INSTITUTE FOR DEFENSE ANALYSES

Improved Surface Gunnery Analysis with Continuous Data

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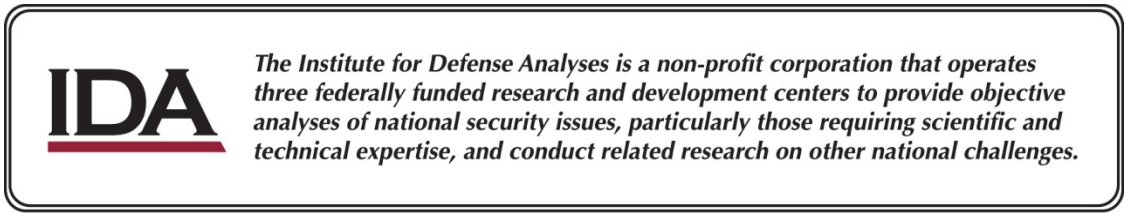

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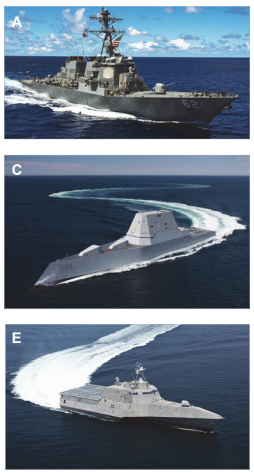
Introduction

Recasting gunfire data from binomial (hit/miss) to continuous (time-to-kill) allows us to draw statistical conclusions with tactical implications from free-play, live-fire surface gunnery events.

The Threat

Small boats combine surprise, speed, and numbers to overwhelm the defenses of even the most capable surface combatants.

US Navy Surface Combatants

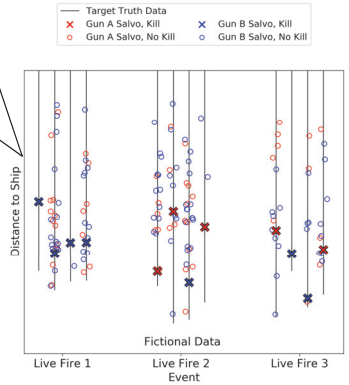


(A) *Arleigh Burke*-class destroyer
(B) *Ticonderoga*-class cruiser
(C) *Zumwalt*-class destroyer
(D) *Freedom*-variant LCS
(E) *Independence*-variant LCS

All data on this poster were fabricated for the purposes of demonstration.

Summary of Gunfire

The ship's performance was **extremely varied** (some targets killed very quickly, some required many salvos), prompting questions about **what factors drove this disparity**.

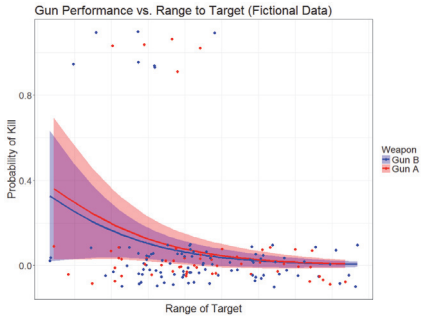


Factors Expected to Influence Gun Performance

Factor Name	Hypothesized Effect
Range	Lower Pk at longer ranges due to round dispersion and (presumably) less accurate tracks
Closure Rate	Lower Pk for targets with large closure rate (positive or negative)
Weapon Type (Gun A or Gun B)	Gun A is expected to have a higher per-salvo Pk given its greater lethality
Target Relative Bearing	Lower Pk in certain regions for the ship's targeting systems
Bearing Rate (degrees/second)	Lower Pk for high bearing rates as the guns must traverse rapidly and correctly predict the target's location
Track Staleness (seconds since last track update)	Lower Pk for stale tracks
Absolute Target / Ownship Speed	Low Pk for very high speeds (ship motion will interfere with accuracy)
Track Source (e.g., radar, EO/IR camera)	The EO/IR camera will be more accurate (higher Pk) than the radar
Range*Range	Pk may be highest in a sweet spot, with low Pk at both very long and very close ranges
Range*Weapon Type	Gun A's greater range suggests it will retain its accuracy at longer ranges
And more…	

Binomial Data Limit our Insight

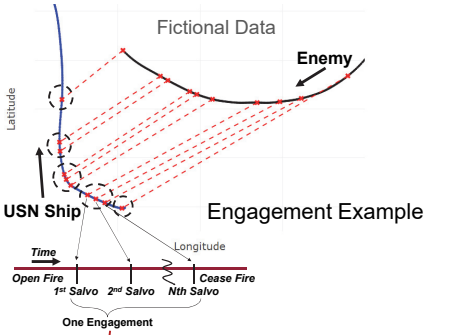
Difficult to achieve acceptable power for factor analysis with binary data unless many runs (often >100) can be resourced.

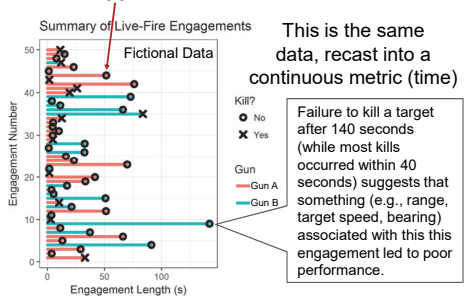


We cannot fit more than two factors to our data with logistic regression, and we have large error bars.

Moving From Binomial to Continuous Responses

Instead of considering each salvo (trigger pull) as an independent event, we consider closely-spaced salvos as part of a larger "engagement".





This is the same data, recast into a continuous metric (time)

Failure to kill a target after 140 seconds (while most kills occurred within 40 seconds) suggests that something (e.g., range, target speed, bearing) associated with this this engagement led to poor performance.

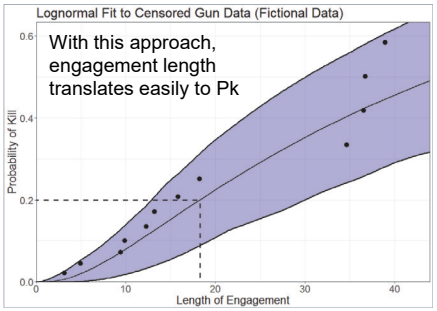
Analysis of Censored Data

We use the probability density function (PDF) and cumulative distribution function (CDF) to create the maximum likelihood function.

$$P(x) = \frac{1}{x\sigma\sqrt{2}} e^{\frac{(\ln x - \mu)^2}{2\sigma^2}}$$

$$L = \prod_{i=1}^{\#\ data\ points} [PDF(\mu, \sigma | t_i)]^{(1-\delta_i)} \times [1 - CDF(\mu, \sigma | t_i)]^{\delta_i}$$

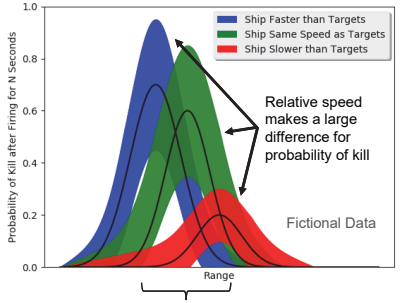
(parameters TBD, data)



We can now introduce factors

$$\mu = b + \beta_1 * \text{Factor 1} + \beta_2 * \text{Factor 2} + \ \ldots$$

To create results with tactical implications



Probability of kill is much higher in the "sweet spot" than at close and long ranges

Conclusion

Our analysis provided the Navy with suggestions for improvements to its tactics and the employment of its weapons.

A censored analysis enabled us to do so, where other methods fell short.