2021

VLS Missile Mix, Firing Policy, and Deterrence Against Red Salvos

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Monterey, California: Naval Postgraduate School

http://hdl.handle.net/10945/69903

NAVAL RESEARCH PROGRAM
NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

VLS MISSILE MIX, FIRING POLICY, AND DETERRENCE AGAINST RED SALVOS

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Prepared for:
Topic Sponsor Lead Organization: N8 - Integration of Capabilities & Resources
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This research is supported by funding from the
Naval Postgraduate School, Naval Research Program (PE 0605853N/2098).

Project Summary

The U.S. Navy (USN) utilizes the Vertical Launch System (VLS) to store and launch both their offensive and defensive missiles. The number of VLS silos on a given ship is fixed. Thus, in order to maximize offensive capability, the USN wishes to minimize the number of interceptors to combat incoming, anti-surface missiles. Current firing policies may be overly conservative and expend too many interceptors per incoming threat, which results in a substantial fraction of VLS silos dedicated to defensive missiles. Decision makers need an analysis tool to explore the tradeoff between missile consumption and probability of raid annihilation (PRA) for various firing policies; they would also benefit from a prescriptive algorithm to help inform missile expenditure. This project provides a model to optimize VLS firing policy using multiple interceptor types while accounting for range limitations, travel time, multi-interceptor salvos, battle damage assessment, and range dependent probability of kill. Additionally, the project derives analytical results for the optimal allocation of interceptors in the single interceptor case, which in turn generates insight into how to structure sequential salvos.

Keywords: *firing theory, salvo model, battle damage assessment*

Background

Modern USN surface ships and submarines are outfitted with a common launching "mount" known as the VLS. VLS allows for missile compatibility regardless of the specific platform that carries them. Ships can be outfitted to fit mission needs and can utilize future missiles that will be developed later in the ship's life-cycle. VLS inventory is divided into separate mission sets such as anti-submarine, anti-surface, land-attack (commonly known as "strike"), integrated air and missile defense (IAMD), ballistic missile defense, etc.

Depletion of IAMD loadouts will result in a total degradation of combat effectiveness as a ship is rendered defenseless and — assuming it survives — must return to port to reload. This VLS replenishment is a multi-day voyage to and from a shore installation with additional time potentially spent waiting in port if the reloading infrastructure is preoccupied with other ships. During this duration, the vessel is not on station and therefore is not conducting any missions.

This project focuses on the employment of defensive (counterfire) interceptors, which falls under the IAMD mission set. Traditionally, a USN ship's captain decides how to deploy and employ missiles against incoming threats, and this firing policy is usually the same for all threat types. A firing sequence consists of a series of salvos fired at the incoming threat. Each salvo is a collection of interceptors which may include duplicates of a single interceptor type or a combination of different types of interceptors. After each salvo, the blue (defending) force performs battle damage assessment (BDA) to determine the outcome of the salvo. There is a "cost" to fire each interceptor, whether financial or in opportunity.

Current policies such as shoot-look-shoot do not consider situation specifics such as detection range, inventory, or threat. We focus on improving the engaging sequence by exploring policies regarding the interceptor composition of each salvo relevant to a specific situation. Our model is a heuristic based on simplifying assumptions that generates effective heterogeneous firing sequences against a given threat. It factors in constraints of minimum and maximum interceptor ranges, interceptor transition time between launch and impact, range-dependent probability of kill, BDA, and time to conduct BDA.

First, we analyze one salvo to compute the probable impact point (PIP) of each interceptor. The PIP is the input to range-dependent single-shot probability of kill (SSPK). We next string together several salvos to construct a firing sequence. Aggregating the SSPKs across all interceptors and salvos yields the PRA.

To determine the best firing sequence, we develop a recursive algorithm to generate all feasible firing sequences. This recursion provides a heuristic approximation for the lowest-cost sequence that surpasses a user-specified PRA threshold, Q.

In addition to the general model that includes heterogeneous mixes of interceptors, we explore a simplified case with homogeneous interceptors distributed across multiple salvos. This portion of the project does not include BDA delay or range-dependent SSPK.

Findings and Conclusions

The key finding of this analysis is that sequences should be structured such that they are monotonically non-decreasing with salvo index. If the optimal sequence — from an expected cost perspective — has two interceptor in a salvo, all subsequent salvos will have two or more interceptors.

Additional findings for the homogeneous case include: (a) expected cost decreases as the number of salvo firing opportunities increases; (b) the optimal fraction of interceptors allocated to each salvo does not depend on SSPK and instead depends on the number of salvo opportunities and PRA threshold Q. This implies SSPK only impacts the number of interceptors required, not the optimal structure of sequence; and, (c) above a certain SSPK the optimal firing sequence has one interceptor in all salvos except the last one, which fires the remaining interceptors. This suggests that a sufficiently high SSPK simplifies allocation as only the final salvo needs adjustment.

Our work suggests that the key to decreasing the expected number of interceptors expended per threat is maximizing the number of salvo opportunities in a firing sequence. This can be done through early detection — improving detection and classification range — and having the requisite interceptors to match this expanded capability. Firing opportunities can also be increased through improved BDA time and having high-velocity interceptors with improved minimum range. After maximizing salvo opportunities, the next important aspect is interceptor allocation. We prove that salvos should be monotonic, non-decreasing in size for the homogeneous case; however, our preliminary results show this broadly holds for the heterogeneous case as well. Finally, our work demonstrates that each interceptor type plays a role in generating optimal sequences and that model inputs of detection range and BDA delay have second-order effects on the results.

Ultimately, optimal firing sequences are dependent on the threat type, interceptor availability, and detection range. Exploring the interaction between these factors while considering different interceptor salvos is a complicated task, but our model provides a streamlined approach to modify parameters and generate near-optimal sequences. Examples of how our model can be used include preemptively deriving a firing policy for a given threat scenario, evaluation of new or upgraded interceptors, and feeding into a loadout planner to provide end-to-end optimization from logistics to firing.

Recommendations for Further Research

The main next step would be to incorporate soft-kill interceptors into our model. Soft-kill systems are known for having much lower battle-damage assessment (BDA) quality than hard-kill ones. For soft-kill, false negatives would be the primary concern. A false negative occurs when blue believes it has not killed the incoming threat despite already having a successful interception. False negatives can lead to wasteful expenditure of interceptors. False-positive would have serious implications for firing policy but such assessment is very unlikely; a missile traveling at high speed towards a ship is hard to mistake as being killed.

The difficultly with soft-kill analysis is there are many different types of soft measures and each has a drastically different mechanism of successfully scoring a "kill." Some of these methods include jamming, directed energy, chaff and decoys. The first three provide an instantaneous effect when "deployed." Chaff is a one-time expenditure but can be applied to multiple threats. While jamming and directed energy "impact" instantaneously, they require a certain amount of time on target, after which jamming leads to a soft-kill while energy weapons are more akin to a hard-kill. Decoys are the only non-instantaneous soft-kill measure, as they require transition to the target, after which it remains active for some defined time parallel to additional salvos.

Another extension would be for multiple threats. We focus on a single threat to better explore how the salvos should be structured. Many real-world scenarios face multiple simultaneous threat groupings. This is magnified with the advent of loitering munitions.

Generalizing to multiple threats would require insight from subject matter experts on what simplifying assumptions can be made. The main considerations are: inventory limitations; channel limitation as a finite amount of active or semi-active seekers that can be airborne at a time; and, expenditures such as chaff that effect multiple threats at once. One approach to multiple threats could use our model to generate a diverse collection of sequences for each threat, and then feed those sequences into an optimizer with the appropriate constraints applied.

A last extension could re-examine our assumption about firing a salvo as early as possible. Our model provides near optimal-solutions, but better solutions could exist by optimizing the firing time of each salvo. This would significantly increase the computational complexity of the problem. One approach to incorporate timing into the model in a computational tractable way would be to introduce a "waiting" action into the design. The waiting action would be for a set length of time (e.g., wait 10 seconds before firing a salvo) that an operator could adjust.

Acronyms

BDA	Battle damage assessment
IAMD	Integrated air and missile defense
PIP	Probable impact point
PRA	Probability of raid annihilation
SSPK	Single-shot probability of kill
USN	U.S. Navy
VLS	Vertical Launch System
Q	Probability of Raid Annihilation threshold