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Building End-to-End Sustainment Models for Weapon Systems

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Han Yi

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Building End-to-End Sustainment Models for Weapon Systems

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Executive Summary

Bottom-up emulations of real sustainment systems that explicitly model spares, personnel, operations, and maintenance are a powerful way to tie funding decisions to their impact on readiness, but they are not widely used. The simulations require extensive data to properly model the complex and variable processes involved in a sustainment system, and the raw data used to populate the simulation are often scattered across multiple organizations.

IDA has worked with military and civilian sponsors to construct such end-to-end simulation models for maritime and aviation weapon systems and to investigate the strategic levers that drive readiness. In this conference presentation, we describe the complexities of properly emulating sustainment concepts and argue for the urgency of increased end-to-end modeling efforts in improving readiness across weapon systems.

First, we discuss the challenges in aggregating and interpreting sustainment data to generate component-level metrics and how we employ statistical best practices to overcome these challenges. Next, we showcase notional examples of excursions into specific investments. Finally, we illustrate how the ability to examine the combined effects of multiple investments is pivotal in helping senior decision-makers make better investment decisions to improve readiness.

Building end-to-end sustainment models for weapon systems

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Research Staff Member

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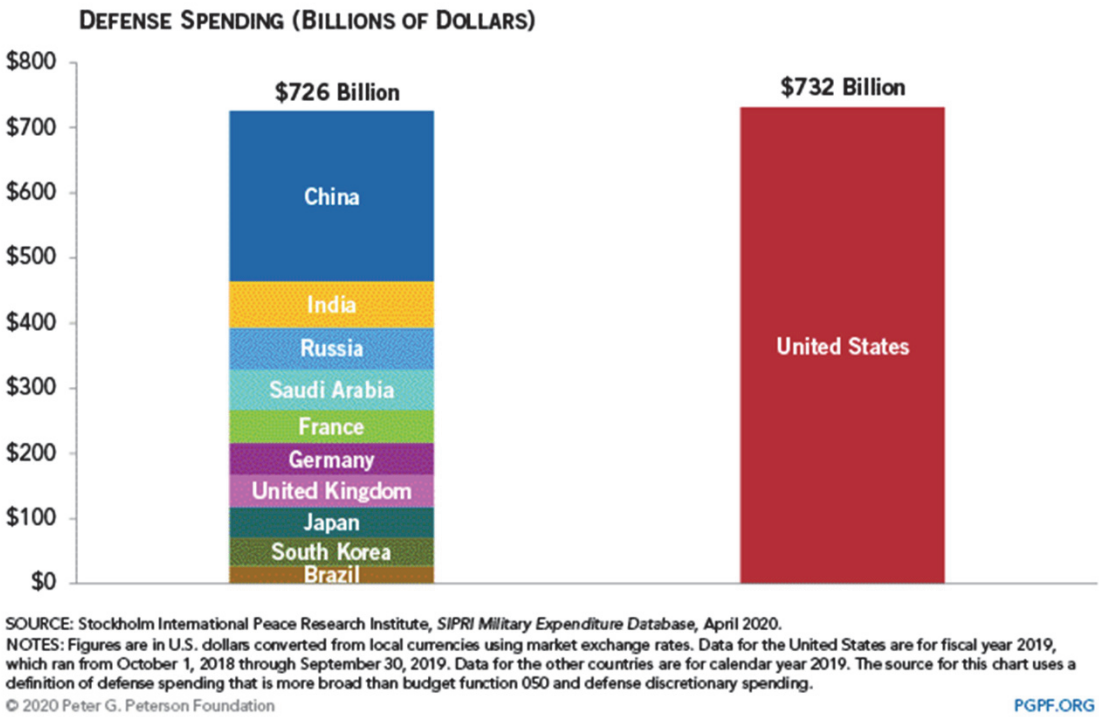
Project Lead

June 2021

Institute for Defense Analyses
4850 Mark Center Drive ● Alexandria, Virginia 22311-1882

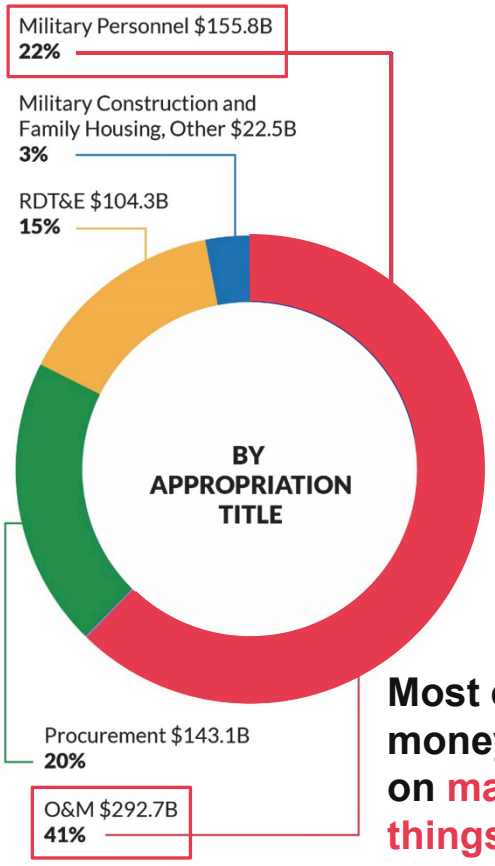
Federal government spends $400B+ / year on operating and sustaining DoD systems

DoD spends $700B+ each year (~$2B/day)



SOURCE: Stockholm International Peace Research Institute, *SIPRI Military Expenditure Database*, April 2020.
NOTES: Figures are in U.S. dollars converted from local currencies using market exchange rates. Data for the United States are for fiscal year 2019, which ran from October 1, 2018 through September 30, 2019. Data for the other countries are for calendar year 2019. The source for this chart uses a definition of defense spending that is more broad than budget function 050 and defense discretionary spending.

PGPF.ORG



https://www.defense.gov/Explore/News/Article/Article/1782973/dod-leaders-make-case-to-congress-for-budget-request/

Most of the money is spent on making sure things work properly

The end metric is system "readiness" to perform missions

Readiness is a persistent challenge for the DoD weapon systems

Breaking News

Mattis orders fighter jet readiness to jump to 80 percent — in one year

By: Aaron Mehta October 9, 2018

+ 354

https://www.defensenews.com/air/2018/10/09/mattis-orders-fighter-jet-readiness-to-jump-to-80-percent-in-one-year/

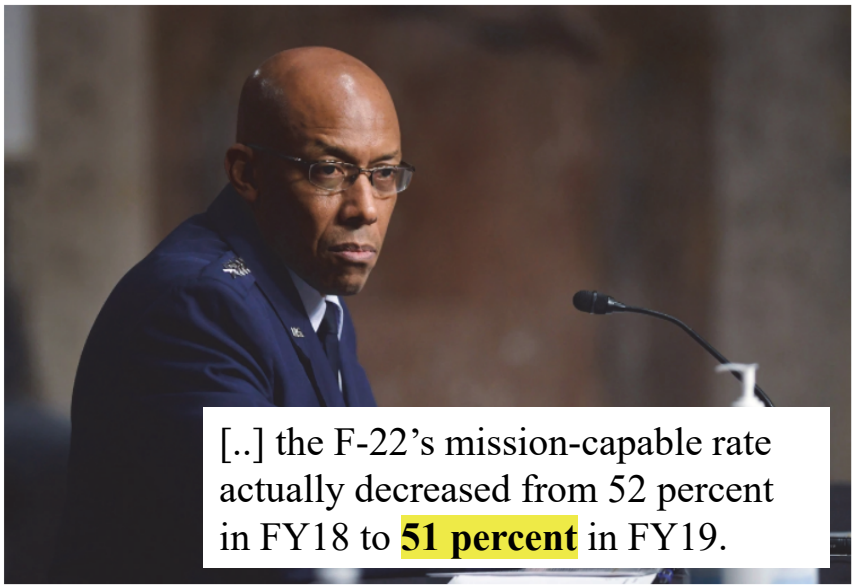
18 months later…

Air

US Air Force bails on Mattis-era fighter jet readiness goal

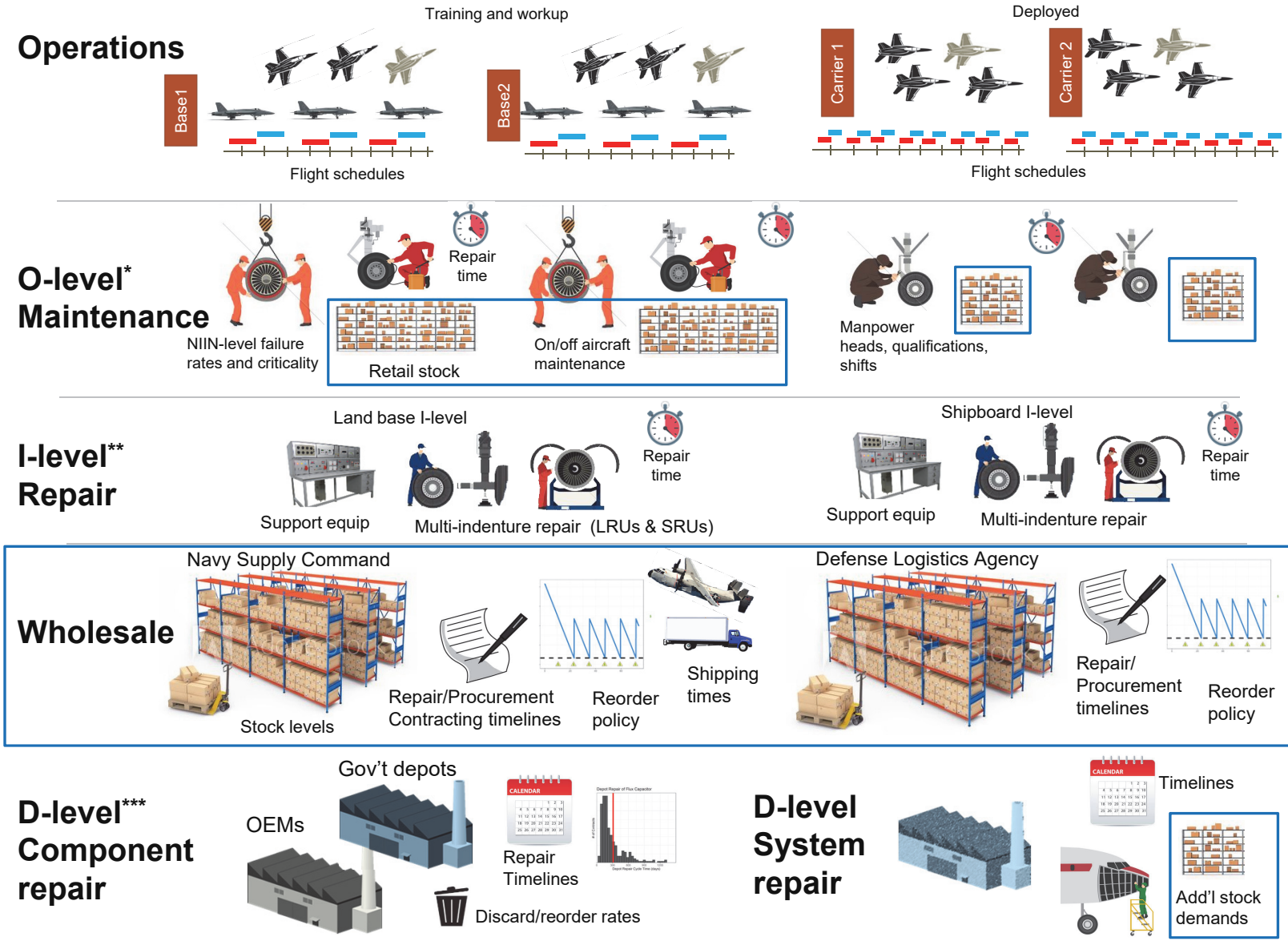
By: Valerie Insinna and Stephen Losey May 7, 2020

+ 66



https://www.defensenews.com/air/2020/05/07/the-air-force-bails-on-mattis-era-fighter-jet-readiness-goal/

Why is readiness so difficult to maintain?



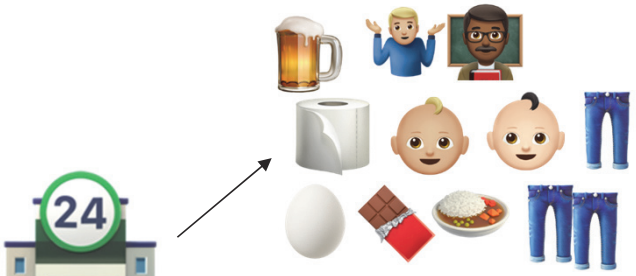
Sustainment: What goes into making sure systems are ready?

* Operational-level
** Intermediate-level
*** Depot-level

The Supply Challenge: Can you order and stock groceries for 1,000+ households a year in advance?

A single household has "demands" with **limited funds**

Optimal purchases must foresee **fluctuating demands** over time



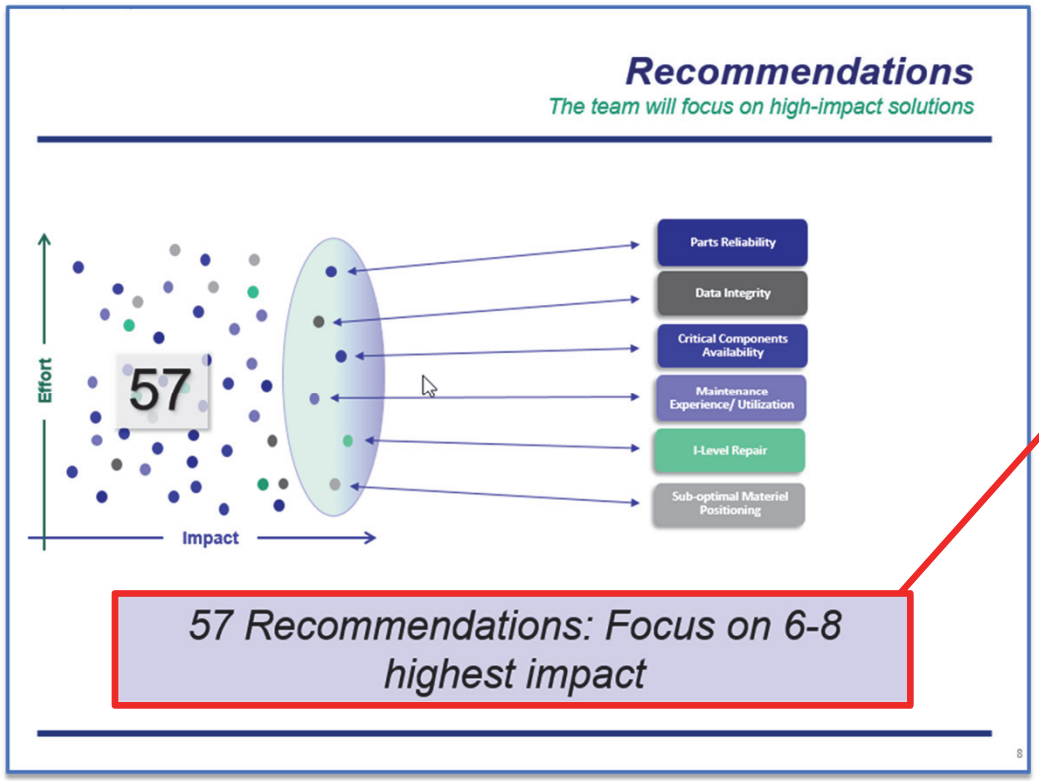
All retail stores are stocked through **wholesale**

Other households will have **different demands**

Local retail stores must have corresponding stock

There is no shortage of potential investments DoD could make to improve readiness

Example readiness report from DoD gives many such recommendations …



… but how do we know which actions are best?

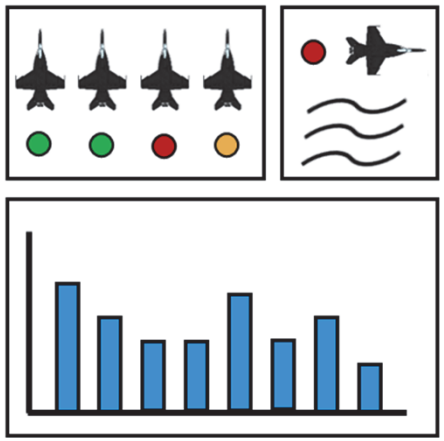
… how much to spend?

… what our returns will be?

IDA model's value added comes from quantification of specific investments

IDA takes a comprehensive simulation-driven approach to map out all aspects of sustainment and their effects on readiness outcomes

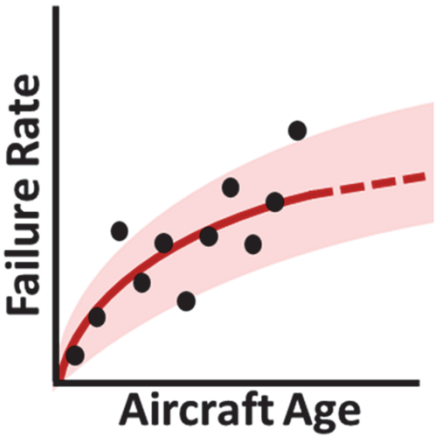
Robust Data-Driven Decision Making =



Data visualization / dashboards

- Quickly provides ground truth
- Good for diagnosing shortcomings
- Can't make predictions
- Can't tie decisions to outcomes

+



Correlative studies

- Statistical approaches including machine learning
- Historical trends can reveal which factors may drive performance
- Not enough details to support decision-making using "what-if" scenarios

+

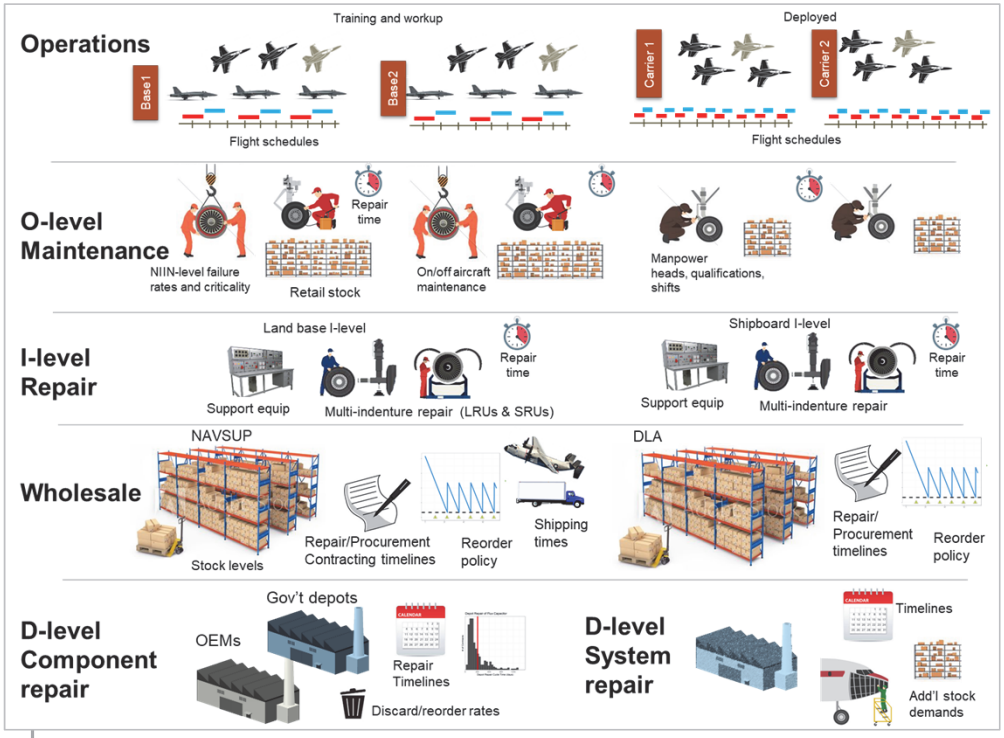
End-to-end simulation

- Explicitly model all aspects of sustainment (spares, manpower, operations, maintenance)
- Make predictions on how specific investments cause changes in readiness
- Model quality is contingent on data quality
- Heavy initial lift to build the model

DoD does little of this approach →

IDA's End-to-End Sustainment Modeling

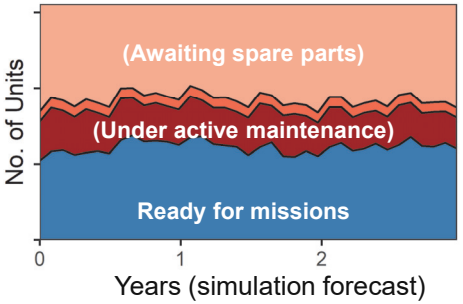
We use time-varying discrete event simulation on the entire sustainment structure (down to individual parts!) such that we can examine end-to-end effects



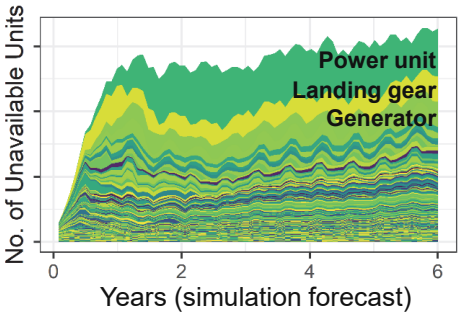
~200,000 lines of input data

What happens …
If wholesale stock is increased? If depot repair times are shortened? …

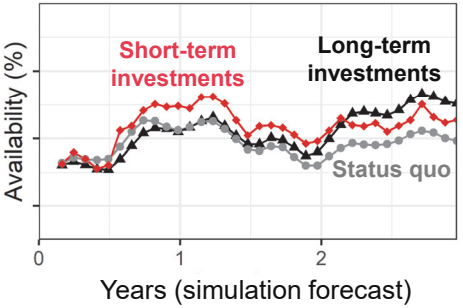
How many units will be "ready"?



Which items are likely to cause problems?

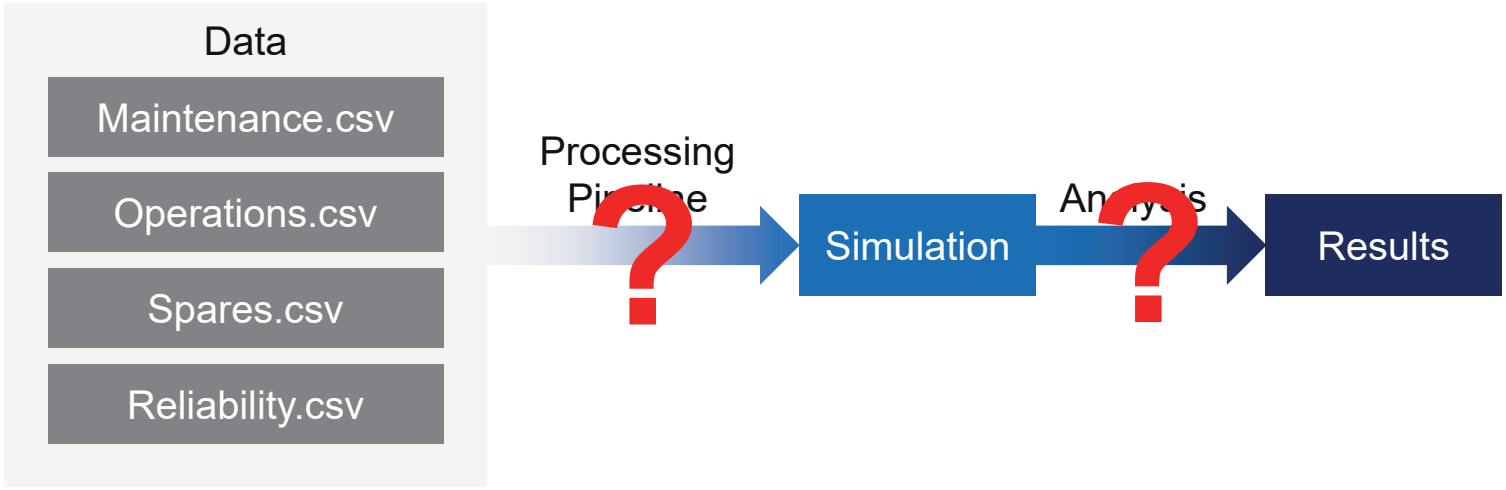


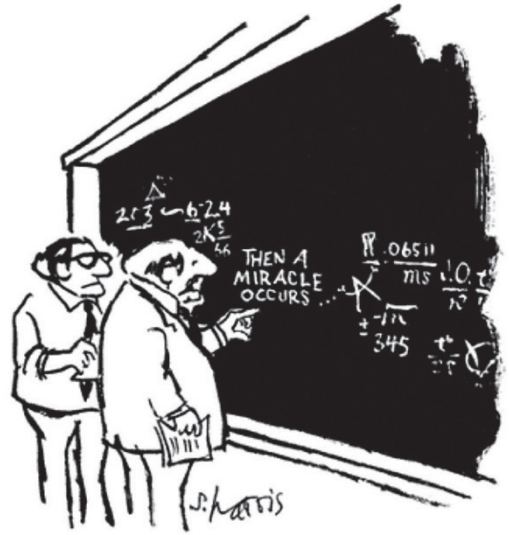
Which investment path meets DoD's needs?



So how do we construct these models?

We want to obtain the ground truth on real-world sustainment, process the data, and enter it in the simulation model to get the results

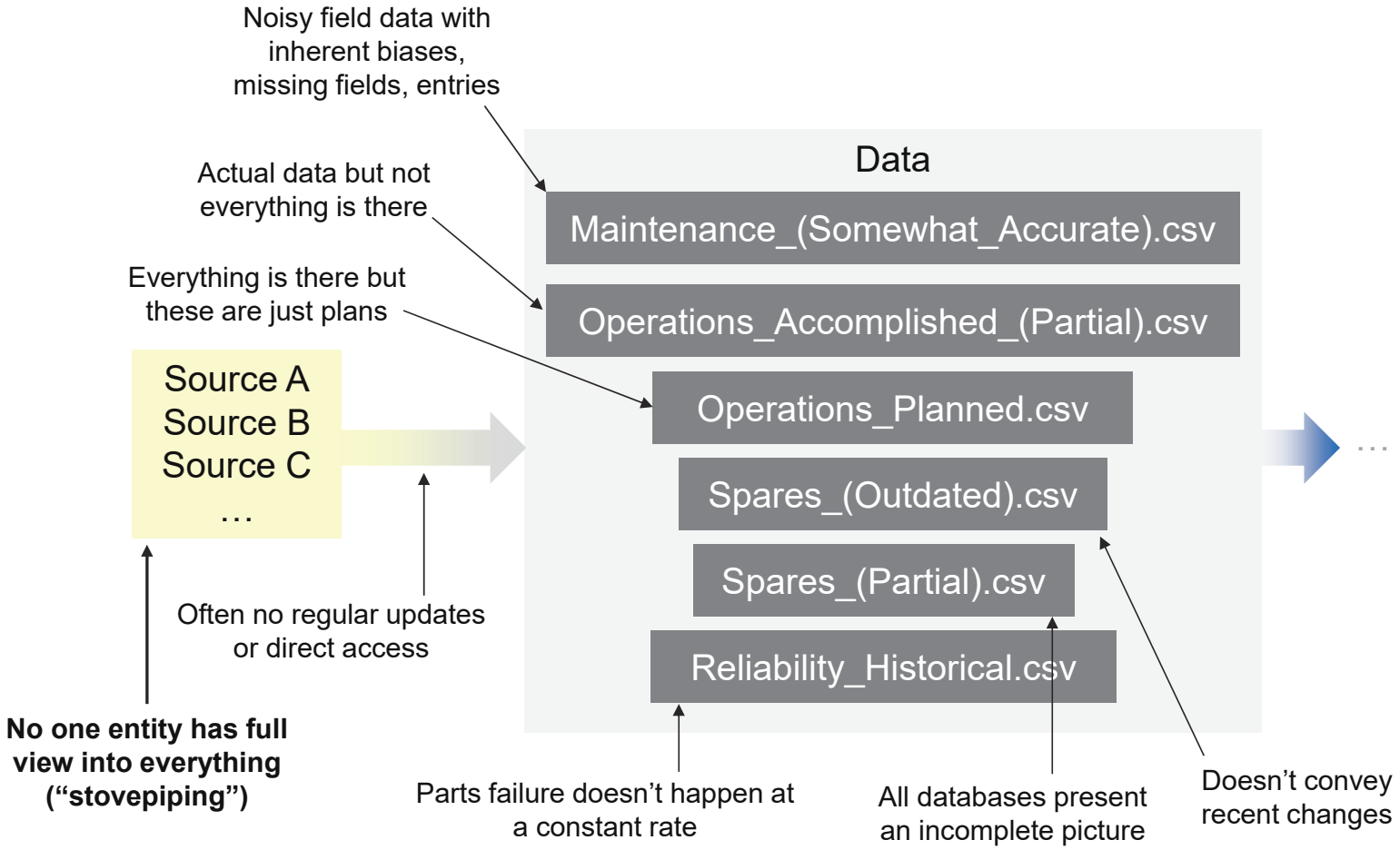




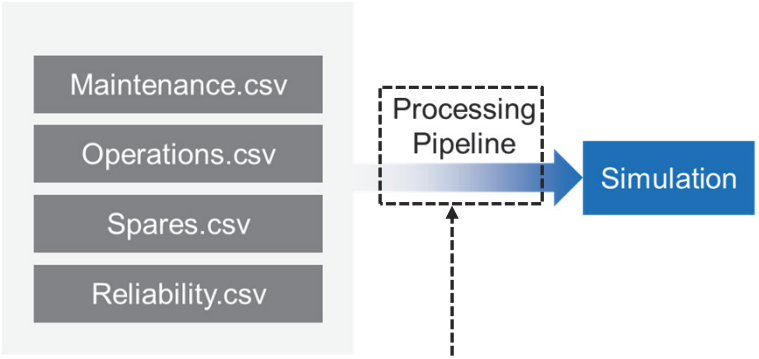
"I think you should be more explicit here in step two."

In practice, this is very difficult to achieve!

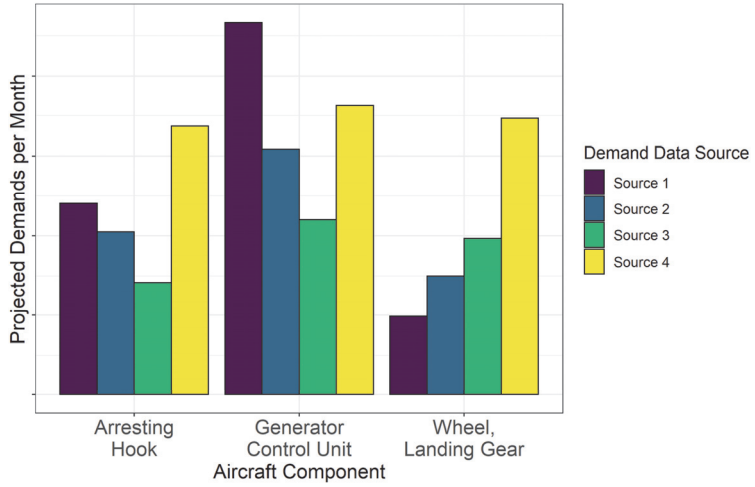
In reality, there is no “one-stop-shop” for all databases in the DoD



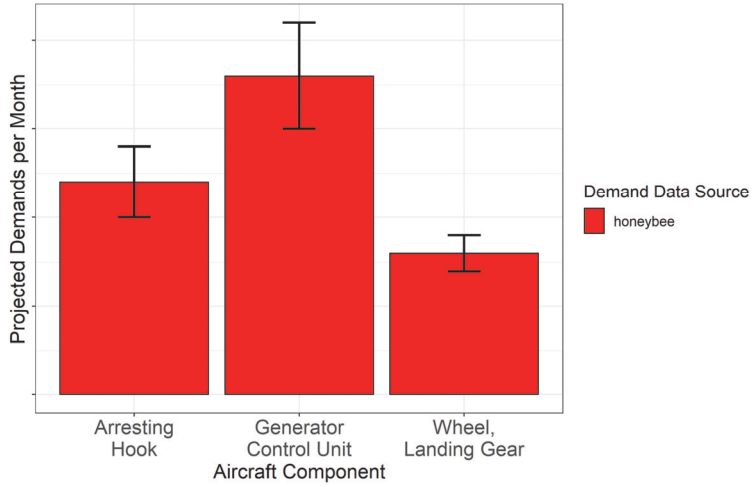
Even after getting the data, there is no “one value” for key metrics



Once we have the raw data, estimating and calculating the inputs to the model should be straightforward, **but …**

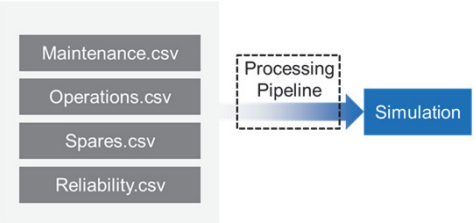


Raw data sources often provide very different calculation methods and estimates for **key metrics** (e.g., how often do these parts fail?)

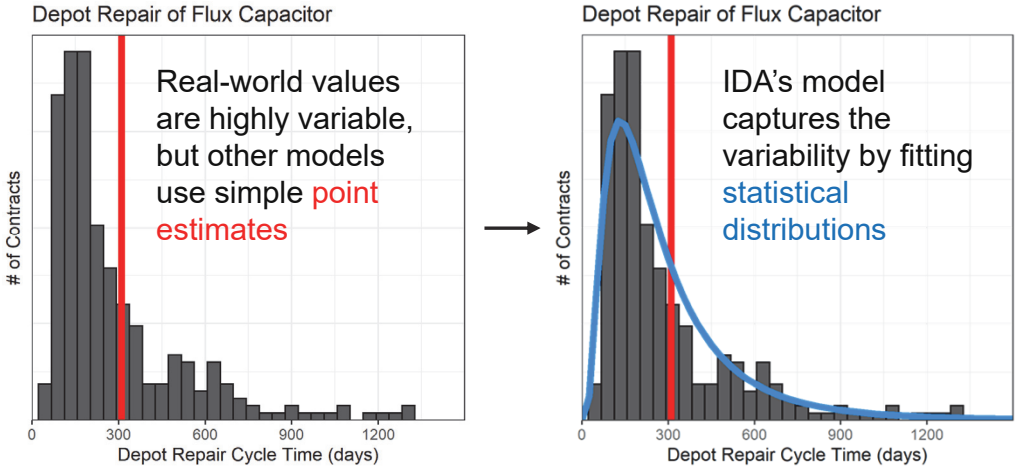


Consulting with subject matter experts enables us come up with **“rules” to translate data into model input**

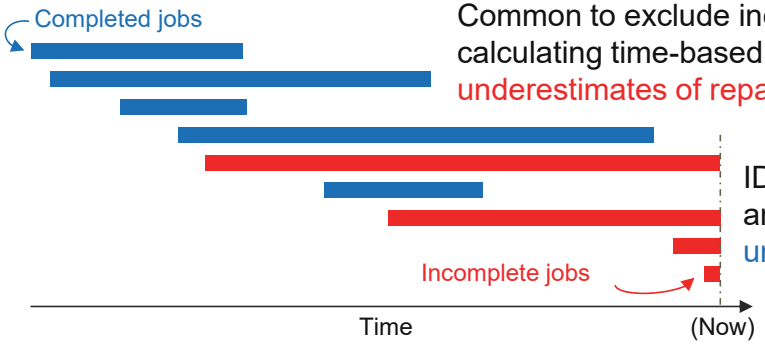
We use statistical best practices to better estimate the model inputs from raw data



1 | Simple parametric fitting



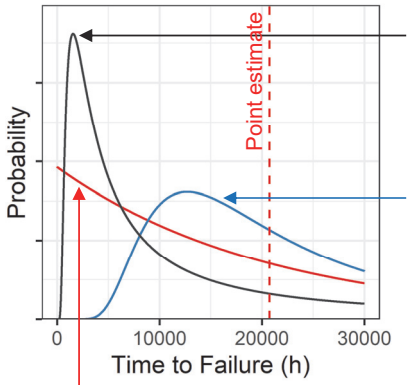
2 | Censored data analysis (Survival Analysis)



Common to exclude incomplete jobs when calculating time-based metrics, resulting in underestimates of repair and delivery times

IDA uses censored data analysis to report unbiased estimates

3 | Bayesian analysis



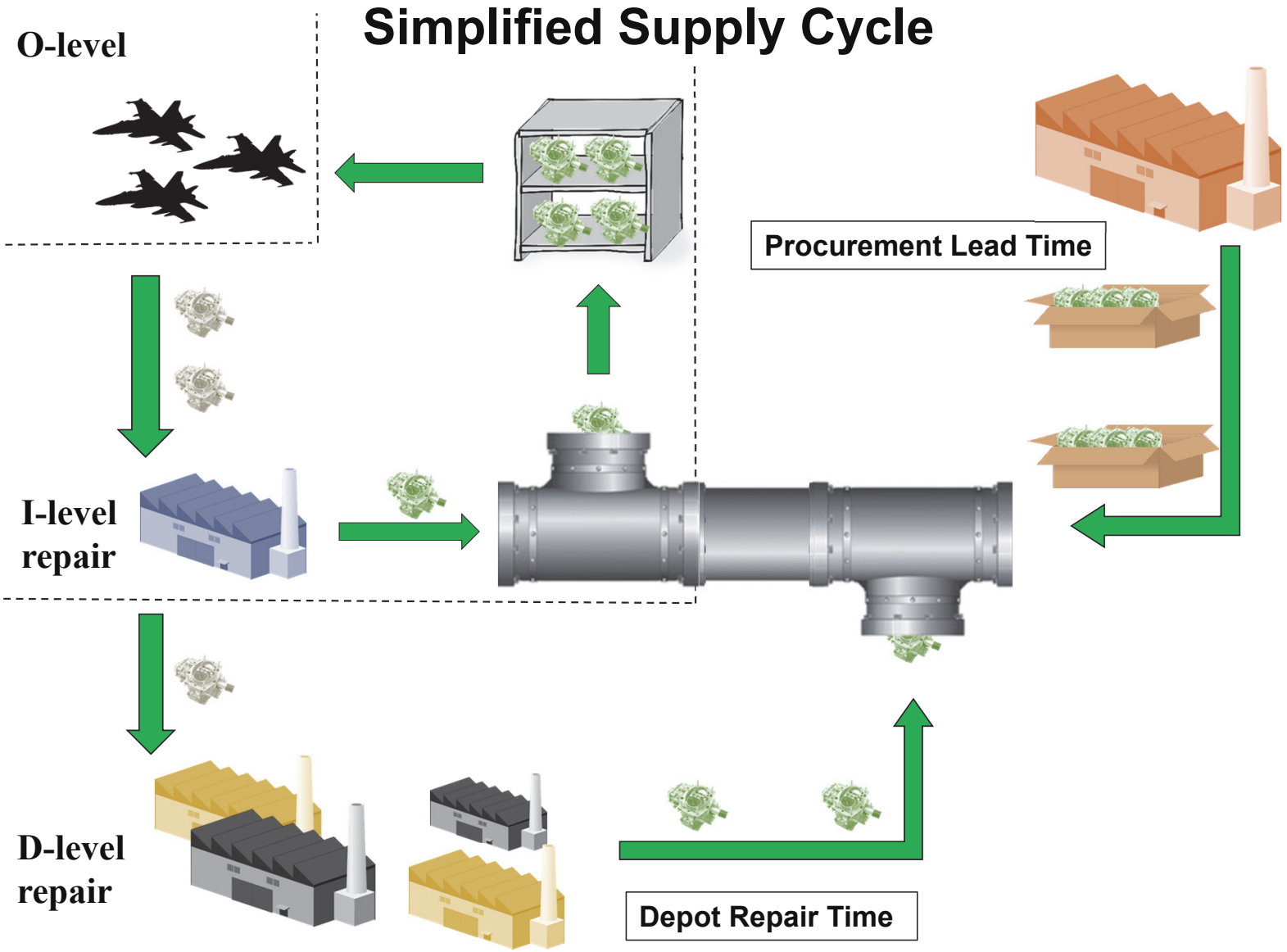
Engineering estimates provide a starting point ("priors")

As the empirical data start to accumulate, we can calibrate the estimates accordingly ("posterior distribution")

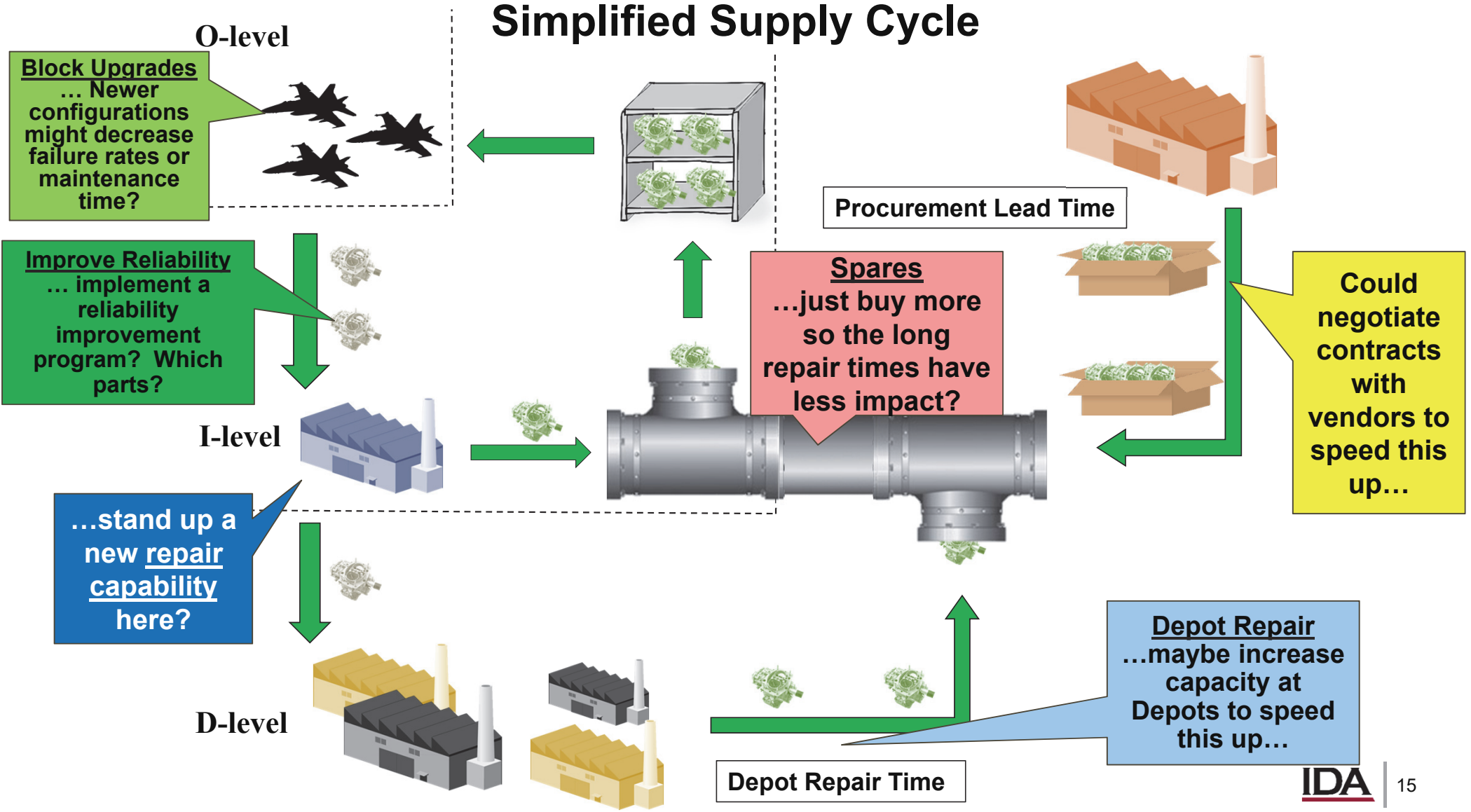
Point estimates are unreliable when the empirical data are scant
(e.g., recently introduced component has failed only once or twice)

Using End-to-End Models to Guide Decision-Making

Simplified Supply Cycle

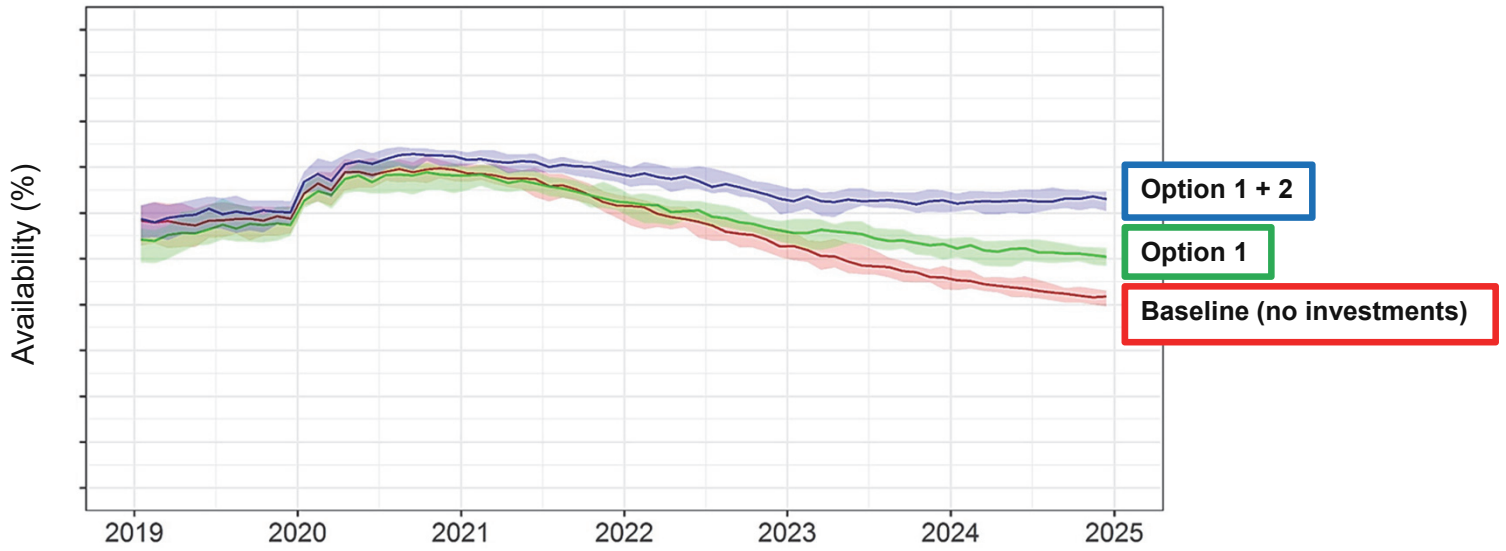


Simplified Supply Cycle



Our efforts guide real-world decision-making by quantifying benefits of specific "what-if" scenarios

1 | What is the timeline for implementing the proposed improvements?



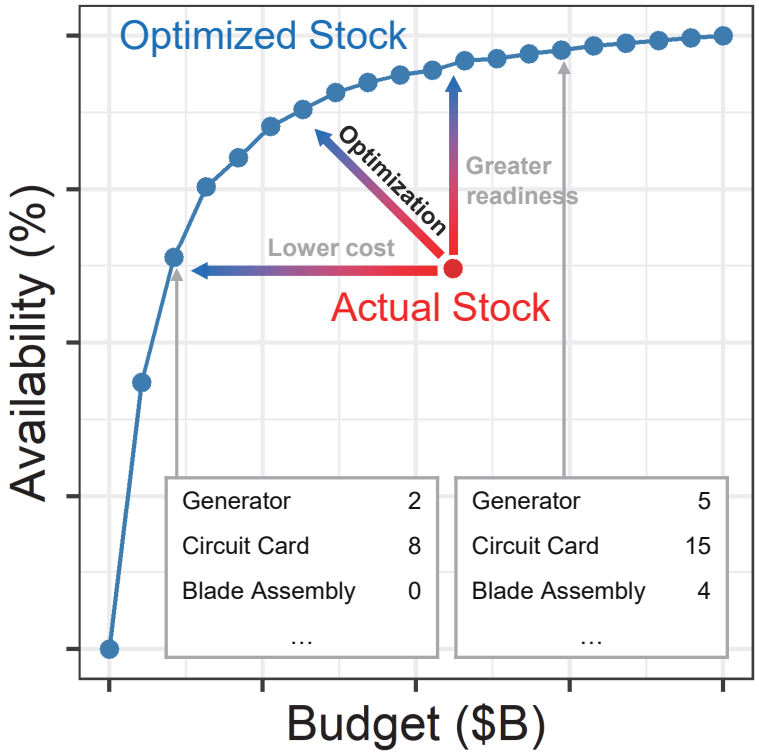
2 | How much will these options cost?

Option	FY20 delta	FY21 delta	FY22 delta	FY23 delta	FY24 delta	Total delta over FYDP	Availability improvement over FYDP
Investment Option #1	$$	$$	$$	$	$	$$$$	X%
Investment Option #2	$$	$$	$$	$$	$$$	$$$$	XX%

Using stock optimization, we can develop detailed stock inventories that will increase readiness and decrease cost

Spares

Readiness-based sparing finds the optimal combination of stocks for a given budget



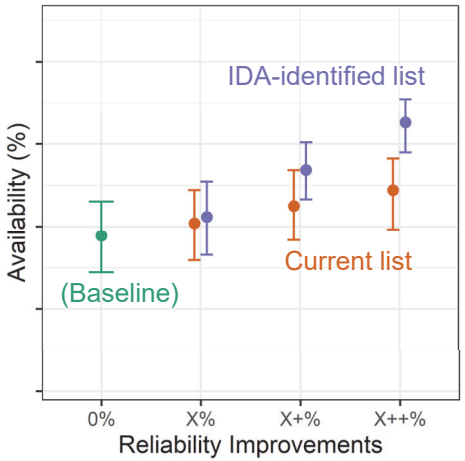
Current stock levels are not optimized for readiness

Our efforts guide real-world decision-making by quantifying benefits of specific "what-if" scenarios

Reliability

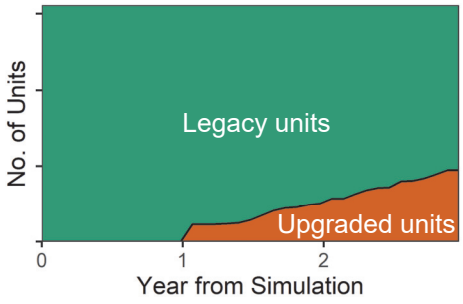
What if we identified parts to focus on for reliability improvements?

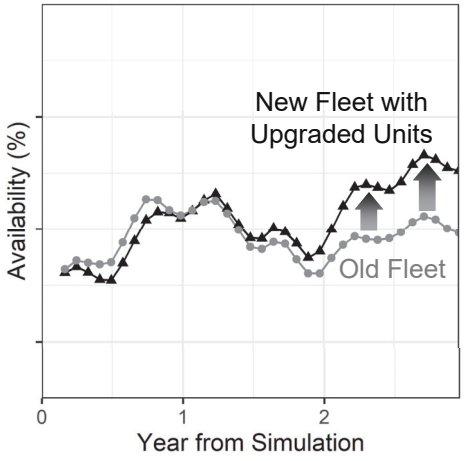
Current "Degrader" List	IDA-identified List
ROTOR GEAR BOX	ROTOR GEAR BOX
GENERATOR	LANDING GEAR
POWER UNIT	TRANSMITTER
FLIGHT CONTROL	GENERATOR
BEARING	POWER UNIT
…	…



Upgrades

What if we upgraded some units to a new configuration?



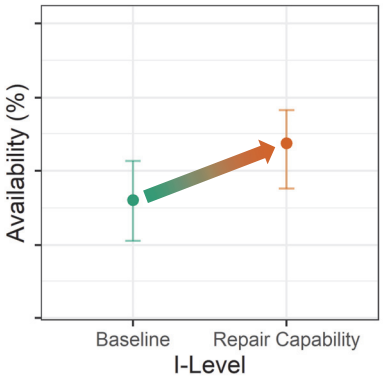


Our efforts guide real-world decision-making by quantifying benefits of specific "what-if" scenarios

Repair capability

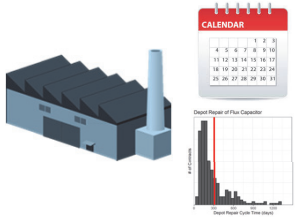
What if we expanded on-base (I-level) repair capability?

Part	Baseline	What-If
Canopy	30%	50%
Wing	10%	40%
Landing Gear	0%	10%
…		

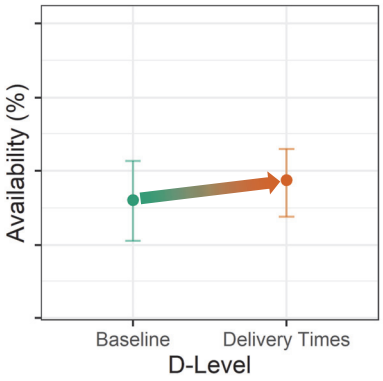


Depot Repair

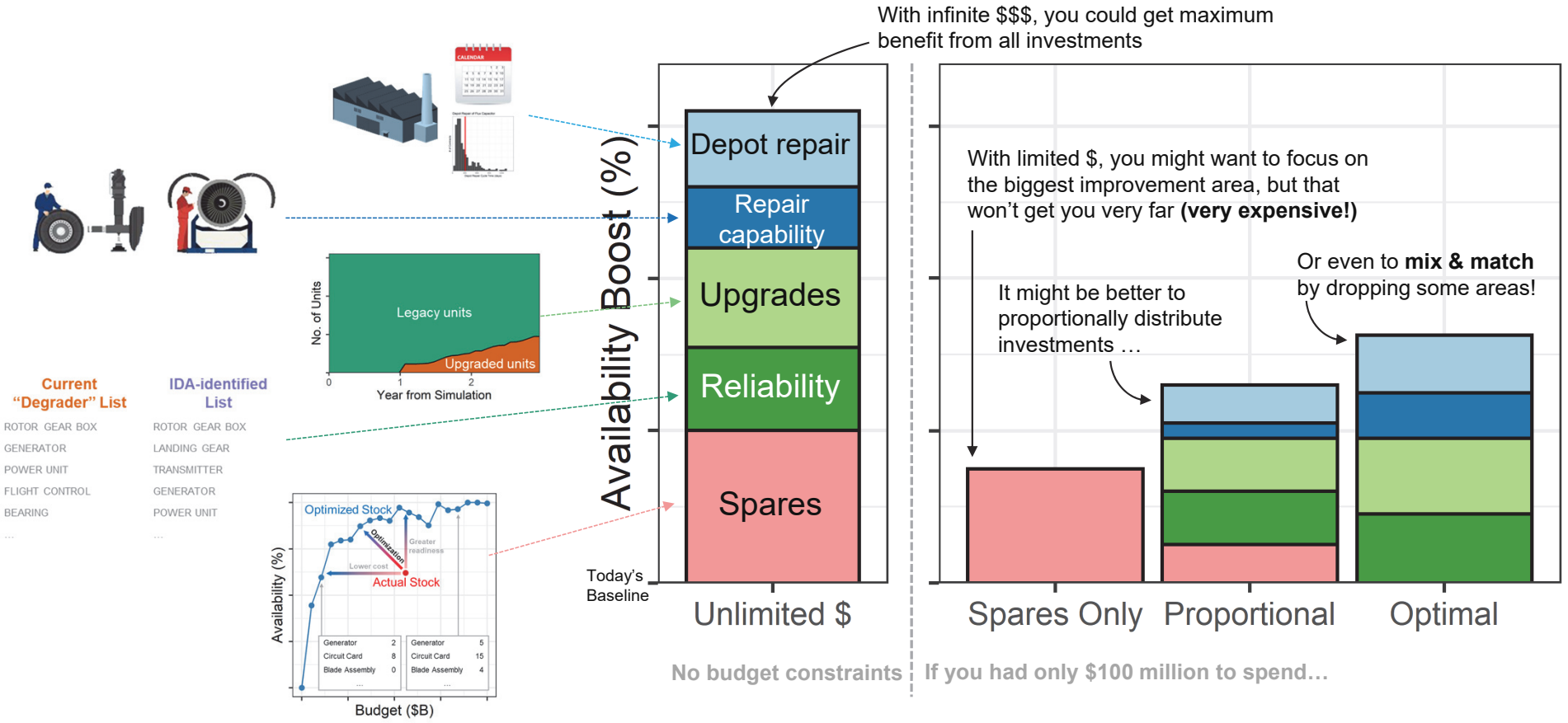
What if we could decrease depot repair time?



Part	Baseline	What-If
Canopy	2 months	1 month
Wing	5 months	4 months
Landing Gear	3 months	2 months
…		



Trade-off analysis: Rack & stack multiple investments



End-to-end modeling can account for synergies and bottlenecks

Key conclusions

Many ideas for how to make things better

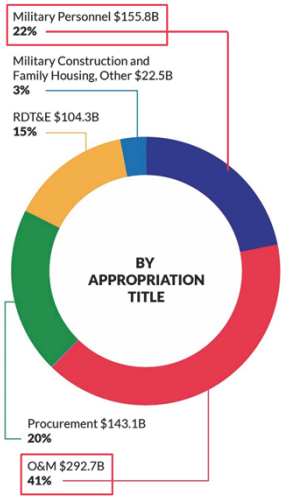
Need an end-to-end modeling capability (at the individual part level, not just full-system) to be able, with one toolset, to understand how investments in very different parts of the sustainment system will affect readiness

Decision-makers need to understand the benefit of improvement in one area relative to others – stovepiped analyses could be blind to the best combination of improvement efforts in a budget-constrained environment

These approaches require the application of strong data science and statistical best practices, subject matter expertise, and comprehensive data for operations, maintenance, supply, manpower, and logistics

Summary: IDA's end-to-end sustainment models can help improve the readiness of DoD weapon systems

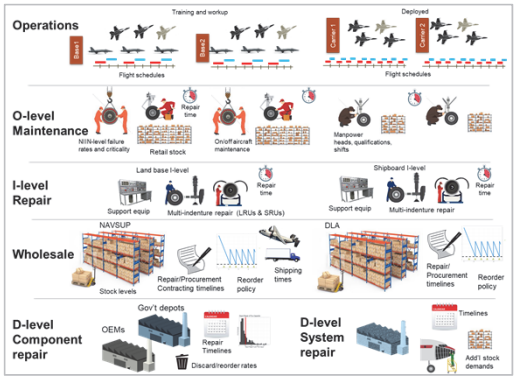
$400B+/year are spent on readiness, but many systems are NOT ready

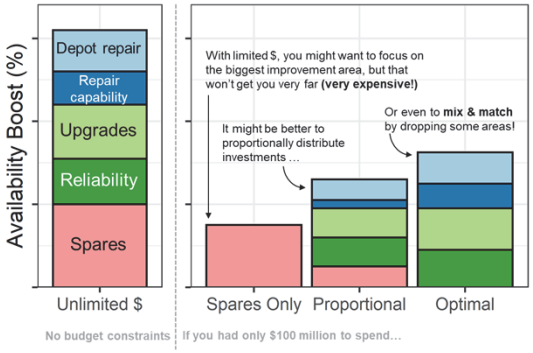


https://www.defense.gov/Explore/News/Article/Article/1782973/dod-leaders-make-case-to-congress-for-budget-request/

https://www.defensenews.com/air/2018/10/09/mattis-orders-fighter-jet-readiness-to-jump-to-80-percent-in-one-year/

IDA builds highly detailed sustainment simulation models that can **guide detailed decision-making**





Thank you for listening!

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14. ABSTRACT

Bottom-up emulations of real sustainment systems that explicitly model spares, personnel, operations, and maintenance are a powerful way to tie funding decisions to their impact on readiness, but they are not widely used. The simulations require extensive data to properly model the complex and variable processes involved in a sustainment system, and the raw data used to populate the simulation are often scattered across multiple organizations.IDA has worked with military and civilian sponsors to construct such end-to-end simulation models for maritime and aviation weapon systems and to investigate the strategic levers that drive readiness. In this conference presentation, we describe the complexities of properly emulating sustainment concepts and argue for the urgency of increased end-to-end modeling efforts in improving readiness across weapon systems.

15. SUBJECT TERMS

Aircraft Maintenance, availability, F/A-18, F-35, MV-22, Materiel Reliability, Modeling and Simulation (M&S), Monte Carlo, Readiness, Readiness-based sparing, Sustainment, OPUS, Readiness-based sparing, SIMLOX

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