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DATAWorks 2023: Back to the Future: Implementing a Time Machine to Improve and Validate Model Predictions

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Executive Summary

At a time when supply chain problems are challenging even the most efficient and robust supply ecosystems, the Department of Defense (DOD) faces the additional hurdle of dealing primarily in low-volume orders of highly complex components that have multi-year procurement and repair lead times. When combined with the DOD's perennial budget shortfalls, these supply chain problems make it imperative for the DOD to spend money efficiently by ordering the "right components" at the "right time" to maximize readiness.

What constitutes the right components and the right time depends on model predictions that are based upon historical demand rates and order lead times. Given that the timescales between decisions and results are often years long, even small modeling errors can cause months-long supply delays or tens of millions of dollars in budget shortfalls. Therefore, we must quantify modeling errors by comparing predictions to actual observations; however, we cannot evaluate the accuracy and efficacy of today's decisions for some years to come.

To address the problem of long feedback times in forward-looking model comparisons, we have built "time machines" to pursue retrospective validation – for a given model, we rewind DOD data sources to some point in the past and compare model predictions, using only data available at the time, against known historical outcomes. This capability allows us to explore different decisions and the alternate realities that would manifest in light of those choices. In some cases, these studies are relatively straightforward, while in others they are complicated by problems familiar to any time-traveler: changing the past can change the future in unexpected ways.

In this presentation, we demonstrate our time machine capabilities for two use cases. The first case calculates the accuracy of historical procurement and repair lead time forecasts against the actual results over a multi-year span. This case is conceptually straightforward, though complex in its implementation. The second case examines the outcomes of different contracting policies – how do different sets of rules for prioritizing what to buy affect the DOD's financial and readiness risk? This example is challenging, because when we "replay" history using the different policies we have to account for how our decisions influence the future. Accomplishing this requires a tradeoff between realism and uniformity to ensure a fair comparison between contracting policies.

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Kyle E. Remley
Olivia Gozdz

April 26, 2023

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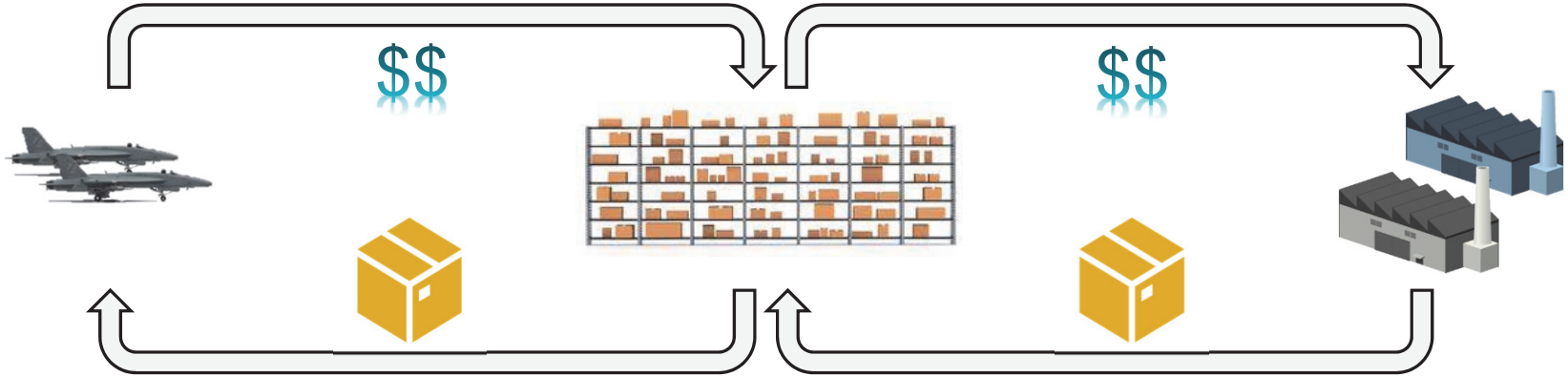
Sustainment is the science of maintaining readiness – can the DOD's assets perform their missions?



The role of wholesale is to ensure the right parts are on the shelf to equip the warfighter

Wholesale's budget is limited, and it relies on data-driven models to quantify the resultant risk to the sustainment system

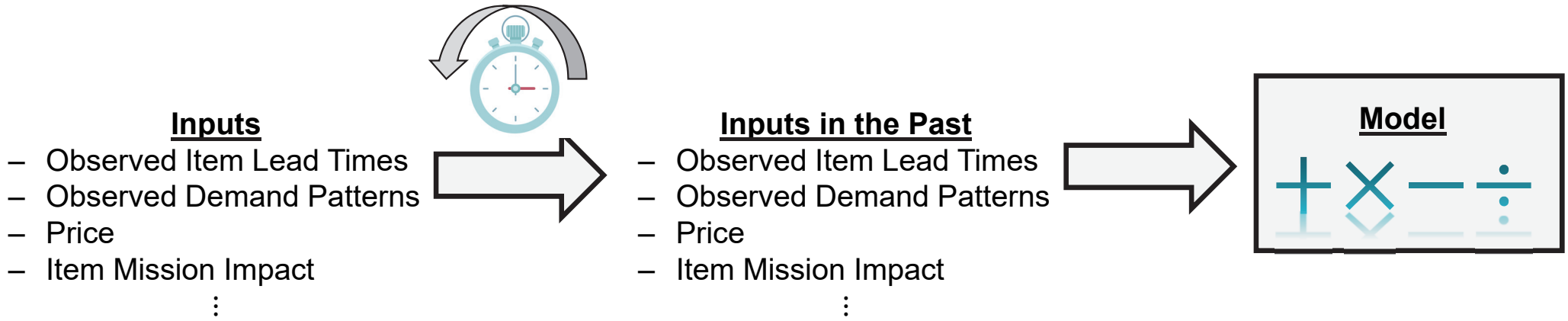
Accurate models are critical for wholesale to make the best decisions possible.

Validation is the key to ensuring models are useful, but there are challenges

Simplest approach: make a prediction and see if it comes true

But it takes a long time to get feedback

An alternative: use a "time machine" to validate model predictions against *historical* observations



Time Machine Overview

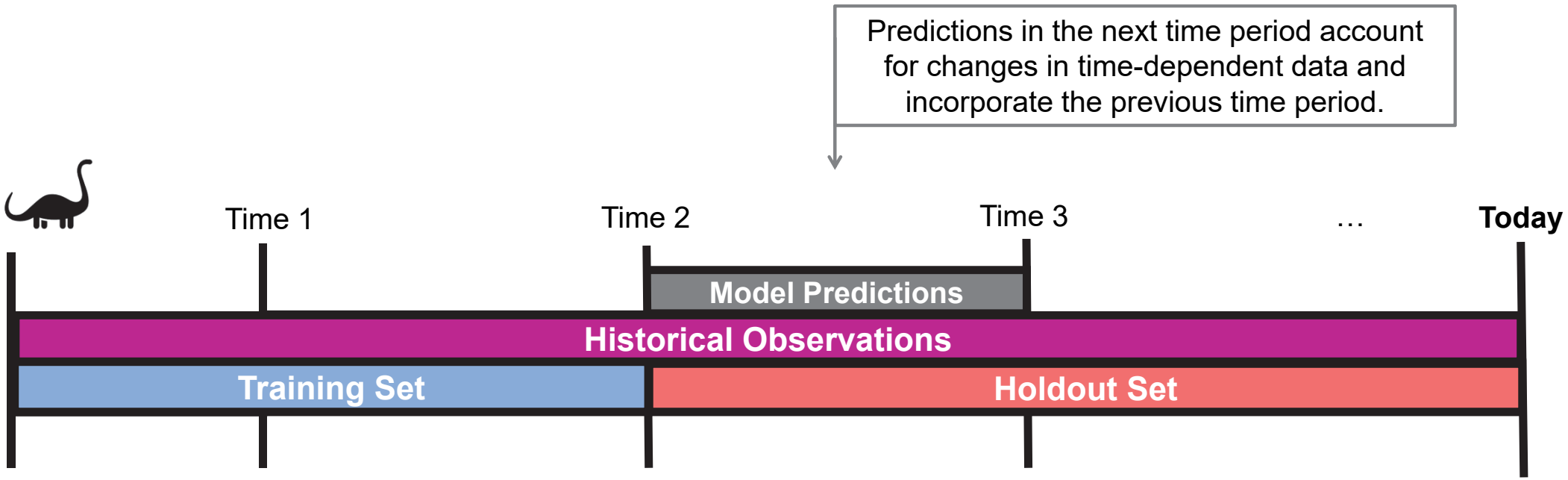
For the time machine to be effective, we have to accurately represent the past reality

One of the biggest challenges is ensuring there is no accidental cheating

Our models must use *only* data that would have been available at the point in the past that we're modeling

The time machine must account for models that "learn" with time

How do you build a time machine for a system that learns?



We iteratively produce model predictions for multiple time periods, comparing each set of predictions to known historical outcomes.

How do we ensure that our data are properly aligned at each time interval?

We don't necessarily have snapshots for every moment in time

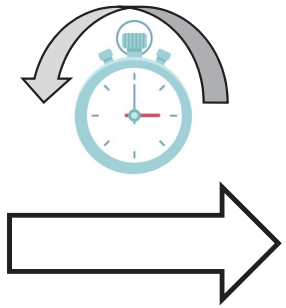
We must "rewind" current snapshot data to reflect the world as it was at any time interval

Today's contract delivery expectation:

Item: Flux Capacitor

Total Contracted: 10

Number Arrived: 8



Empirical delivery data

Yesterday's contract delivery expectation:

Item: Flux Capacitor

Total Contracted: 10

Number Arrived: 2

We need to rewind data to ensure model predictions don't cheat!

Time Machine Case 1: Contract Lead Time Validation

Background

The DOD manages stock levels by contracting with outside entities to produce or repair hundreds of thousands of different items

DOD item managers use estimated repair and procurement lead times to predict how long it takes to acquire new stock

These lead times are point estimates based on historical data and are calculated for each individual item

The ability of the DOD to maintain healthy stock levels heavily depends on having accurate lead time estimates.

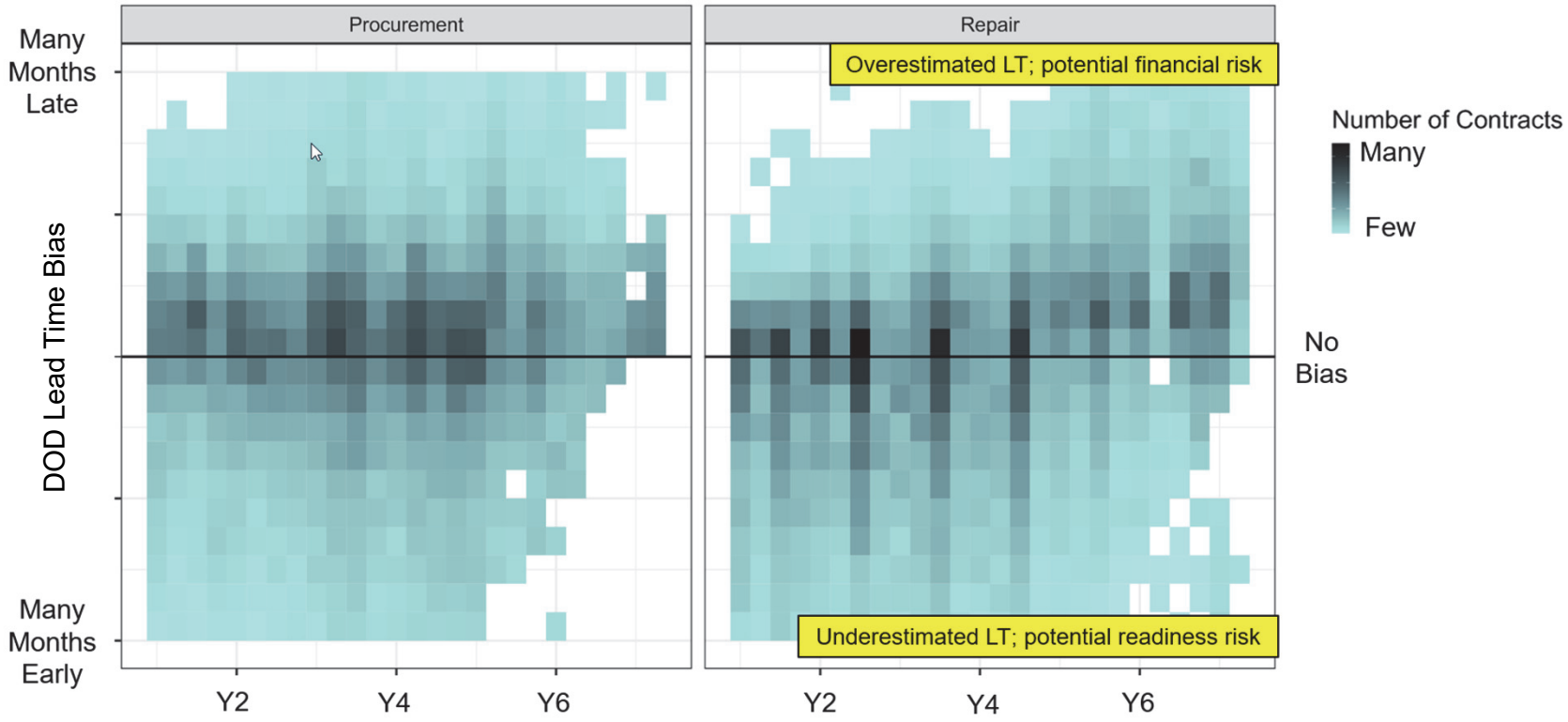
Decisions based on inaccurate lead times introduce financial and readiness risk

Underestimated lead times generally introduce **readiness risk** because you order too late

$$

Overestimated lead times generally introduce **financial risk** because you're paying too soon

The time machine can determine the accuracy and bias of lead time projections



- We can quantify the magnitude of the error of lead time projections.
- This error is significant in proportion to the magnitude of the lead times (not shown).
- We can identify bias in the error, which drives a different kind of risk.
- Our results give us ideas for how to improve these calculated lead times.

Time Machine Case 2: Contracting Policy Validation

The DOD proposed a new policy that focuses contracting efforts on the key items that drive most of the wholesale business

Wholesale manages many items and cannot afford to stock all of them; it must prioritize its contracting actions

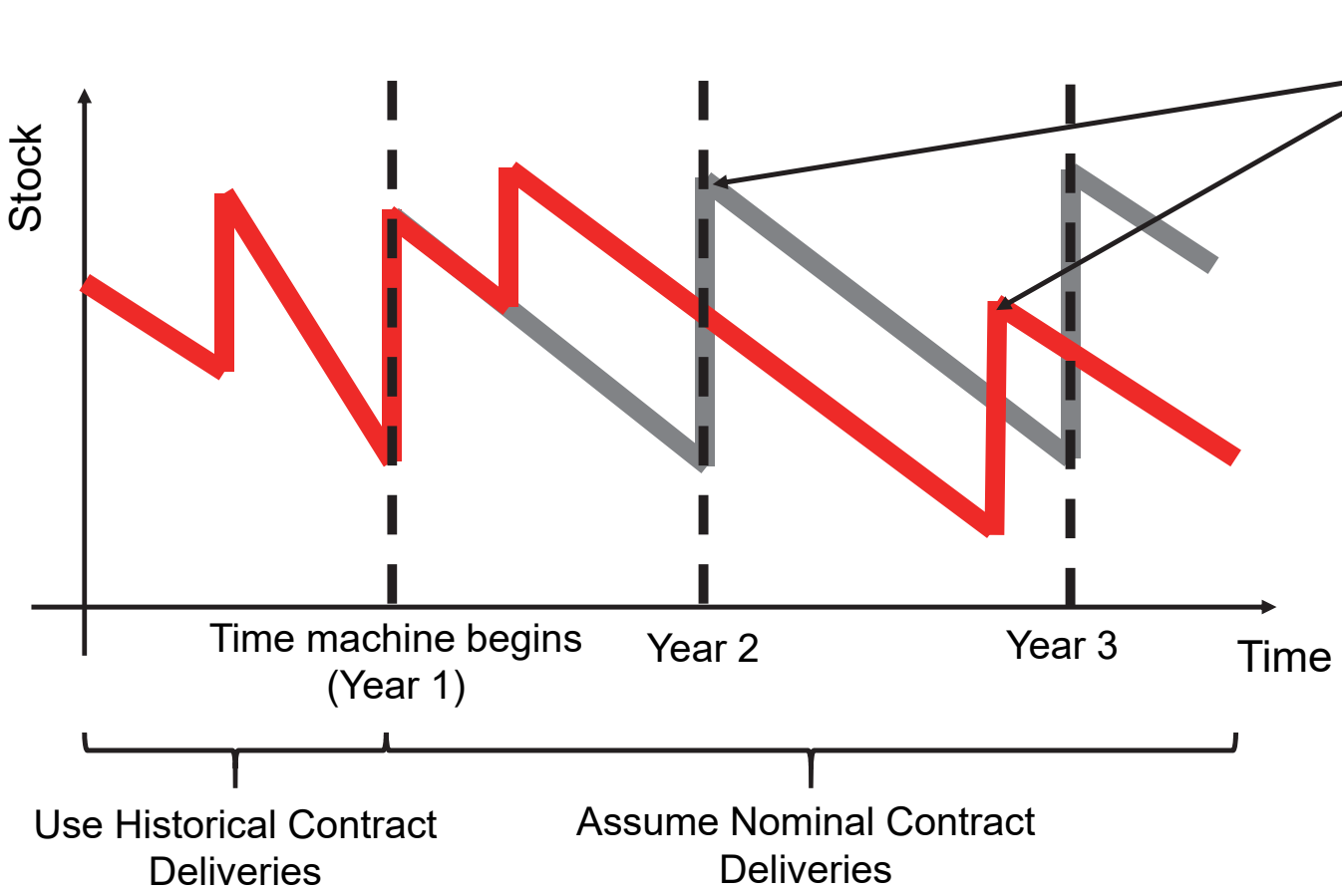
Item inventory can focus on breadth, depth, or some mix

A small number of items account for most of the demand

The DOD aims to limit its risk by increasing depth for this small number of items

This new policy makes new recommendations – “buy this, don’t buy that” – *what is the impact on wholesale*?

We used our time machine methodology to validate the new contracting policy



The new and historical policies are buying different items at different times

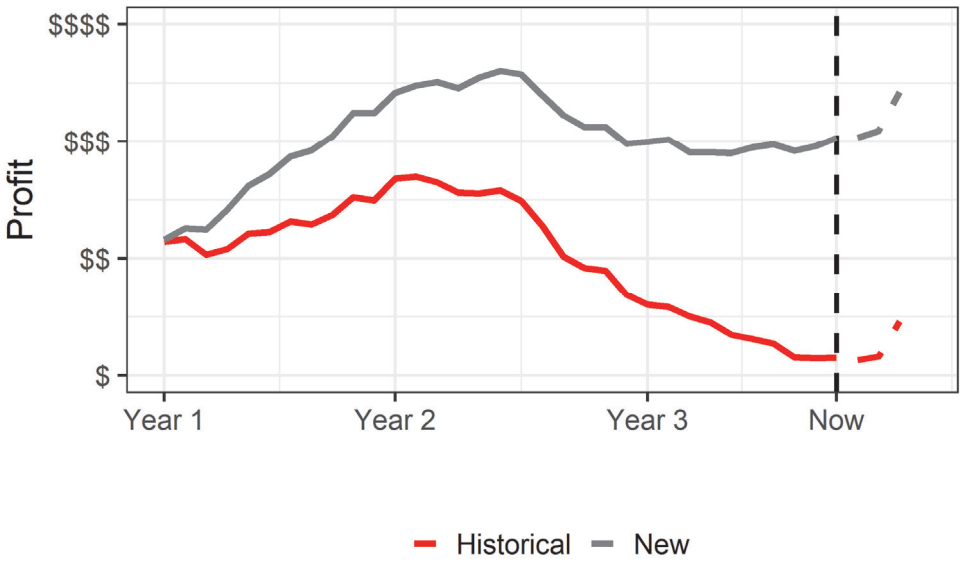
New

Historical

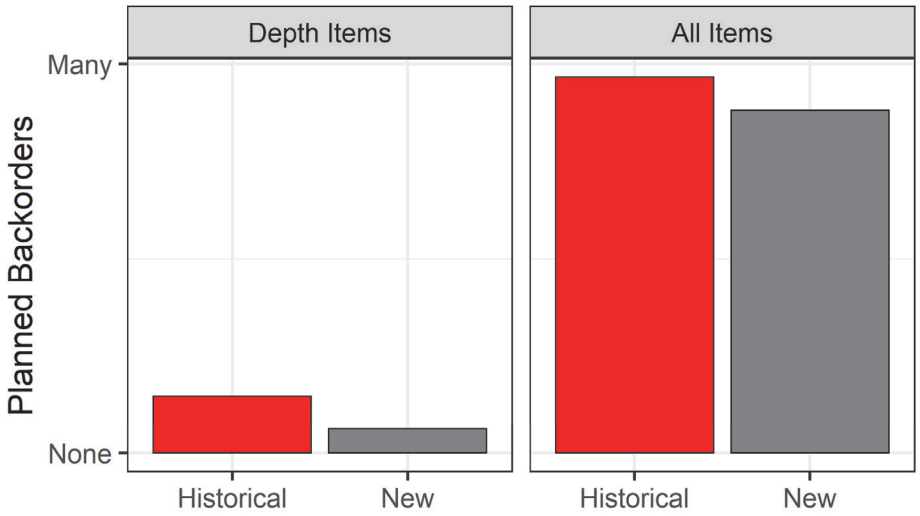
When changing the past, we need to simplify assumptions to generate an apples-to-apples comparisons.

The new policy is successful because it reduces financial risk without compromising readiness risk

Financial Risk

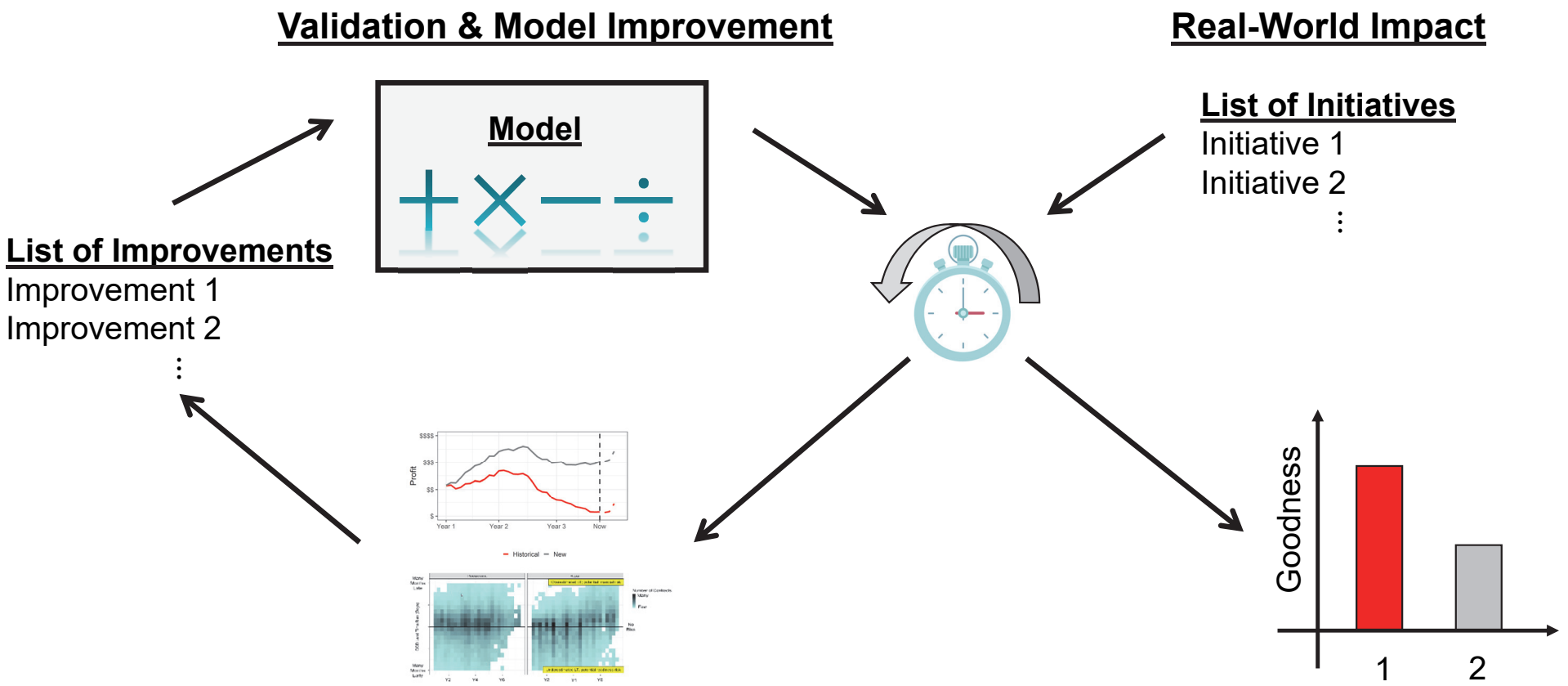


Readiness Risk



Using only the data available at the beginning of each year, the new policy can place orders that outperform the historical orders.

The time machine provides an important “yard stick” for the DOD’s modeling capabilities



We can use this capability to continuously help the DOD improve their models and risk assessments.

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14. ABSTRACT
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