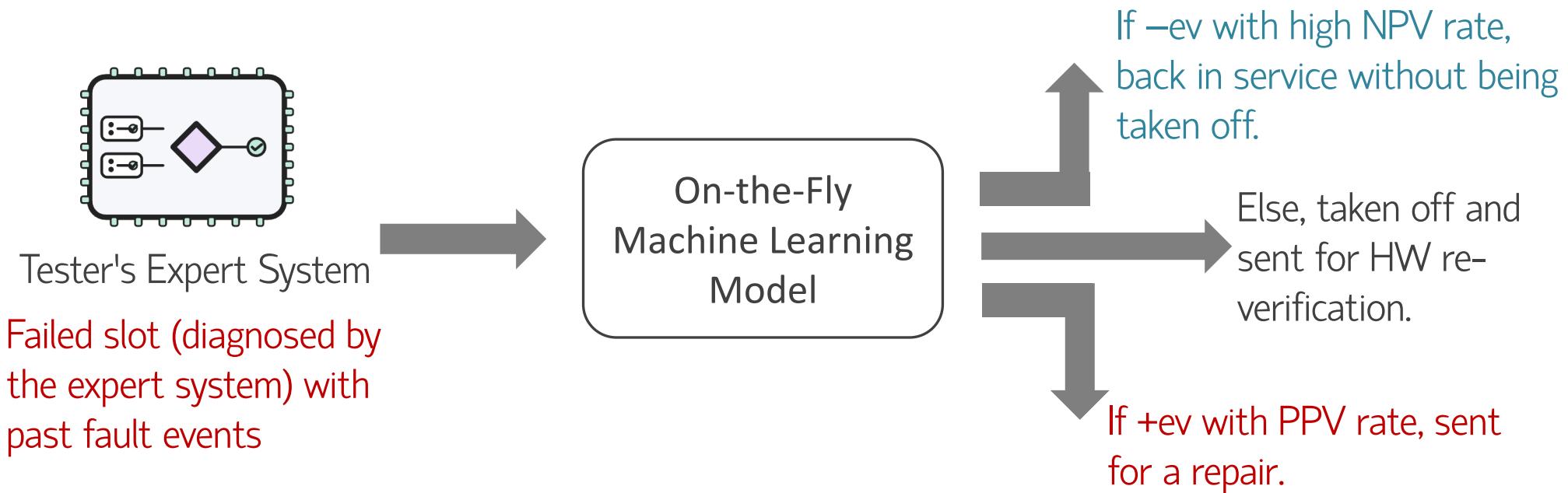
Composite Teaching Case; Synthetic Figures; No Confidential Info.

Operational Constraints

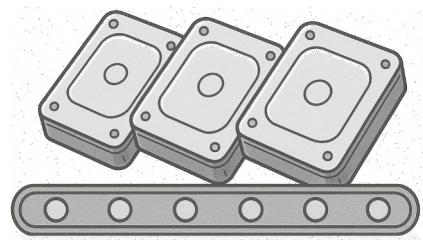
Constraint: Testers are 3rd-Party HW equipment. We cannot easily make changes to the expert system, but we can still consume machine (log) data generated by the equipment.

We cannot just replace the expert system with our machine learning model.

How Do We Utilise Our Predictions?

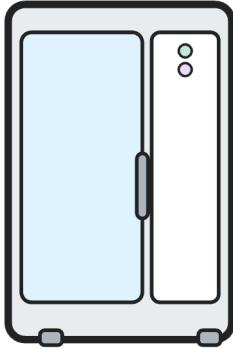


Before



Assembled HDD Drives

Every hard disk drive is quality tested.



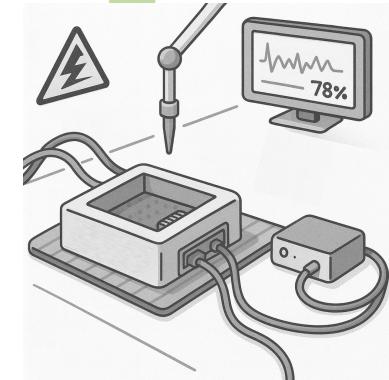
HDD Electrical Tester

It takes 1-4 weeks to test a hard disk drive.

Tested OK from the Lab (3-5 Days Lead Time)

The test slot is put back to a tester and made available for operation.

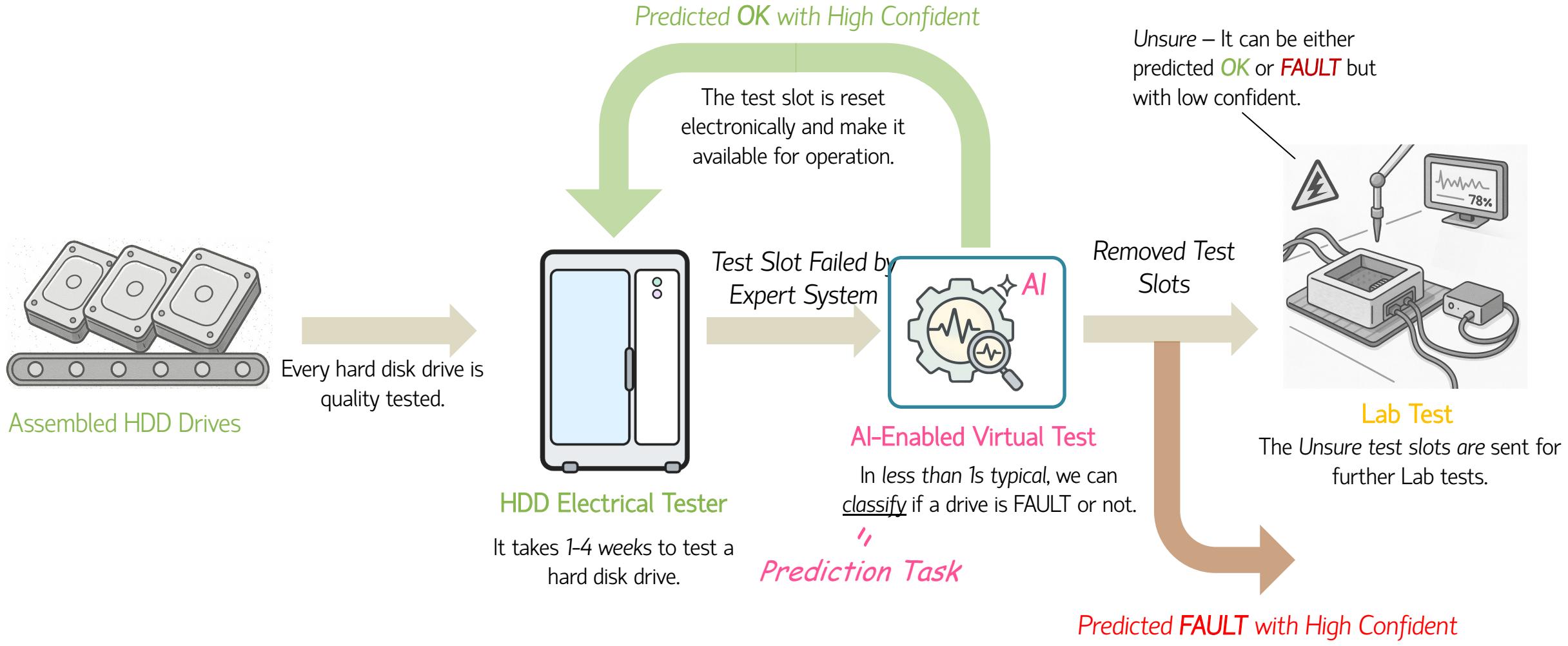
Test Slot Failed by Expert System



Lab Test

The Unsure test slots are sent for further Lab tests.

Process Re-Design



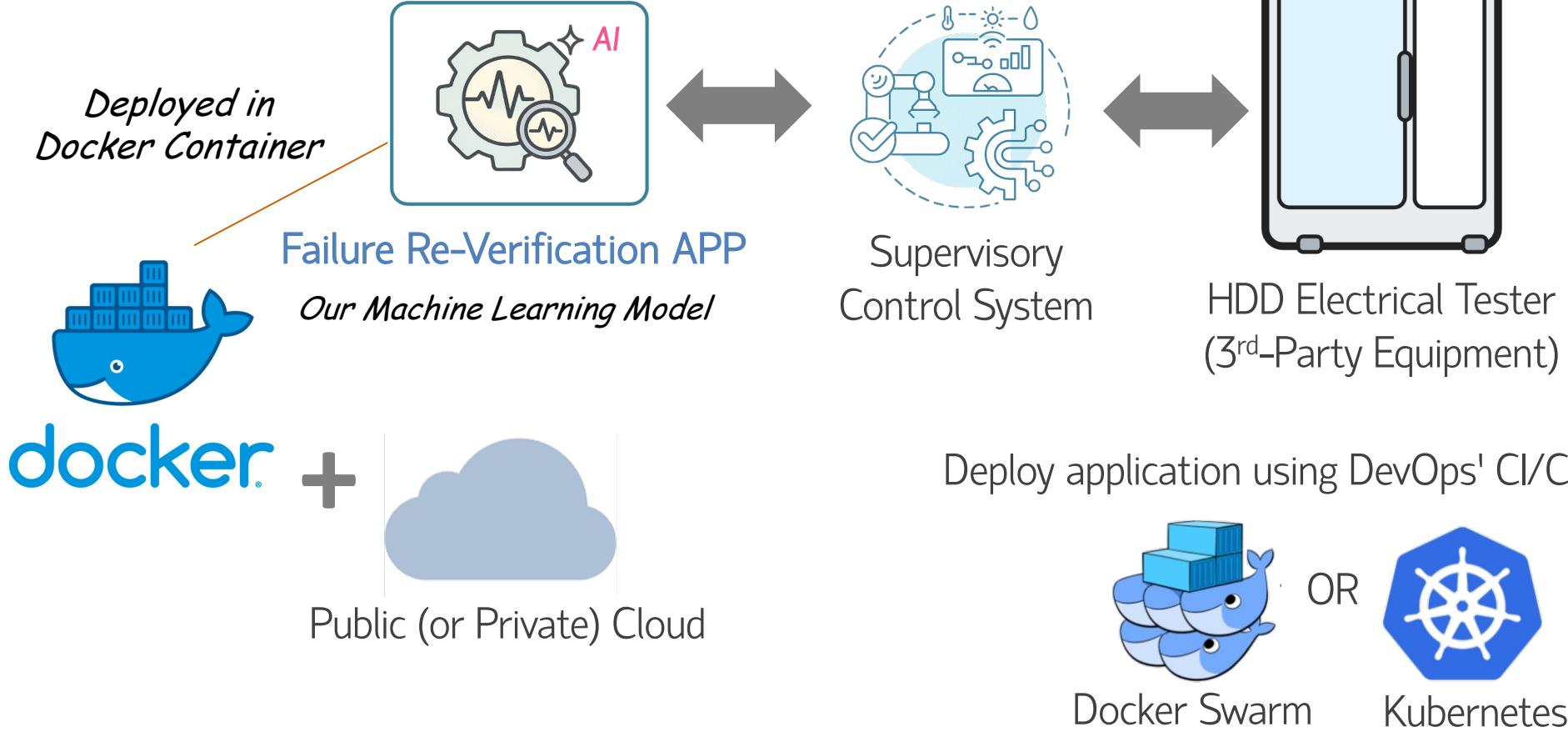
If model $P(\text{fault}) \geq \tau_1 \rightarrow$ route to repair; if $\leq \tau_0 \rightarrow$ electronic reset; else \rightarrow lab.

We send the test slot straight for a repair without Lab test.

Composite Teaching Case; Synthetic Figures; No Confidential Info.

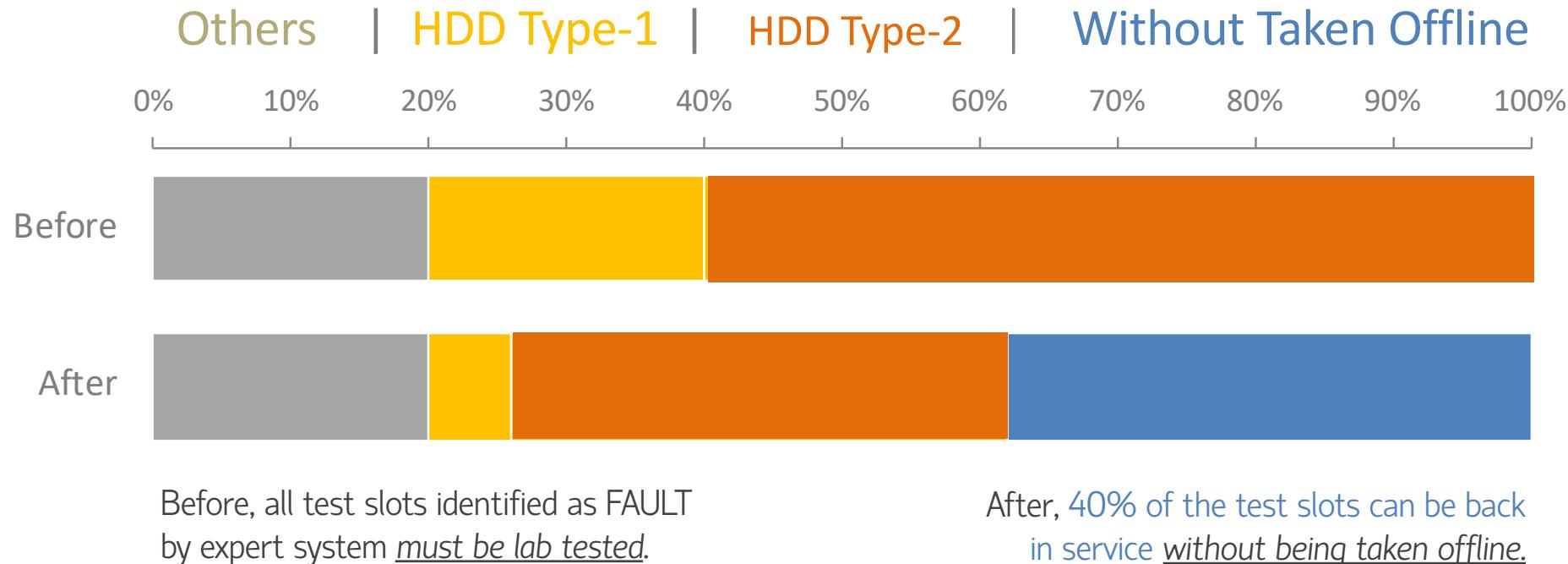
AI-as-a-Service

Integration with Tester's Supervisory Control System



Composite Teaching Case; Synthetic Figures; No Confidential Info.

Productivity Gained From Re-Designed Process



Composite Teaching Case; Synthetic Figures; No Confidential Info.

Illustrated Return on Investment (ROI)

...let put in figures...

~1200 Testers (>2M test slots, that's a lot), each Tester cost ~700k USD.

~0 marginal cost if to scale from 1 test slot to 1M slots.

*We gain additional equipment capacities
of ~2 testers without having to buy them.*

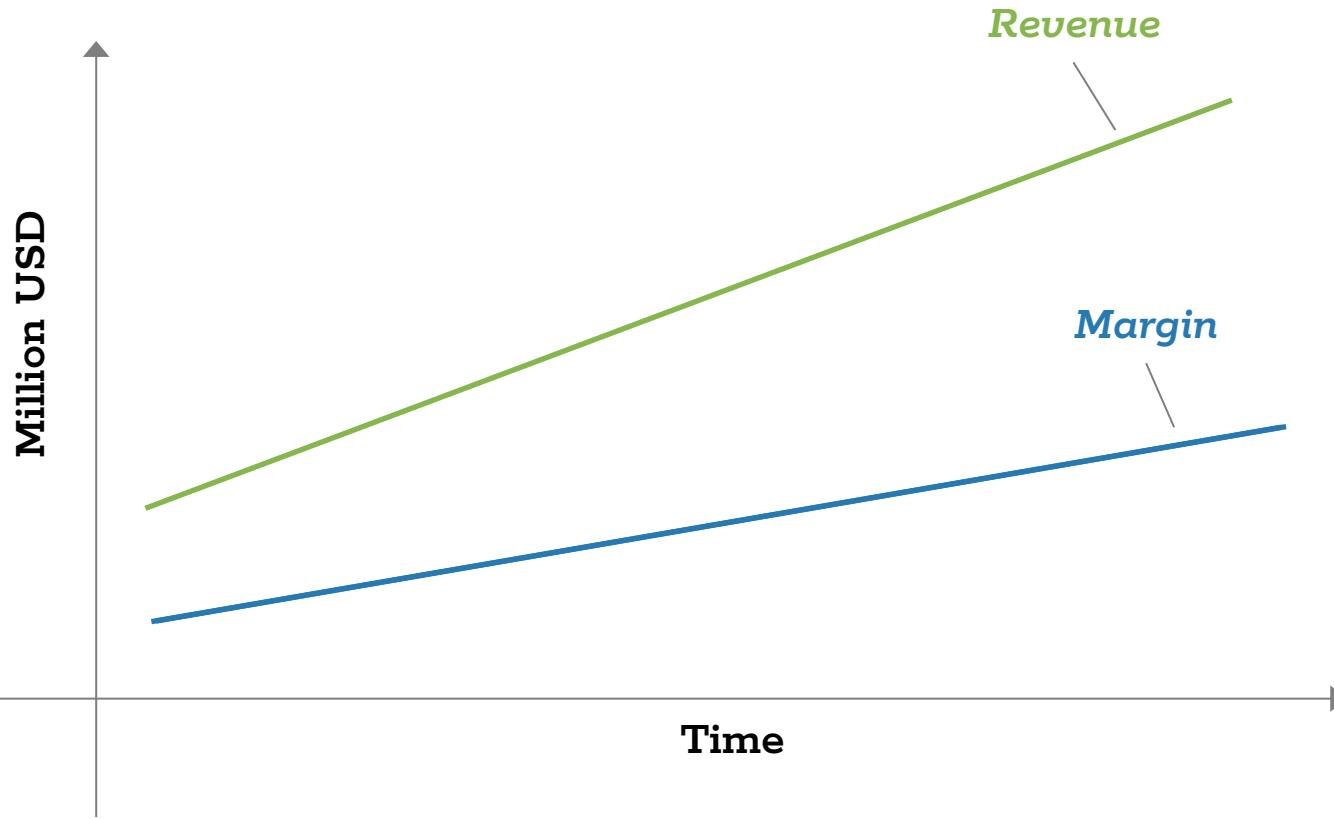
... that's about 2 testers ...

0.4% (1.4M USD)

gain in OEE enabled by our AI-enabled process.

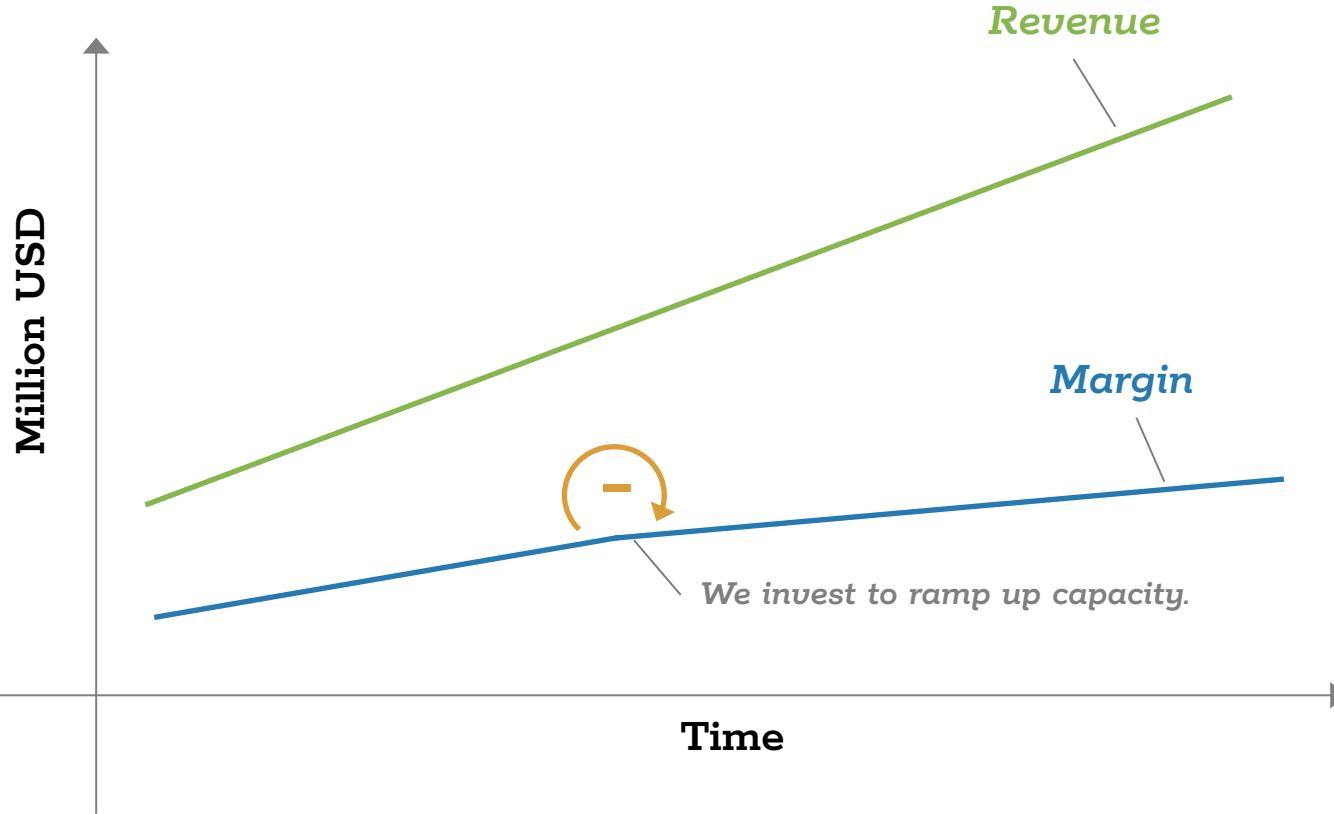
Composite Teaching Case; Synthetic Figures; No Confidential Info.

Closing Thought (1 of 3)



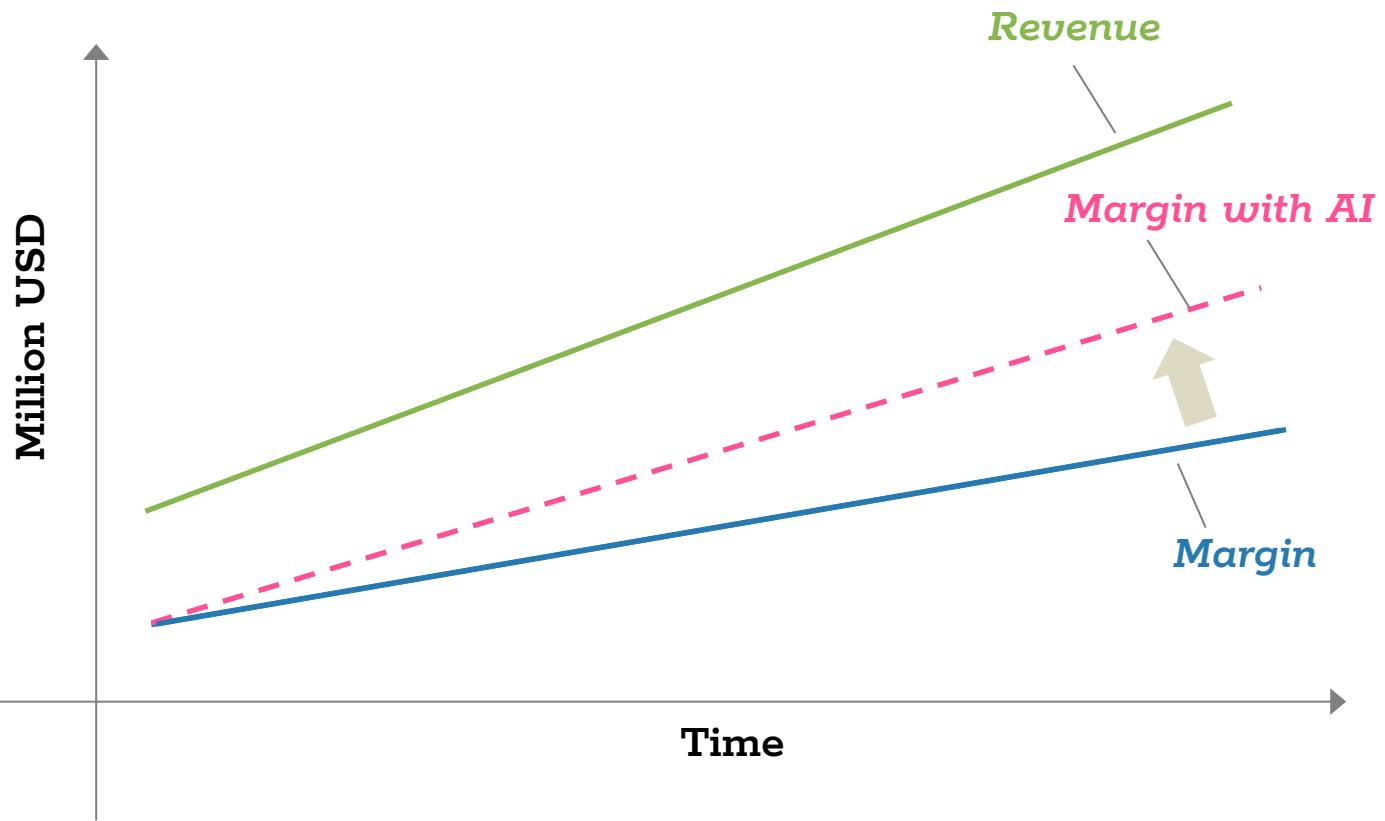
Composite Teaching Case; Synthetic Figures; No Confidential Info.

Closing Thought (2 of 3)



Composite Teaching Case; Synthetic Figures; No Confidential Info.

Closing Thought (3 of 3)



Cheap Prediction (our AI) is to replace expensive tasks.

Summary

- AI is framed as '*Cheap Prediction*', things become less magical. This gives us a focus on its economic (or practical) values which most matter at the *management, strategic level*.
- AI's complements are becoming more critical if we are to succeed in applying AI. Implementing AI algorithms or models are more straightforward in comparison to *problem framing and judgment in using prediction*.
- AI is to replace tasks, not the job. We use *cheap prediction* to replace (or re-design) tasks which are as-is inefficient or expensive. Hence, this enables us to gain back the profit margin.
- Prediction uncertainty is unavoidable. Operation wise, there are cases where high accuracy is a must. We can focus on those predictions with high confident level. Hence, part of in-efficiencies can be off-loaded by our AI.

References

- Agrawal, Ajay, Joshua Gans, and Avi Goldfarb. 2018. **Prediction Machines: The Simple Economics of Artificial Intelligence.** Boston, MA: Harvard Business Review Press.
- McKinsey Global Institute. 2018. "The Economics of Artificial Intelligence." *McKinsey Quarterly*.
- Fox, E. & Guestrin, C., 2016. *Machine Learning: Classification*. Coursera – University of Washington. Available at: <https://www.coursera.org/learn/machine-learning-classification> (Accessed 20 Aug. 2025).