

#### INSTITUTE FOR DEFENSE ANALYSES

### Forecasting Competing Risks for Navy Personnel Management

#### WEAI 2021

Jay Dennis Julie Lockwood Rachel Augustine Michael Guggisberg

June 2021 Approved for public release; distribution is unlimited. IDA Paper NS P-22651 Log: H 21-000158

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#### About This Publication

This work was conducted by the Institute for Defense Analyses under contract HQ0034-14-D-0001, project CA-6-4854, "Expanding the FIFE for Navy Personnel Management" for the Under Secretary of Defense for Personnel and Readiness. The views, opinions, and findings should not be construed as representing the official position of either the Department of Defense or the sponsoring organization.

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### Forecasting Competing Risks for Navy Personnel Management

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To better leverage its wealth of personnel data to achieve a high-quality fighting force, the Assistant Secretary of the Navy, Manpower and Reserve Affairs (ASN M&RA) collaborated with the Institute for Defense Analyses (IDA) to produce high-fidelity predictions regarding retention decisions—including the manner of exit—at the level of the individual sailor. To this end, we expand IDA's time-to-event prediction capability tool, the Finite Interval Forecasting Engine, to accommodate different types of exit to estimate the likelihood that a person exits into each of a finite number of discrete states in some given future period. We demonstrate this capability by predicting the manner of exit for a group of enlisted service members in the U.S. Navy. This page is intentionally blank.



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30 June 2021

### Manner of exit informs current force trajectories and how to target retention efforts

Early interventions can steer individuals toward further service or more favorable exit conditions

The same methodology can be used to model career trajectories

We use a competing risks framework to forecast the probability of exit into one of many states



Source: https://www.navytimes.com/news/your-navy/2020/04/17/heres-how-the-navyis-ramping-up-its-reenlistment-bonus-policy-to-retain-sailors/

### **Expansion of IDA capabilities**

IDA's Finite Interval Forecasting Engine (FIFE) was designed to forecast when an individual leaves service

We expand the FIFE to forecast how an individual leaves service conditional on leaving and incorporate this into a competing risks framework

We'll talk about the performance of this expansion and an application to Enlisted Navy Personnel

## Extending the Finite Interval Forecasting Engine (FIFE) for Competing Risks



# A competing risks framework models the occurrence of many different manners of exit

Without competing risks: Probability of Exit at Time *t* 

$Pr(T \le t)$	2021	2022	2023
Leave	0.1	0.3	0.8
Stay in	0.9	0.7	0.2

With competing risks:

Probability of Exit at Time t by manner d

$Pr(T \le t \text{ and } D = d)$	2021	2022	2023
Honorable	0.0	0.0	0.4
Administrative	0.1	0.2	0.3
Dishonorable	0.0	0.0	0.0
Medical	0.0	0.1	0.1
Stay in	0.9	0.7	0.2

Competing risks expands the resolution of force trajectories from *when* to *how* individuals attrite

It can also be used to predict any set of mutually exclusive outcomes... Such as exit into other ratings/designators, components, positions, etc.

## Example: Competing risks in individual career trajectories



## Example: Competing risks in individual careertrajectoriesWould occur if observed



### **Competing Risks**

There are *K* mutually exclusive outcomes

Each outcome occurs at time  $T_{ik}$  for k = 1, 2, ..., K

Right Censoring occurs at  $T_{i0}$  (no outcome observed)

We only observe the outcome that occurs first (or censoring) and the associated time:

 $d_i = argmin\{T_{i0}, T_{i1}, \dots, T_{iK}\}$  and  $T_i = min\{T_{i0}, T_{i1}, \dots, T_{iK}\}$ 

If event k occurs at time  $T_i = T_{ik}$ , then a different event could eventually occur had event k not occurred.

### Forecasting the Cause-Specific Hazard

The cause-specific hazard estimates the probability\* of exiting at time t in manner d

$$P(T = t \text{ and } D = d | T \ge t, X_t) = P(D = d | T = t, X_t) P(T = t | T \ge t, X_t)$$

FIFE models the probabilities of exit and manner of exit separately

$$P(T = t | T \ge t, X_t) = 1 - \frac{1}{1 + \exp\{-f_t(X_t)\}}$$

$$P(D = d | T = t, X_t) = \frac{\exp\{-g_{dt}(X_t)\}}{\sum_{m=1}^{K} \exp\{-g_{mt}(X_t)\}}$$

Estimation of f and g uses a tree based modeler

\*also conditional on non-censoring



## The Cumulative Incidence Function helps visualize this probability over time

Define  $\tilde{T} = T - T_0$  as the time after censoring.

$$P(0 < \tilde{T} \le t, D = d | \tilde{T} \ge 0, X_t) = \sum_{k=1}^t P(\tilde{T} = k, D = d | \tilde{T} \ge 0, X_t)$$



### Performance under controlled conditions

### **Simulation Experiment Setup**

ID	Period	$X_1$	$X_2$	$X_3$	Exit Type
0	39	В	0.068	0.392	No_exit
0	40	В	0.281	0.492	No_exit
1	7	С	-0.569	0.660	Х
1	8	С	0.456	0.860	Х
1	9	С	-0.155	1.060	Х
1	10	С	1.106	1.260	Х
1	11	С	-0.535	1.460	Х

Sample Data

This illustrative data generating process (DGP) is simple:

- Only  $X_1$  is predictive of Exit Type.  $X_1 \in \{A, B, C\}$
- Probability of exit is fixed in a given period
- Exit Type  $\in$  {*No* Exit, X, Y, Z}

### **Simulation Experiment Setup**

**Expected Predictivity:** 

	Med	ium			L	OW				Н	igh	
	DG	iP 1			DC	GP 2				D	GP 3	
	$P(\mathbf{e}$	exit ty	rpe)		P(	exit typ	pe)	-		P	(exit typ	e)
$X_1$	X	Y	Z	$X_1$	X	Y	Z		$X_1$	X	Y	Z
A	0.7	0.2	0.1	A	0.7	0.2	0.1		A	0.95	0.025	0.025
В	0.2	0.7	0.1	В	0.33	0.33	0.33		В	0.025	0.95	0.025
С	0.1	0.2	0.7	С	0.33	0.33	0.33		С	0.025	0.025	0.95

An individual with  $X_1 = A$  is more likely to exit into state X, etc.

 $X_1$  is most predictive of exit type for DGP 3 and least predictive for DGP 2

### Performance – AUROC\*



Shaded area is 95% confidence interval (MC)

Better performance for shorter forecast horizons, when more data is available,

and when the covariates are more predictive of the outcome Other specifications provide similar results

\* Area Under the Receiver Operating Characteristic curve (AUROC)



### **Cumulative Incidence Functions**



N=10000, censoring is at 20 periods, probability of exit is fixed at 50% per period

Probability of exit into each exit category grows with the forecast horizon Ranking of exit type probabilities by group is correctly captured CIFs approach the estimated probabilities of exit type conditional on exit



### Application

### **Application – Overview**

Item	Details
Source	DMDC Active Duty Master
Population	AD Navy Enlisted
Time Period	2015 - 2020, Monthly
Sample	20%
N	93984
$N_{\text{censored}}$	59050
Observation Count	3995318

Predictors come from DMDC and other sources:

- Demographics,
- Family characteristics,
- Service Retention Bonus eligibility,
- Time to end of contract,
- Economic conditions
- and many others

### **Application – Outcome Statistics**

Se	ervice D	esire		Service Mer	nber's De	esire
Category	y	Ν	Percent Category		N	Percent
Unknow	n 1	7153	48.1	Unknown	7445	20.9
Want to let l	eave	8817	24.7	Want to leave	20934	58.7
Want to ke	eep	5050	14.2	Want to stay	7117	20.0
Beyond con	ntrol	4637	13.0	Beyond control	161	0.5
Service M	ember's	Choic	e	Exit Gre	oup	
Service M Category	ember's N	Choic Perc	e cent	Exit Gro Category	oup N	Percent
Service M Category Voluntary	1000000000000000000000000000000000000	Choic Perc 60	cent	Exit Gro Category Artificial Exit	$\frac{N}{638}$	$\frac{\text{Percent}}{1.8}$
Service M Category Voluntary Involuntary	ember's N 21580 12058	Choic Perc 60 33	e cent .5 .8	Exit Gro Category Artificial Exit Released, general	oup <u>N</u> 638 6180	Percent 1.8 17.3
Service M Category Voluntary Involuntary Unknown	ember's N 21580 12058 2019	Choic Perc 60 33 5.	e cent .5 .8 7	Exit Gro Category Artificial Exit Released, general Life Events	oup N 638 6180 4700	Percent 1.8 17.3 13.2
Service M Category Voluntary Involuntary Unknown	ember's N 21580 12058 2019	Choic Perc 60 33 5.	e cent .5 .8 7	Exit Gro Category Artificial Exit Released, general Life Events Unsuitable	oup N 638 6180 4700 7177	Percent 1.8 17.3 13.2 20.1

### Application – Forecasting Exit into "Unsuitable"



### Application – Forecasting Want to Keep/Want to Leave



### Conclusion

We started with the ability to forecast survival of individual service members

We expanded this capability to forecast exit into multiple states

The competing risks framework allows us to forecast both timing and manner of exit of individual service members

Performance looks good so far

We demonstrated its use in flagging service members for interventions





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### Appendix

### **Appendix: Summary Statistics**

### How the 36,280 USN personnel attrited in FY 2019

Character of service	Number (total)	%	Number (enlisted)	%	Number (officer)	%
Honorable	24,625	68%	20,983	65%	3,642	90%
Uncharacterized	7,535	21%	7,535	23%	0	0%
Under honorable conditions	1,882	5%	1,821	6%	61	2%
Missing	1,241	3%	907	3%	334	8%
Under other than honorable conditions	941	3%	924	3%	17	<1%
Bad conduct	56	<1%	56	<1%	0	0%
Total	36,280		32,226		4,054	

### Reenlistment eligibility of FY 2019 enlisted attritions

Eligibility criteria	Number	Percent
Eligible	13,563	42%
Eligible with waiver	5,614	17%
Ineligible	4,487	14%
Eligible with restrictions	3,884	12%
Temporary medical condition or unsatisfactory initial performance	3,329	10%
Missing	1,117	3%
Ineligible due to high tenure	232	1%
Total	32,226	

### Top 10 reasons of separation for officers and enlisted

Reason (officer)	Number	%*	Reason (enlisted)	Number	%*
Expiration of term of service	1,284	33%	Expiration of term of service	13,452	46%
Retirement, 20 – 30 years	1,113	28%	Retirement, 20 – 30 years	3,581	12%
Retirement, failure of selection for promotion	388	10%	Erroneous enlistment or induction	3,385	12%
Unknown	312	8%	Unqualified for active duty	2,229	8%
Retirement, 30+ years	308	8%	Entry level performance and conduct	1,867	6%
Failure of selection for promotion	201	5%	Drugs	1,119	4%
Involuntary release	103	3%	Fraudulent entry	983	3%
Retirement, other	73	2%	Unknown	976	3%
Temporary disability	71	2%	Temporary disability retirement	964	3%
Unfitness or unacceptable conduct	54	1%	Commission of serious offense	869	3%
Total	3,907		Total	29,425	

\*Percentage out of top 10 reasons, not total separations

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Machel Augustine Michael Guggisberg       CA-6-4854         51. WORK UNIT NO.       51. WORK UNIT NO.         7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Institute for Defense Analyses Alexandria, VA 22311-1882       6. PERFORMING ORGANIZATION REPORT NO. IDA Paper NS P-22631 Log: H 21-000158         8. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) OUSD (P&R) 1500 Defense Pentagon, 2E556       10. SPONSOR'S / MONITOR'S ACRONYM(S) OUSD (P&R)         12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.       11. SPONSOR'S / MONITOR'S REPORT NO(S).         13. SUPPLEMENTARY NOTES       The Adaptating particular terms and paper	Julie Lockwood			5e. TASK NO.		
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