DATAWorks 2026: Using Survival Analysis to Support Navy Supply Operations

Tyler Pleasant

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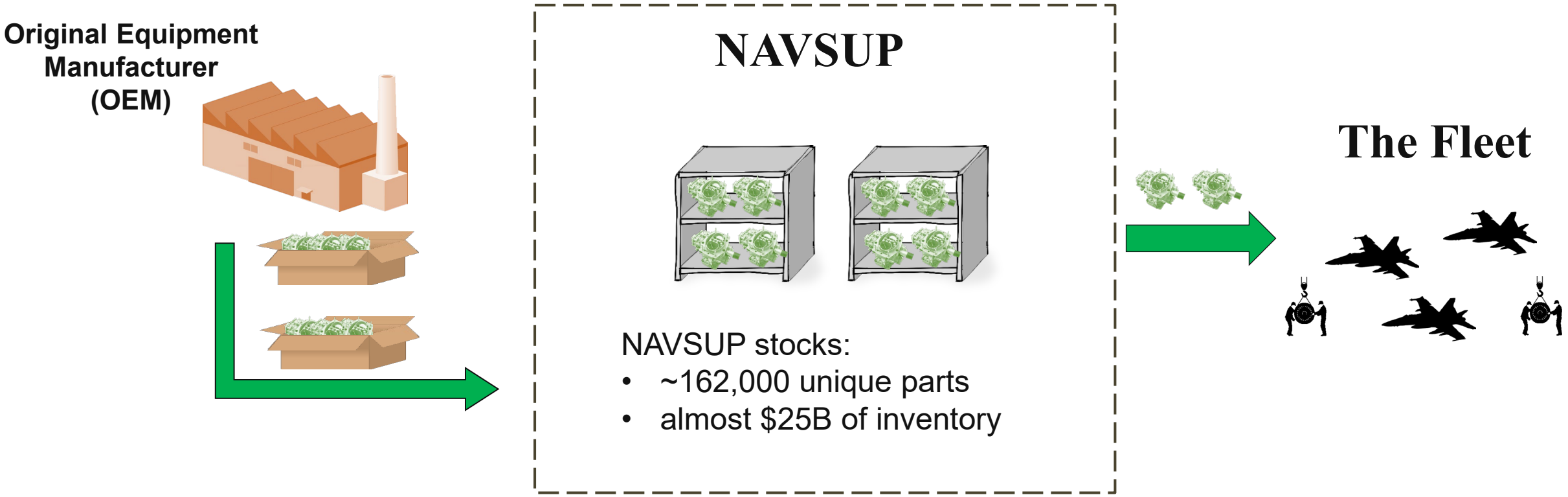
Institute for Defense Analyses
730 East Glebe Road ● Alexandria, Virginia 22305

~$7.5B is spent annually on the parts NAVSUP manages, largely to sustain Navy's existing systems.



NAVSUP connects the fleet and defense industrial base; efficient NAVSUP purchases that meet fleet needs improve fleet readiness and reduce cost passed on to the fleet.

NAVSUP: Naval Supply Systems Command, OEM: Original Equipment Manufacturer

NAVSUP needs to understand how many parts the fleet actually needs to decide how many parts are required to satisfy current and future fleet orders.

Unfulfilled Orders for a Part:

Order Number	Days Since Update
1	10
2	150
3	33
4	3
5	5
6	4
7	400

NAVSUP has five of the item on the shelf.

Is that sufficient to meet the customer's needs for these unfulfilled orders?

Problem: Many orders placed with NAVSUP don't materialize; seven orders does not mean that NAVSUP will have to fulfill all seven.

Note: Data in this example are notional.
NAVSUP: Naval Supply Systems Command

NAVSUP currently has a process to determine which orders represent a "real" need for a given part.

Unfulfilled Orders for a Part:

Order Number	Days Since Update	NAVSUP Counts as "Real"
1	10	No, canceled
2	150	No, internal transfer
3	33	Yes
4	3	Yes
5	5	Yes
6	4	Yes
7	400	Yes

NAVSUP believes it will need to fulfill five orders for this part.

Is this reasonable?

Quantify success with the absolute price error: (Item Price)*|Expected Qty-Needed Qty|

We define an order as "real" if NAVSUP will eventually have to send out the spare parts to fulfill it.*

*The key assumption here is that the fleet will not find an alternative source for the item when it takes a while for NAVSUP to fulfill the order, e.g., due to a backorder.

Note: Data in this example are notional.
NAVSUP: Naval Supply Systems Command, Qty: Quantity

Previous IDA work showed that status codes, which inform the customer of the current state of an order, correlate with the chance an order is fulfilled.*

Unfulfilled Orders for a Part:

Order Number	Status Code	Days Since Update	NAVSUP Counts as "Real"
1	BQ	10	No, canceled
2	BA	150	No, internal transfer
3	BD	33	Yes
4	Missing	3	Yes
5	BA	5	Yes
6	BB	4	Yes
7	BZ	400	Yes

BD and missing status orders were found to almost never be fulfilled.*

We now suspect three orders will be realized.

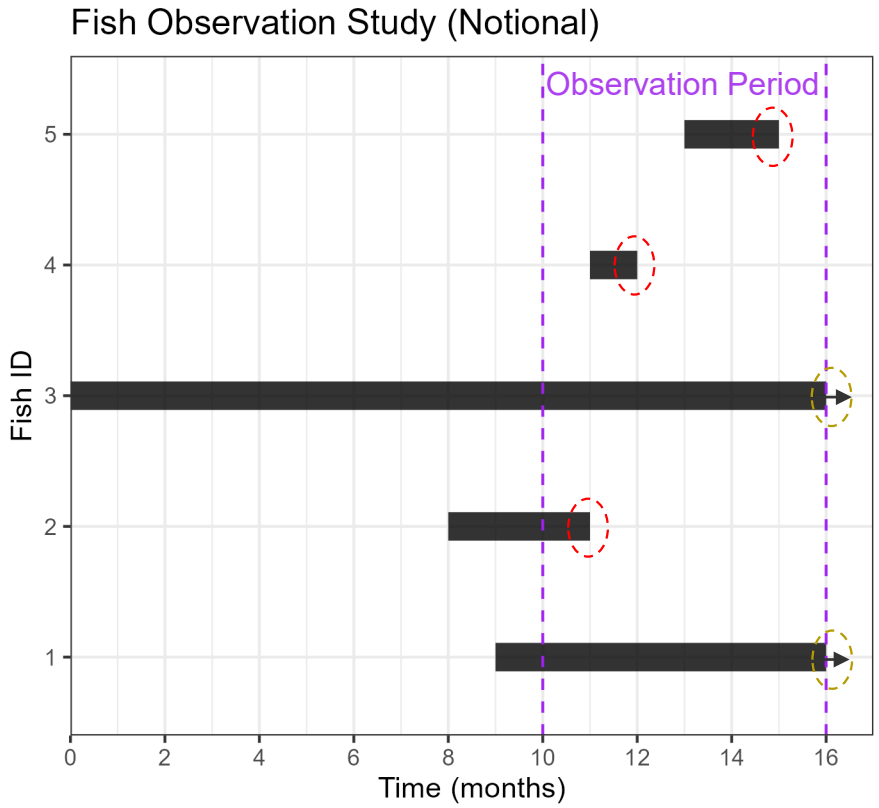
Can we do better?

Although it's helpful to remove "bad" status codes, NAVSUP can further refine its processes for identifying which orders count as "real" if time since the last update is also included.*

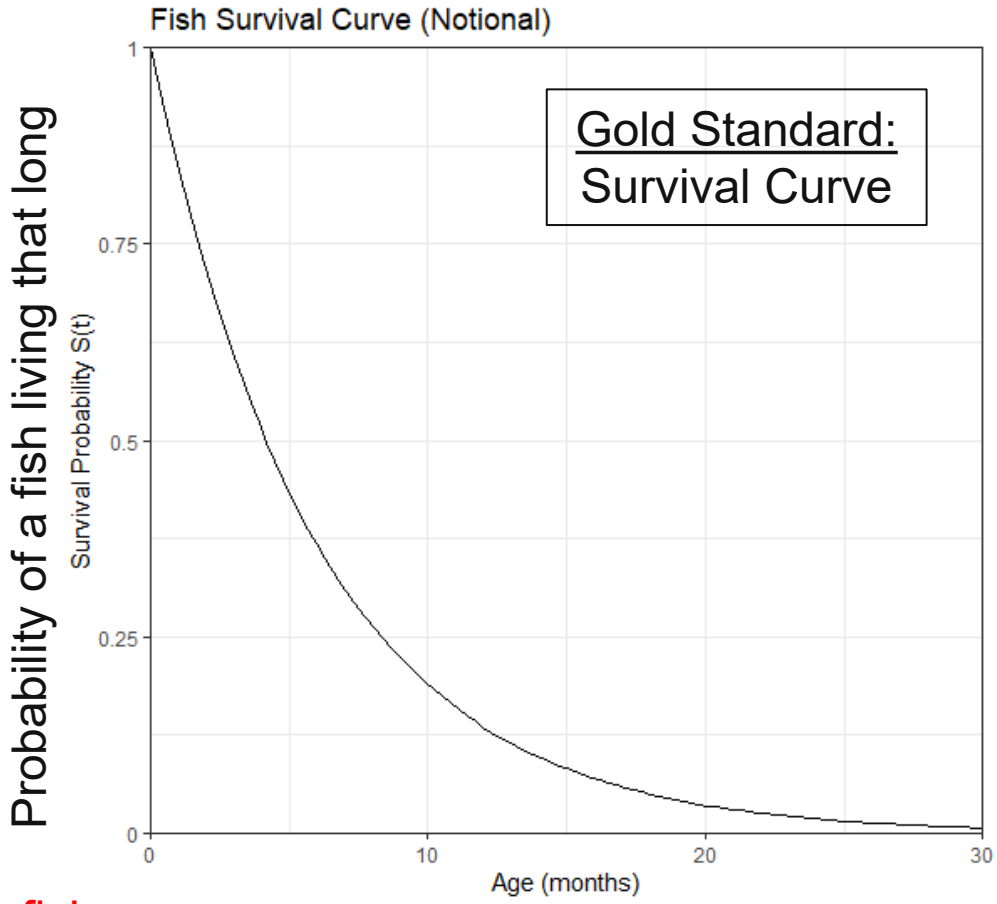
* Pleasant, Tyler J. 2025. "What Counts as a Demand for Forecastability?" IDA Document 3006084
Note: Data in this example are notional.
IDA: Institute for Defense Analyses, NAVSUP: Naval Supply Systems Command, BA: processing for issuance, BD: delayed, BQ: Canceled
See https://www.logtool.com/Toolbox/dod-supply-status-codes for definitions of other status codes.

Survival analysis, originally developed to analyze mortality data, can be used to analyze the distribution of time until an event occurs when data are incomplete.

Example: Want to understand the distribution of fish lifetimes from 6-month observation study



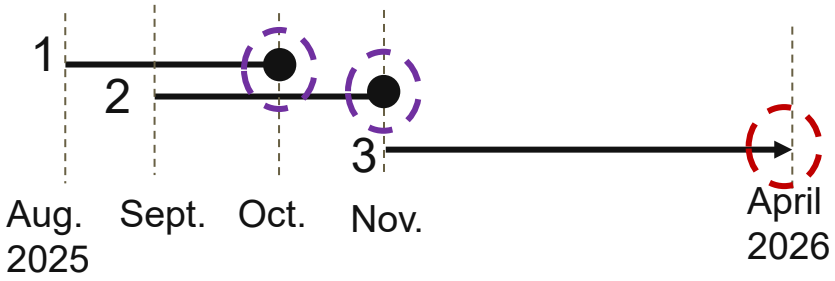
Fish ID	Age At End	Status
5	2	Dead
4	1	Dead
3	16	Alive
2	3	Dead
1	7	Alive



We observed the final age of three fish
Two fish were still alive at end of study
(Right Censored)

Similarly, the time to order fulfillment data are censored due to uncertainty about when or if some fulfillment occurred.

Right-Censoring: Issuances*



Orders 1 and 2 were issued two months after purchase

Order 3 hasn't been issued yet five months after purchase

How long does it take NAVSUP to issue this item after the order comes in?

(Assume orders for this item always end up being issued.)

Often censored data are thrown out, in this case causing the mean issue time to be underestimated by at least a month.

To make an informed guess on how long it takes NAVSUP to issue this item, we need to do survival analysis to account for Order 3.

* The data used for this example are notional.
NAVSUP: Naval Supply Systems Command

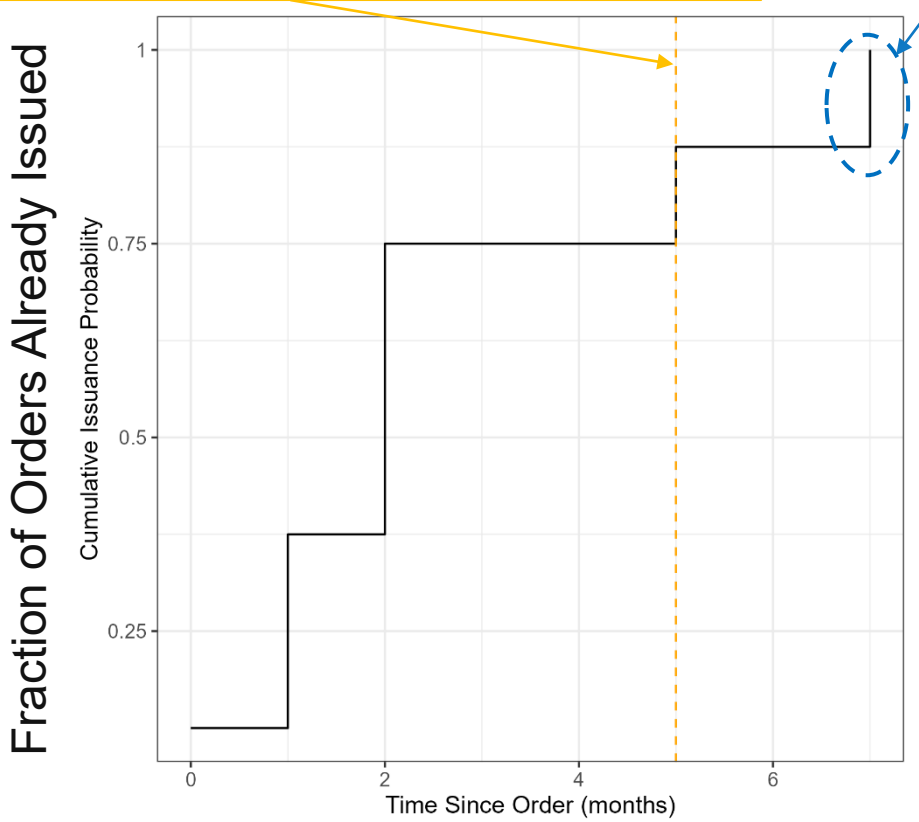
The Kaplan-Meier estimator calculates the survival function of right-censored data; here it encodes how the cumulative chance of issuing an order increases with time.

Using historical orders, NAVSUP can compute the survival function, S(t).*

For ease of interpretation, we'll show "fulfillment curves," i.e., 1-S(t) throughout this talk.**

After five months, what happens to Order 3?

The only historical order that's lasted beyond five months was issued at seven months.



An educated guess for when Order 3 might be fulfilled is at 7 months after the order was placed.

As more data are added, the empirical fulfillment curve better reflects the time-to-fulfillment distribution.

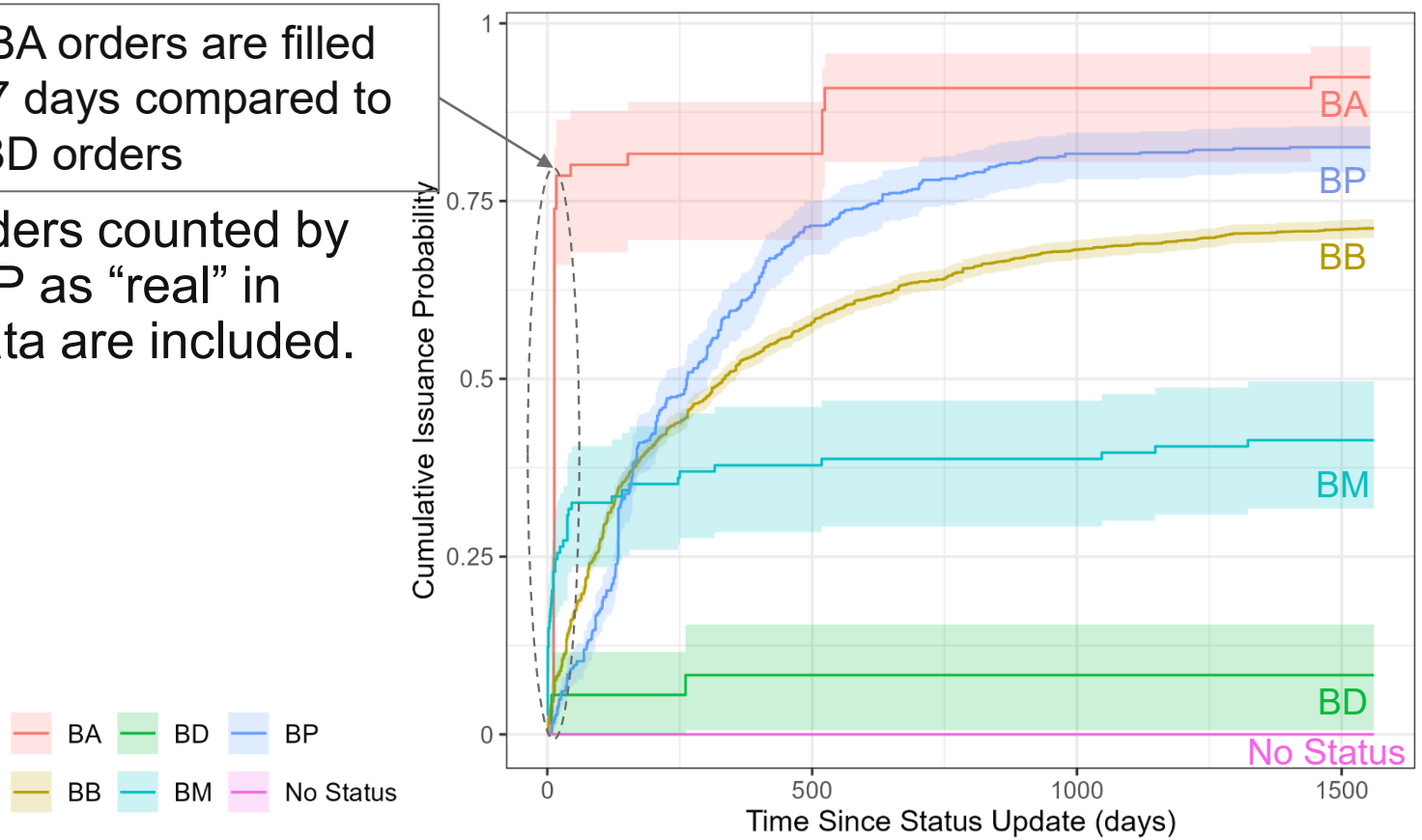
Properly accounting for censoring allows better estimation of how long it takes NAVSUP to issue an order and, as we'll see, if an order is likely to be issued at all.

* The data used to produce this slide are notional.
** In this case, the curve 1-S(t) corresponds to the cumulative distribution function. This will not hold for later slides as the probability never reaches one.
NAVSUP: Naval Supply Systems Command, S(t): Survival Function

To generate fulfillment curves for each status code, we look at recently updated, unfulfilled orders from 2021 data and see whether they were fulfilled by 2026.

79% of BA orders are filled within 17 days compared to 8% for BD orders

Only orders counted by NAVSUP as "real" in 2021 data are included.



Three statuses (BA, BP, BB) are more likely than not to be filled, albeit on different timescales.

Notice that the curves never reach one; this aligns with our expectation that not all orders will eventually be fulfilled.

As identified in a previous study, BD and missing statuses almost never get filled.*

Fulfilment curves vary by status codes; these curves plateau at different fulfillment probabilities and exhibit statistically distinct fulfillment behavior.**

* The sample size is low for orders without a status, although a previous study found 1.6% of them were eventually filled. (Pleasant, "What Counts as a Demand")
** See supplemental information section for statistical test results; note this does not apply to orders without a status due to insufficient data.
NAVSUP: Naval Supply Systems Command, BA: processing for issuance, BB: backorder, BD: delayed,
See https://www.logtool.com/Toolbox/dod-supply-status-codes for definitions of other status codes.

Since some orders are never fulfilled, this can be thought of as a mixture cure model, where orders that are never fulfilled are "cured."

$$S(t) = p_{nf} + (1 - p_{nf})U(t)$$

- p_{nf}: Prob. order is never fulfilled
- $U(t)$: Prob. an order that will be fulfilled is not yet fulfilled at time t

If an order survived up to time t, what's the probability it will be fulfilled?

$$P(A|B) = \frac{S(t) - p_{nf}}{S(t)}$$

Interpretation: The fraction of survival probability due to orders that are eventually fulfilled.

Bayes' Rule

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$

A=order will be fulfilled

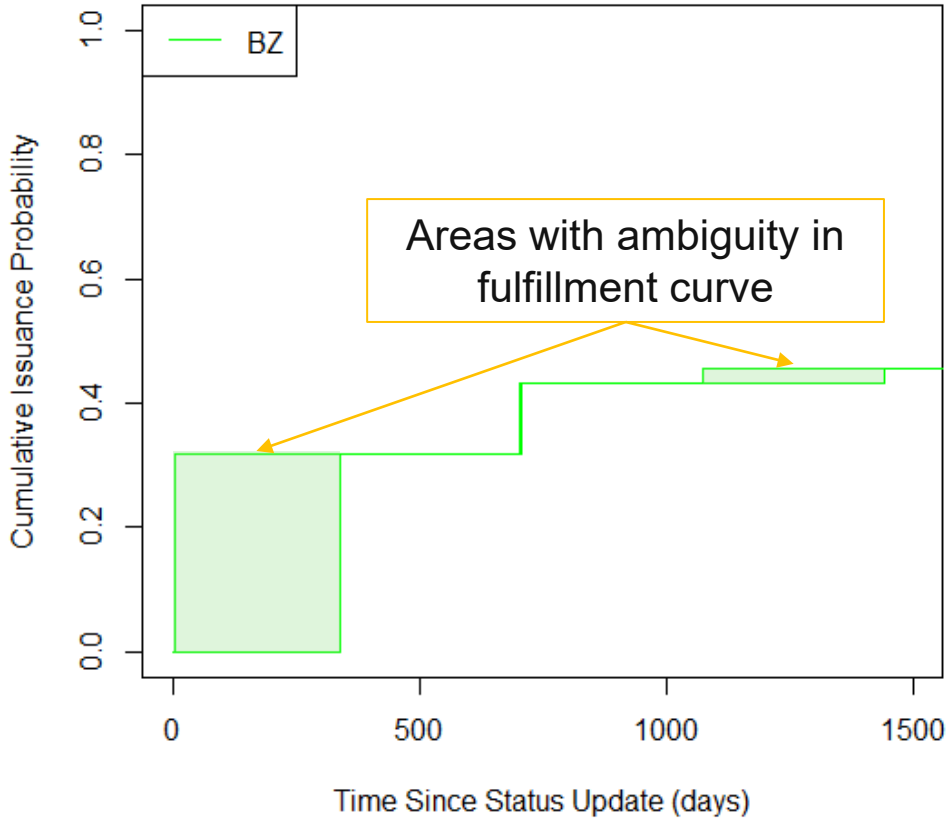
B=order is unfulfilled at time t

Using the S(t) and p_{nf} for each status code, the probability an order will be fulfilled can be estimated based on its status code and time since the last status update.

NAVSUP: Naval Supply Systems Command, S(t): Survival Function, p_{nf}: Probability of Remaining Unfulfilled, U(t): Uncured Population Survival Function, P(A|B): Probability of A conditional on B

One complication is that issuance data are rarely recorded for orders where NAVSUP relies on a vendor to procure and ship the item to the customer.

We know the fiscal year the money was collected and thus only have bounds on the issuance date, which is *interval censored*.



It's still possible to quantify fulfilment behavior for status codes with interval censored orders, but there may be ambiguity in which curve best fits the data.

Note: The curve for BV status orders can be found in the supplemental information section.

NAVSUP: Naval Supply Systems Command, BV: procured by direct vendor and on contract to ship, BZ: being procured by direct vendor

Using the calculated survival functions, the probability that each order will be fulfilled can be estimated.

Unfulfilled Orders for a Part:

Order Number	Status Code	Days Since Update	Probability to Order is "Real"
1	BQ	10	0 (canceled)
2	BA	150	0 (internal transfer)
3	BD	33	0.03
4	Missing	3	0
5	BA	5	0.92
6	BB	4	0.70
7	BZ	400	0.20

Example:

$p_{nf} = 0.076$

$S(\mathrm{t} = 2) = 0.9846$

$$P = \frac{0.9846 - 0.076}{0.9846} = 0.92$$

We now suspect these only reflect two needs for the item.

Survival analysis uses historical data to make an educated guess on what will occur...
But does it outperform NAVSUP's current approach?

NAVSUP: Naval Supply Systems Command, BA: processing for issuance, BD: delayed, BB: backorder, BZ: being procured by direct vendor
See https://www.logtool.com/Toolbox/dod-supply-status-codes for definitions of other status codes.

NAVSUP uses 2 years of demand history to inform stocking goals, so this approach was tested in its ability to correctly predict fiscal year 2021 and 2022 demands.

The data are from early fiscal year 2023, when around 7% of the orders in the window were still unfulfilled.

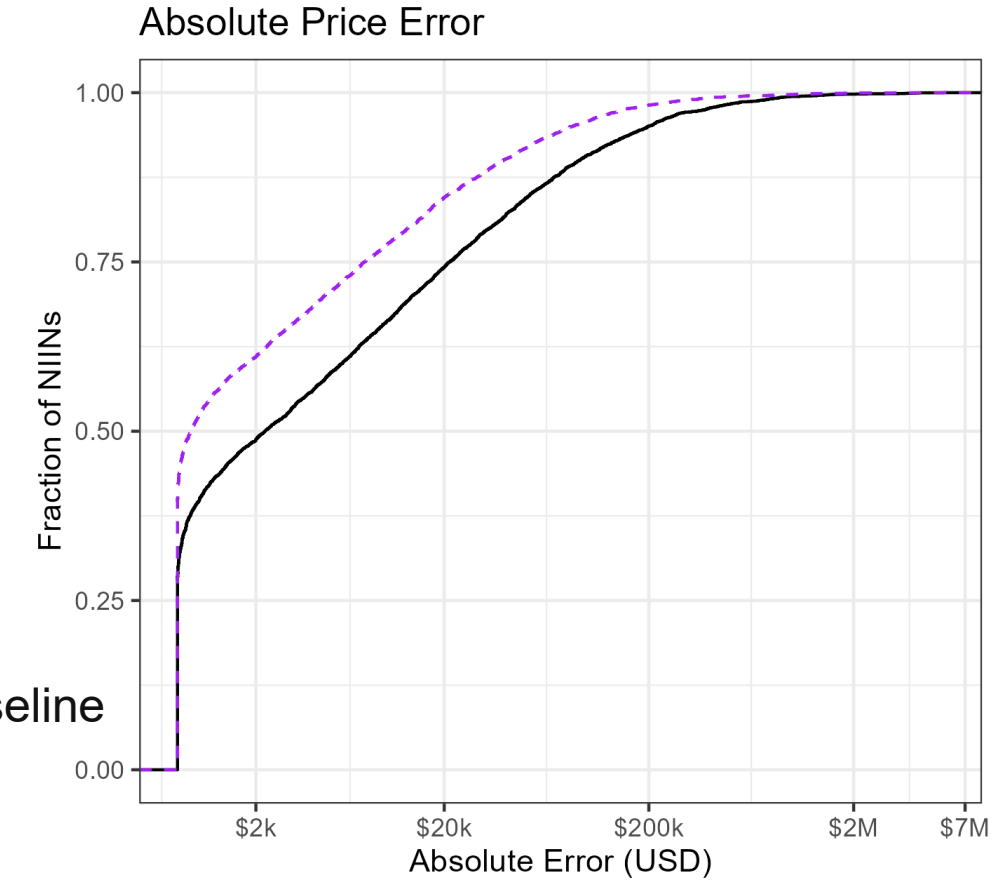
	NAVSUP Baseline	Prediction
Exact Estimate	24% of NIINs	36% of NIINs
Mean Qty Error	10.7 units	9.6 units

Using only order status and age since last status update, predicted results correctly identify the demand quantity for 12% of NIINs where existing methods do not.

NAVSUP: Naval Supply Systems Command, NIIN: National Item Identification Number, Qty: Quantity

Demand history predictions are important because it drives NAVSUP investment; therefore, the absolute price error best describes potential financial impacts.

	NAVSUP Baseline	Prediction
Median Price Error	$2,295	$308
Mean Price Error	$46,317	$21,058
Total Price Error	$254M	$116M



Switching to a survival analysis–informed prediction, NAVSUP could improve demand planning by reducing the price error of its eight quarter demand estimates by more than 50%.

NAVSUP: Naval Supply Systems Command, NIIN: National Item Identification Number, M: Million

NAVSUP can improve demand planning by using censored estimates of historical demand to prioritize investments to address current orders.

Survival analysis helps leverage order status and age to quantify how likely the order needs to be acted on, greatly reducing the price error compared to NAVSUP's current approach.

Survival analysis techniques can be applied to improve other areas of supply planning; IDA has also used survival analysis to estimate:

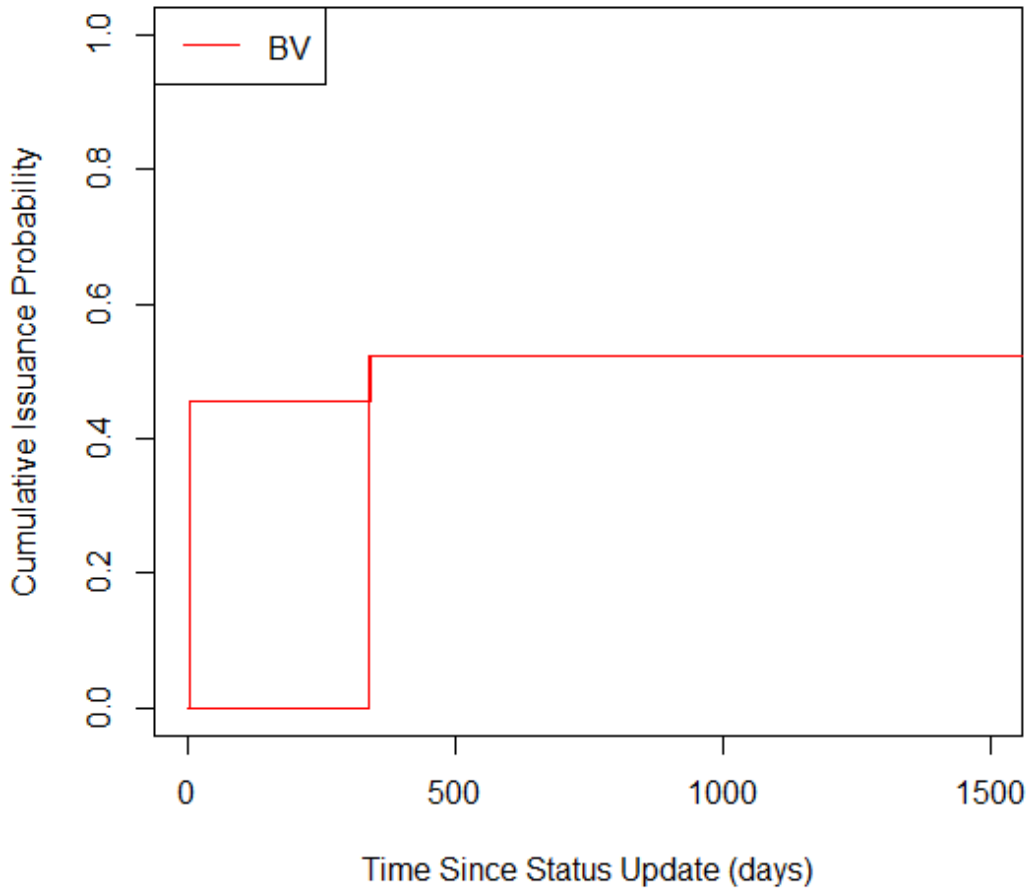
- lead times to procure or repair a spare part
- the time it takes the fleet to return broken but repairable parts.

Survival analysis methodologies can be useful in fields far beyond the biomedical applications it was originally developed for.

IDA: Institute for Defense Analyses, NAVSUP: Naval Supply Systems Command

Supplemental Information

Most BV orders that are eventually issued did so in the first year, although there is significant ambiguity in the curve during that time.



BV: procured by direct vendor and on contract to ship

Five years appears sufficient to evaluate whether an order was realized; mixture cure models of right-censored data align with the limiting non-fulfilment probability.

Status	Limiting Prob. Of Non-Fulfilment (K-M)	Cure Probability (Mixture Cure Model)
BA	0.076 (CI: 0.033, 0.175)	0.077
BB	0.288 (CI: 0.276, 0.302)	0.288
BD	0.917 (CI: 0.845, 0.994)	0.936
BM	0.586 (CI: 0.503, 0.682)	0.591
BP	0.174 (CI: 0.145, 0.209)	0.175
No Status	1.000*	Not Calculated*
BV	0.478 (CI: 0.190, 1.000)	Not Calculated**
BZ	0.545 (CI: 0.274, 1.000)	Not Calculated**

CI calculated with the log transformation method

* Due to no observed fulfilment for no status orders, it was not possible to produce confidence intervals or fit a mixture cure model to estimate cure probability.
** None of the tested R packages were able to fit mixture cure models to interval censored data.

See https://www.logtool.com/Toolbox/dod-supply-status-codes for definitions of status codes
CI: Confidence Interval, K-M: Kaplan-Meier, Prob.: Probability

Almost all survival curves are statistically different, aside from some comparisons to BV, BZ, and missing status orders.

	BA	BB	BD	BM	BP	No Status	BV	BZ
BB	~0*	-	-	-	-	-	-	-
BD	1e-15	7e-14	-	-	-	-	-	-
BM	3.4e-7	0.02	2e-5	-	-	-	-	-
BP	~0*	0.08	~0*	2e-3	-	-	-	-
No Status	2e-5	1e-3	0.5	0.04	2e-4	-	-	-
BV	3e-5	0.1	5e-7	0.7	5e-3	0.01	-	-
BZ	2e-7	2e-3	4e-5	0.6	2e-5	0.03	0.2	-

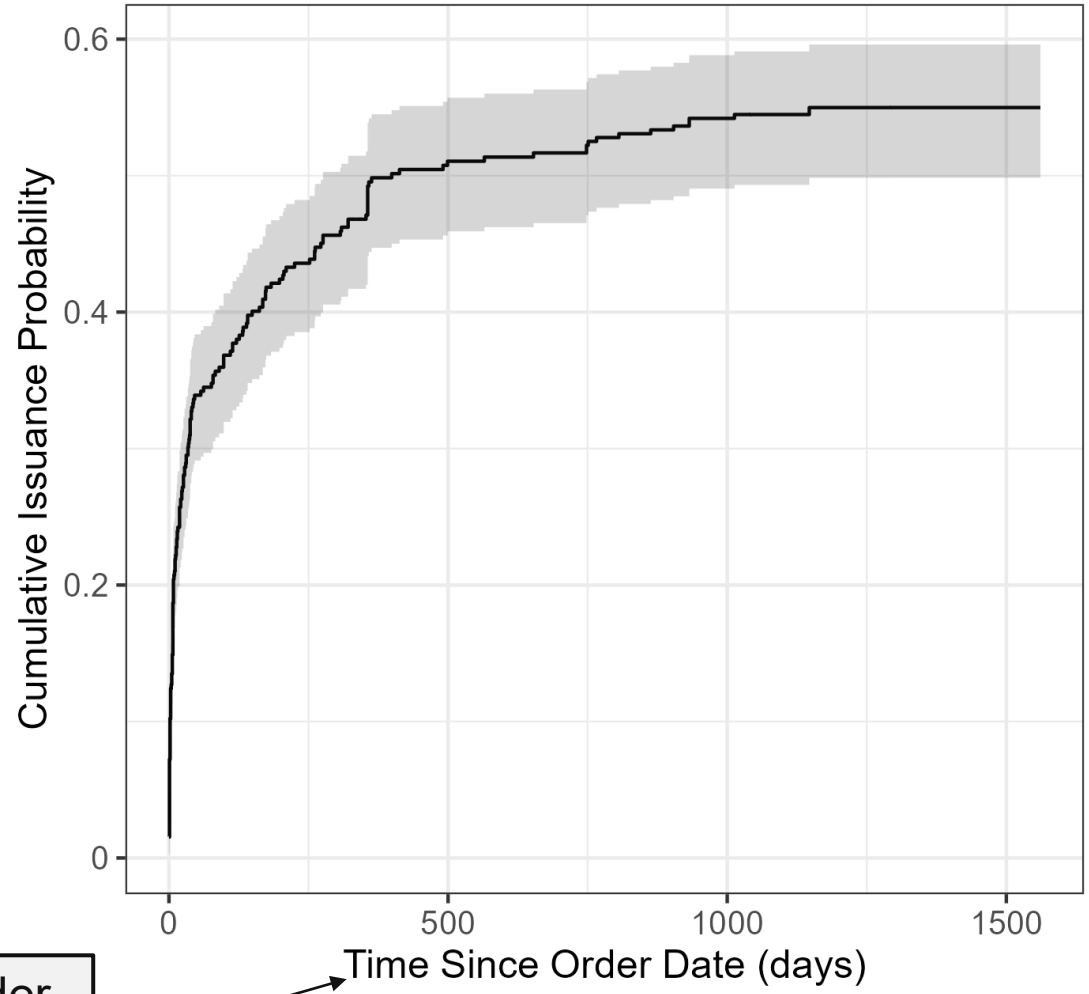
A value is red if it larger than the p-value threshold of 0.05, indicating there is insufficient evidence to rule out statistical similarity.

A generalization of the Wilcoxon two-sample test for interval censored data integrated into R package "interval" was used to avoid reliance on additional data assumptions.

BV, BZ, and no status orders all have less than 100 data points in the sample set; more data are necessary to evaluate whether those have distinct survival curves from other statuses.

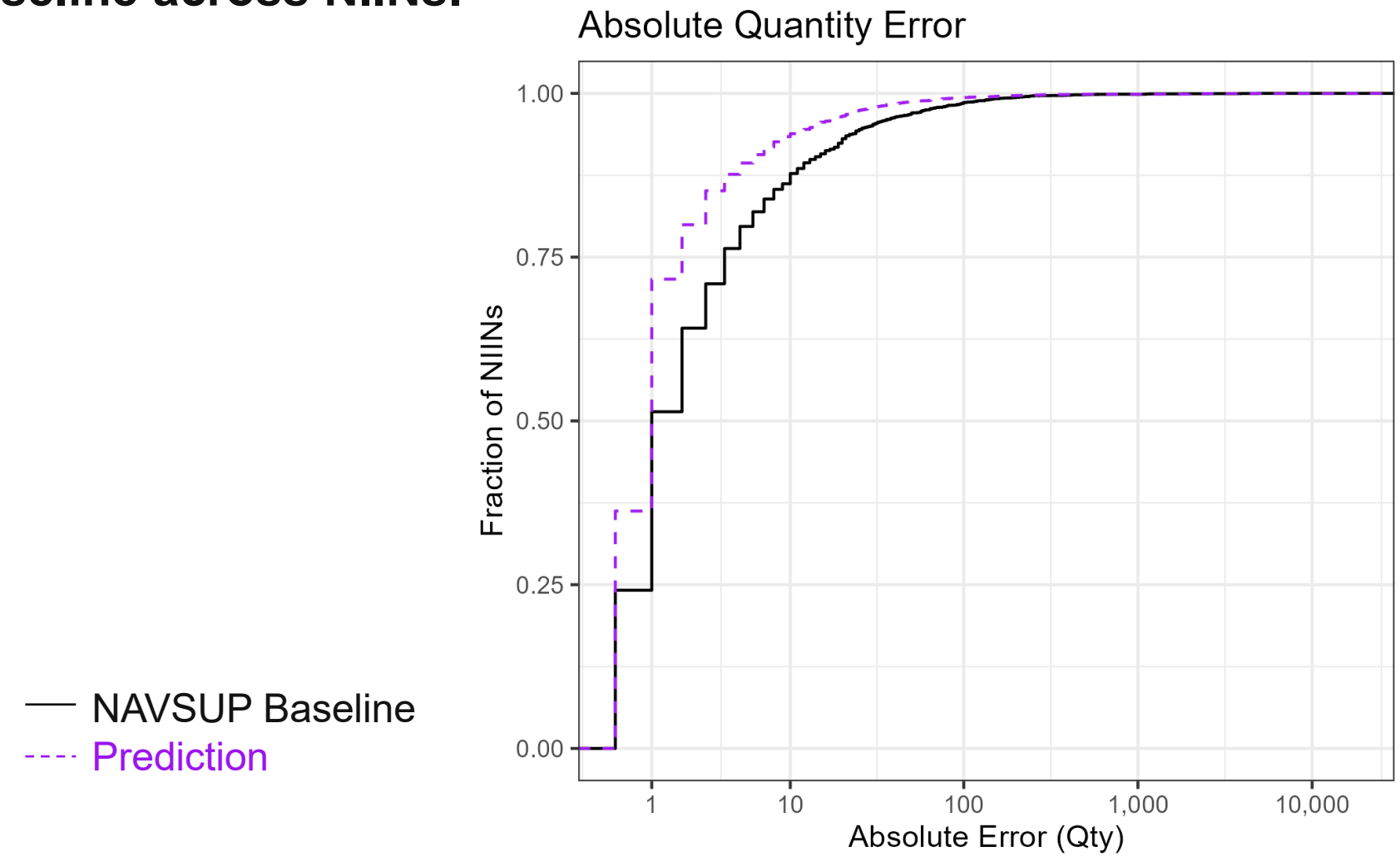
*~0 is used whenever the p-value was small enough the function could not calculate it, i.e., < 2.2e-16.
BV: procured by direct vendor and on contract to ship, BZ: being procured by direct vendor
See https://www.logtool.com/Toolbox/dod-supply-status-codes for definitions of other status codes

The eight status codes in the sample dataset accounted for 99% of validation orders; for others statuses we used the fulfillment curve for all orders.



Note this depends on order age rather than age of last status update.

Based on the absolute quantity error CDF, the prediction does at least as good as baseline across NIINs.



CDF: Cumulative Distribution Function, NAVSUP: Naval Supply Systems Command, NIIN: National Item Identification Number, Qty: Quantity