

Staying Profitable with AI

Virtual Test and Process Redesign

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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

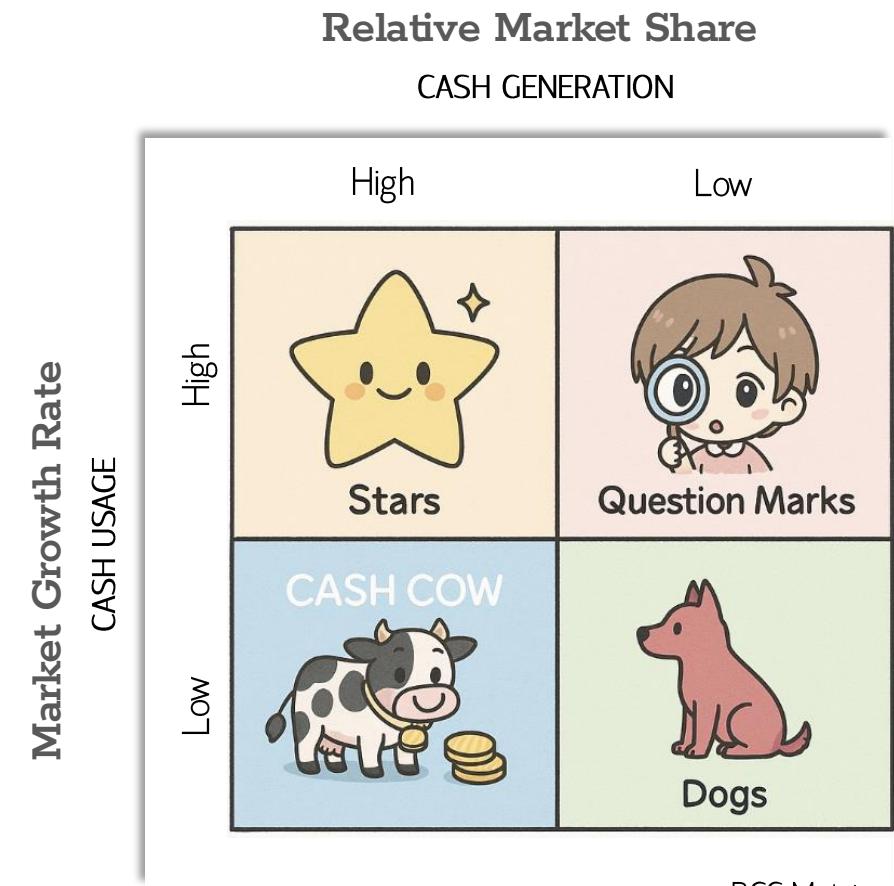
Threat: Solid State Drive (SSD), High Performance, Expensive (but getting cheaper), Simple Technology

Sunsetting Technology

Near Term: Cloud Expansion → High Demand in Data Storage

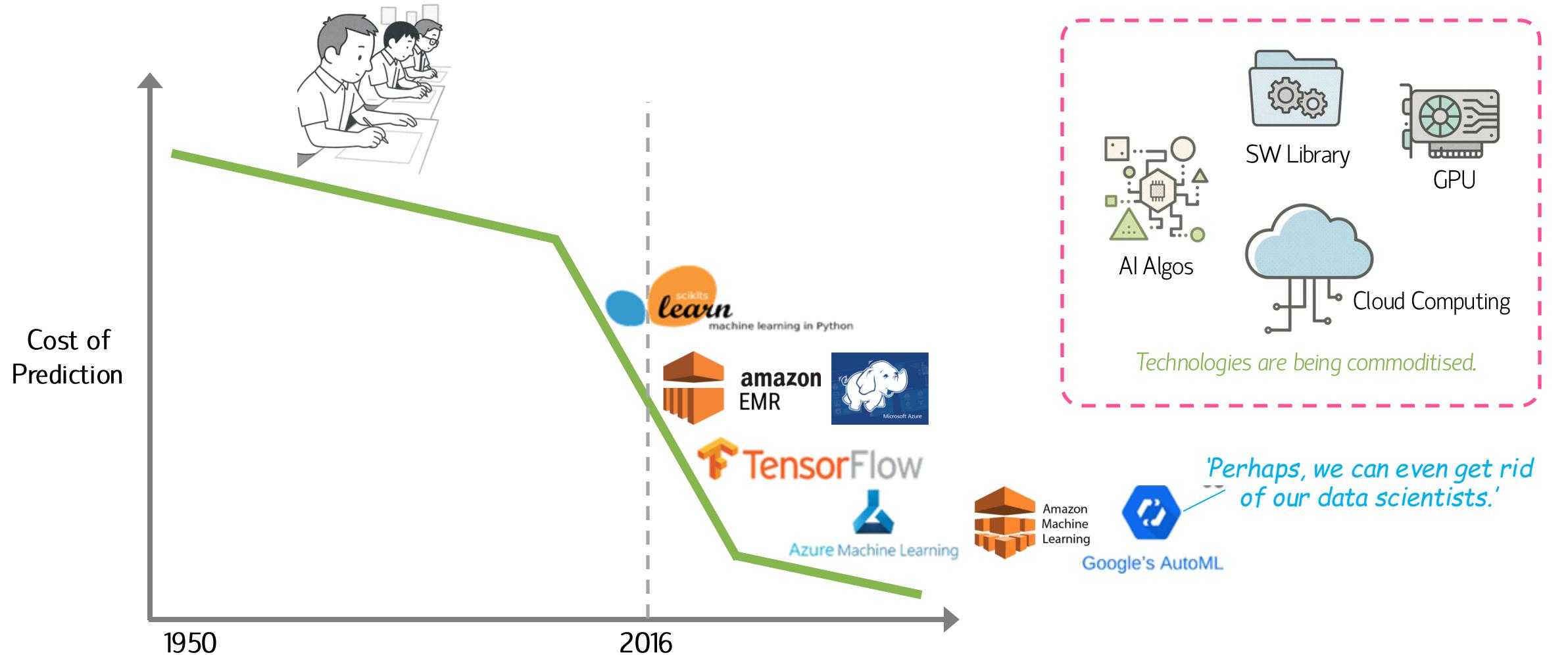
Outlook: Sunsetting Technology (being replaced by SSD)

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.

Artificial Intelligence (AI)



(Agrawal, Gans and Goldfarb 2018)

Composite Teaching Case; Synthetic Figures; No Confidential Info.

What Is AI?

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

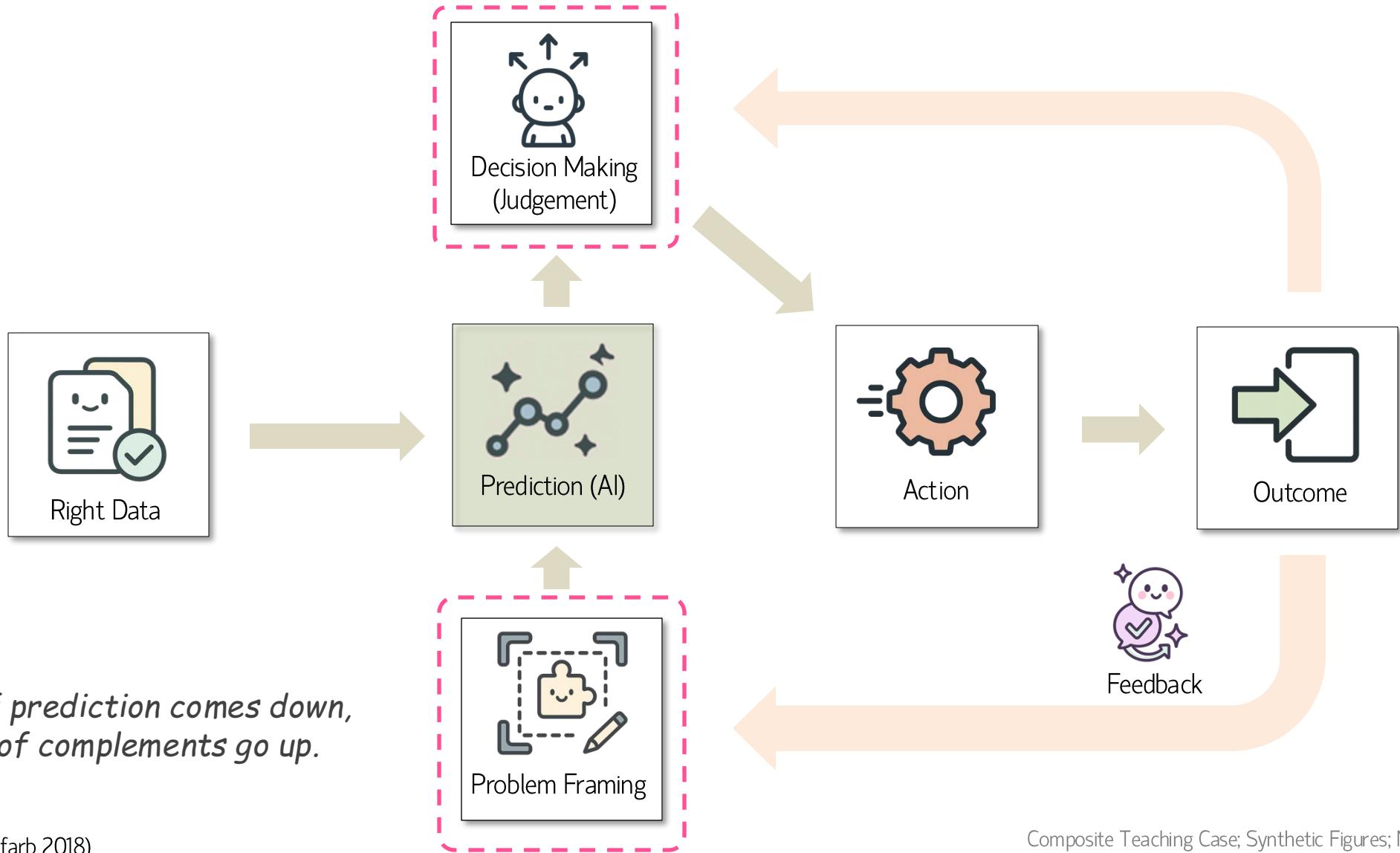
Business Meaning of AI

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

What will happen when prediction becomes cheap?

Surely, we will use more of it.

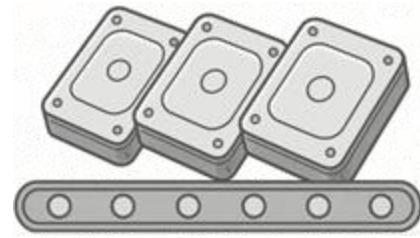
AI's Complements



(Agrawal, Gans and Goldfarb 2018)

Composite Teaching Case; Synthetic Figures; No Confidential Info.

HDD Test Process: Operation Bottleneck

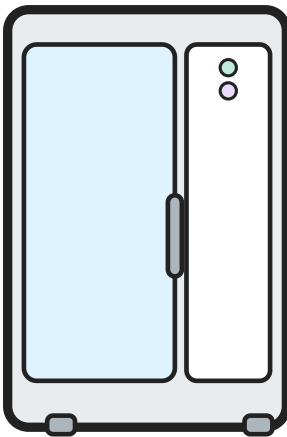


Assembled HDD Drives

Every hard disk drive is quality tested.

Assembled Hard Disk Drives

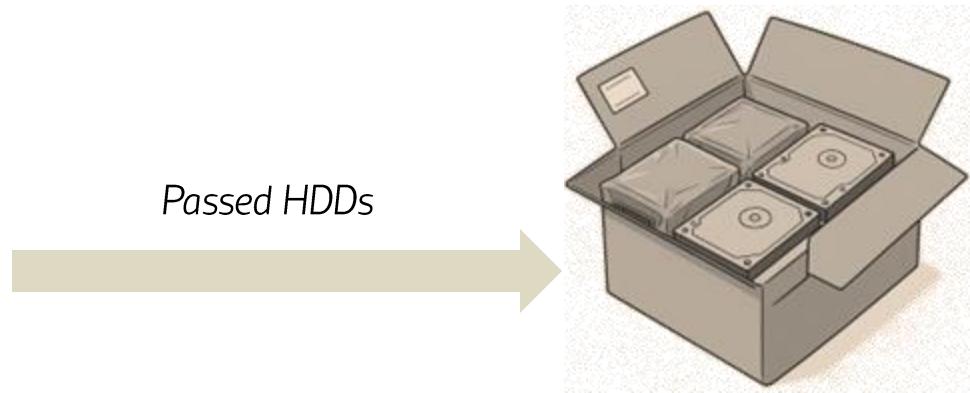
Every hard disk drive is quality tested.



HDD Electrical Tester

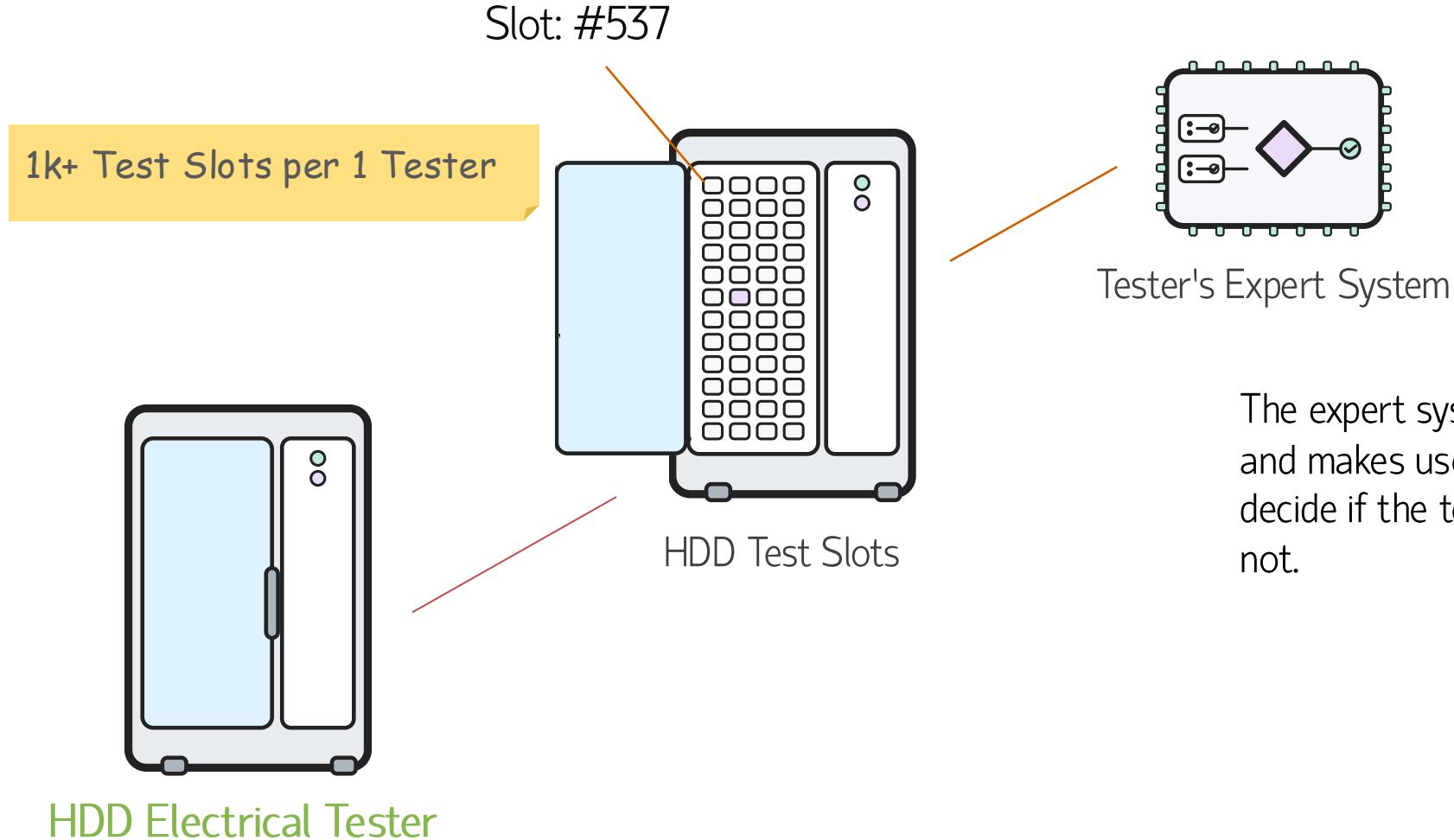
It takes 1-4 weeks to test a hard disk drive.

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



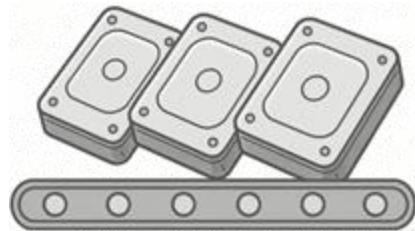
Package & Ship

Who Test the The Tester?



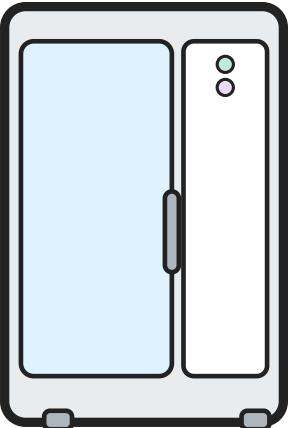
Composite Teaching Case; Synthetic Figures; No Confidential Info.

Test Slots Do Fail

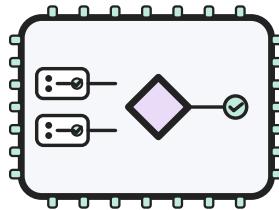


Assembled HDD
Drives

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



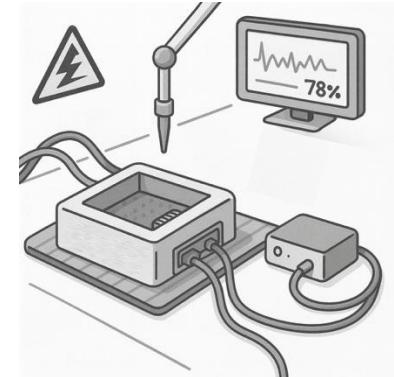
HDD Electrical Tester
It takes 1-4 weeks to test a hard disk drive.



Tester's Expert System

Test Slot Failed by BIT

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

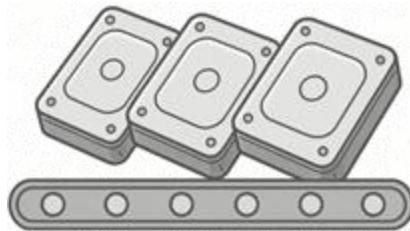


Lab Test

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.

Composite Teaching Case; Synthetic Figures; No Confidential Info.

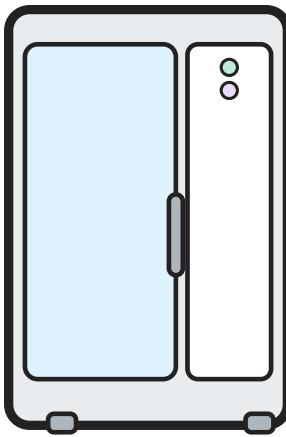
Pain Point



Assembled HDD
Drives

Assembled Hard Disk Drives

Every hard disk drive is quality tested.

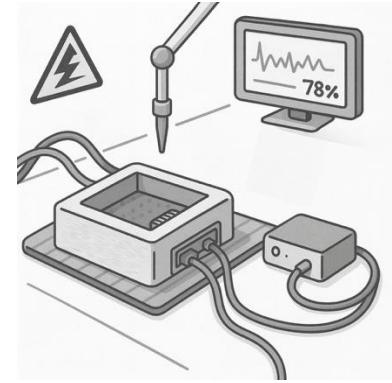


HDD Electrical Tester

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

Test Slot Failed by BIT

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4-6 hours of lead time.



Lab Test

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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.

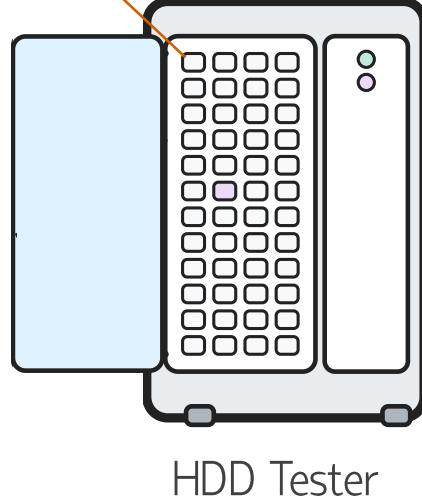
WHAT-IF Seconds vs Days

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

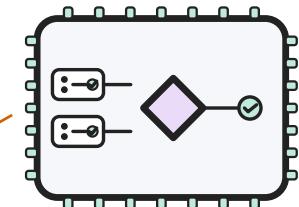
THEN: 1% OEE can be re-gained, which is an additional test capacity of ~5 more testers.

Measurements

Slot: #537



>1k Test Slots per 1 Tester



Tester's Expert System

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

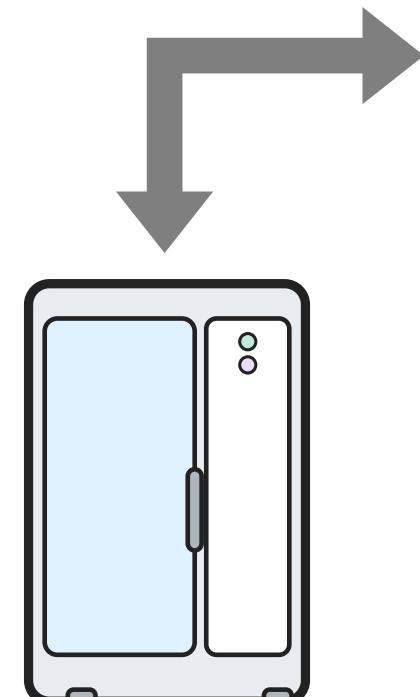
The expert system tracks slot's usage and determine if a slot needs to be repaired based on error codes occurred during the past 7 HDD tests.

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

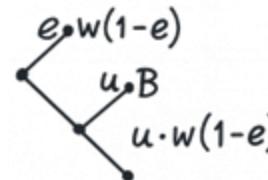
Isn't that a definition of 'Recall'?

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

Recap: Who Is Testing the Testers?



Tester's Expert System



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

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*

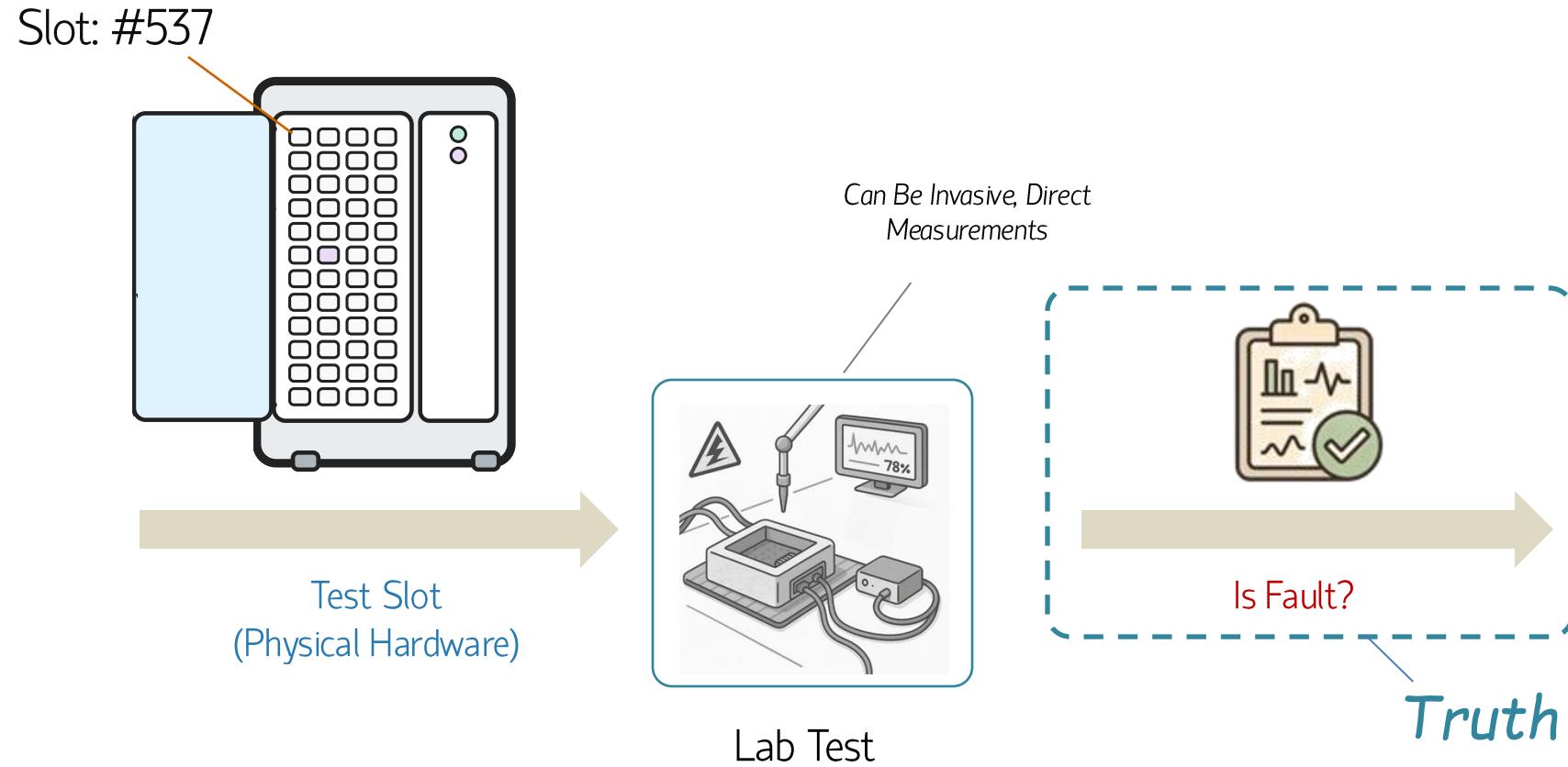
Composite Teaching Case; Synthetic Figures; No Confidential Info.

What Is Prediction?

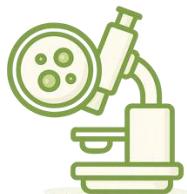
PREDICTION is the process of filling in missing information.

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

Lab Test



Analogy:



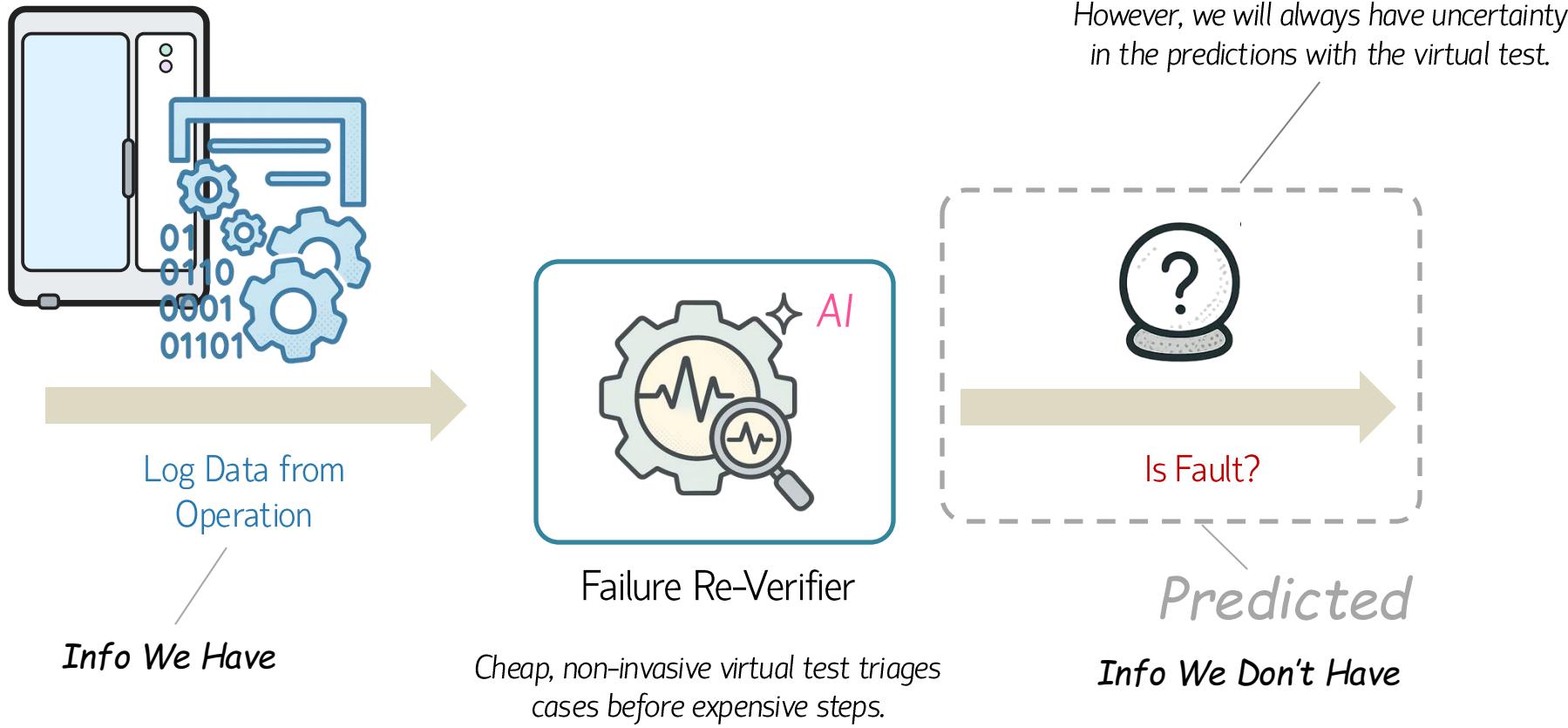
Biopsy in Medicine



GCSE/A-Level Exam

Composite Teaching Case; Synthetic Figures; No Confidential Info.

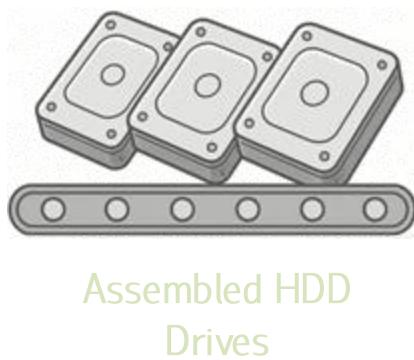
(AI-Enabled) Virtual Test



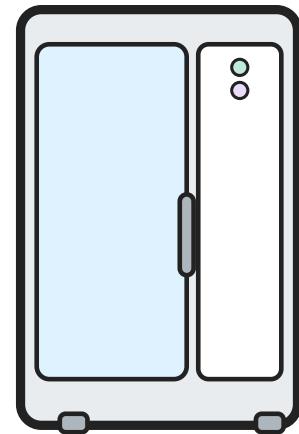
We don't know the physical conditions of the electronic components inside the test slots.

Composite Teaching Case; Synthetic Figures; No Confidential Info.

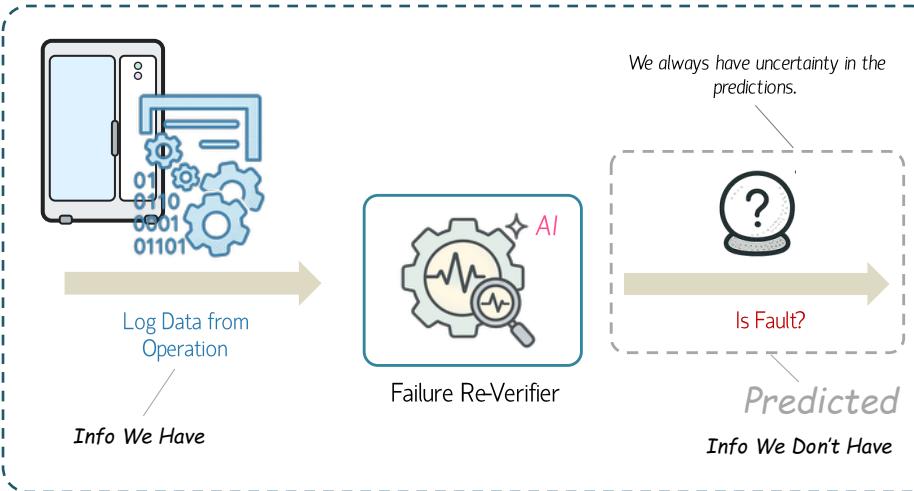
Expensive Job Task



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



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



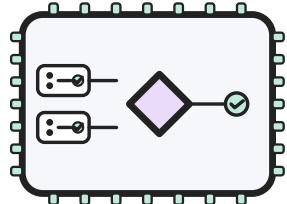
Cheap Virtual Test

Test 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.

Lab Test

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.



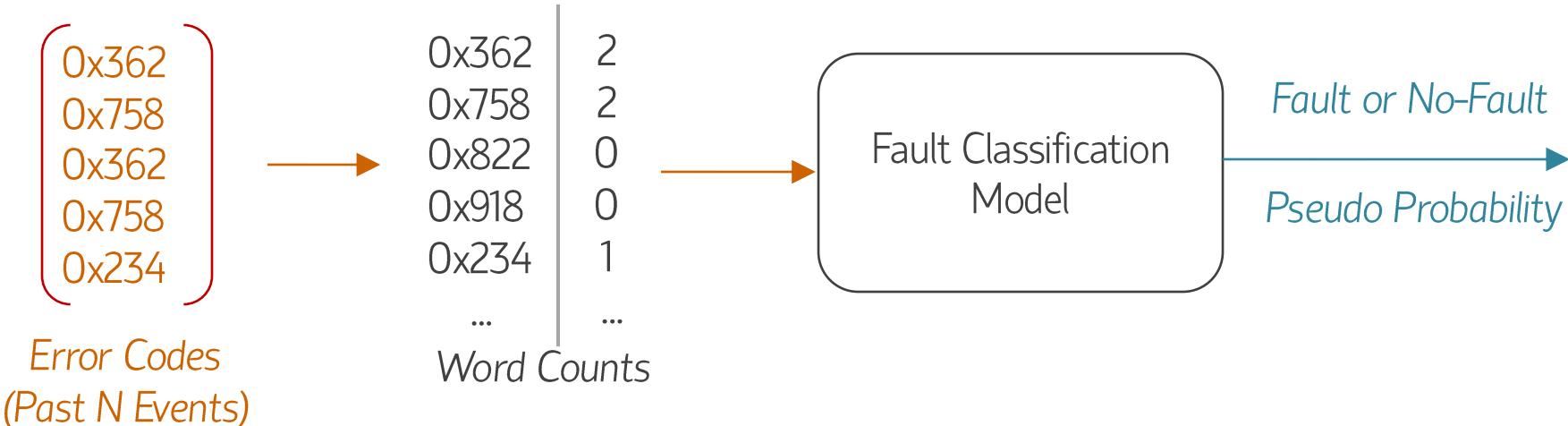
All the sushi was delicious. Easily best sushi in Bangkok.



You know what, how about we do Sentiment Analysis?

Machine Learning Model

Our Bag of Word: *Error Codes*



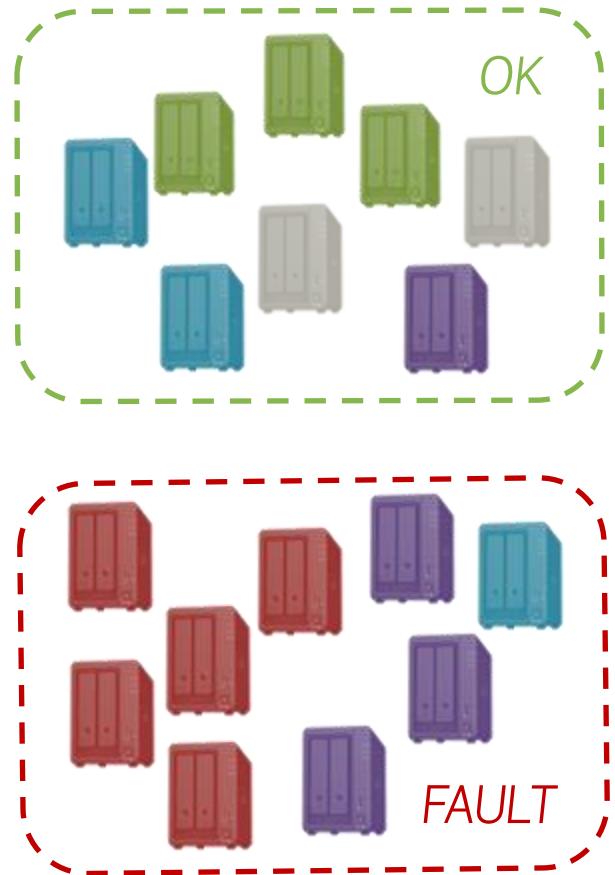
There are 7 words in a (review) sentence.

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



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.

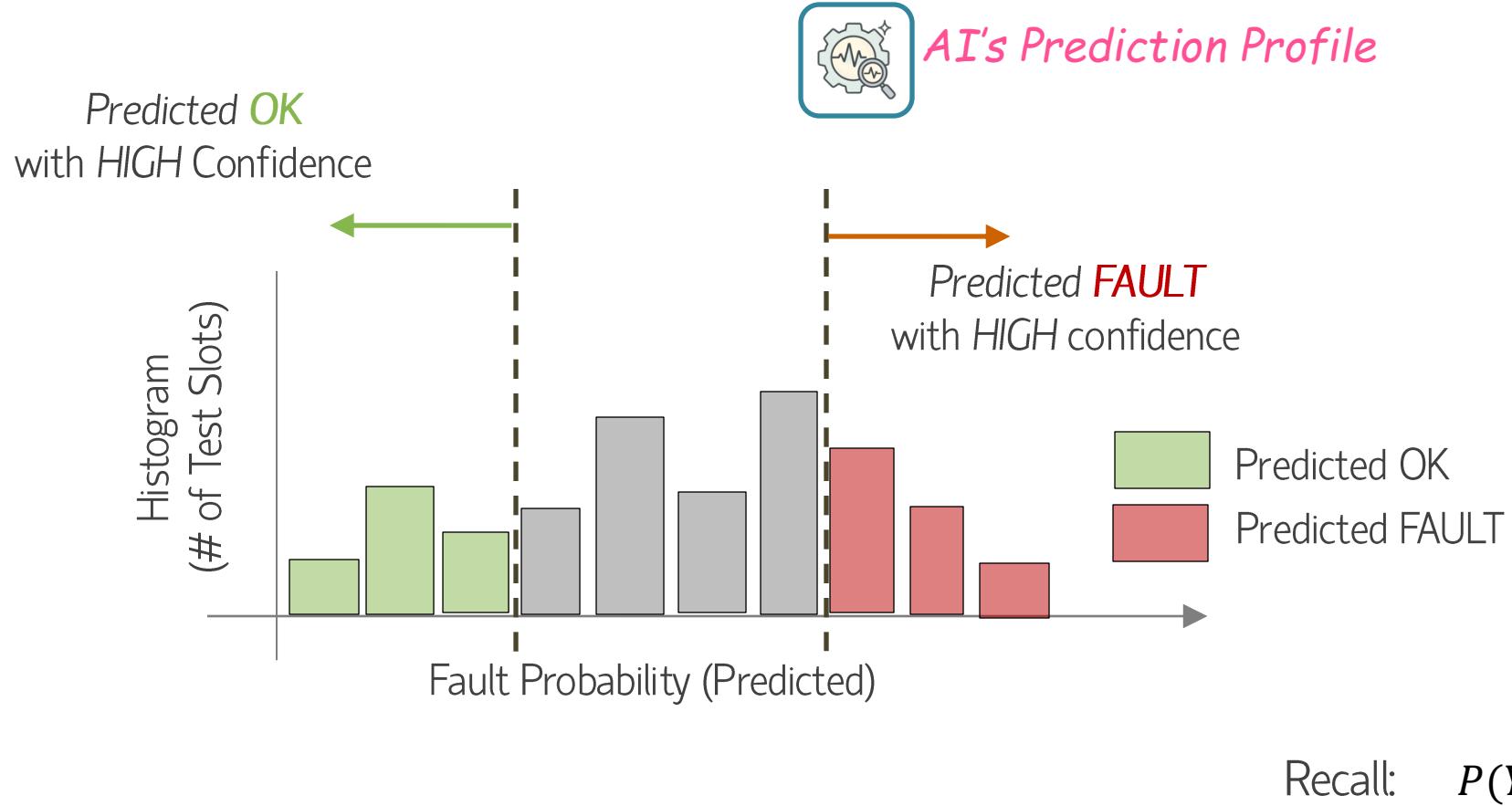
Not really. We can focus on those cases that we're sure if they're fault or no fault.



**Equipment
Engineering Manager**

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

Imperfect Predictions



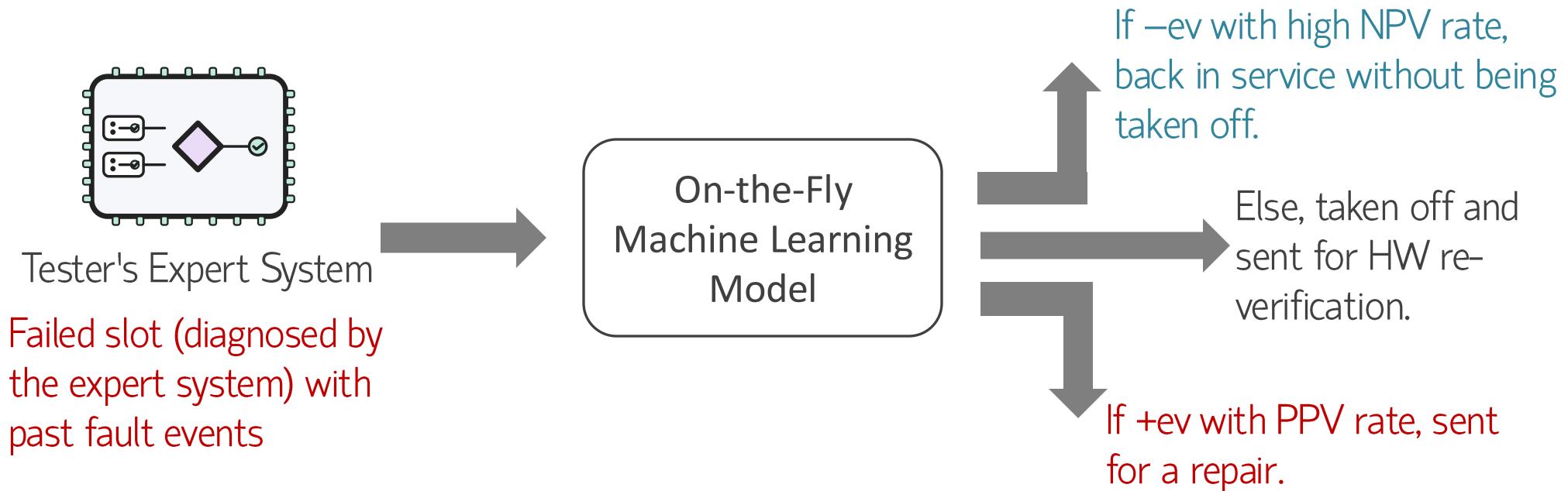
Composite Teaching Case; Synthetic Figures; No Confidential Info.

Operational Constraints

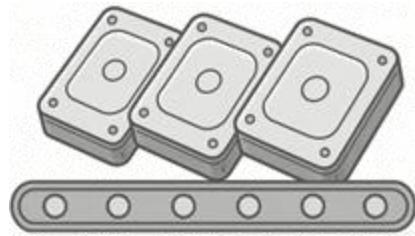
Constraint: Testers are 3rd-Party HW equipment. We cannot easily make changes to the expert system, but we can still consume machine (log) data generated by the equipment.

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

How Do We Utilise Our Predictions?

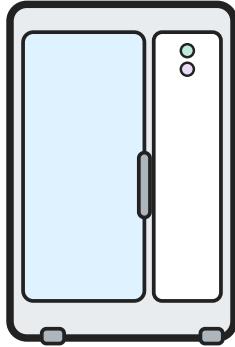


Before



Assembled HDD Drives

Every hard disk drive is quality tested.



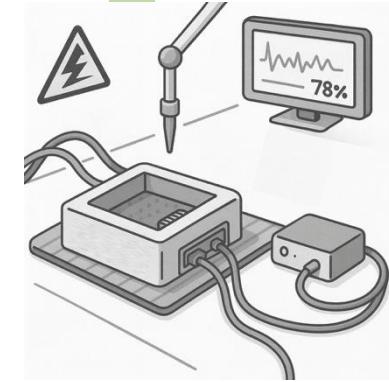
HDD Electrical Tester

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

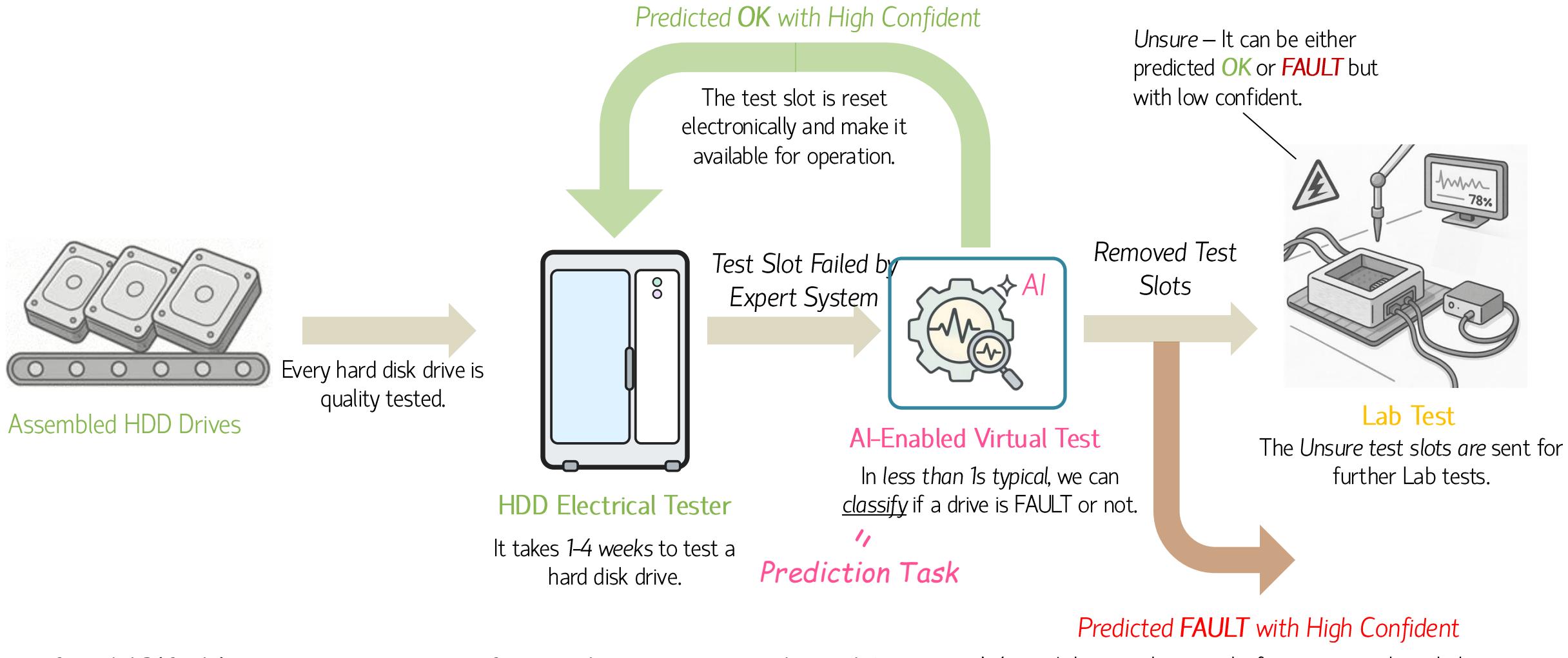


Lab Test

The Unsure test slots are sent for further Lab tests.

Composite Teaching Case; Synthetic Figures; No Confidential Info.

Process Re-Design

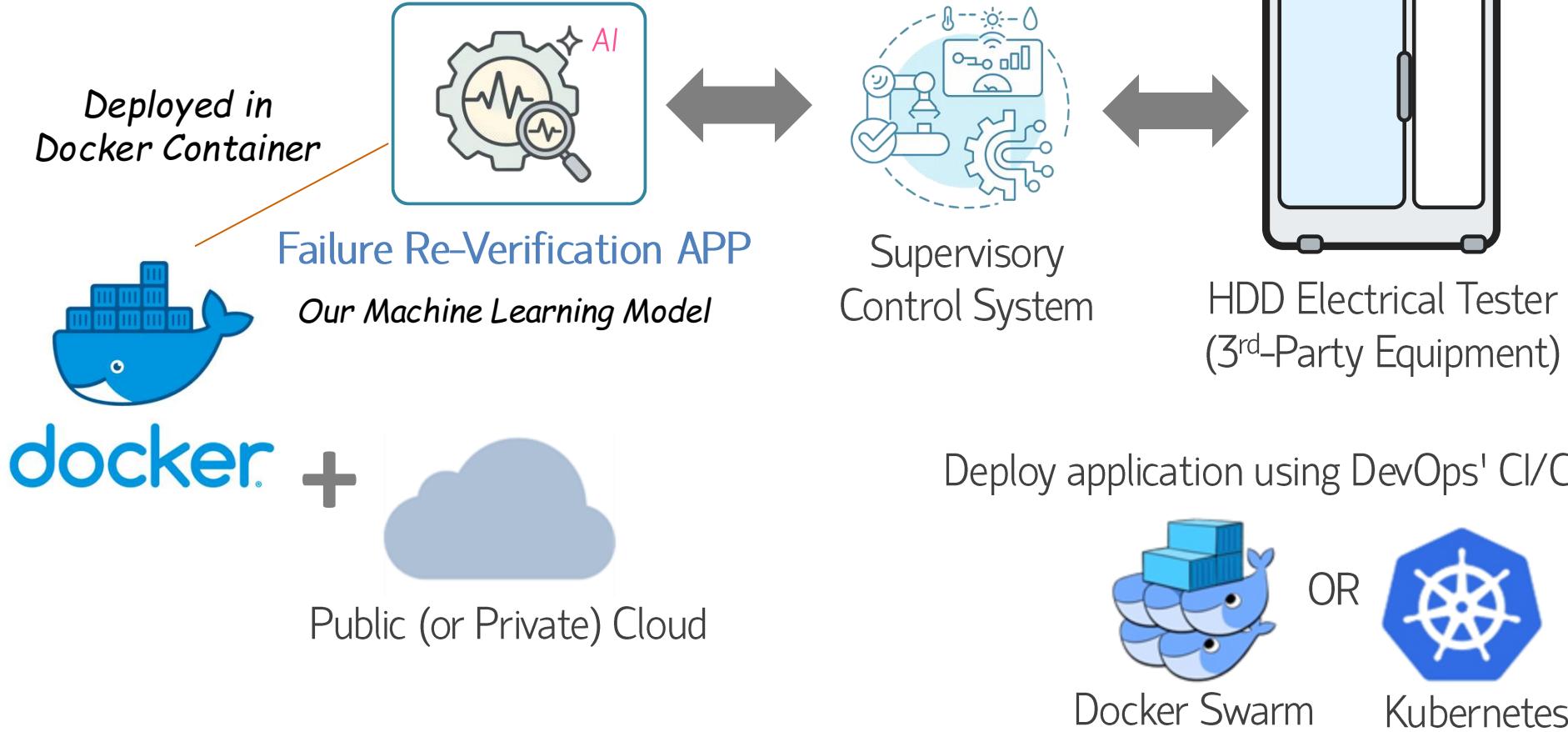


If model $P(\text{fault}) \geq \tau_1 \rightarrow \text{route to repair}; \text{if } \leq \tau_0 \rightarrow \text{electronic reset}; \text{else} \rightarrow \text{lab.}$

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

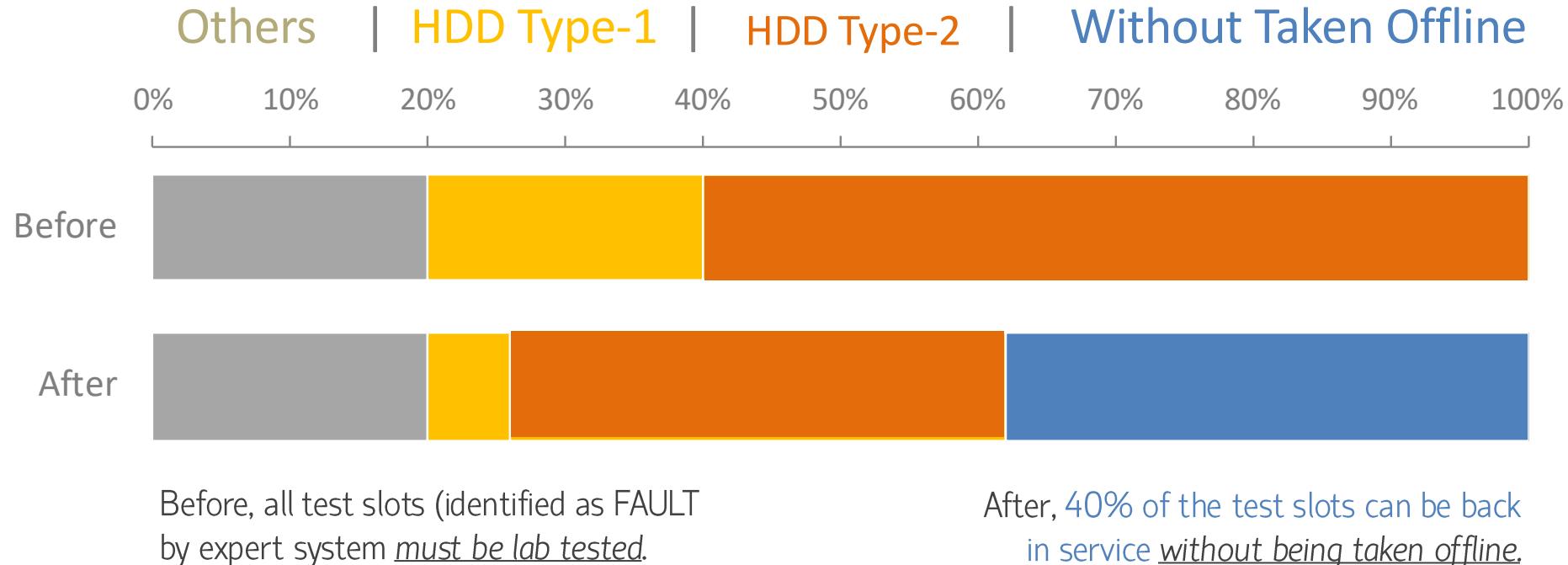
AI-as-a-Service

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.

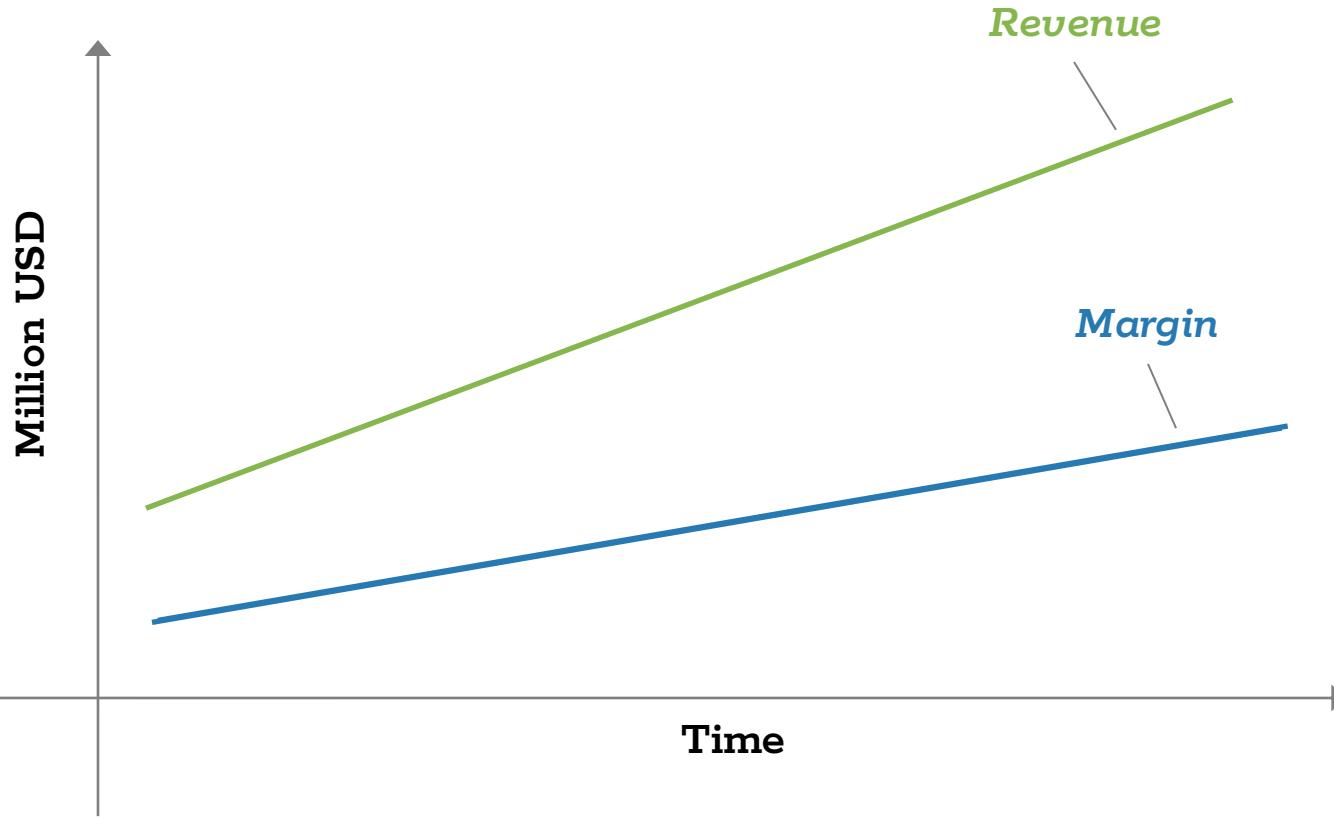
... that's about 2 testers ...

0.4% (1.4M USD)

gain in OEE enabled by our AI-enabled process.

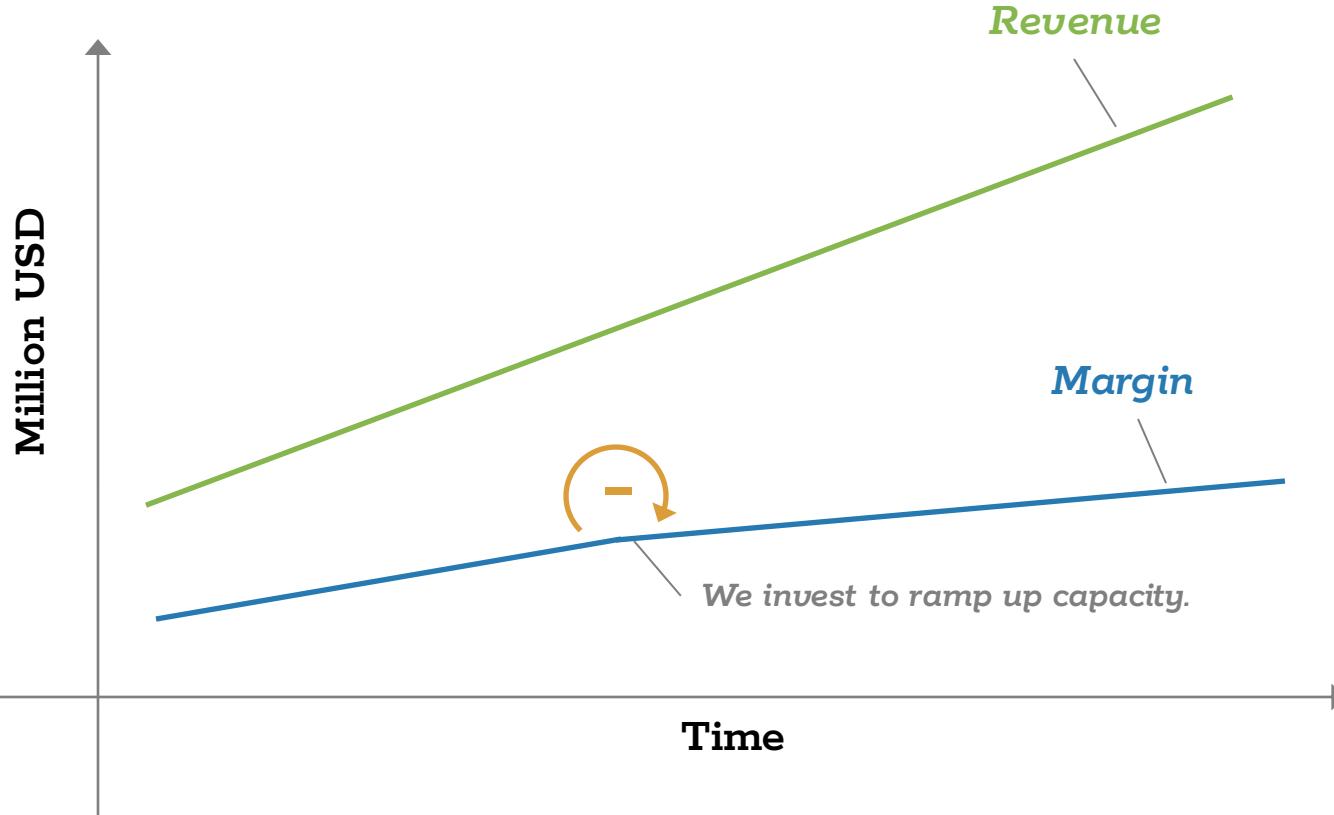
Composite Teaching Case; Synthetic Figures; No Confidential Info.

Closing Thought (1 of 3)



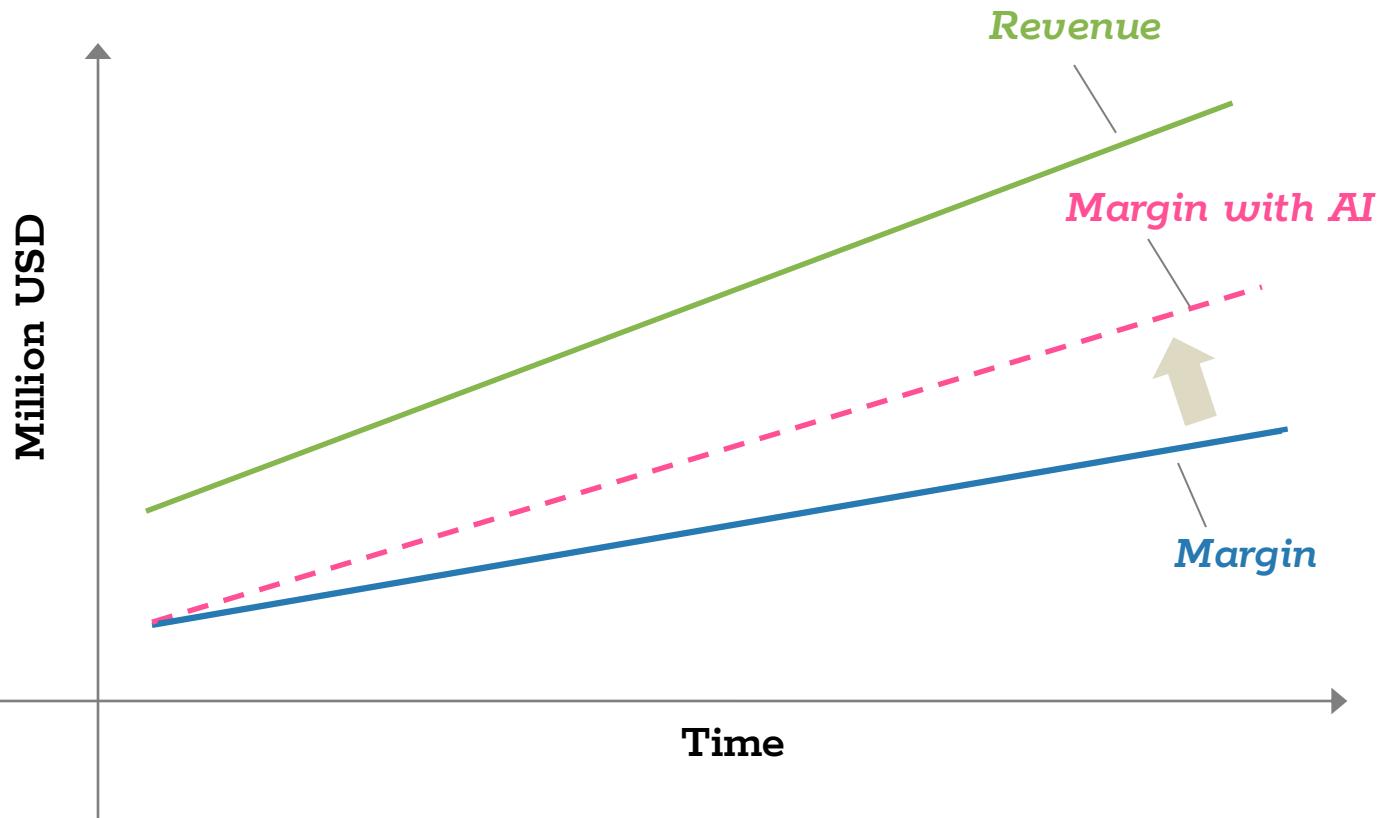
Composite Teaching Case; Synthetic Figures; No Confidential Info.

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 is 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).