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Theater Torpedo Inventory Optimization

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THEATER TORPEDO INVENTORY OPTIMIZATION

EXECUTIVE SUMMARY

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Project Summary

Torpedo loadout decisions for anti-submarine warfare (ASW) depend on threat scenarios, capacities, capabilities of ASW platforms, and constraints on inventory and/or budget. These decisions are crucial as U.S. adversaries continue to grow their fleets and expand their global operations. Such torpedo loadout decisions are typically made in advance of the detection of an adversary submarine or even before an ASW unit is deployed. Currently, loadout plans for the Mk-54 lightweight torpedoes are made manually, and the goal of the project was to develop a decision aid, using formal mathematical optimization, for allocating ASW torpedoes in an uncertain environment.

We developed the Torpedo Allocation Stochastic Optimization Model (TASOM), which has two versions. TASOM is a mixed-integer, stochastic optimization model that seeks to minimize expected failure to meet operational goals measured by probability of kill. The optimization is subject to budget and inventory constraints, as well as other operational constraints.

Keywords: *anti-submarine warfare, ASW, torpedoes, optimal loadout*, *stochastic optimization*

Background

The Mk-54 torpedo type is employed by the MH-60R Seahawk helicopter, P-8 maritime patrol aircraft, and surface ships when conducting ASW operations. The "mod 0" and "mod 1" variants of the Mk-54 are currently in use. The delivery of a "mod 2" variant is expected in fiscal year 2026. Of particular interest is the procurement and allocation of mod 2 torpedoes, as they are anticipated to have significantly improved performance compared to previous variants, but at a substantially higher cost.

This trend of high-effectiveness, high-cost torpedoes underscores the need for efficient allocation of these weapons among the various platforms: helicopters, patrol aircraft and surface ships.
Given a stockpile of torpedoes, a set of weapon-delivery platforms, each with its own capacities and capabilities, and a set of possible scenarios, each of which may realize, with a certain probability, the problem is how best to allocate the stockpile of torpedoes among the platforms.
The problem addressed in this research belongs to a large family of weapon-allocation (Page, 1991; Avital, 2004; Brown and Kline, 2021), and target-assignment (Manne, 1958; Ahuja et al., 2007) problems. Our model advances the existing literature on this topic by developing analytic (vs. simulation) models, which consider multiple shooters against multiple targets in an uncertain environment.

Findings and Conclusions

Two optimization models were developed: TASOM-1 and TASOM-2. Their measures of effectiveness are combinations of torpedoes' cost and expected cost of not meeting operational goals of adversary's targets killed. The key difference between both models relates to the assessment of fire engagements that do not reach a desired probability of kill threshold. TASOM-1 minimizes the expected *number* of missed submarines when the consideration is binary: kill probability threshold fully met or not (in which case the target is considered safe). TASOM-2 minimizes the expected *shortfall* from (i.e., deviation below) the probability of kill threshold. In this case, partial credit is given to engagements that do not fully achieve the desired threshold. Both models also consider constraints on budget for: purchasing torpedoes; inventory of torpedoes already in stock; limited magazine capacity for P-8 squadrons; ships with embarked helicopter detachments; and a limited salvo size for aircraft units.

The TASOMs are stochastic. Instead of assuming perfect information regarding a specific threat scenario, which includes number of targets (adversary submarines) and identity of ASW platforms that will engage them, our stochastic models assume probabilistic information about the likelihood of several possible threat scenarios. The solution that TASOM recommends is a torpedo loadout plan that is not tailored to a deterministic threat scenario; instead, it reaches a compromise among all potential scenarios that are considered in the analysis. Thus, the solution that minimizes the total cost of (a) torpedo purchases; and (b) either expected number of missed submarines (for TASOM-1) or expected shortfall from the desired probability of kill threshold (for TASOM-2), applies to a wide range of possible threat scenarios and not just a single one. The assessed cost for not meeting a probability of kill threshold for a submarine is a planner's input.

To show the value of the stochastic programming approach over a typical deterministic planning, we present a notional case designed to represent an ASW operation where four destroyers with embarked MH-60R detachments and two P-8 squadrons are patrolling an area for adversary submarines. We assume the adversary fleet comprises 20 submarines of different classes, out of which 5 to 10 submarines are deployed. The desired probability of kill threshold is 90% for all submarine threats. One hundred threat scenarios are randomly generated where a subset of the submarine fleet deploys and appears to the patrolling ASW units. Here, we define a scenario as a configuration of deployed adversary submarines, available ASW units, and subsets of ASW units that can engage a certain submarine.

From running simulations, we observe that TASOM-1 loadout performs marginally better than the average loadout solution that can be obtained using a deterministic approach. The TASOM-2 value over manual or deterministic planning is more apparent.

Our models are combined with an accessible user interface, which facilitates generating scenarios and accessing pertinent results. TASOM uses mathematical optimization, explicitly deals with uncertain scenarios, and facilitates sensitivity analysis. Together, this research provides planners with a decision aid tool that can be used to guide torpedo allocation and budget decisions under uncertainty.

Recommendations for Further Research

We recommend further development of Torpedo Allocation Stochastic Optimization Model-2 (TASOM-2) over TASOM-1. The soft constraint used for the desired kill probability threshold is more realistic than the hard, binary, constraint in TASOM-1. Additionally, TASOM-2 solves significantly faster than TASOM-1 and has demonstrated greater performance improvements when compared to the deterministic model for the average loadout and "all-targets" loadout.

Recommended future work includes exploring the effects of penalizing the probability of kill shortfall differently. For example, an exponential penalty of degree n would incentivize spreading the probability of kill shortfall among different targets ($n > 1$) or concentrate them on fewer targets ($n < 1$). This would involve pre-calculating the penalty on the shortfall of a combination in an engagement.

Finally, only one test case was considered in this thesis, but additional cases should be tested to verify model results. Additional cases can be expanded to consider more realistic anti-submarine warfare (ASW) operations. In our case, all ASW units and all deployed adversary submarines were confined to one area. A more realistic case may involve ASW units patrolling their own separate areas, as in a barrier defense plan. Adversary submarines appearing in one of many areas can easily be controlled when creating scenarios. Additionally, friendly submarines, with their own, separate torpedo inventory, operating in their own, separate area, can be incorporated in a case study to represent a more comprehensive ASW operation. Multiple cases with multiple areas can be run in a series to consider a campaign-level setting.

References

Ahuja, R. K., Kumar, A., Jha, K. C., & Orlin, J. B. (2007). Exact and heuristic algorithms for the weapon target assignment problem. *Operations Research, 55*(6), 1136–1146.

Avital, I. (2004). *Two-period, stochastic supply-chain models with recourse for naval surface warfare*. [Master's thesis, Naval Postgraduate School]. NPS Archive: Calhoun. http://hdl.handle.net/10945/1707

Brown G. G., & Kline, J. E. (2021). Optimizing missile loads for U.S. Navy combatants. *Military Operations Research, 26*(2). https://www.jstor.org/stable/27028854

Manne, A. S. (1958). A target-assignment problem. *Operations Research, 6*(3), 346–351.

Page, J. M. (1991). *The optimal force mix and allocation of fires for the future field artillery*. [Master's thesis, Naval Postgraduate School]. NPS Archive: Calhoun. http://hdl.handle.net/10945/26671

Acronyms

ASW	anti-submarine warfare
TASOM	Torpedo Allocation Stochastic Optimization Model