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Diversified submarine weapon suite a systems engineering approach

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THESIS

DIVERSIFIED SUBMARINE WEAPON SUITE: A SYSTEMS ENGINEERING APPROACH

by

Steven A. Dawley

December 2008

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DIVERSIFIED SUBMARINE WEAPON SUITE:
A SYSTEMS ENGINEERING APPROACH

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LIST OF ABBREVIATIONS AND ACRONYMS

ADCAP	Advanced Capability
AOR	Area of Responsibility
ASW	Anti-Submarine Warfare
ASuW	Anti-Surface Warfare
ECM	Electronic Countermeasures
HWT	Heavyweight Torpedo
IR	Infrared
ISR	Intelligence, Surveillance, Reconnaissance
LHT	Lightweight Hybrid Torpedo
SOF	Special Operations Forces
SSN	Submersible Ship, Nuclear
SSGN	Submersible Ship, Guided Missile, Nuclear
TASM	Tomahawk Anti-Shipping Missile
TLAM	Tomahawk Land Attack Missile

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I. INTRODUCTION

A. BACKGROUND

The significance of the submarine in furthering naval power is an undisputed fact of history, as is the importance of the submarine in influencing future events. As with all platforms, submarine evolution relies on advancing design, improved tactics, and skilled operators to maintain advantage over the threats posed by an adversary. As the nature of the threat and the missions assigned to submarines evolve, these critical aspects of performance must also change to maintain the submarine advantage. Although many areas exist for development, one such area that is rich in opportunity is the submarine weapon system. Throughout history, submarines have been the platform for the delivery of many weapons, each developed in response to the operating methods and threats of the time. The threats of today, combined with the evolving role of submarine missions in carrying out the defense of our nation, create the need for reevaluation of submarine weapon employment.

Today's submarine weapon systems, consisting of ballistic missiles, cruise missiles, and heavyweight torpedoes, are the result of a Cold War submarine strategy. During the Cold War anti-submarine warfare (ASW) against the Soviet submarine force was the primary stated mission of the U.S. submarine force, with covert ISR and SOF operations playing a smaller role. Submarine weapon systems in support of these missions were focused on sub-on-sub engagements, and relied heavily on stealth for self-defense [O'Rourke 2008, 3]. With the end of the Cold War, submarine missions and operating patterns have undergone a transition from the deep ocean to the littorals while facing a growing range of threats. Growing numbers of diesel submarines, continued improvement in ASW technologies and practices, advances in helicopter based sonar and improved torpedo capability have changed the landscape of submarine operations. Threats are no longer contained beneath the waves but spread across the battle space. Effective submarine operations will require that submarines enter that battle space with the ability to engage across the spectrum of threats.

The expanding and transformational missions that the submarine force performs today, and those that will emerge in the future, must be examined so that the weapons carried by submarines are capable of dealing with the threats of a new century. The growing emphasis on littoral operations and the threat of anti-access strategies will greatly influence future submarine operations [U.S. Congress, 2000]. Missions requiring continued presence in areas of shallow water with high traffic density will likely become more frequent; "going deep, and going fast" to avoid detection may be difficult or impossible. Considering the increasing importance of communications and connectivity any type of interruptions may be detrimental to mission accomplishment. Developing the ability of the submarine to "stand and fight" will greatly impact mission accomplishment in these situations. Situations in which hostile fire arises will demand the ability of submarines to challenge the adversary and establish control of the operating area to ensure mission success.

The value of a single submarine to the overall force capability is rapidly increasing. Given the current submarine force, scheduled construction, and losses due to age, the submarine force will decline in size over the next twenty years [O'Rourke 2008, 9]. Taken at time when the demand for submarine missions is growing and number of potential threats is increasing throughout the world, the capital value of the submarine force is reaching an all-time high. In situations of conflict, even the loss of a single platform could endanger the ability of the submarine force to deliver on its commitments to the overall naval and national strategies. In this light, the value of submarine self-defense has never been greater. Ensuring that submarine weapon systems provide the self-defense needed in the face of all threats is one way to minimize the risk of losing such a valuable asset.

Today, a submarine enters an operating area with two assets to provide self-defense. The first is stealth, which is extremely effective. Not only does the silent operation of submarines protect them, it is also one of the attributes that earn submarines their unique set of missions. The second is the MK-48 ADCAP torpedo, which is also extremely effective. The torpedo, though, is limited to engaging targets on or under the water, neglecting several important threats faced by submarines. Given this limited set of options, the expanding set of threats, the evolving missions of the submarine force, and the high level of value that submarines represent, it is appropriate to reexamine the submarine weapons system to determine the most effective system to address these concerns. New ship designs or revolutionary weapons might address these issues, but the development and acquisition of these solutions is time-consuming and costly. A short-term approach, utilizing existing systems, will increase the performance of today's platforms while informing the development of future systems.

B. STATEMENT OF THE PROBLEM

Attempt to define a submarine weapon system of systems that will enhance submarine mission accomplishment and increase survivability of the submarine platform in direct engagements against the range of threats to be encountered. Confine the solution to a system that could be in place within five to eight years, limiting the components to those already in or nearing production and able to be employed in today's submarine force. This system will be referred to throughout this thesis as the Diversified Submarine Weapons Suite (DSWS).

C. SYSTEMS ENGINEERING APPROACH

The DSWS development will be based on a systems engineering process. As shown in Figure 1, systems engineering take place across the entire system life cycle, from the initial conceptual design through disposal. This thesis is constrained to the conceptual design phase of the system life cycle shown on the far left of Figure 1. Conceptual design is the first and most important phase of the system design and development process. Selection of a path forward for the design and development of a preferred system configuration, which will ultimately be responsive to customer requirements, is a major responsibility of conceptual design [Blanchard and Fabrycky 2004, 54]. Constraint of this thesis to the conceptual design phase removes from consideration such important issues as launcher design, command and control of weapons, system maintenance, and many other aspects of the system that must be addressed in the systems engineering process. This decision allows for the detailed development of the conceptual design that meets the needs of the submarine force. The development of the DSWS will be the first step in establishing the requirements for a modern submarine weapon system and proposing a system that fulfills those requirements.

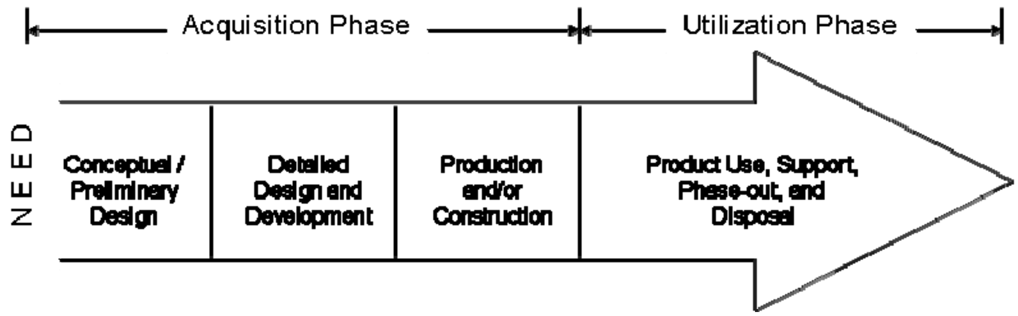

Figure 1. The System Life-cycle [Blanchard and Fabrycky 2004, 27]

The systems engineering process used will begin by identifying the critical stakeholders in the DSWS. These stakeholders are the organizations and individuals who have an interest in the end product, each stakeholder offering a different perspective and level of interest. Determining which stakeholders should have the greatest level of input to the development of DSWS will be accomplished through stakeholder analysis that addresses the conceptual level at which the DSWS is being developed. Once these critical stakeholders have been identified, their needs will represent the starting point for the development of system requirements. The needs identified will be interpreted and filtered appropriately in order to derive from them the system level requirements that DSWS must fulfill. These system requirements must be clearly defined The process of identifying needs and developing them into meaningful requirements will be undertaken through decomposition of each need and the application of operating and environmental factors. This process will result in a detailed set of system requirement that will influence the remaining steps of the development process to ensure that the resulting system meets the needs of the stakeholders.

The selection of inputs, or sub-systems, which will contribute to the fulfillment of the requirements, is the next step to be taken. These inputs must be capable of fulfilling any applicable system requirements at both an individual level and in combination with other inputs at the larger system level. Thorough consideration of a wide range of available options and the final selection of inputs must represent a diverse set capable of delivering the required performance in different ways. This diversity ensures that subsequent analysis will reveal any important relationships that exist at the system level. This carefully selected set of inputs can then be combined into alternative systems which meet all of the established requirements. Using a morphological process to combine the selected inputs into a comprehensive set of alternatives which meet the requirements generates a diverse group of proposed systems to be analyzed.

The final step in achieving the conceptual design that is the goal of this thesis is the analysis of alternatives. The alternatives investigated will be evaluated across a range of operating scenarios to determine those alternatives which offer the best overall performance. This analysis will be a unique method which addresses not only the performance of the alternatives but also the most effective load out of the submarine employing that alternative in the given scenario. The results of this analysis will strive to not only identify the alternative that offers the greatest performance, but also to suggest the optimal allocation of weapons within that alternative and bring attention to the important interactions between system components. This knowledge will be critical to the follow-on systems engineering processes that must take place for the DSWS to become an operational system. Figure 2 provides a visual aid to understanding the critical systems engineering steps that will be employed in developing the DSWS.

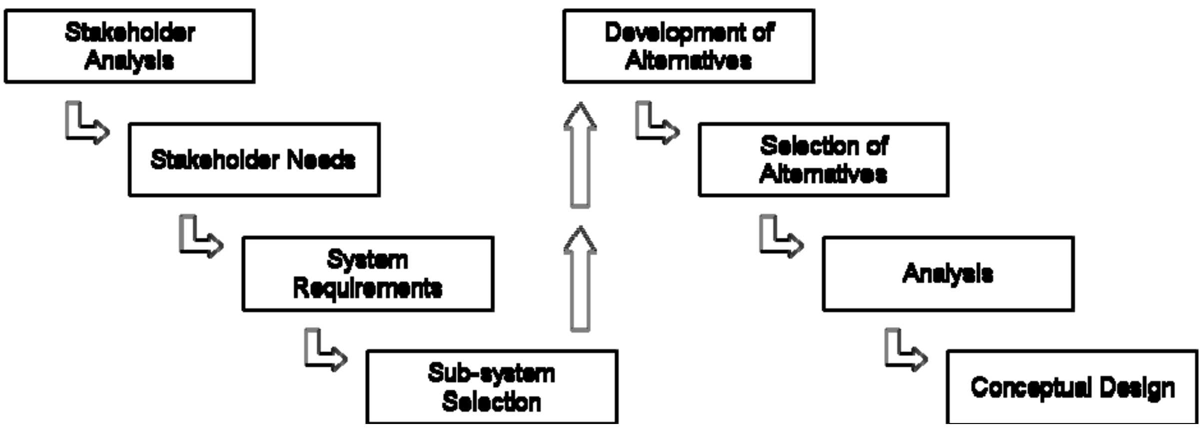

Figure 2. DSWS Conceptual Design System Engineering Process Model

II. GENERATING REQUIREMENTS

The development of DSWS will begin with generating detailed system requirements. Generating these requirements begins with identification of critical stakeholders and their needs. These needs will drive the development of the detailed requirements needed to guide system development.

A. STAKEHOLDER ANALYSIS

Before defining any requirements for a submarine weapons system, it is necessary to perform stakeholder analysis to determine those with a critical stake in the requirements process. This analysis is approached by first indentifying stakeholders across the system life cycle and assigning each to a position on the timeline of the system life cycle. By defining the role of each stakeholder in this way, it is possible to isolate the stakeholders with the largest role in the conceptual design of the DSWS from those with critical stakes that will have greater impact on later stages of development. Since this thesis is not focused on the development of specific weapons, launcher systems, tactics, or the command and control aspects of employing a weapon system of systems, those stakeholders with roles closely associated with these activities will be given less emphasis. The result of this stakeholder development is reflected in Figure 3.

Reviewing Figure 3 shows that in the conceptual design phase of DSWS, which is the focus of this thesis, the Combatant Commanders, the OPNAV staff responsible for Undersea Warfare, and Operational Forces represent the key stakeholders in the development of requirements. It will be the needs represented by these groups that will be reflected in the requirements for DSWS. Those that fall just after these major contributors, and bridge the transition to specific systems design and construction, will be considered in a lesser role, with the understanding that as the system life cycle progress, they will have growing importance. Far down the progression shown in Figure 3, stakeholders such as training commands and maintenance activities, while clearly important, are not specifically involved in the conceptual design and thus are excluded from the development of requirements in this thesis.

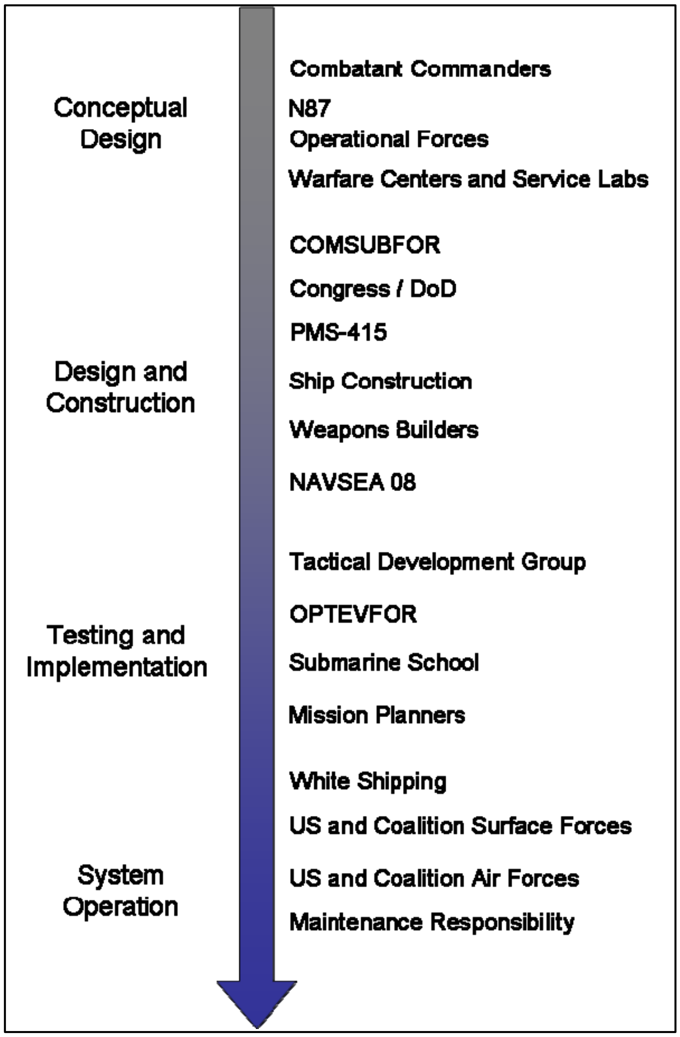

Figure 3. Stakeholder Input Over the System Life Cycle

This group of stakeholders will contribute to the development of requirements in differing ways. It is important to understand their roles within the submarine community in order to effectively establish their role in the development of requirements. With the overall responsibility for the conduct of forces inside their geographic AORs, a Combatant Commander's role in the command structure of the military makes them responsible for defining the missions to which submarine assets are assigned and the synchronization of these missions within theaters. By defining the missions in which submarines are engaged, or in which they wish to use submarines in the future, the Combatant Commanders define in large part the needs that the submarine force must fulfill in achieving the overall goals of the military. OPNAV N87, as the lead staff for the development of undersea warfare, is responsible for the development of submarine capabilities and their integration into naval operations. They contribute to innovative development of undersea technologies to fulfill future missions as well as to enable those being carried out today. This group will also play a large role in defining the needs that must be met by the submarine force and DSWS. In addition to the development of new capabilities, N87 is also vital in moving ideas forward in OPNAV in order to secure funding for research and development. The operational forces will provide the understanding necessary to interpret the needs of the previous group and to decompose these needs into operational factors. Once a set of missions (needs) is defined it is then necessary to turn to the operational forces to determine those requirements that enable mission success. Through their understanding of operations, tactics and ship limitations this group of stakeholders brings a greater level of detail to the requirements. The input of these forces play a vital role in advancing the high level needs of the previously mentioned stakeholders to the level of specificity needed for the development of system specific requirements. Although the service laboratories and research centers will be more closely associated with the detailed design phase of the system life cycle, they are important to consider here because of the practical limitations that they bring when reviewing design options. Considering these organizations lends an element of accountability to the process by ensuring that later stages of the system development are capable of moving forward.

B. REQUIREMENTS

Having identified the key stakeholders for the conceptual design of the DSWS, the development of requirements can begin. In the previous stakeholder analysis it is seen that conceptual design requirements for DSWS were going to be heavily influenced by high level planners. In order to arrive at meaningful system level requirements beginning with a high level need required a multistep process – beginning with the highest level mission needs of the previously identified key stakeholders and decomposing these needs to an operational level, applying the environment of operations, and finally arriving at the needed specific system requirements.

The first step, identifying the needs of the key stakeholders, is achieved through a review of congressional testimony and published mission statements from the key stakeholders. This information leads to a set of roles and missions for the submarine force that represent the highest level of needs to be addressed. The critical missions that submarines are performing today and will likely be called on to perform in the near future include, ISR, Land Strike, insertion and extraction of SOF, and Sea Power, ASW and ASuW [O'Rourke 2008, 2; U.S. Senate 2000a; U.S. Senate 2000b]. The ability to effectively conduct these missions in any environment throughout the world represents the top level of a requirements pyramid that must be developed several levels down in order to draw out those requirements specific to DSWS (Figure 4).

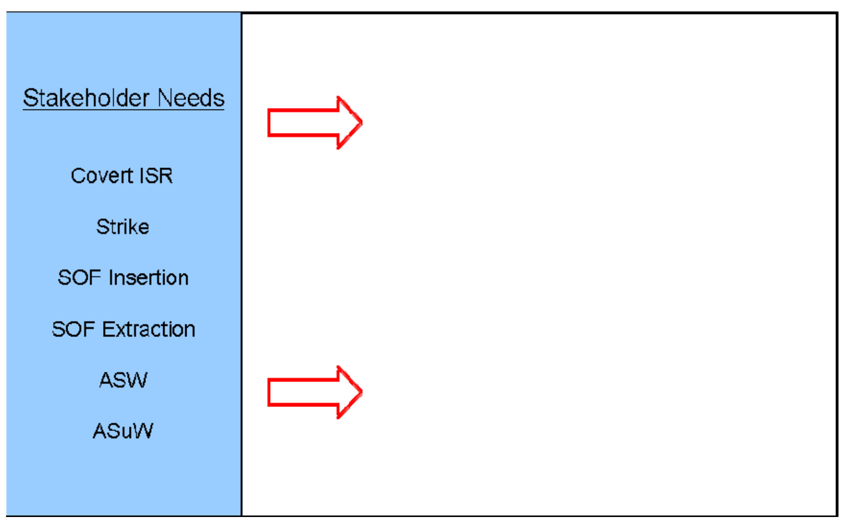

Figure 4. Stakeholder Needs

Beginning with a covert ISR mission, an initial requirement of covert transit to and from the operating area represents one of these operational level needs. Regardless of the nature of ISR to be performed, whether it is electronic surveillance, visual survey, or some other form of monitoring, successful collection necessitates extended periscope or antenna exposure which can only be accomplished from periscope depth. Increased importance can be placed on this requirement when considered in conjunction with the need to communicate collected information or receive guidance through communication which also requires antennae exposure. Based on the top-level need for covert collection, mitigation of detection threats also becomes an operational requirement, which in peacetime can only be achieved through stealth and tactical employment of the platform, but in hostile situations might be greatly enabled by engagement of these threats. A final operational requirement that will carry through the several missions to be discussed is the ability to act in self defense against those threats which can hold the platform at risk.

Similar to the ISR mission described above, the strike mission will require covert transit to and from the launch area, self defense capability and extended time at periscope depth in order to achieve the needed level of coordination that is typical of strike planning and operation, and also to facilitate launch. An important difference in the conduct of the strike mission involves the abandonment of stealth during the launch and the time critical nature of some strikes conducted. In order to ensure mission success, in this case an on-time launch, the option of evasion to avoid detection is lost and, carried one step further, the ability to evade during salvo launch is limited or mission impacting. Combined with the fact that at the time of launch any threat platforms in the area will be alerted to the submarine's position this leads to a requirement for the ability to remove such threats prior to launch or during launch to ensure mission success. A final distinction of the strike mission is that its successful conduct requires the platform to carry mission specific equipment into the operation area, in this case a land attack missile.

The differences noted between the ISR mission and the strike mission are instructive when looking at submarine insertion and extraction of SOF forces. A SOF insertion, similar to the ISR mission, requires covert posture with the exception of self defense situations in order to achieve mission success. The successful extraction, on the other hand, places a decreased emphasis on stealth for mission accomplishment, instead requiring extended loiter time regardless of the threat environment. In both cases the additional requirement generated involves the self defense of not only the submarine but the expansion of the self defense bubble to include the SOF forces as well. As with the previously discussed missions, requirements for covert transit exist, while extended time of antennae exposure and communications requirements are less important for the SOF missions.

The final missions defined by our stakeholders to be considered are ASW and ASuW. In both situations, a continuous covert posture is required in order to enable attacks against enemy targets and prevent those targets from enjoying a tactical advantage. Detection of enemy targets at tactically significant ranges is also an important requirement, with mission success rounded out by a need for sufficient and adequate weapons to engage the desired targets.

These operational needs, arising from the mission needs of our stakeholders, can be combined and distilled to a relatively small set of operational needs. These operational needs are:

- Stealth
- Operate at Periscope/Communications Depth
- Threat Mitigation / Self Defense
- Mission Specific Equipment

Each of these operational needs influences the system requirements in a different way. Because of its importance to mission accomplishment, stealth places a constraint on DSWS to have no negative impact on the stealth character of the ship. The second need, periscope / communications depth, is not directly impacted by our system, but does place additional emphasis on the threat from airborne platforms that are of lesser concern when submerged. Threat mitigation is directly affected by DSWS, and is the key operational need that will drive the specific requirements of the system. Threat mitigation can take two forms, evasion or engagement, and while evasion relies on the previously mentioned stealth, the engagement option will be enabled by the platform's weapon system. The final identified mission need of specific equipment, again acts to place a constraint on the overall system design by requiring that some portion of DSWS be reserved for delivering ordnance needed for the conduct of the mission rather than in an enabling role. The transition from the high-level stakeholder needs to operational needs is illustrated in Figure 5.

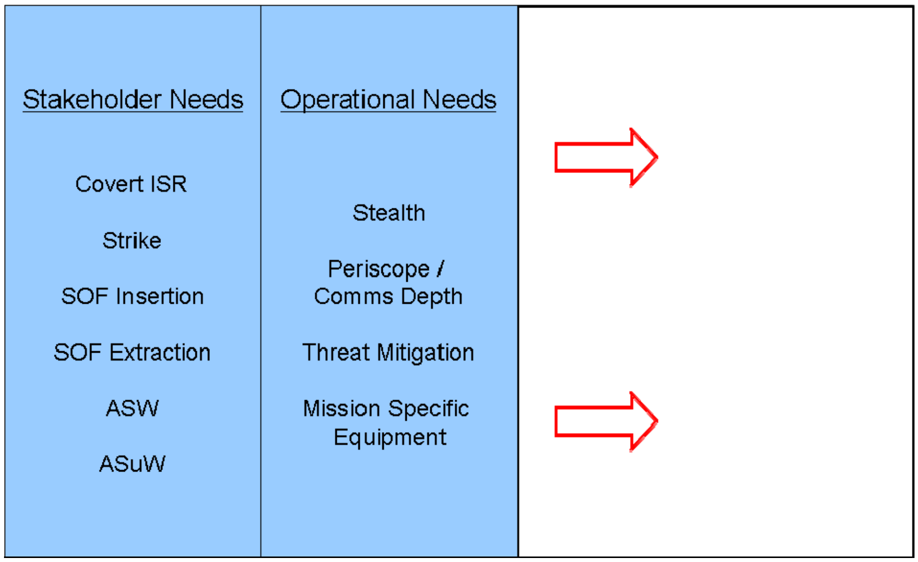

Figure 5. Transition of Stakeholder Needs to Operational Needs

In order to move from these operational level needs toward system requirements the environment must be considered. This environment consists of three separate but equally important facets. The first is the physical environment including the geography and the traffic patterns of assigned operating areas. With increased operational assignment to littoral areas, the presence of neutral shipping and interfering contacts forms the basis for a requirement related to target discrimination. Responsible use of weapons in these environments requires that DSWS be able to discriminate between targets and non-targets to some quantifiable level in order for operators to make informed decisions related to engagement. The environmental concern of physical geography is best understood through the recognition of submarine operational limitations which provide a performance window for the system being considered. Submarines operating at periscope depth are realistically constrained to operations in a water depth not less than 100 feet while open ocean operations typically encompass depths in the range of 250-600 feet with occasional operations extending even deeper. The resulting requirement is that the system under development should be capable of delivering performance across the range of depths from 100-600+ feet and can not impact the ability of the submarine to operate in this depth envelope. This particular limitation impacts the ability of the platform to adequately and safely evade threat targets. Because of increasing frequency of operations in shallower water, the platform's ability to effectively evade threats by "going deep, going fast," can have a great impact on the decision to evade a threat vice engage a threat to mitigate risk to the platform, leading to an increased emphasis on engagement ability rather than evasion. Another facet of the environment to be considered is the acquisition environment. Given the platform design and construction lifecycle of submarines, requirements for constraints such as size, space and weight within which DSWS is developed are limited. Since the conceptual design being sought does not address significant changes to submarine construction methods or drastic redesign of submarine hull forms, there are resulting requirements that the system must occupy a similar space, utilize existing hull openings, and be of similar weight to existing systems. The final facet of the operating environment includes the likely threat platforms to be encountered. These threats can be categorized into broad classes of large surface vessels, small fast moving surface vessels, submarines, and aircraft (both fixed and rotary wing). Introduction of these more specific platforms in place of the general term of threats adds a level of specificity to the requirements (Figure 6).

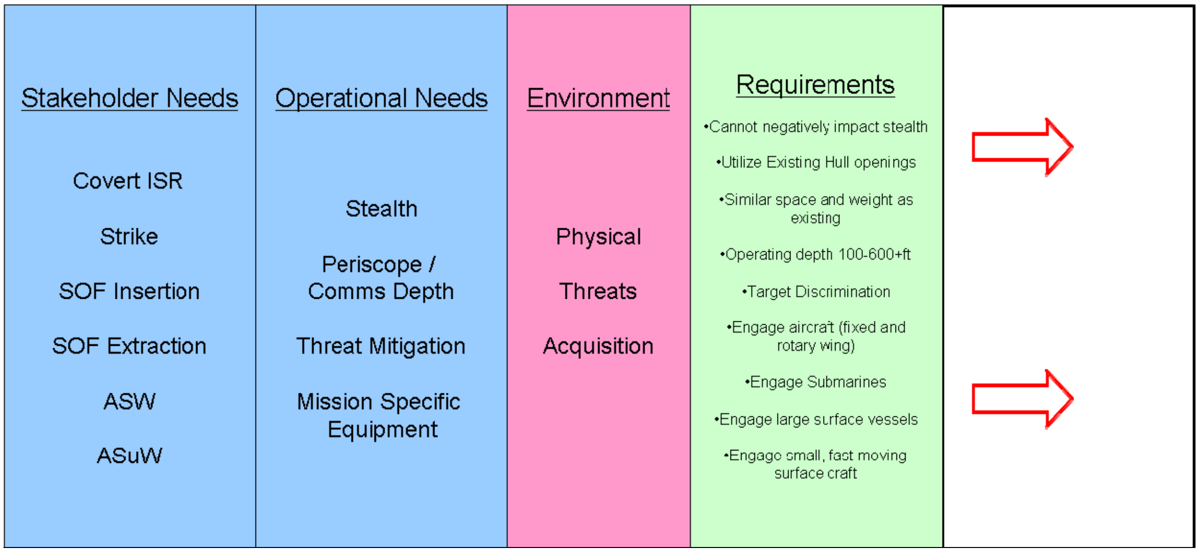

Figure 6. DSWS Requirement Development With Consideration of Environmental Factors

Having now moved from high level mission needs, through operational needs and arriving at a broad set of requirements that accounts for the environment, a final set of specific system requirements needed to carry out the conceptual design of the system being considered can be formed. Reaching the level of specificity needed to move forward requires certain assumptions to be made regarding each class of previously discussed threat. Giving consideration to such attributes as detection ranges, engagement ranges, and evasion speed a minimum engagement range for each group of targets moves the requirements forward to a level that is suitable for conceptual design. The assumptions for each class of targets are presented in Table 1, along with the minimum engagement range that informs the final specific system requirement. It is important to note that Table 1 represents the author's assumptions based on a review of open source literature and is not reflective of any specific platforms or perceived threats.

Application of the assumptions from Table 1 to the previously generated requirements results in set of specific system requirements that can be used through a systems engineering process to arrive at a recommended weapons system that will enable mission accomplishment. The development of these requirements from stakeholder needs through operational needs, the application of environmental influence, and the final specific application based on threat assumptions is summarized in Figure 7.

Threat Class	**Detection Range (against US Submarine, Kyds)**	**Engagement Range (Against US Submarine, Kyds)**	**Evasion Speed (kts)**	**Minimum Engagement Range Required to Mitigate Threat (Kyds)**
Small, Fast Moving Surface Vessel	5	0.5	40	5
Large Surface Vessel	10	20	25	20
Submarine	10	15	30	15
Fixed Wing Aircraft	10	5	200	10
Rotary Aircraft	5	5	150	5

Table 1. Assumptions for Various Classes of Threats and the Associated Minimum Engagement Ranges

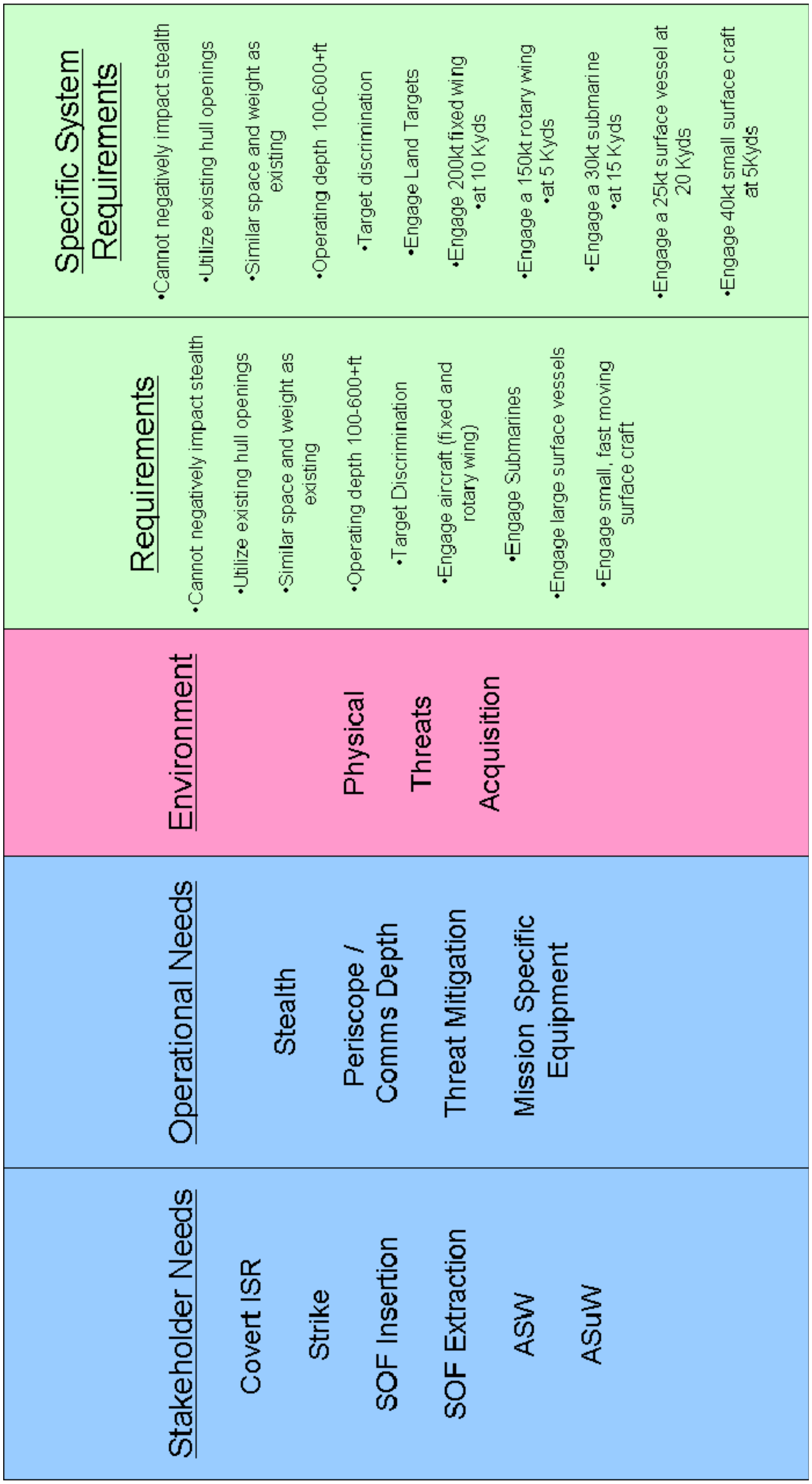

Figure 7. Summary of Requirements Development from Stakeholder Needs to Specific System Requirements

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III. DEVELOPMENT OF ALTERNATIVES

A. ALTERNATIVE SYSTEM COMPONENTS

In order to meet the established requirements, attention is now turned to the individual weapons that should be considered for inclusion in the DSWS. These selected weapons are the alternative inputs to the larger system and were selected to represent existing weapons systems in order to meet the time frame proposed for DSWS. Further selection criteria included general consideration of size constraint and the supporting systems required to employ each weapon. While the selected weapons are not an exhaustive list of all possible alternative inputs to the DSWS system, they represent a cross section of the classes and capabilities that are available. A more detailed listing of the weapons considered, their characteristics, and the factors for their inclusion (or lack thereof) in the input set are provided in the Appendix.

1. Torpedoes

Torpedoes define the broad class of underwater weapons with a primary use of ASW and ASuW. Torpedoes are limited to operation in the underwater environment and typically employ an onboard sensor system, some type of explosive charge, and a propulsion system suitable for underwater use. The U.S. Navy arsenal of torpedoes includes the MK-46, MK-50, MK-54, and the MK-48 ADCAP.

In various modifications, from Mod 1 through the most recently developed Mod 7, the MK-48 ADCAP is designed for submarine launch and is the only HWT in the U.S. arsenal. Capable of both active and passive sonar detection, the MK-48 can be wire guided providing two way communications with the launch platform. In the absence of wire guidance, the weapon is capable of autonomous search using preset conditions and firing solutions to select a search pattern [Federation of American Scientists 1998d]. Variable speed control of the weapon allows for control of stealth and range making it a very flexible weapon for widely varying tactical situations. Recent modifications to processing hardware have attempted to adjust capability of this weapon to account for the challenges of littoral operations [Jane's Underwater Warfare Systems 2006]. The MK-48 is included as an input based current use as a submarine weapon and demonstrated performance against surface and submerged targets.

The remaining torpedoes in the U.S. arsenal belong to the class of lightweight torpedoes. These torpedoes were developed for launch by aircraft and surface vessels against submerged targets and consist of three variants – the MK-46, the MK-50, and the MK-54 LHT. All three variants contain active and passive detection capability and sufficient depth of operations to engage today's most capable submarines [Federation of American Scientists 1998c and 1998d]. The MK-50 represents an incremental improvement on the MK-46 which has been surpassed with the introduction of the MK-54 LHT. MK-54 LHT borrows from the MK-46, MK-50, and MK-48 programs to deliver better performance in extreme environments and improved performance against countermeasures [Scott 2007]. Based on this improved performance, the MK-54 was selected to represent light weight torpedoes in the development of DSWS alternatives; this weapon provides the capability to engage submerged contacts at all reasonable speeds and depths. Although engagement of surface vessels is not the primary design consideration of this weapon, it is reasonable to assume that it would be effective against vessels of moderate to deep draft.

2. Missiles

The next class of weapons to be considered is submarine launched missiles. Missiles provide a unique challenge for submerged launch, having to first traverse a water column followed by transition to flight. Several systems exist that overcome this challenge. Submarine launched TLAMs are common, as is the ability to launch Trident D5 ballistic missiles. The selection of missiles for inclusion in DSWS does not focus on the ability to launch the selected missile, but rather on the capability of the missile to deliver on the requirement, assuming that a mechanism can be found to launch any of the missiles selected. Other considerations taken in selecting these missiles included the guidance systems and the applicable ranges for engagement.

Because of its current role as the strike weapon of choice in the U.S. military and its' established presence in the submarine force the TLAM is the only land strike missile to be included as an input to the DSWS. The Tomahawk missile has a proven track record for precision strike from both surface and submarine launch platforms, and continued development in precision guidance systems make future variants of this weapon likely to remain the preeminent land attack missile of the U.S. Navy. For submarine launch, torpedo or VLS tubes are flooded as the missile is pressurized to prevent it being crushed by the outside water pressure. A water pulse from the torpedo ejection system expels the missile from the canister, to which it remains attached by a lanyard, the booster being ignited when the lanyard is pulled taut after the missile has cleared the submarine. The booster then carries the missile to the surface, with air being vented to equalize internal and external pressure [Mateski and Kravitz 1997]. Land attack missiles are designed to approach their targets at low level to reduce the chances of radar detection. In approaching enemy coasts, the missile can adopt high- or low-altitude approaches. The former, up to 100 m above the surface, are used to extend missile range while the latter, down to 15 m, are designed to reduce the chances of detection. Over land the inertial navigation system guides the missile on an indirect approach at a maximum altitude of 30 m. Capable of delivering various payloads to land targets at ranges of 1600 km, the ability to target surface vessels also exists in the anti-ship variant (TASM) [Federation of American Scientists 2008b].

The remaining missiles to be considered focus on the engagement of air and surface threats. The first to be considered is a missile that has previously been carried and launched from submarines, the Harpoon anti-ship missile. The Harpoon utilizes an active radar seeker to target surface vessels. The missile is carried in a special, unpowered, buoyant capsule, which is launched from the torpedo tube [Federation of American Scientists 2008a]. As the capsule leaves the torpedo tube at a velocity of some 15.25 m/s, stabilizing fins and hydroplanes unfold to establish a proper glide angle to enable the weapon to reach the surface. A sensor detects when the missile is near the surface and initiates the sequence in which both the nose cap and the aft body are jettisoned and the booster is ignited. The booster burns for 3 seconds and takes the missile out of the water to near cruise velocity at which point the turbojet operates. After booster separation, the missile descends to a low-cruise altitude determined by its altimeter and flies towards the target by heading reference guidance, under the power of its turbofan engine. The Block 1C and 1G versions can execute mid-course waypoints based on preset data to avoid obstacles in the trajectory, approach the target from a desired direction or provide multiple-missile simultaneous arrival on target. At a point preset by the launch platform the J-band, frequency-agile, two-axis active radar seeker is activated into its search and acquisition mode [Mateski and Kravitz 1997]. The missile is usually launched in this preset range and bearing launch mode, turning on the radar seeker at the last moment to acquire the target. The radar can be set for large, medium or small acquisition windows that determine the range-to-target at which the seeker is activated. The smaller the window, the more precise the initial target data must be, and the less chance that the missile will succumb to ECM. Once the target is detected and the seeker is locked on its tracking mode the Block 1A missile climbs rapidly at about 1,800 m from the target in a pop-up maneuver before diving down onto the target at an angle of about 30. The later Block 1B, 1C and 1G missiles have a sea-skimming terminal attack profile. The Block 1C and 1G have an optimal shallow 'pop-up' maneuver. The Block 1G, instead of self-destructing at the end of the search phase, will turn and execute a reattack maneuver if it missed the target on its first pass [Jane’s Naval Weapons Systems 2008]. Although the Harpoon has shown capability against larger surface targets, it ability to detect and prosecute small fast moving surface craft and aircraft is not established.

The next missile to be considered is the AIM-9X Sidewinder, developed for short-range air-to-air engagements. The AIM-9X can utilize several modes depending on the avionics; primarily there is the simple boresight mode, an uncaged scan mode and a mode with the missile seeker slaved to an aircraft radar or to a helmet-mounted sight [Jane’s Air Launched Weapons 2008a]. The bore sight mode could be incorporated in a submarine launched version to achieve a target lock after launch, while the helmet mounted sight might be adaptable to a submarine periscope linked guidance system. The AIM-9X airframe with four clipped tip fixed forward fins (or wings) and four actuated tail fins, linked to the thrust-vectoring control system. The seeker is a 128 x 128 element mid-range focal plane array imaging IR system, markedly superior to the single element IR seeker of previous versions. The AIM-9X seeker sits behind a sapphire dome and is linked to an internal closed-circuit cryogenic cooling system and tracking system. This missile has a full 90° off boresight capability [Federation of American Scientists 2000b]. The 9.1 kg WDU-17/B warhead is the same as the AIM-9M carried in a hollow central cavity of the warhead and ensures that the missile arms itself at a safe distance from the launch platform. The warhead itself is a PBXN-3 explosive-loaded, end-initiated, annular blast/fragment unit, with 194 titanium fragmentation rods [Jane's Air Launched Weapons 2008a]. The AIM-9X has a reported maximum range of 10 km but the true range is most likely greater [Federation of American Scientists 2000b]. Given the capability of its' IR seeker and high level of maneuverability the AIM-9X is included as an effective weapon against fixed and rotary wing aircraft as well as fast moving small boats.

The final missile to be included in the DSWS input set is the Advanced Short Range Air-to-Air Missile (ASRAAM). THE ASRAAM is a highly maneuverable air combat missile capable of engaging modern combat aircraft. Utilizing a high sensitivity IR seeker is capable of achieving target lock after firing without input from the firing platform while remaining very resistant to electronic countermeasures [Federation of American Scientists 1998a]. ASRAAM is powered by a solid propellant rocket motor, and maneuvers using clipped delta control fins (the missile is wingless) [Jane's Air Launched Weapons 2008b]. The ASRAAM is included as an effective weapon against both rotary and fixed wing aircraft.

3. Guns

Although there is historical context for the use of deck guns on submarines, due to their minimal effectiveness and impacts on stealth they have long since been removed from service. Although modern submarines require stealth that would be greatly reduced by a deck mounted gun, guns that could be retracted and stored without affecting stealth could offer some value, but must be balanced by the fact that accurate delivery of projectiles would require the gun system to be positioned above the water line (either by extension or surfacing of the platform). Further consideration would also require a remotely operated mechanism and a continuous feed that would prevent the need for personnel to physically man the gun. The GAU-19 represents one such gun that could be effectively employed within the considerations of DSWS. There are many similar gun systems that could be employed with similar effects, but the GAU-19 was selected as a representative of these systems. As previously stated this weapon would require the submarine to surface for employment, but would provide an effective short range weapon against rotary wing aircraft and small boats. Additionally, it would provide credible force protection for surface transits.

B. SYSTEM MORPHOLOGIES

Having arrived at a series of inputs to the development of alternative DSWS configurations the next step is to determine the range of possible alternatives that will meet the requirements for DSWS. To achieve this goal a morphological process is employed, in which the performance based requirements is placed in a matrix against the various weapons selected for consideration. Each intersection within the matrix represents the ability of a selected weapon to fulfill the associated requirement. This completed matrix is then analyzed to identify the range of alternatives that will meet all system requirements. This matrix, in its completed form, is shown in Table 2.

Before moving forward in generating alternatives, consideration of the morphology matrix developed provides two instances that might affect future analysis. The first of these is the unique nature of the TLAM missile and the mission requirement that it fills. As the only input which meets the requirement for land attack, it is obvious that the TLAM will be included in all off the alternatives developed. But the land based target of the TLAM is different tan the other targets identified because it does not hold the launch platform at risk. While this difference does not affect the development of alternatives, this difference may require special consideration when assessing the performance of alternatives. The second item of importance is the GAU-19 and the ability to employ it aboard a fast attack submarine. Although the larger SSGN has adequate space to include such a weapon, it is not feasible for employment on the smaller platform. The GUA-19 also differs from the other weapons included as inputs because the space that it occupies is not definitively related to the number of targets that it can engage. These differences will be addressed in the method of analysis presented in the following chapter.

	Engage a 30 kt Submerged Target at 15 Kyds	Engage a 30 kt Surface Vessel at 20 Kyds	Engage 200 kt Fixed Wing Aircraft at 10 Kyds	Engage a 150 kt Rotary Wing Aircraft at 5 Kyds	Engage Small Fast Moving Surface Targets at 2 Kyds	Engage Land Targets
MK-48 ADCAP	X	X				
MK-54 LHT	X	X				
Harpoon		X				
ASRAAM			X	X		
AIM-9X			X	X	X	
GAU-19				X	X	
TLAM						X

Table 2. Morphology Matrix of Selected Weapons and Requirements

Alternative	Weapons Included
A	MK-48, AIM-9X, TLAM
B	MK-48, HARPOON, ASRAAM, AIM-9X, TLAM
C	MK-48, HARPOON, AIM-9X, TLAM
D	MK-48, ASRAAM, AIM-9X, TLAM
E	MK-54, AIM-9X, TLAM
F	MK-54, HARPOON, ASRAAM, AIM-9X, TLAM
G	MK-54, HARPOON, AIM-9X, TLAM
H	MK-54, ASRAAM, AIM-9X, TLAM
I	MK-48, MK-54, AIM-9X, TLAM
J	MK-48, MK-54, HARPOON, ASRAAM, AIM-9X, TLAM
K	MK-48, MK-54, HARPOON, AIM-9X, TLAM
L	MK-48, MK-54, ASRAAM, AIM-9X, TLAM
M	MK-48, HARPOON, ASRAAM, GAU-19, TLAM
N	MK-48, ASRAAM, GAU-19, TLAM
O	MK-54, HARPOON, ASRAAM, AIM-9X, TLAM
P	MK-54, ASRAAM, GAU-19, TLAM
Q	MK-48, MK-54, HARPOON, ASRAAM, GAU-19, TLAM
R	MK-48, MK-54, ASRAAM, GAU-19, TLAM
S	MK-48, AIM-9X, GAU-19, TLAM
T	MK-48, HARPOON, ASRAAM, AIM-9X, GAU-19, TLAM
U	MK-48, HARPOON, AIM-9X, GAU-19, TLAM
V	MK-48, ASRAAM, AIM-9X, GAU-19, TLAM
W	MK-54, AIM-9X, GAU-19, TLAM
X	MK-54, HARPOON, ASRAAM, AIM-9X, GAU-19, TLAM
Y	MK-54, HARPOON, AIM-9X, GAU-19, TLAM
Z	MK-54, ASRAAM, AIM-9X, GAU-19, TLAM
AA	MK-48, MK-54, AIM-9X, GAU-19, TLAM
BB	MK-48, MK-54, HARPOON, ASRAAM, AIM-9X, GAU-19, TLAM
CC	MK-48, MK-54, HARPOON, AIM-9X, GAU-19, TLAM
DD	MK-48, MK-54, ASRAAM, AIM-9X, GAU-19, TLAM

Table 3. DSWS Alternatives Developed by System Morphology

IV. ANALYSIS OF ALTERNATIVES

In order to arrive at a final system configuration that represents the most effective DSWS a detailed evaluation of the alternatives is needed. This chapter develops the method of analysis used to evaluate the performance of the alternatives and provides an example of this method.

A. ANALYSIS METHOD

Having developed a set of alternatives which meet the requirements for DSWS (Table 3), it is now necessary to analyze these alternatives in order to determine which alternative delivers the greatest performance. The overall performance of the system will depend on three factors as well as the application of certain assumptions. Developing a method to combine these factors and assumptions will result in a quantitative evaluation of each alternative developed in the previous chapter. The method for this analysis will be described in the following text supplemented by an example.

The first factor to be considered is the relative threat posed by each of the targets groups represented in the requirements. These target groups are large surface vessels, submarines, fixed wing aircraft, rotary wing aircraft, and small boats. This factor is composed of an estimate of the risk each target group poses to the mission accomplishment and survivability of the platform as well as probability associated with encountering each target group during operations. Depending on the mission scenario and the perceived threats, these sets of target values encompass a wide range. In order to represent the variation of the possible target values that could arise, ten select sets of these values were developed for the testing of the DSWS alternatives. These sets of target values, designated TV1-TV10, were developed to test the DSWS alternatives against a broad range of the possible values that might arise. TV1 and TV8-TV10 are intended to represent real-world mixtures of threat contacts at various levels of importance. TV2 accounts for a case in which all target sets represent an equal threat, and the remaining sets (TV3-TV7) consider the case for one substantial threat with all other threats being equal and much less important. Through this use of diverse target values, the analysis of alternatives will capture performance across a wide range of scenarios. The values assigned to each of these target value sets for use in the evaluation are presented in Table 4.

Target Value Set	Target Values [Surface, Sub, Fixed Wing, Rotary, Small Boat]
TV1	0.24 0.49 0.09 0.12 0.16
TV2	0.20 0.20 0.20 0.20 0.20
TV3	0.60 0.10 0.10 0.10 0.10
TV4	0.10 0.60 0.10 0.10 0.10
TV5	0.10 0.10 0.60 0.10 0.10
TV6	0.10 0.10 0.10 0.60 0.10
TV7	0.10 0.10 0.10 0.10 0.60
TV8	0.45 0.45 0.033 0.033 0.033
TV9	0.15 0.80 0.017 0.017 0.017
TV10	0.30 0.30 0.05 0.30 0..05

Table 4. Target Value Sets for the Analysis of DSWS Alternatives

The second factor of importance to the analysis of the alternatives is the effectiveness of a given weapon against each target set. Table 2 from the previous chapter shows those targets against which a selected weapon would be effective, but for the purpose of analysis, a numerical measure of this effectiveness is needed. The measure of weapon effectiveness against a target group depends on many factors including the attributes of the target, employment methods, weapon range, and targeting efficiency. Because the development of detailed analysis related to the efficiencies of each weapon against each target is beyond the scope of this thesis, these efficiency values will be varied to measure the performance of the alternatives. To insure that the analysis of alternatives considers the range of values that are possible, three selected sets of weapon efficiencies will be used. In each of the selected sets of weapon efficiencies shown in Table 5 the relationships between the performances of each weapon against the targets has been varied to provide the final analysis applicability across a wide range of real-world weapon efficiency values.

		Surface Vessel	Sub. Vessel	Fixed Wing	Rotary Wing	Small Boat
Weapon Efficiency Set 1	MK-48	0.8	0.8			
	MK-54	0.4	0.3			
	Harpoon	0.75				
	ASRAAM			0.35	0.3	
	AIM-9X			0.3	0.45	0.25
	GAU-19				0.25	0.3
Weapon Efficiency Set 2	MK-48	0.75	0.75			
	MK-54	0.2	0.25			
	Harpoon	0.5				
	ASRAAM			0.2	0.15	
	AIM-9X			0.2	0.25	0.1
	GAU-19				0.05	0.15
Weapon Efficiency Set 3	MK-48	0.6	0.6			
	MK-54	0.25	0.2			
	Harpoon	0.3				
	ASRAAM			0.5	0.25	
	AIM-9X			0.4	0.5	0.3
	GAU-19				0.1	0.1

Table 5. Weapon Efficiency Values for the Analysis of DSWS Alternatives

These two factors, target value and weapon efficiency, can be combined to generate a number that will be referred to as the weapon score. A weapon score for each of the input weapons is found by multiplying the weapon efficiency of each individual weapon by the target value that it is associated with and then summing those products. The result represents that weapon's performance for the given scenario of target values and weapon efficiencies. These weapon scores will be used to establish a final performance rating for each alternative (when combined with the number of each weapon to be included) and will also be used for optimizing the number of each weapon to be included within each alternative. As an example of calculating the weapon scores for a scenario, Figure 8 shows this calculation when using TV1 and Weapon Efficiency Set 1.

TV1		Surface	Sub	Fixed Wing	Rotary Wing	Small Boat
		0.24	0.49	0.09	0.12	0.16
Weapon Efficiency Set 1	MK-48	0.8	0.8			
	MK-54	0.4	0.3			
	Harpoon	0.75				
	ASRAAM			0.35	0.3	
	AIM-9X			0.3	0.45	0.25
	GAU-19				0.25	0.3

MK-48	0.584
MK-54	0.243
Harpoon	0.180
ASRAAM	0.069
AIM-9X	0.092
GAU-19	0.041

Multiply the target value for each target set down the column

Summing across the rows results in the weapon scores for the scenario of TV1 and Weapon Efficiency Set 1

	Surface	Sub	Fixed Wing	Rotary Wing	Small Boat
MK-48	0.192	0.392			
MK-54	0.096	0.147			
Harpoon	0.180				
ASRAAM			0.042	0.027	
AIM-9X			0.036	0.043	0.015
GAU-19				0.021	0.018

Figure 8. Example Calculation of Weapon Score Values Using TV1 and Weapon Efficiency Set 1

The final factor in determining the performance of the alternatives is the number of weapons that each alternative will allow based on the limited space available. Allocating weapons effectively will build on the previously developed weapon score the number of TLAMs included and the basic assumptions regarding the size and launch restrictions that exist for the weapons included in the alternatives. The TLAM receives the special consideration because it is the only weapon included in the DSWS that is designed to precision strike against land targets and will be present in all of the alternatives considered. Because of this TLAM need not be ranked against the other weapons considered but the effect of carrying this missile on the amount of space available for the remaining weapons must be taken into account. The GAU-19 input will be treated in a similar fashion due to the fact that only a single unit would be included in the final configuration. Because of this there is no reason to make a comparison for the purpose of allocating weapons. This treatment of TLAMs and the GAU-19 with the assumptions that are made about the weapon sizes and launch restrictions will greatly influence the allocation of weapons within each alternative. Many of the weapon inputs have a significantly smaller diameter than either the VLS cell or the torpedo tube; it is assumed that in order to meet the requirements for submerged launch all weapons will require an entire torpedo tube diameter for launch. A further assumption is that VLS tubes are single use, capable of holding only a single weapon of any type. For torpedo tube launched weapons the storage capacity will be based on the length of the weapon. Thus, a MK-48 ADCAP, a Harpoon Missile and a TLAM all occupy an equivalent amount of space, while double the number of the MK-45, ASRAAM, and AIM-9X (at approximately half the length of the MK-48) is achievable. The remaining assumption is that the MK-48 and MK-54 torpedoes are not capable of launch from a VLS cell, but all of the remaining weapons can be launched from either VLS cells or torpedo tubes. This combination of assumptions is the basis used for calculating the most effective load out of candidate weapons within each alternative.

To effectively allocate the weapons of a given alternative, a method of pair comparisons is undertaken. This method considers each possible pair of weapons in isolation to determine the performance relationship between that pair. This is achieved by calculating the maximum number of each weapon in the pair that could be carried based on the assumptions stated above and the number of TLAMs to be included in the analysis. Multiplying the Weapon Score for each of the weapons being compared by the maximum number that could be carried results in a performance score that represents the effectiveness of those weapons. The difference between these two scores reflects the advantage or disadvantage of one weapon in relation to the other, with a positive result indicating advantage and a negative value a disadvantage. Repeating this method for the possible remaining weapon pairs results in a matrix of values that represent the advantage or disadvantage that is present between each pair. Figure 9 shows the development of a comparison between the MK-48 and the AIM-9X with a load of twelve TLAMs and also shows the completed advantage matrix that will be used in the following steps.

Weapon	Max Number	Comment
MK-48	24	With 12 TLAMs the entire torpedo stowage space is available
AIM-9X	48	With 12 TLAMs the max number is achieved by placing all AIM-9X in the torpedo tube stowage. AIM-9X has only half the length of MK-48 and as a result 48 can be carried

For the pair being considered determine the maximum number allowed by assumptions and TLAM load

Multiply the maximum load by the Weapon Score to determine the performance of each weapon. Take the difference to determine the advantage/disadvantage

Weapon	Max Number	Weapon Score	Performance Rating (Max Number * Weapon Score)	Advantage/Disadvantage
MK-48	24	0.584	14.016	14.016 – 4.392 = 9.624
AIM-9X	48	0.092	4.392	4.392 – 14.016 = -9.624

Place the resulting advantage/disadvantage into a matrix

	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X
MK-48					9.624
MK-54					
Harpoon					
ASRAAM					
AIM-9X	-9.624				

Repeat the process for each weapon pair to populate the advantage/disadvantage matrix

	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X
MK-48		2.352	9.696	10.704	9.624
MK-54	-2.352		7.344	8.352	7.272
Harpoon	-9.696	-7.344		1.008	-0.072
ASRAAM	-10.704	-8.352	-1.008		-0.252
AIM-9X	-9.624	-7.272	0.072	0.252	

Figure 9. Example of Paired Comparison Between a MK-48 and an AIM-9X to Develop an Advantage Matrix

Using this matrix containing the advantages and disadvantages of each weapon pair, effective ratios of weapons in the final allocation for each alternative can now be calculated. This is done by first eliminating the rows and columns of those inputs that are not included in the alternative being considered. The remaining values are summed across the rows resulting in a singe value for each weapon present in the alternative. These values are the final ratios of weapons that will be used to determine the number of each weapon present in that alternative. These ratios require some adjustment in order to ensure that each of the inputs is represented in the final allocation. In cases where a weapon has no net advantage over any of the other inputs, the resulting ratio value will be negative, these values are reassigned a value of one. In a similar fashion, weapons with a resulting ratio value of less than one (indicating a very small advantage over the remaining weapons) are also reassigned a value of one. Repeating this method for each of the alternatives being compared gives the resulting ratios needed to determine the need allocations. The example presented in Figure 10, shows the determination of these ratios and the necessary adjustments for Alternatives G using the data developed in the previous examples.

Alternative G includes the MK-54, Harpoon, and AIM-9X so the remaining rows and columns are eliminated

	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X
MK-48		2.352	9.696	10.704	9.624
MK-54	-2.352		7.344	8.352	7.272
Harpoon	-9.696	-7.344		1.008	-0.072
ASRAAM	-10.704	-8.352	-1.008		-0.252
AIM-9X	-9.624	-7.272	0.072	0.252	

The remaining rows are summed to arrive at the ratio values for the weapons included in Alternative G

MK-54	7.344 + 7.272 = 14.616
HARPOON	-7.344 + -0.072 = -7.416
AIM-9X	-7.272 + 0.072 = -7.20

These ratio values are then adjusted to ensure that all of the inputs are included in the final allocation. Values less than 1.0 are reassigned a value equal to 1.0

	Final Adjusted Ratio
MK-54	14.616
HARPOON	1
AIM-9X	1

Figure 10. Example Determination of Weapon Ratios Using an Advantage Matrix

Armed with these ratios the remaining step in determining the load out for each alternative is the assignment of weapons in these ratios to that available space aboard the submarine. The assumptions stated earlier regarding the space need for each weapon and the restrictions on which launchers are usable by each weapon must be considered. Using the ratios determined two methods of allocation are performed simultaneously. In the first determination the ratio of the torpedo tube only weapons (MK-48 and MK-54) are used to allocate the space available in only the torpedo tubes, with the remaining weapon ratios are used to assign weapons to the available VLS or missile tubes. This established the upper bound for torpedo tube weapons and the lower bound for the number of VLS/missile tube weapons. The second allocation considers the ratios for all weapons for placement in all of the available space (torpedo tubes and VLS/missile tubes). This will result in the optimum load separate from the constraints mentioned. Comparison of the two results produces the final allocation of weapons. For the torpedo weapons (limited to torpedo tube launch) the smaller of the two values is taken (either the optimum number or the maximum number), while for the remaining weapons the larger value is chosen (representing the minimum to achieve a full load or the optimum), in both cases the number produced is truncated to produce a final allocation of whole numbers of each weapon. Figure 11 provides an example of the torpedo tube limited method while Figure 12 shows the use of all available space. Both examples use Alternative G (ratios developed in the previous example) and Alternative J with an inventory of twelve TLAMs. In Figure 13, the selection of the appropriate values from each method is shown to arrive at the final allocation for these two Alternatives.

Alternative G

	Final Adjusted Ratio
MK-48	0
MK-54	14.62
HARPOON	1
ASRAAM	0
AIM-9X	1

Considering only the torpedo weapons, the MK-54 represents 100% of the allocation.

Both the Harpoon and the AIM-9x represent 50% of the load, but with 12 TLAMs no tubes are available resulting in zero of each in this method

	Percent of Torpedo Space	Number of Weapons
MK-48	0	0
MK-54	100%	48
HARPOON	50%	0
ASRAAM	0	0
AIM-9X	50%	0

Alternative J

	Final Adjusted Ratio
MK-48	32.38
MK-54	20.62
HARPOON	1
ASRAAM	1
AIM-9X	1

With two torpedoes in the alternative, the ratio is divided by the sum of the two torpedo values to get the percentage.

Again, each missile is equally represented but the TLAMs leave no tube available

	Percent of Torpedo Space	Number of Weapons
MK-48	61.1 %	14.66
MK-54	38.9 %	18.67
HARPOON	33.3 %	0
ASRAAM	33.3 %	0
AIM-9X	33.3 %	0

Figure 11. Example of Allocating Weapons – Torpedo Tube Restricted Considerations

Alternative G

	Final Adjusted Ratio
MK-48	0
MK-54	14.62
HARPOON	1
ASRAAM	0
AIM-9X	1

When all space is considered, the percentage of each weapon is found by dividing each weapon ratio by the sum of all the ratios

	Percent of Torpedo Space	Number of Weapons
MK-48	0	0
MK-54	88 %	42.2
HARPOON	6 %	1.4
ASRAAM	0	0
AIM-9X	6 %	2.9

Alternative J

	Final Adjusted Ratio
MK-48	32.38
MK-54	20.62
HARPOON	1
ASRAAM	1
AIM-9X	1

Each percentage of space then accounts for the assumed size of the weapon to reach the final number

	Percent of Torpedo Space	Number of Weapons
MK-48	57.8 %	13.9
MK-54	36.8 %	17.7
HARPOON	1.79 %	.4
ASRAAM	1.79 %	.9
AIM-9X	1.79 %	.9

Figure 12. Example of Allocating Weapons Unrestricted by Launcher Considerations

Alternative G

	Number Determined By Torpedo Tube Limited Case	Number Determined By Unrestricted Case	Final Allocation – Selected Number of Weapons (Rounded)
MK-48	0	0	0
MK-54	48	42.2	42
HARPOON	0	1.4	2
ASRAAM	0	0	0
AIM-9X	0	2.9	3

For the torpedoes, select the smaller value and round down to nearest whole weapon

For the remaining weapons select the greater value and round up to the nearest whole weapon.

Alternative J

	Number Determined By Torpedo Tube Limited Case	Number Determined By Unrestricted Case	Final Allocation – Selected Number of Weapons (Rounded)
MK-48	14.66	13.9	13
MK-54	18.67	17.7	17
HARPOON	0	.4	1
ASRAAM	0	.9	1
AIM-9X	0	.9	1

Figure 13. Example of Combining Two Allocation Methods to Arrive at the Final Weapon Allocation

With the allocation of weapons within each alternative, the overall performance score can now be calculated. Multiplying the number of each weapon determined by the by the associated Weapon Score and summing the results of all the weapons produces a performance score. The greatest score out of all the alternatives considered represents the best performance for the given scenario (target value set, weapon efficiency, and TLAM load). Figure 14 concludes the example by showing the determination of the Performance Scores for Alternatives G and J.

Alternative G

	Number Determined By Torpedo Tube Limited Case	Weapon Score	Number of Weapons * Weapon Score
MK-48	0	0.584	0
MK-54	42	0.243	10.206
HARPOON	2	0.180	0.360
ASRAAM	0	0.069	0
AIM-9X	3	0.092	0.276
		Sum of All Weapons	10.842

This represents the Performance score for Alternative G

Alternative J

	Number Determined By Torpedo Tube Limited Case	Weapon Score	Number of Weapons * Weapon Score
MK-48	13	0.584	7.592
MK-54	17	0.243	4.131
HARPOON	1	0.180	0.180
ASRAAM	1	0.069	0.069
AIM-9X	1	0.092	0.092
		Sum of All Weapons	12.064

This represents the Performance score for Alternative J. For the given scenario Alternative J is expected to perform better than Alternative G (since 12.064 > 10.842)

Figure 14. Example Calculation of the Performance Score for Two Alternatives

Beginning with the target values, weapons efficiencies, and TLAM inventory, this process (Figure 15) determines the alternative that has the greatest performance. By applying the assumptions related to weapon size and launcher restrictions it also determines the number of each weapon to be allocated with each alternative based on the scenario defined. When this analysis process is applied to each of the alternatives being considered the relative performance of each alternative in a given scenario is determined. The resulting performance of each alternative is then viewed over the range of scenarios by varying each combination of target value (TV1-TV10), weapon efficiency (Sets 1, 2, and 3) and TLAM inventory (five values) to make a determination of overall performance. These combinations result in one-hundred fifty scenarios being tested that represent a wide range of possible conditions.

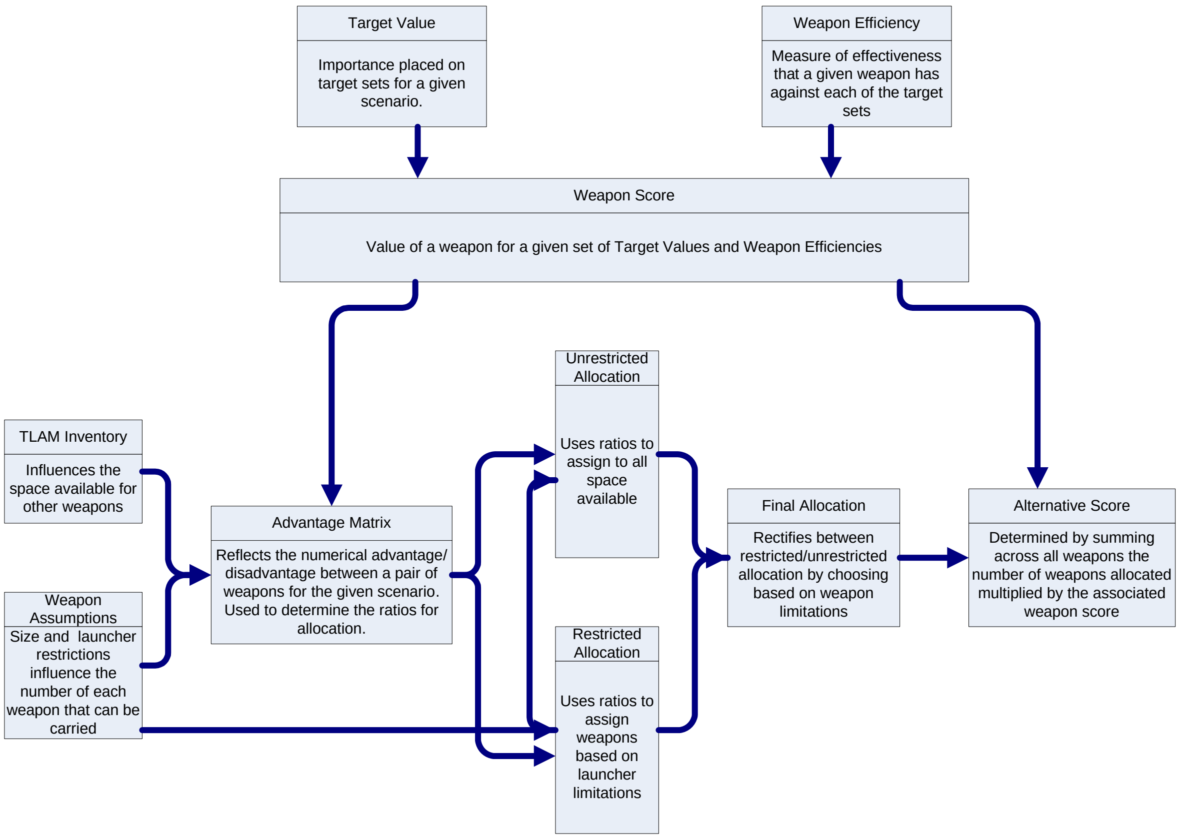

Figure 15. Diagram Summarizing the Analysis Process Used to Develop Weapon Allocations and Alternative Performance

Before applying this method to the alternatives developed in the previous chapter, an additional distinction was made to account for the various configurations of submarines that exist in the current force. The remaining analysis for DSWS will be separated to focus on two generic platforms. These platforms are differentiated on the basis of payload size, with one representing a typical SSN with twelve VLS cells and stowage for twenty-four MK-48 sized weapons. The other represents an SSGN with twenty-four converted D5 missile tubes each with the capacity of seven VLS cells and stowage for twenty-four MK-48 sized weapons. The results of applying the process developed here to these to cases are presented in the following sections.

B. SSN ANALYSIS

The analysis for the SSN begins with specific consideration of the weapons and their relationship to the available space. The GAU-19 option, which will require a larger amount of space than any available on the SSN platform cannot be considered a viable option for the SSN platform. The exclusion of the GAU-19 leaves Alternatives A-L from Table 3 to be considered for the SSN. As discussed in the development of the analysis method, the number of TLAMs was varied within the analysis. For the SSN case, the TLAM values assigned were chosen to represent reasonable load out of these missiles and ranged from zero to twenty-four missiles using increments of six missiles. Based on the weapon assumptions of the analysis and the space available for weapons aboard the SSN the maximum number of each weapon was determined (Table 6).

	VLS Cells	Torpedo Tube	Maximum Available
MK-48	0	24	24
MK-54	0	48	48
Harpoon	12	24	36
ASRAAM	12	48	60
AIM-9X	12	48	60
TLAM	12	24	36

Table 6. Maximum Weapon Allocation for SSN Consideration

Use of the method developed in the previous section to analyze Alternatives A-L (Table 3) results in a ranking of each alternative for each scenario. This analysis includes the one hundred fifty scenarios defined by varying target values (Table 4), weapon efficiency values (Table 5), and the number of TLAMs in the load out. From the results of this analysis the best performing alternative and the second best alternative are selected for further analysis, the resulting data set is presented as an appendix. A histogram Figure 8) shows the number of times each alternative resulted in the best or second-best performance.

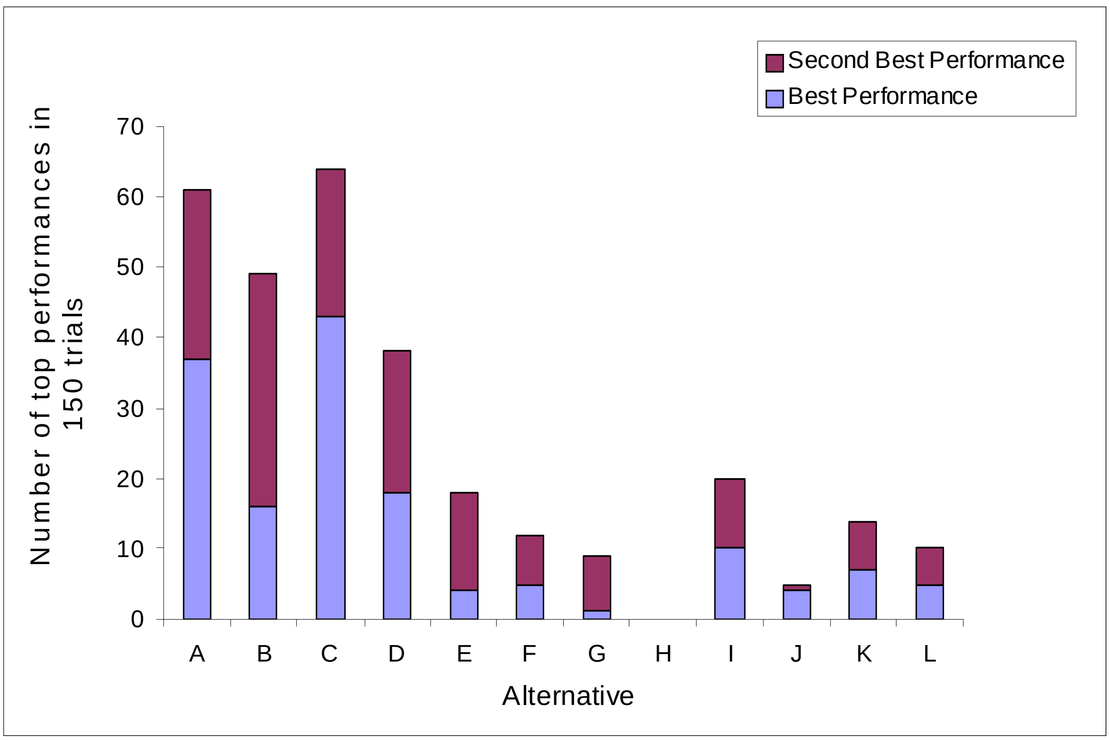

Figure 16. Performance of DSWS SSN Alternatives Showing the Highest Rated Alternative and the Second Best Alternative for the 150 Scenarios Analyzed

From the results shown in Figure 16 it is seen that Alternatives A, B, C, and D represent the strongest performance across the range of scenarios tested, representing either the best or second best alternative in over 70% of the trials. The four alternatives demonstrating the strongest performance are those which include the MK-48 as the only torpedo option, suggesting that there is little advantage in including a smaller torpedo (alone or in combination with a HWT) in the DSWS. The combination of the ASRAAM missile with the AIM-9X also shows little advantage. Comparison of Alternatives including both missiles with Alternatives employing only the AIM-9X shows that in only one of the six pairs does the combination perform better.

Alternative C was the best performer, representing a top alternative in over 40% of the scenarios analyzed. Alternative C showed equal performance over all three of the weapon efficiency sets used, and at least some level of performance against all but one of the included sets of target values. The target value set which placed a high level of importance on fixed wing aircraft was the only target set in which this alternative did not achieve at least some success. The remaining Alternatives (A, B, and D) all showed a similar equal performance across all three weapon efficiency sets, as well as a measure of success in all ten representations of target value. As a final consideration, the performance of each of these alternatives was independent of the number of TLAM strike weapons included in the weapon load, indicating that each alternative was capable of supporting any level of strike. Table 7 includes the average weapon allocations that resulted in the performance of these alternatives.

	MK-48	Harpoon	ASRAAM	AIM-9X	TLAM
A	13	0	0	18	13
B	15	2	5	8	11
C	18	3	0	7	10
D	9	0	7	20	13

Table 7. Average Weapon Allocations for the Top Four Performing SSN Alternatives

C. SSGN ANALYSIS

The analysis for the SSGN is conducted in similar fashion to that of the SSN. The significant difference is the larger number of weapons that can be supported by the SSGN. Also, because of its large diameter missile tubes, the SSGN is capable of supporting the GAU-19 which was excluded from the SSN analysis due to space constraints. The inclusion of the GAU-19 was limited to one unit, taking the space of one entire D5 missile tube. Converted missile tubes aboard the SSGN will follow the assumptions made in the previous section with regard to weapon sizing and use in VLS cells, with each tube capable of supporting seven weapons regardless of weapon diameter. In order to account for SOF equipment and special use of some missile tubes, DSWS will only consider eighteen of the twenty-four missile tube available for use. The TLAM values assigned for the SSGN case were chosen to represent reasonable load out of these missiles and ranged from seventy to one hundred twenty-six missiles using increments of fourteen missiles. Table 8 summarizes these considerations and the resulting effect on the maximum load of each weapon for the SSGN analysis.

	Converted Missile Tubes	Torpedo Tube	Maximum Available
MK-48	0	24	24
MK-54	0	48	48
Harpoon	140	24	150
ASRAAM	140	48	174
AIM-9X	140	48	174
TLAM	140	24	150
GAU-19	1	0	1

Table 8. Maximum Weapon Allocation for SSGN Consideration

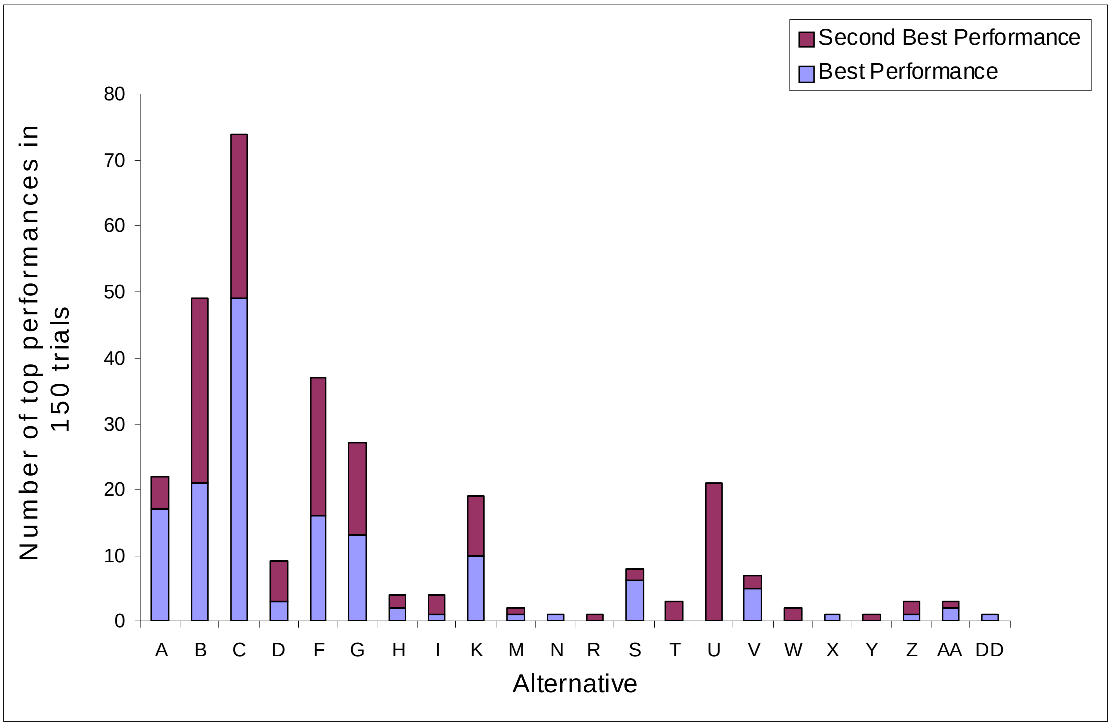

Figure 17. Performance of DSWS SSGN Alternatives Showing the Highest Rated Alternative and the Second Best Alternative for the 150 Scenarios Analyzed

From the results shown in Figure 17 it is seen that Alternative C represents the strongest performance with Alternatives A, B, F, G, and K having lower but significant levels of performance. Similar to the SSN analysis it can be seen that the most successful alternatives (A, B, and C) were those including the MK-48 ADCAP as the only torpedo. Although in the SSGN case there was some level of performance from the smaller torpedo cases, the results again suggest that there is little advantage in including lightweight torpedoes in the DSWS. The small number of top performances by Alternatives M-DD indicates that the GAU-19 was not an effective addition to the DSWS.

From the results shown in Figure 9, it is seen that Alternatives C is the dominant performer for the SSGN platform. Alternative C demonstrated the strong performance in nearly 50% of the scenarios considered. Alternative C showed equal performance over all three of the weapon efficiency sets used, as well as performance against all of the included sets of target values. For Alternative C, as well as the remaining top

Alternatives (A, B, F, G, and K), performance was independent of the number of TLAM strike weapons included in the weapon load, indicating that each alternative was capable of supporting any level of strike. Table 9 includes the average weapon allocations that resulted from the analysis and contributed to the performance of these alternatives.

	MK-48	Harpoon	ASRAAM	AIM-9X	TLAM
A	23	0	0	31	100
B	18	18	11	28	97
C	17	12	0	44	95

Table 9. Average Weapon Allocations for the Top Three Performing SSGN Alternatives

V. CONCLUSIONS

A. DISCUSSION

The DSWS represents a submarine weapons system that will deliver the greatest opportunity for mission success and platform defense. The development of DSWS, using systems engineering processes and tools, suggests a system that is greatly expanded from the systems in use today. The analysis conducted by this thesis recommends that the greatest level of performance across a range of threat targets is achieved by a DSWS that includes the MK-48 ADCAP, the Harpoon anti-shipping missile, and the AIM-9X missile, in addition to the TLAM. For both the SSN and SSGN platforms, this conceptual system satisfied the requirements developed, and demonstrated the greatest flexibility in addressing diverse situations.

The MK-48 torpedo remains the weapon of choice for engaging submerged and surface vessels. Over a wide range of threat scenarios, the greater effectiveness of the heavyweight torpedo was shown to provide better performance than a larger number of smaller weapons. This performance, combined with the greater level of control that can be exercised over a wire-guided weapon, reinforces the use of the MK-48 as the premier weapon for submarine use. In both the SSN and SSGN the top performing alternatives in this analysis included heavyweight torpedoes at levels that are supported by current submarine design and weapon inventories. The results of this thesis strongly indicate that the HWT will continue to be an integral part of the submarine weapon system and to have great value to the submarine force.

It is recognized the submarine launched Harpoon is not currently a factor in submarine armament. However, the Harpoon missile system would offer improved performance of the submarine weapon system. The extended range of the Harpoon missile and its ability to be VLS launched expand the capability of the submarine to engage surface targets. The analysis shows that large numbers of these missiles are not needed to deliver this increased performance. For the SSN the inclusion of a small number, ranging from two to six, was sufficient to deliver an advantage. In the SSGN, with its greater capacity, the inclusion of up to eighteen Harpoon missiles was shown to be effective. Because of the ability to launch submarine Harpoon missiles has been previously developed, the inclusion of this component in the DSWS should represent a small investment of time and effort, with the majority of the effort being the ability to launch these weapons from VLS cells.

The AIM-9X Sidewinder missile brings new capabilities to the submarine platform. The ability to engage airborne targets is a new submarine capability that must be met. In this analysis the engagement of airborne contacts was achieved through the use of both the AIM-9X and the ASRAAM missile. For SSN use, the combination of both missiles provided no gain in performance over the inclusion of only the AIM-9X. For the SSGN there was little difference in performance between the two configurations. Due to its ability to target small fast moving boats, the AIM-9X showed greater performance across the range of scenarios investigated. Independent of which missile is included in DSWS, the development of an underwater launcher system for missile weapons is critical to their use aboard submarines. Based on the requirements developed in this thesis, realization this underwater launch system is extremely important to future submarine capability.

The methodology used in the development DSWS is an effective method for determining weapon selection based on operational requirements. The results presented in this thesis reflect a limited selection of input weapons, and are based on engineering assumptions for several influential values. Conservative estimates of the size and space requirements for weapons, estimates of weapon effectiveness, and assumed target values all affect the results presented here. The methodology employed to develop requirements, select weapons, construct alternatives, allocate weapons and evaluate performance is not intended to represent the perfect solution to the submarine weapon selection problem, but to demonstrate the value of applying these methods to the conceptual design of the system. The method allows for changing conditions and assumptions that can be adjusted and updated to understand the impact of small changes on the overall system performance. In this way, it is the method for arriving at a conceptual design that represents the greatest value in this work.

A diversified weapon system, defined by the systems engineering process developed in this thesis will result in the system that offers the greatest levels of mission accomplishment and submarine survivability. The mix of weapons proposed by this analysis increases mission performance and lowers the risk to the submarine force for the short term. This mix demonstrates how current forces can be better equipped to face the challenging missions without significant changes to submarine design or the costly development of new weapons. The process employed to reach these conclusions can be of great value in investigating individual operating scenarios as well as informing overall development strategies. By using the systems engineering process to define the requirements and develop an integrated solution the submarine force can continue to dominate the battle space.

B. FUTURE WORK

The DSWS represents the development of a conceptual design for a submarine weapon system. Many of the inputs selected are based on the author's interpretation of real world scenarios and selected cases to probe the boundaries of performance. Continued work to clarify these assumptions and give greater credibility to the results would contribute greatly to the development of submarine weapons systems. Based on the work completed here, further development in both technical areas and operational areas would be of great value in moving forward the development of submarine weapons systems.

Further studies of the operational considerations in this thesis are needed. Analysis of submarine operations aimed at the development of more accurate target value sets would add a greater level of specificity to the analysis method used. Consideration of specific operating areas and specific adversary force structures to determine improved target values would result in a more focused assessment of performance. Target threat values must also expand to include the development of new weapon and sensor capabilities gained by adversaries. The development of accurate weapon efficiency values would also be of benefit. The development of these values was not undertaken by this work in an effort to avoid the use of classified information, but would provide the analysis with a higher level of accuracy. The use of weapon efficiencies determined with a focus on weapon ranges, probabilities of hit and kill (and other factors) are an important factor in the analysis process.

Technical development opportunities are also highlighted through this DSWS design process. The foremost of these being the ability to conduct submerged launch of the weapons considered. Design criteria for encapsulation systems or submerged operation of weapons are a critical aspect of bringing such a system beyond the design phase of the life-cycle. Investigation of an adaptable system that could be used for the launch of several types of weapons represents great value to the future of submarine weapon design. Further opportunities exist in developing the required operator interface for weapons considered and command and control functions of the weapon system. With the diversity of weapons available, these supporting systems must be developed to provide the operator with the ability to effectively employ the system.

APPENDIX A. WEAPONS CONSIDERED FOR INCLUSION IN DSWS

This appendix provides a brief description of the physical characteristics and operational utility of the weapons considered for inclusion in the DSWS. Several weapons considered but not meeting the stealth requirements of the DSWS system are not included in this listing. These omitted considerations include such weapons as the Barak (Israeli), the Crotale (France), and the Hellfire which require command guidance, and manned systems which could meet the target set requirements, but would require a sacrifice in stealth of the launch platform to employ.

A. AIM-9X

The Aim-9X is a supersonic, air-to-air guided missile which employs a passive IR target acquisition system and an Active Optical Target Detector (AOTD). The missile is propelled by the AIM-9M solid-propellant rocket motor and carries an annular blast fragmentation warhead. Lift and stability are provided by four forward mounted, titanium wings while maneuvering is accomplished by four control fins activated by a control actuation system which uses thrust vector control to direct flow of the rocket exhaust. Based on the speed of the AIM-9X and the capability of the IR seeker, this weapon was selected for inclusion in the input set of DSWS [The Federation of American Scientists 2000b; Jane's Air Launched Weapons 2008a]. The AIM-9X could be launched from VLS or torpedo tubes.

Length (in)	119
Body Diameter (in)	5
Weight (lbs)	188
Speed	Mach 2.5
Range	20 kyds
Warhead	25 lb Blast/Fragmentation
Guidance	IR Seeker

B. ADVANCED SHORT RANGE AIR-TO-AIR MISSILE (ASRAAM)

THE ASRAAM is a highly maneuverable sir combat missile capable of engaging modern combat aircraft. Utilizing a high sensitivity IR seeker is capable of delivering fire and forget capability while remaining very resistant to electronic countermeasures. ASRAAM is powered by a solid propellant rocket motor, and maneuvers using clipped delta control fins (the missile is wingless) [The Federation of American Scientists 1998a; Jane's Air Launched Weapons 2008b].

Length (in)	114.2
Body Diameter (in)	6.54
Weight (lbs)	188
Speed	
Range	11 kyds
Warhead	Blast/Fragmentation
Guidance	Imaging IR

C. ENHANCED FIBER OPTIC GUIDED MISSILE (EFOG-M)

Under development by the U.S. Army, the EFOG-M utilizes a direct fiber optic command link to provide the operator with control and visual imaging from the missiles high resolution infrared video camera. Capable of flying a preprogrammed flight path, the missile relies on operator designation of targets which are prosecuted using and infrared seeker [The Federation of American Scientists 1998b; Jane's Electro-Optic Systems 2002]. Envisioned as a torpedo tube launched weapon, implementation of the EFOG-M would require a continuous fiber link to the launch platform, and extensive supporting system installations Based on these limitations the EFOG-M was not included in the input set of DSWS.

Length (in)	76.5
Body Diameter (in)	6.55
Weight (lbs)	173
Speed	100 m/s
Range	16 kyds
Warhead	8 lb Shaped Charge
Guidance	IR Seeker

D. EVOLVED SEA SPARROW MISSILE (ESSM)

The ESSM is a short range missile designed for self protection of surface vessels [Mateski and Kravitz 1997]. Capable of VLS or torpedo tube launch, the ESSM was not included in the input set for DSWS due to its similarities with the Harpoon.

Length (in)	144
Body Diameter (in)	10
Weight (lbs)	620
Speed	Mach 3
Range	56 kyds
Warhead	25 lb Blast/Fragmentation
Guidance	Semi-active Radar

E. GABRIEL

The Gabriel is a medium range anti-ship missile in use by Israeli forces. Utilizing a solid propellant sustainer and a booster, the missile employs active radar to delver a 150 kg, high explosive warhead [The Federation of American Scientists 1999b; Jane's Air

Launched Weapons, 2008c]. Due to the similarity with the U.S. produced Harpoon missile the Gabriel was not selected as an input to DSWS

Length (in)	153.5
Body Diameter (in)	13.4
Weight (lbs)	1323
Speed	840 km/hr
Range	44 kyds
Warhead	330 lb High Explosive
Guidance	Active Radar (I-band)

F. GAU-19

The GAU-19 is a 0.50 caliber three barrel machine gun capable of delivering lethal firepower to many air, land or sea targets [Jane's Infantry Weapons, 2008]. Based on its lightweight and large ready fire ammunition storage, the GAU-19 was selected as an input to the DSWS.

Length (in)	47.2
Weight (lbs)	74
Muzzle Velocity	884 m/s
Range	1500 m
Firing Rate	1000-2000 Rounds/min

G. HARPOON

Previously employed by submarines, the Harpoon is a long range anti-ship missile. Utilizing an active radar seeker and an integrated GPS/INS system the Block II version is included in the DSWS input set [The Federation of American Scientists 2008a; Jane's Naval Weapons Systems, 2008].

Length (in)	151.6
Body Diameter (in)	13.5
Weight (lbs)	1226
Speed	
Range	131 kyds
Warhead	500 lb High Explosive
Guidance	Active Radar with GPS/INS

H. HIGH-SPEED ANTI-RADIATION MISSILE (HARM)

Designed as an air-to-surface missile to destroy radar equipped sir defense systems, the HARM utilizes a fixed antenna to home on target radar emissions [The Federation of American Scientists, 2000a]. Because of the HARM's limited effectiveness against a non-emitting target, it was not included in the DSWS input set.

Length (in)	164
Body Diameter (in)	10
Weight (lbs)	800
Speed	760 mph
Range	162 kyds
Warhead	150 lb Blast/Fragmentation
Guidance	Radar Homing

I. MK-46 LIGHTWEIGHT TORPEDO (MK-46)

The MK-46 torpedo is designed to be launched from surface combatant torpedo tubes, ASROC missiles and fixed and rotary wing aircraft. Capable of passive or active acoustic homing the MK-46 utilizes a two-speed, reciprocating external combustion engine fueled by a monopropellant (Otto fuel). In 1989, a major upgrade program began to enhance the performance of the MK-46 Mod 5 in shallow water, resulting in the Mod 5A and Mod 5A(S). The MK-46 Mod 5 torpedo is the backbone of the Navy's lightweight ASW torpedo inventory and is expected to remain in service until the year 2015 [Jane's Underwater Warfare Systems 2006; Scott 2007]. Based on its similarity in size and capability to the newer, MK-54 LHT, the MK-46 was not included in the input set for DSWS.

Length (in)	102.4
Body Diameter (in)	12.75
Weight (lbs)	518
Speed	45 kts
Range	12 kyds
Warhead	98 lb High Explosive
Guidance	Passive Active Acoustic

J. MK-48 ADVANCED CAPABILITY TORPEDO (MK-48 ADCAP)

The MK 48 can be used against surface ships or submarines, and has been test fired under the Arctic ice pack and in other arduous conditions. The ADCAP version, in comparison with earlier MK 48 torpedoes, has improved target acquisition range, reduced vulnerability to enemy countermeasures, reduced shipboard constraints such as warm-up and reactivation time, and enhanced effectiveness against surface ships. The MK 48 is propelled by a piston engine with twin, contra-rotating propellers in a pump jet or shrouded configuration. The engine uses a liquid monopropellant fuel, and the torpedo has a conventional, high-explosive warhead. The MK 48 has a sophisticated guidance system permitting a variety of attack options. As the torpedo leaves the submarine's launch tube a thin wire spins out, electronically linking the submarine and torpedo. This enables an operator in the submarine, with access to the submarine's sensitive sonar systems, initially to guide the torpedo toward the target. The wire is severed and the torpedo's high-powered active/passive sonar guides the torpedo during the final attack. The MK 48 Mod 5 ADCAP torpedo is an improvement to the MK 48 submarine launched torpedo. It is a heavyweight acoustic homing torpedo with sophisticated sonar and a fused warhead. The ADCAP enhancement includes all digital guidance and control systems, digital fusing systems, and propulsion improvements that add speed, depth, and range capability [The Federation of American Scientists 1998d; Scott 2005]. As the premier weapon for submarine employment the MK-48 was included as an input to the DSWS.

Length (in)	228
Body Diameter (in)	21
Weight (lbs)	3695
Speed	55+ kts
Range	50+ kyds
Warhead	650 lb High Explosive
Guidance	Passive/Active Acoustic, Wire Guided

K. MK-50 LIGHTWEIGHT TORPEDO (MK-50)

The MK 50 torpedo was developed as the next generation lightweight torpedo to gradually replace the existing MK 46 torpedo as the Navy's primary ASW weapon for aircraft (fixed wing and helicopters) and surface ships. The MK 50 provides an air or surface ship launched anti-submarine weapon for force protection. The MK-50 represents an interim development between the MK-46 and the MK-54 LHT and never reached full rate production [Jane's Underwater Warfare Systems, 2006]. Based on this the MK-50 was not included in the input set for DSWS.

Length (in)	112
Body Diameter (in)	12.75
Weight (lbs)	750
Speed	45 kts
Range	12 kyds
Warhead	98 lb High Explosive
Guidance	Passive/Active Acoustic

L. MK-54 LIGHTWEIGHT HYBRID TORPEDO (MK-54 LHT)

The MK-54 torpedo was designed to replace the MK-46 for use as an ASW by airborne platforms and surface vessels. The MK-54 utilizes the warhead portion of a MK-46, the guidance and processing capability of the MK-50, and control capability from the MK-48 [The Federation of American Scientists 1998e; Jane's Underwater Warfare Systems, 2006]. The Mk-54 represents the future of U.S. lightweight torpedoes and was included as an input to DSWS. (The specifications below are combination of the relevant MK-46 and MK-50 specifications)

Length (in)	112
Body Diameter (in)	12.75
Weight (lbs)	750
Speed	45+ kts
Range	12+ kyds
Warhead	98 lb High Explosive
Guidance	Passive/Active Acoustic

M. PENGUIN

Originally developed as a ship-to-ship missile, the Penguin missile was designed to a specialized Norwegian requirement for use in the complex littoral environment of the Norwegian fjords. The Penguin Mk 2 Mod 7, the helicopter-launched version, has four forward-mounted swept canard control fins and four folding rounded leading-edge delta-wings just aft of mid-body with ailerons for roll stabilization. This version uses an inertial mid-course guidance system with radio altimeter with provision for preprogrammed step changes in both altitude and direction, as well as the capability to fly over land and water. A completely passive launch can be made, using third-party targeting data or the missile's own electro-optical seeker. The missiles will follow a random course with pop-up maneuvers and waypoint turns of up to 180° en route to the target. The missile can also be preprogrammed to overfly a selected number of ship targets before making an attack. Both versions have a passive IR terminal seeker that is highly resistant to countermeasures [The Federation of American Scientists 1999a]. The Penguin missile has a large wingspan that would require significant redesign to meet the requirements for submarine launch, for this reason it was excluded from the input set of DSWS.

N. TOMAHAWK LAND ATTACK MISSILE (TLAM)

The TLAM is a precision land strike weapon utilizing various inertial navigation and terrain mapping for guidance. The guidance system is given the coordinates of the ship and the target before launching and ensures that the missile makes landfall at the predetermined point. The two most current versions of the weapon, designated TLAM-C and TLAM-D fulfill different roles within the land strike mission. The TLAM-C is designed to neutralize important hard shore targets such as naval bases or airfields. The alternative role is to weaken such targets before they are attacked by manned naval aircraft, for example by destroying command posts and air defense networks. TLAM-D is designed for attacks on softer targets such as aircraft, troop concentrations and defensive sites. The TLAM-D payload consists of 24 packages arranged along the missile axis and containing a total of 166 Aerojet Ordnance Combined Effects Bomblets (CEB) each combines armor-piercing, fragmentation and incendiary effects. The packages can be dispensed in groups against as many as three targets in succession [The Federation of American Scientists 2008b]. The TLAM is employed aboard submarines for delivery against land targets, representing one of the core missions of the DSWS. For this reason the TLAM is included in the DSWS input set.

Length (in)	120.5
Body Diameter (in)	11.2
Weight (lbs)	847
Speed	Mach 1.2
Range	51 kyds
Warhead	110 lb High Explosive
Guidance	IR/Inertial

Length (in)	246
Body Diameter (in)	20.4
Weight (lbs)	3201
Speed	Mach 0.75
Range	1013 kyds
Warhead	454 kg High Explosive, (TLAM-C) CEBs (TLAM-D)
Guidance	Inertial/TERCOM DSMAC

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APPENDIX B. EXAMPLE CALCULATION OF DATA

The steps of the analysis method presented in Chapter IV of this thesis were carried out using an Excel spreadsheet. The example below demonstrates the function of the spreadsheet used to calculate alternative scores while varying the parameters of target value, weapon efficiency, and number of TLAMs. The construction of the spreadsheet was such that a single example can be used to demonstrate the functionality. The data collected from these calculations are presented as separate appendices.

This example presents the evaluation of Alternatives A-L (an SSN example), using the values of Target Value set 1 (TV1) and Weapon Efficiency Set 1 with a load of six TLAMs. The first action undertaken is to place these values into the areas provided by the spreadsheet as shown in Figure 18.

	Required Targets						
	Surface Vessel	Submarine	Fixed Wing	Rotary Wing	Small Boat		
Weapon Choices	0.24	0.49	0.12	0.09	0.06	Threat Level Associated with Target	Number of TLAM included for strike 6
MK-48	0.8	0.8				Weapon Effectiveness	
MK-54	0.4	0.3					
Harpoon	0.75						
ASRAAM			0.35	0.3			
AIM-9X			0.3	0.45	0.25		
GUI-19A				0.25	0.3		

Figure 18. Spreadsheet Inputs for the Evaluation of Alternatives

The spreadsheet uses the provided values to calculate the weapon score by multiplying each weapon efficiency by the associated target value, then summing the result for each weapon. These weapon values are returned by the spreadsheet for the user's information and as inputs to further calculations. The next action undertaken is the development of the advantage matrix. Using the maximum number of weapons that can be placed on the platform due to weapon assumptions (see Table 6 for the SSN values, Table 8 for the SSGN values) and correcting this value for the number of TLAMs results in the maximum number of each weapon that can be carried for the given scenario. For each possible weapon pair, the maximum and minimum numbers of weapons are multiplied by the respective weapon scores. Figure 19 shows these calculations for the example being discussed.

MK-48

MK-48	MK-54	MK-54 Score	Harpoon	Harpoon Score	ASRAAM	ASRAAM Score	AIM-9X	AIM-9X Score
24	0	14.016	6	15.096	6	14.43	6	14.565
0	48	11.664	30	5.4	60	4.14	60	5.49

MK-54

MK-54	Harpoon	Harpoon Score	ASRAAM	ASRAAM Score	AIM-9X	AIM-9X Score
48	6	12.744	6	12.078	6	12.213
0	30	5.4	60	4.14	60	5.49

Harpoon

Harpoon	ASRAAM	ASRAAM Score	AIM-9X	AIM-9X Score
30	0	5.4	0	5.4
0	60	4.14	60	5.49

ASRAAM

ASRAAM	AIM-9X	AIM-9X Score
60	0	4.14
0	60	5.49

Figure 19. Spreadsheet Calculation of Performance Based on Maximum Number of Weapons and Weapon Scores

The advantage matrix is then populated by taking the difference between these values and placing them in matrix format. Once this matrix is filled, the spreadsheet uses a set of defined alternatives configurations to eliminate the appropriate rows and columns for each alternative, and sums the remaining entries in the matrix to deliver the ratios needed for allocation; this is shown near the center of Figure 20. These ratios are then adjusted to eliminate values that are less than one, to prevent a weapon from being excluded; this is seen at the bottom of Figure 20.

Advantage Matrix

	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X
MK-48		2.352	9.696	10.29	9.075
MK-54	-2.352		7.344	7.938	6.723
Harpoon	-9.696	-7.344		1.26	-0.09
ASRAAM	-10.29	-7.938	-1.26		-1.35
AIM-9X	-9.075	-6.723	0.09	1.35	

Alternatives Being Considered

Alternative					
A	MK-48				AIM-9X
B	MK-48		HARPOON	ASRAAM	AIM-9X
C	MK-48		HARPOON		AIM-9X
D	MK-48			ASRAAM	AIM-9X
E		MK-54			AIM-9X
F		MK-54	HARPOON	ASRAAM	AIM-9X
G		MK-54	HARPOON		AIM-9X
H		MK-54		ASRAAM	AIM-9X
I	MK-48	MK-54			AIM-9X
J	MK-48	MK-54	HARPOON	ASRAAM	AIM-9X
K	MK-48	MK-54	HARPOON		AIM-9X
L	MK-48	MK-54		ASRAAM	AIM-9X

Resulting ratios after eliminating rows and columns of weapons not included in Alternative

MK-48	MK-54	Harpoon	ASRAAM	AIM-9X
18.15	0	0	0	-18.15
58.122	0	-17.052	-25.8	-15.27
37.542	0	-19.572	0	-17.97
38.73	0	0	-23.28	-15.45
0	13.446	0	0	-13.446
0	44.01	-12.348	-21.096	-10.566
0	28.134	-14.868	0	-13.266
0	29.322	0	-18.576	-10.746
22.854	8.742	0	0	-31.596
62.826	39.306	-31.74	-41.676	-28.716
42.246	23.43	-34.26	0	-31.416
43.434	24.618	0	-39.156	-28.896

Adjusted ratios. Values less than one set equal to one.

MK-48	MK-54	Harpoon	ASRAAM	AIM-9X
18.15	0	0	0	1
58.122	0	1	1	1
37.542	0	1	0	1
38.73	0	0	1	1
0	13.446	0	0	1
0	44.01	1	1	1
0	28.134	1	0	1
0	29.322	0	1	1
22.854	8.742	0	0	1
62.826	39.306	1	1	1
42.246	23.43	1	0	1
43.434	24.618	0	1	1

Figure 20. Spreadsheet Determination of Weapon Ratios Based on Advantage Matrix and Predefined Alternatives

Using the strategies discussed in the development of the analysis, these adjusted ratios are then used to calculate weapon allocation based on two schemes. The first scheme, shown in the center of Figure 21, represents the restricted case in which torpedoes are limited to torpedo tubes only. The second allocation scheme, in which the ratios are applied to all available space, is shown on the right of Figure 21.

MK-48	MK-54	Harpoon	ASRAAM	AIM-9X
18.15	0	0	0	1
58.122	0	1	1	1
37.542	0	1	0	1
38.73	0	0	1	1
0	13.446	0	0	1
0	44.01	1	1	1
0	28.134	1	0	1
0	29.322	0	1	1
22.854	8.742	0	0	1
62.826	39.306	1	1	1
42.246	23.43	1	0	1
43.434	24.618	0	1	1

Adjusted Ratios

MK-48	MK-54	Harpoon	ASRAAM	AIM-9X
24.0	0.0	0.0	0.0	6.0
24.0	0.0	2.0	2.0	2.0
24.0	0.0	3.0	0.0	3.0
24.0	0.0	0.0	3.0	3.0
0.0	48.0	0.0	0.0	6.0
0.0	48.0	2.0	2.0	2.0
0.0	48.0	3.0	0.0	3.0
0.0	48.0	0.0	3.0	3.0
17.4	13.3	0.0	0.0	6.0
14.8	18.5	2.0	2.0	2.0
15.4	17.1	3.0	0.0	3.0
15.3	17.4	0.0	3.0	3.0

Resulting allocation – restricted case

MK-48	MK-54	Harpoon	ASRAAM	AIM-9X
28.4	0.0	0.0	0.0	3.1
28.5	0.0	0.5	1.0	1.0
28.5	0.0	0.8	0.0	1.5
28.5	0.0	0.0	1.5	1.5
0.0	55.8	0.0	0.0	4.2
0.0	56.2	0.6	1.3	1.3
0.0	56.0	1.0	0.0	2.0
0.0	56.2	0.0	0.2	0.2
21.0	16.1	0.0	0.0	1.8
17.9	22.4	0.3	0.6	0.6
18.7	20.8	0.4	0.0	0.9
18.6	21.1	0.0	0.9	0.9

Resulting allocation – unconstrained case

Figure 21. Spreadsheet Determination of Weapon Allocation Using Two Allocation Schemes

The final allocation is completed by a comparison of the two resulting allocation schemes, with the smaller of the torpedo values accepted and the larger value for the remaining weapons. These values are rounded to produce the final allocation which is shown in Figure B. The resulting numbers of weapons are multiplied by the associated weapon score and the result summed for each alternative. These resulting performance scores are ranked by the spreadsheet to demonstrate the order of performance from greatest to least as shown in Figure 22.

MK-48	MK-54	Harpoon	ASRAAM	AIM-9X			
24.0	0.0	0.0	0.0	6.0	3	A	14.565
24.0	0.0	2.0	2.0	2.0	2	B	14.697
24.0	0.0	3.0	0.0	3.0	1	C	14.8305
24.0	0.0	0.0	3.0	3.0	4	D	14.4975
0.0	48.0	0.0	0.0	6.0	11	E	12.213
0.0	48.0	2.0	2.0	2.0	10	F	12.345
0.0	48.0	3.0	0.0	3.0	9	G	12.4785
0.0	48.0	0.0	3.0	3.0	12	H	12.1455
17.0	13.0	0.0	0.0	6.0	6	I	13.636
14.0	18.0	2.0	2.0	2.0	8	J	13.231
15.0	17.0	3.0	0.0	3.0	5	K	13.7055
15.0	17.0	0.0	3.0	3.0	7	L	13.3725

Best Alternative	C	14.8305
Second	B	14.697

Summary Block showing that Alternative C delivers the highest performance score for this scenario. Alternative B is second best.

Final allocation of weapons.

Performance score (Summation of number of each weapon times it's associated weapon score)

Alternative

Ranking of alternative

Figure 22. Spreadsheet Calculation of Final Performance Score and Ranking of Alternatives

This example is presented to demonstrate how the analysis method developed previously was implemented to arrive at the data used to evaluate the performance of alternatives. The data from this example and data from the duplication of this process across all of the scenarios resulting from the variation of parameters is presented in Appendices C and D.

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APPENDIX C. DATA SET FOR SSN ANALYSIS OF DSWS ALTERNATIVES

Following the analysis method presented in Chapter IV (and supported by Appendix B) the performance of Alternatives A-L was evaluated for the SSN platform. The data presented here represents the top two performing Alternatives for each of one hundred fifty scenarios. These scenarios are defined by the target value (TV), the weapon efficiency set, and the number of TLAMs carried. For each of the weapons presented the number in the data indicates the number recommended by the allocation process developed in Chapter IV (supported by Appendix B). It is important to note that the Alternative score presented in this data is applicable only to the scenario being considered and comparison of these scores across does not reflect any performance advantage or disadvantage.

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
1	1	0	24	0	6	0	6	C		15.645
1	1	0	24	0	4	4	4		B	15.378
1	1	6	24	0	2	2	2		B	14.697
1	1	6	24	0	3	0	3	C		14.8305
1	1	12	21	0	0	0	5		A	12.7215
1	1	12	21	0	1	2	2	B		12.765
1	1	18	15	0	0	0	4		A	9.126
1	1	18	10	13	0	1	1	J		9.1595
1	1	24	10	0	1	1	1	B		6.1805
1	1	24	10	0	0	2	2		D	6.161
2	1	0	4	0	0	9	54		D	13.25
2	1	0	3	6	0	6	54	L		13.38
2	1	6	7	0	0	0	45		A	11.24
2	1	6	2	4	0	4	48	L		11.32
2	1	12	0	3	2	0	42		G	9.12
2	1	12	2	4	0	0	40	I		9.2
2	1	18	3	0	0	6	24	D		6.54
2	1	18	0	11	0	0	25		E	6.54

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
2	1	70	0	7	7	7	138		F	30.54
2	1	70	0	11	12	0	137	G		30.74
3	1	126	14	0	15	1	1		B	14.755
3	1	126	0	28	16	1	1	F		14.925
3	1	112	18	0	36	2	2	B		26.61
3	1	112	0	34	38	2	2		F	26.61
3	1	98	20	0	60	2	2	B		38.53
3	1	98	0	38	62	2	2		F	38.49
3	1	84	21	0	84	2	2		B	49.89
3	1	84	0	41	87	2	2	F		50.55
3	1	70	22	0	110	2	2		B	62.15
3	1	70	0	43	113	2	2	F		62.79
4	1	126	21	0	0	0	5		A	12.26
4	1	126	21	0	0	0	5	S		12.315
4	1	112	24	0	0	0	14	A		14.84
4	1	112	24	0	7	0	7		C	14.665
4	1	98	24	0	0	0	28	A		16.24
4	1	98	24	0	14	0	14		C	15.89
4	1	84	24	0	0	0	42	A		17.64
4	1	84	24	0	21	0	21		C	17.115
4	1	70	24	0	0	0	56	A		19.04
4	1	70	24	0	0	0	49		S	18.395
5	1	126	1	0	0	21	25	V		11.505
5	1	126	0	2	0	21	25		Z	11.485
5	1	112	2	0	0	32	40	D		18
5	1	112	0	4	0	32	40		H	17.96
5	1	98	1	0	2	47	53	B		24.84
5	1	98	0	2	2	47	53		F	24.82
5	1	84	0	2	2	60	67	F		31.44
5	1	84	0	4	5	0	123		G	31.405
5	1	70	1	0	3	72	82		B	38.165
5	1	70	0	5	5	0	150	G		38.225
6	1	126	1	0	0	3	43	V		14.96
6	1	126	0	1	1	0	45		Y	14.95
6	1	112	1	0	0	4	69		D	23.445
6	1	112	0	3	0	4	69	H		23.495

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
6	1	12	1	0	0	0	45	A		14.785
6	1	12	0	1	1	0	45		G	14.77
6	1	18	0	1	1	0	33		G	10.87
6	1	18	0	1	1	0	33	K		10.87
6	1	24	1	0	0	0	21		A	6.985
6	1	24	0	3	0	0	21	E		7.035
7	1	0	1	0	1	2	65	B		14.99
7	1	0	0	3	2	0	65		G	14.985
7	1	6	3	0	0	0	54	A		12.63
7	1	6	0	2	1	0	55		G	12.59
7	1	12	0	4	0	0	44		E	10.18
7	1	12	1	2	0	0	44	I		10.2
7	1	18	0	5	0	0	31	E		7.325
7	1	18	0	1	1	2	31		F	7.25
7	1	24	1	0	0	3	19	D		4.63
7	1	24	0	5	0	0	19		E	4.625
8	1	0	24	0	10	1	1	B		20.70945
8	1	0	24	0	6	0	6		C	19.503
8	1	6	24	0	5	1	1	B		19.02195
8	1	6	24	0	3	0	3		C	18.3915
8	1	12	22	0	0	0	3		A	15.939
8	1	12	22	0	1	0	2	C		16.2435
8	1	18	16	0	0	0	3		A	11.619
8	1	18	16	0	1	0	2	C		11.9235
8	1	24	10	0	0	0	3		A	7.299
8	1	24	10	0	1	0	2	C		7.6035
9	1	0	24	0	4	4	4		B	18.80022
9	1	0	24	0	6	0	6	C		19.0152
9	1	6	24	0	2	2	2		B	18.52011
9	1	6	24	0	3	0	3	C		18.6276
9	1	12	22	0	0	0	3		A	16.7701
9	1	12	22	0	1	0	1	C		16.8492
9	1	18	16	0	0	0	3		A	12.2101
9	1	18	16	0	1	0	1	C		12.2892
9	1	24	7	8	0	0	1		K	7.7367
9	1	24	7	8	0	1	1	L		7.747555

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
10	1	0	24	0	0	0	15	A		13.9575
10	1	0	24	0	6	0	6		C	13.845
10	1	6	24	0	3	0	6	C		13.17
10	1	6	24	0	0	6	6		D	13.14
10	1	12	14	9	0	0	9		I	10.0725
10	1	12	15	9	0	4	4	L		10.17
10	1	18	14	0	2	0	4	C		7.82
10	1	18	14	0	0	4	4		D	7.8
10	1	24	8	0	2	0	3		C	4.7775
10	1	24	6	7	1	1	1	J		4.845
1	2	0	24	0	4	4	4		B	13.98
1	2	0	24	0	6	0	6	C		14.175
1	2	6	24	0	2	2	2		B	13.56
1	2	6	24	0	3	0	3	C		13.6575
1	2	12	21	0	1	0	2		C	11.7225
1	2	12	21	2	0	0	3	I		11.996
1	2	18	16	0	1	1	1	B		8.97
1	2	18	16	0	0	2	2		D	8.94
1	2	24	10	0	0	0	4		A	5.685
1	2	24	10	0	1	0	2	C		5.7
2	2	0	23	0	0	0	25	A		9.65
2	2	0	23	0	2	4	16		B	9.14
2	2	6	16	0	0	0	27	A		7.77
2	2	6	20	0	0	9	10		D	7.73
2	2	12	12	0	0	0	24	A		6.24
2	2	12	13	0	0	8	14		D	6
2	2	18	10	0	0	0	15		A	4.65
2	2	18	14	0	0	7	0	D		4.69
2	2	24	6	0	0	0	12	A		3.12
2	2	24	7	3	0	3	3		L	2.91
3	2	0	24	0	10	2	2	B		15.78
3	2	0	24	0	8	0	4		C	15.22
3	2	6	22	0	6	2	2		B	13.53
3	2	6	24	0	3	0	4	C		13.72
3	2	12	21	0	1	0	3	C		11.49
3	2	12	21	2	0	0	3		I	11.48

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
3	2	18	15	0	1	0	3		C	8.34
3	2	18	15	1	1	0	2	K		8.43
3	2	24	9	0	2	1	1		B	5.415
3	2	24	10	0	0	2	2	D		5.43
4	2	0	24	0	0	0	12	A		13.26
4	2	0	24	0	6	0	6		C	13.23
4	2	6	24	0	0	0	6	A		12.93
4	2	6	24	0	3	0	3		C	12.915
4	2	12	21	0	0	0	5	A		11.3
4	2	12	21	0	0	2	2		D	11.205
4	2	18	16	0	1	1	1		B	8.54
4	2	18	16	0	1	0	2	C		8.56
4	2	24	10	0	1	0	2		C	5.41
4	2	24	10	0	0	2	2	D		5.43
5	2	0	4	0	0	16	47		D	10.045
5	2	0	0	3	2	0	64	K		10.155
5	2	6	5	0	0	0	50	A		8.5
5	2	6	3	0	0	16	38		D	8.5
5	2	12	3	0	0	0	41		A	6.805
5	2	12	2	0	0	14	30	D		6.84
5	2	18	0	2	1	13	19		F	4.84
5	2	18	0	2	1	0	31	K		4.945
5	2	24	1	0	1	8	12	B		3.14
5	2	24	0	2	1	0	19		K	3.085
6	2	0	2	0	2	0	63		C	11.74
6	2	0	0	4	2	0	64	G		11.8
6	2	6	4	0	0	0	52	A		9.96
6	2	6	0	3	2	0	54		G	9.955
6	2	12	1	0	0	4	41		D	7.97
6	2	12	1	2	0	0	43	I		7.98
6	2	18	0	6	0	0	30		E	5.67
6	2	18	1	2	1	0	30	K		5.69
6	2	24	1	0	1	3	17		B	3.59
6	2	24	0	1	1	4	17	F		3.595
7	2	0	4	0	5	0	54		C	6.52
7	2	0	0	13	0	0	58	I		6.675

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
7	2	6	9	0	0	0	40	A		5.55
7	2	6	0	13	0	0	47		E	5.52
7	2	12	6	0	0	0	35	A		4.575
7	2	12	0	9	0	0	39		E	4.5
7	2	18	8	0	0	0	19		A	3.195
7	2	18	0	8	0	0	28	I		3.3
7	2	24	6	0	0	0	12	A		2.16
7	2	24	0	7	0	0	16		I	1.995
8	2	0	24	0	8	2	2	B		18.0594
8	2	0	24	0	6	0	6		C	17.6589
8	2	6	24	0	2	2	2		B	16.7094
8	2	6	24	0	3	0	3	C		16.92945
8	2	12	22	0	1	1	1		B	15.1047
8	2	12	22	0	1	0	2	C		15.1113
8	2	18	16	0	1	1	1		B	11.0547
8	2	18	16	0	1	0	2	C		11.0613
8	2	24	10	0	1	1	1		B	7.0047
8	2	24	10	0	1	0	2	C		7.0113
9	2	0	24	0	4	4	4		B	17.46012
9	2	0	24	0	6	0	6	C		17.60511
9	2	6	24	0	2	2	2		B	17.28006
9	2	6	24	0	3	0	3	C		17.35256
9	2	12	22	0	0	0	3		A	15.70256
9	2	12	22	0	1	0	1	C		15.75919
9	2	18	16	0	0	0	3		A	11.42756
9	2	18	16	0	1	0	1	C		11.48419
9	2	24	10	0	0	0	3		A	7.152555
9	2	24	10	0	1	0	1	C		7.209185
10	2	0	24	0	4	4	4		B	11.98
10	2	0	24	0	6	0	6	C		12.24
10	2	6	24	0	0	0	9	A		11.61
10	2	6	24	0	3	0	4		C	11.61
10	2	12	20	0	0	0	8	A		9.72
10	2	12	20	2	1	0	2		K	9.6
10	2	18	15	0	1	2	2	B		7.19
10	2	18	15	0	0	3	3		D	7.185

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
10	2	24	9	0	0	0	6		A	4.59
10	2	24	9	2	1	0	2	K		4.65
1	3	0	24	0	0	0	12	A		11.844
1	3	0	24	0	0	6	6		D	11.673
1	3	6	24	0	0	0	11	A		11.733
1	3	6	24	0	0	5	5		D	11.4795
1	3	12	19	0	0	0	10	A		9.432
1	3	12	19	3	0	3	3		L	9.3765
1	3	18	15	0	1	2	2	B		7.029
1	3	18	15	0	1	0	3		C	6.975
1	3	24	9	0	1	2	2		B	4.401
1	3	24	8	3	0	0	4	I		4.422
2	3	0	0	3	2	0	65		G	15.99
2	3	0	0	2	1	0	67	K		16.32
2	3	6	2	0	0	4	52	D		13.56
2	3	6	0	6	0	0	54		E	13.5
2	3	12	1	0	1	0	44		C	10.86
2	3	12	0	4	0	0	44	E		10.92
2	3	18	0	1	1	0	32		K	7.83
2	3	18	1	2	0	0	31	L		7.86
2	3	24	3	0	0	0	18	A		5.04
2	3	24	0	5	0	0	19		E	5.01
3	3	0	24	0	0	0	14		A	11.76
3	3	0	24	0	6	0	6	C		11.88
3	3	6	23	0	0	0	13		A	11.22
3	3	6	24	0	3	0	5	C		11.22
3	3	12	21	0	2	0	0	C		9.18
3	3	12	19	0	0	5	5		D	8.955
3	3	18	14	0	2	0	4	C		6.72
3	3	18	14	0	0	4	4		D	6.66
3	3	24	8	0	0	0	8	A		4.32
3	3	24	7	4	0	0	5		I	4.22
4	3	0	24	0	0	0	14		A	11.76
4	3	0	24	0	2	3	12	B		11.805
4	3	6	23	0	0	0	13	A		11.22
4	3	6	24	0	0	5	5		D	11.055

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
4	3	12	18	6	0	0	6	I		9.15
4	3	12	19	3	0	3	3		L	9
4	3	18	15	0	1	0	3	C		6.69
4	3	18	14	0	0	4	4		D	6.66
4	3	24	8	0	0	0	8	A		4.32
4	3	24	8	4	1	0	2		K	4.21
5	3	0	0	0	1	36	34		B	22.61
5	3	0	0	1	1	36	34	F		22.655
5	3	6	0	0	0	30	29	B		19.03
5	3	6	0	0	0	30	29		F	19.03
5	3	12	0	0	0	24	23	B		15.16
5	3	12	0	0	0	24	23		F	15.16
5	3	18	0	0	0	17	17		B	10.965
5	3	18	0	0	0	18	17	D		11.29
5	3	24	0	0	0	11	11		B	7.095
5	3	24	0	0	0	11	11	D		7.095
6	3	0	1	0	0	3	67	D		25.51
6	3	0	1	2	0	0	68		I	25.37
6	3	6	1	0	0	2	56	D		21.24
6	3	6	0	3	0	0	57		E	21.225
6	3	12	1	0	0	0	46	A		17.14
6	3	12	0	2	0	0	46		E	17.11
6	3	18	1	0	0	0	33	A		12.33
6	3	18	0	2	0	0	33		E	12.3
6	3	24	1	0	0	0	21	A		7.89
6	3	24	0	2	0	0	21		E	7.86
7	3	0	0	0	1	2	67		B	18.27
7	3	0	0	1	1	2	67	F		18.315
7	3	6	1	0	1	0	56		C	15.27
7	3	6	0	4	0	0	56	E		15.3
7	3	12	0	3	0	0	45		E	12.285
7	3	12	0	1	1	1	45	F		12.3
7	3	18	2	0	0	0	32		A	8.88
7	3	18	1	0	0	2	32	D		8.91
7	3	24	1	0	0	2	20	D		5.67
7	3	24	0	1	1	1	20		F	5.55

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
8	3	0	24	0	4	4	4		B	13.7574
8	3	0	24	0	6	0	6	C		14.0076
8	3	6	24	0	2	2	2		B	13.3587
8	3	6	24	0	3	0	3	C		13.4838
8	3	12	21	0	1	0	2		C	11.5542
8	3	12	22	0	0	2	2	D		12.0087
8	3	18	16	0	0	0	4		A	8.7984
8	3	18	16	0	1	1	1	B		8.83935
8	3	24	10	0	1	1	1		B	5.59935
8	3	24	10	0	1	0	2	C		5.6142
9	3	0	24	0	4	4	4		B	13.99026
9	3	0	24	0	6	0	6	C		14.07024
9	3	6	24	0	2	2	2		B	13.83513
9	3	6	24	0	3	0	3	C		13.87512
9	3	12	22	0	0	0	4		A	12.62016
9	3	12	22	0	1	0	2	C		12.62508
9	3	18	16	0	1	1	1		B	9.197565
9	3	18	16	0	1	0	2	C		9.20508
9	3	24	10	0	1	1	1		B	5.777565
9	3	24	10	0	1	0	2	C		5.78508
10	3	0	18	0	0	0	36	A		13.14
10	3	0	13	0	0	7	39		D	12.595
10	3	6	12	0	0	0	34	A		10.61
10	3	6	4	8	0	0	43		I	10.475
10	3	12	6	0	0	0	34	A		8.45
10	3	12	0	3	2	0	42		G	8.355
10	3	18	9	0	0	0	18	A		6.57
10	3	18	7	0	0	5	17		D	6.165
10	3	24	6	0	0	0	12	A		4.38
10	3	24	3	7	0	0	10		I	3.875

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APPENDIX D. DATA SET FOR SSGN ANALYSIS OF DSWS ALTERNATIVES

Following the analysis method presented in Chapter IV (and supported by Appendix B) the performance of Alternatives A-DD were evaluated for the SSGN platform. The data presented here represents the top two performing Alternatives for each of one hundred fifty scenarios. These scenarios are defined by the target value (TV), the weapon efficiency set, and the number of TLAMs carried. For each of the weapons presented the number in the data indicates the number recommended by the allocation process developed in Chapter IV (supported by Appendix B). It is important to note that the Alternative score presented in this data is applicable only to the scenario being considered and comparison of these scores across does not reflect any performance advantage or disadvantage.

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
1	1	126	21	0	2	0	2		C	12.807
1	1	126	16	13	0	0	3	AA		12.818
1	1	112	24	0	5	5	5		B	15.7185
1	1	112	24	0	7	0	7	C		15.9165
1	1	98	24	0	9	9	9		B	17.0805
1	1	98	24	0	14	0	14	C		17.817
1	1	84	24	0	21	0	21	C		19.7175
1	1	84	24	0	18	0	18		U	18.9435
1	1	70	24	0	31	13	13	B		21.6825
1	1	70	24	0	28	0	28		C	21.618
2	1	126	0	3	3	3	39		F	9.06
2	1	126	8	0	0	0	32	S		9.07
2	1	112	0	4	4	4	63		F	14.28
2	1	112	0	6	7	0	63	G		14.49
2	1	98	0	5	6	6	87	F		19.78
2	1	98	0	8	8	0	87		G	19.72
2	1	84	0	6	7	7	112		F	25.2
2	1	84	0	10	10	0	112	G		25.3

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
2	1	70	0	7	7	7	138		F	30.54
2	1	70	0	11	12	0	137	G		30.74
3	1	126	14	0	15	1	1		B	14.755
3	1	126	0	28	16	1	1	F		14.925
3	1	112	18	0	36	2	2	B		26.61
3	1	112	0	34	38	2	2		F	26.61
3	1	98	20	0	60	2	2	B		38.53
3	1	98	0	38	62	2	2		F	38.49
3	1	84	21	0	84	2	2		B	49.89
3	1	84	0	41	87	2	2	F		50.55
3	1	70	22	0	110	2	2		B	62.15
3	1	70	0	43	113	2	2	F		62.79
4	1	126	21	0	0	0	5		A	12.26
4	1	126	21	0	0	0	5	S		12.315
4	1	112	24	0	0	0	14	A		14.84
4	1	112	24	0	7	0	7		C	14.665
4	1	98	24	0	0	0	28	A		16.24
4	1	98	24	0	14	0	14		C	15.89
4	1	84	24	0	0	0	42	A		17.64
4	1	84	24	0	21	0	21		C	17.115
4	1	70	24	0	0	0	56	A		19.04
4	1	70	24	0	0	0	49		S	18.395
5	1	126	1	0	0	21	25	V		11.505
5	1	126	0	2	0	21	25		Z	11.485
5	1	112	2	0	0	32	40	D		18
5	1	112	0	4	0	32	40		H	17.96
5	1	98	1	0	2	47	53	B		24.84
5	1	98	0	2	2	47	53		F	24.82
5	1	84	0	2	2	60	67	F		31.44
5	1	84	0	4	5	0	123		G	31.405
5	1	70	1	0	3	72	82		B	38.165
5	1	70	0	5	5	0	150	G		38.225
6	1	126	1	0	0	3	43	V		14.96
6	1	126	0	1	1	0	45		Y	14.95
6	1	112	1	0	0	4	69		D	23.445
6	1	112	0	3	0	4	69	H		23.495

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
6	1	98	1	0	3	0	98		C	32.235
6	1	98	2	0	0	5	95	D		32.27
6	1	84	1	0	3	0	125		C	41.01
6	1	84	0	3	3	0	125	G		41.06
6	1	70	1	0	4	0	152		C	49.86
6	1	70	0	3	4	0	152	G		49.91
7	1	126	3	0	0	0	42		S	10.135
7	1	126	0	1	1	2	43	X		10.155
7	1	112	1	0	2	2	69		B	15.965
7	1	112	0	3	4	0	69	G		16.035
7	1	98	2	0	5	0	95	C		22.07
7	1	98	0	4	5	0	95		G	22.03
7	1	84	1	0	3	3	122		B	28.03
7	1	84	0	3	3	3	122	F		28.08
7	1	70	1	0	4	4	149		B	34.245
7	1	70	0	3	4	4	149	F		34.295
8	1	126	22	0	2	0	2	C		16.581
8	1	126	22	0	1	0	2		U	16.26165
8	1	112	24	0	18	1	1	B		23.40945
8	1	112	0	48	22	1	1		F	22.59945
8	1	98	24	0	35	2	2	B		29.2014
8	1	98	0	48	41	2	2		F	29.0664
8	1	84	24	0	55	2	2		B	35.9514
8	1	84	0	48	62	2	2	F		36.1539
8	1	70	24	0	76	2	2		B	43.0389
8	1	70	0	48	85	2	2	F		43.9164
9	1	126	22	0	1	1	1	B		16.86006
9	1	126	22	0	1	0	1		U	16.85839
9	1	112	24	0	5	5	5		B	18.94028
9	1	112	24	0	7	0	7	C		19.1444
9	1	98	24	0	14	0	14	C		20.0488
9	1	98	24	0	11	0	11		U	19.67039
9	1	84	24	0	21	0	21	C		20.9532
9	1	84	24	0	18	0	18		U	20.57479
9	1	70	24	0	28	0	28	C		21.8576
9	1	70	24	0	25	0	25		U	21.47919

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
10	1	126	14	14	3	0	3	K		10.8225
10	1	126	20	0	0	4	4		V	10.77
10	1	112	24	0	0	0	16		A	14.120
10	1	112	24	0	7	0	7	C		14.233
10	1	98	24	0	14	0	14	C		16.945
10	1	98	16	15	14	0	14		K	16.255
10	1	84	24	0	21	0	21	C		19.658
10	1	84	16	15	21	0	21		K	18.968
10	1	70	24	0	28	0	28	C		22.37
10	1	70	16	15	28	0	28		K	21.68
1	2	126	21	2	0	0	3		AA	12.0095
1	2	126	22	0	0	4	0	N		12.2085
1	2	112	24	0	5	5	5		B	14.19
1	2	112	24	0	7	0	7	C		14.3475
1	2	98	24	0	14	0	14	C		15.555
1	2	98	24	0	11	0	11		U	15.051
1	2	84	24	0	21	0	21	C		16.7625
1	2	84	24	0	18	0	18		U	16.2585
1	2	70	24	0	28	0	28	C		17.97
1	2	70	24	0	25	0	25		U	17.466
2	2	126	18	0	6	0	6	C		6.66
2	2	126	17	3	4	0	7		K	6.54
2	2	112	24	0	0	0	26	A		10.06
2	2	112	24	0	5	5	17		B	9.92
2	2	98	24	0	0	0	36	A		11.16
2	2	98	24	0	6	6	26		B	11.08
2	2	84	0	21	11	11	88		F	13.44
2	2	84	0	21	21	0	90	G		13.89
2	2	70	0	24	13	13	110		F	16.47
2	2	70	0	25	25	0	110	G		16.85
3	2	126	19	0	7	1	1	B		12.165
3	2	126	21	0	3	0	3		C	12.09
3	2	112	24	0	22	2	2	B		19.38
3	2	112	0	23	47	0	6		G	17.765
3	2	98	0	27	71	3	3		F	25.485
3	2	98	0	25	72	0	6	G		25.555

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
3	2	84	0	28	97	3	3		F	33.43
3	2	84	0	26	99	0	7	G		33.855
3	2	70	0	29	124	3	3		F	41.675
3	2	70	0	27	126	0	7	G		42.1
4	2	126	22	0	1	2	0	M		11.69
4	2	126	20	5	0	3	0		R	11.475
4	2	112	24	0	0	0	14	A		13.37
4	2	112	24	0	7	0	7		C	13.335
4	2	98	24	0	0	0	28	A		14.14
4	2	98	24	0	14	0	14		C	14.07
4	2	84	24	0	0	0	42	A		14.91
4	2	84	24	0	21	0	21		C	14.805
4	2	70	24	0	0	0	56	A		15.68
4	2	70	24	0	28	0	28		C	15.54
5	2	126	0	2	3	0	42	K		6.75
5	2	126	3	0	0	12	30		V	6.74
5	2	112	0	5	5	0	66		G	10.705
5	2	112	0	4	4	0	68	K		10.92
5	2	98	3	0	7	0	90		C	14.75
5	2	98	0	5	5	0	94	K		15.045
5	2	84	4	0	8	0	116		C	18.98
5	2	84	0	6	6	0	120	K		19.17
5	2	70	0	8	8	0	144		G	23.08
5	2	70	0	6	7	0	146	K		23.25
6	2	126	2	0	0	5	39	V		7.915
6	2	126	0	6	0	0	42		W	7.875
6	2	112	2	0	5	0	67	C		12.61
6	2	112	3	0	0	7	63		D	12.56
6	2	98	2	0	6	0	93	C		17.34
6	2	98	2	4	4	0	92		K	17.24
6	2	84	3	0	7	0	119	C		22.22
6	2	84	0	6	6	0	120		G	22.17
6	2	70	3	0	7	0	145	C		26.9
6	2	70	0	6	7	0	146		G	26.9
7	2	126	0	9	0	0	39		I	4.5
7	2	126	0	9	0	0	39	AA		4.595

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
7	2	112	0	8	8	0	60		G	7.06
7	2	112	0	14	0	0	62	I		7.14
7	2	98	5	0	12	0	80		C	9.75
7	2	98	0	10	10	0	84	G		9.77
7	2	84	6	0	14	0	104	C		12.52
7	2	84	0	7	7	7	110		F	12.46
7	2	70	7	0	15	0	129	C		15.345
7	2	70	0	7	8	8	136		F	15.275
8	2	126	22	0	2	0	2	C		15.3363
8	2	126	22	0	1	0	2		U	15.1179
8	2	112	24	0	10	2	2	B		18.5094
8	2	112	24	0	7	0	7		C	17.90205
8	2	98	24	0	23	2	2	B		21.4344
8	2	98	24	0	18	2	2		T	20.316
8	2	84	24	0	37	2	2	B		24.5844
8	2	84	0	48	64	3	3		F	24.2091
8	2	70	24	0	54	2	2		B	28.4094
8	2	70	0	48	86	3	3	F		29.1591
9	2	126	22	0	1	1	1	B		15.76503
9	2	126	22	0	1	0	1		U	15.76253
9	2	112	24	0	5	5	5		B	17.55015
9	2	112	24	0	7	0	7	C		17.6893
9	2	98	24	0	14	0	14	C		18.27859
9	2	98	24	0	11	0	11		U	18.02938
9	2	84	24	0	21	0	21	C		18.86789
9	2	84	24	0	18	0	18		U	18.61867
9	2	70	24	0	28	0	28	C		19.45718
9	2	70	24	0	25	0	25		U	19.20797
10	2	126	21	0	2	2	2	B		10.04
10	2	126	21	0	1	2	2		T	9.9125
10	2	112	24	0	5	5	5		B	12.275
10	2	112	24	0	7	0	7	C		12.48
10	2	98	24	0	14	0	14	C		14.16
10	2	98	22	2	14	0	14		K	13.53
10	2	84	24	0	21	0	21	C		15.84
10	2	84	22	2	21	0	21		K	15.21

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
10	2	70	24	0	28	0	28	C		17.52
10	2	70	22	2	28	0	28		K	16.89
1	3	126	20	0	0	0	8	S		9.663
1	3	126	21	0	1	3	0		M	9.5325
1	3	112	24	0	0	0	14	A		12.066
1	3	112	24	0	0	7	7		D	11.8665
1	3	98	24	0	0	0	28	A		13.62
1	3	98	24	0	0	14	14		D	13.221
1	3	84	24	0	0	0	42	A		15.174
1	3	84	21	5	0	0	42		I	14.65
1	3	70	24	0	0	0	56	A		16.728
1	3	70	21	5	0	0	56		I	16.204
2	3	126	0	1	2	0	44		K	10.77
2	3	126	1	2	0	0	43	DD		10.78
2	3	112	1	0	4	0	69		C	17.04
2	3	112	0	2	3	0	70	K		17.16
2	3	98	2	0	5	0	95		C	23.58
2	3	98	0	3	3	0	97	K		23.73
2	3	84	2	0	5	0	122		C	30.06
2	3	84	0	4	4	0	124	K		30.36
2	3	70	2	0	6	0	149		C	36.6
2	3	70	0	4	5	0	151	K		36.9
3	3	126	20	0	4	0	4	C		9.6
3	3	126	20	0	2	0	4		U	9.26
3	3	112	24	0	5	5	5		B	11.955
3	3	112	24	0	7	0	7	C		12.18
3	3	98	24	0	9	9	9		B	13.455
3	3	98	24	0	14	0	14	C		14.28
3	3	84	24	0	21	0	21	C		16.38
3	3	84	24	0	18	0	18		U	15.5
3	3	70	24	0	32	12	12		B	18.18
3	3	70	24	0	28	0	28	C		18.48
4	3	126	20	0	0	4	4		D	9.18
4	3	126	20	0	0	4	4	V		9.2
4	3	112	24	0	0	0	14		A	11.76
4	3	112	24	0	3	3	13	B		11.955

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
4	3	98	24	0	0	0	28	A		13.44
4	3	98	24	0	4	4	24		B	13.38
4	3	84	24	0	0	0	42	A		15.12
4	3	84	0	48	5	5	63		F	15.045
4	3	70	0	48	6	6	82	F		17.43
4	3	70	0	48	9	0	82		G	17.07
5	3	126	0	1	0	24	23		H	15.205
5	3	126	0	1	0	24	23	Z		15.225
5	3	112	0	0	1	38	36		B	23.9
5	3	112	0	1	1	38	36	F		23.945
5	3	98	0	0	1	52	50		B	32.93
5	3	98	0	1	1	52	50	F		32.975
5	3	84	0	0	2	66	63		B	41.67
5	3	84	0	1	2	66	63	F		41.715
5	3	70	0	0	2	80	77		B	50.7
5	3	70	0	1	2	80	77	F		50.745
6	3	126	1	0	0	0	45	S		16.84
6	3	126	0	2	0	0	45		W	16.81
6	3	112	0	1	2	0	72		G	26.745
6	3	112	0	2	0	3	71	H		26.96
6	3	98	1	0	2	0	99	C		36.81
6	3	98	0	2	2	0	99		G	36.78
6	3	84	1	0	3	0	127	C		47.2
6	3	84	0	2	3	0	127		G	47.17
6	3	70	1	0	3	0	154	C		57.19
6	3	70	0	2	3	0	154		G	57.16
7	3	126	1	0	0	2	44	V		12.22
7	3	126	0	2	0	2	44		Z	12.19
7	3	112	1	0	3	0	71		C	19.38
7	3	112	0	1	2	2	71	F		19.425
7	3	98	1	0	2	2	97	B		26.52
7	3	98	0	2	2	2	97		F	26.49
7	3	84	1	0	2	2	125	B		34.08
7	3	84	0	2	2	2	125		F	34.05
7	3	70	1	0	3	3	152	B		41.475
7	3	70	0	2	3	3	152		F	41.445

TV	Weapon Efficiency Set	TLAM	MK-48	MK-54	Harpoon	ASRAAM	AIM-9X	Best Alternative	Second Best	Score
8	3	126	22	0	0	0	4		A	12.0384
8	3	126	22	0	0	0	4	S		12.045
8	3	112	24	0	5	5	5		B	13.95675
8	3	112	24	0	7	0	7	C		14.1822
8	3	98	24	0	14	0	14	C		15.4044
8	3	98	24	0	11	0	11		U	14.8872
8	3	84	24	0	23	10	10	B		16.7085
8	3	84	24	0	21	0	21		C	16.6266
8	3	70	24	0	40	8	8	B		18.8748
8	3	70	24	0	35	7	7		T	18.14205
9	3	126	22	0	2	0	2	C		12.67008
9	3	126	22	0	1	0	2		U	12.62842
9	3	112	24	0	5	5	5		B	14.06783
9	3	112	24	0	7	0	7	C		14.13528
9	3	98	24	0	14	0	14	C		14.59056
9	3	98	24	0	11	0	11		U	14.39878
9	3	84	24	0	21	0	21	C		15.04584
9	3	84	24	0	18	0	18		U	14.85406
9	3	70	24	0	28	0	28	C		15.50112
9	3	70	24	0	25	0	25		U	15.30934
10	3	126	12	0	0	0	24		A	8.76
10	3	126	12	0	0	0	24	S		8.795
10	3	112	19	0	0	0	38	A		13.87
10	3	112	15	0	5	0	41		C	13.435
10	3	98	24	0	0	0	52		A	18.26
10	3	98	19	0	6	0	59	C		18.295
10	3	84	22	0	7	0	79		C	23.165
10	3	84	19	0	0	11	83	D		23.295
10	3	70	24	0	5	5	102	B		28.46
10	3	70	21	0	0	12	106		D	28.37

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