NPS-__-23-248

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Optimal Prepositioning Sites in the Contested Environment

March 2023

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The research presented in this report was supported by the Acquisition Research Program of the Department of Defense Management at the Naval Postgraduate School.

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ABSTRACT

The United States military has had the privilege to operate and conduct logistics uncontested on a global scale for several decades. The ascent of China as a near-peer competitor as well as the country's exponential investments in its military and expansion of its contact layer has caused intense analysis and reassessment of logistics in a contested environment. As a result, the Commandant of the Marine Corps issued his guidance on *Force Design 2030* (FD2030) to meet this challenge. Additionally, he issued guidance for the Marine Corps Prepositioning Network (MCPN) to be tailored to better support FD2030. The purpose of this research is to explore how the Marine Corps can assess and improve the prepositioning network as the Marine Corps reorganizes and tailors MCPN to support FD2030.

This research uses a facility location model as a framework to identify the optimum locations to preposition assets. Since the locations of future Expeditionary Advanced Bases (EAB) are unknown, we generate three sets of EAB locations and measure the distance between the proposed preposition sites to count as cost. The results of the model are determined in a series of scenarios and captured for follow-on analysis. This research recommends the optimum locations to prepositions assets while minimizing distance between randomly generated EAB sets within the contested areas.

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ACKNOWLEDGMENTS

First, thank you to my wife, Shea, and our kids, Gracelyn, Olivia, Timmy, and Elisia. The challenges of returning to school and adjusting to a wildly different environment have put a tremendous amount of stress on all of us. I could not have done it without your continued love and support.

Second, thank you to my advisors, Chad Seagren and Aruna Apte, for all their wisdom and countless hours of working with me throughout this process. I learned a tremendous amount from each of you and truly appreciate the journey.

Last, I want to thank the Department of Defense Management, the faculty, and the Marines at Programs and Resources, Headquarters Marine Corps. Their instruction, guidance, and discussions helped me to be successful. Being a student and returning to academia has been a pleasure. I will never forget my time here and look forward to the opportunities to apply what I've learned for the benefit of the United States Marine Corps.

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Prepared for the Naval Postgraduate School, Monterey, CA 93943.

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LIST OF ACRONYMS AND ABBREVIATIONS

A2/AD	anti-access aerial denial
AO	area of operations
AOR	area of responsibility
CARE	Cooperative for Assistance and Relief Everywhere
CMC	Commandant of the Marine Corps
DMO	distributed maritime operations
EAB	expeditionary advanced base
EABO	expeditionary advanced base operations
FD2030	force design 2030
FSV	fast supply vessel
HADR	humanitarian aid and disaster relief
INDO-PACOM	Indonesia-Pacific Command
LAW	light amphibious warship
LOCE	littoral operations in a contested environment
MCPN	Marine Corps prepositioning network
MLR	marine littoral regiment
MPF	maritime prepositioning force
NGLS	next generation logistic ship
PLA	People's Liberation Army
PLN	People's Liberation Navy
PNTC	prepositioning network tailoring cycle
PRC	People's Republic of China
PSV	platform supply vessel
SIF	stand-in forces
SLOC	sea lines of communication
WEZ	weapon engagement zone

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I. INTRODUCTION

A. OVERVIEW

Throughout the last several decades the United States has benefited from having a competitive advantage in the Indonesia-Pacific Command (INDO-PACOM) theater. China is an emerging competitor and threat through their investment in naval forces and anti-access/area denial capabilities. Because of this, the Marine Corps is executing the Commandant of the Marine Corps' (CMC) *Force Design 2030* (FD2030) by training, equipping, and manning the force to conduct distributed maritime operations in support of the Navy through Expeditionary Advanced Based Operations (EABO) (Marine Corps, 2019).

In the 1970s the Marine Corps' strategic prepositioning capabilities rapidly introduced combat forces into Europe or the Middle East to counter then peer competitor, the Soviet Union (Bergen, 2019). Strategic prepositioning capabilities are designed to hold the equipment and supplies of a Marine Expeditionary Brigade. The CMC is shifting the Marine Corps to a leaner fighting force built around a Marine Littoral Regiment (MLR). The CMC recognizes the need to update our support to current and future operating concepts. This shift to supporting future concepts requires us to reanalyze the purpose and employment of the Marine Corps Prepositioning Network (MCPN). In the CMC's MCPN planning guidance, he tasks Headquarters Marine Corps to begin planning for the Prepositioning Network Tailoring Cycle (PNTC) that supports transition from current operating concepts to those aligned with FD2030 (Headquarters Marine Corps, 2022). Our adversaries' technological advancements and A2/AD capabilities enable them to target and degrade our ability to use and rely on large logistic bases to mobilize, deploy, and resupply our Stand In Forces (SIF). While operating in the Indo-Pacific region, naval forces can expect a high operational tempo that undoubtedly stress maritime logistics (Walton et al., 2019). To create an integrated logistics network leads to the question: Other than our large established logistic bases, where can the Marine Corps preposition assets ashore to support the MLR in a contested environment while meeting the projected demand to sustain the Navy and Marine Corps forces?

B. PURPOSE OF STUDY

The purpose of our study is to develop a mathematical programming model to select locations for the MCPN ashore. We provide an optimal solution of a scalable number of locations that supports the MLR using notional data. The model provides a framework for the selection of locations ashore in support of FD2030 that meet future Navy and Marine Corps operations of distributed maritime operations (DMO). The output informs a recommendation of the optimal locations to establish prepositioned gear and equipment. The model focuses on the distances of each potential location to randomly generated EAB sites within and outside the weapons engagement zone (WEZ). This unbiased recommendation of potential facility locations informs planners during future PNTCs. More specifically, our research aims to address the following objectives:

- Develop a facility location model to identify the optimal location(s) to establish prepositioning sites ashore that support the MLR in a contested environment.
- Analyze how the optimal location/s change as the number and/or location of demand sites change.
- Provide future planners with recommendations on the ideal locations for future prepositioning of MLR assets.
- Provide an analysis of the locations selected.

The result of our study further supports the transition from current operating concepts of the MCPN to one that is better suited for FD2030. This provides a quantitative and qualitative assessment of future ashore locations to build a resilient integrated logistics network that strengthens our network of alliances and partnerships.

C. SCOPE

The scope of our study solely focuses on ashore prepositioning sites where the Marine Corps currently does not have a presence. The model assumes the following parameters:

1. The Marine Corps will utilize these sites as a “break the glass in case of emergency” situation when our traditional standing bases in the Indo-Pacific region will not be available. This limitation does not include the effectiveness of proposed sites to augment the existing infrastructure.
2. Demand is user generated to provide a generic framework that is able to be updated in future use as data and research becomes more available. Additionally, this model can be incorporated at a higher classification to meet the needs of future planners.
3. Proposed locations will support multiple EABs.
4. The required surface vessels will be available to transport equipment from the supply to demand points.
5. Funding to establish and maintain the prepositioned sites will be available.
6. Countries the model selects for preposition sites will support the establishment of a facility. The scope of the study does not consider the geo-political considerations in the setup of a prepositioning site.

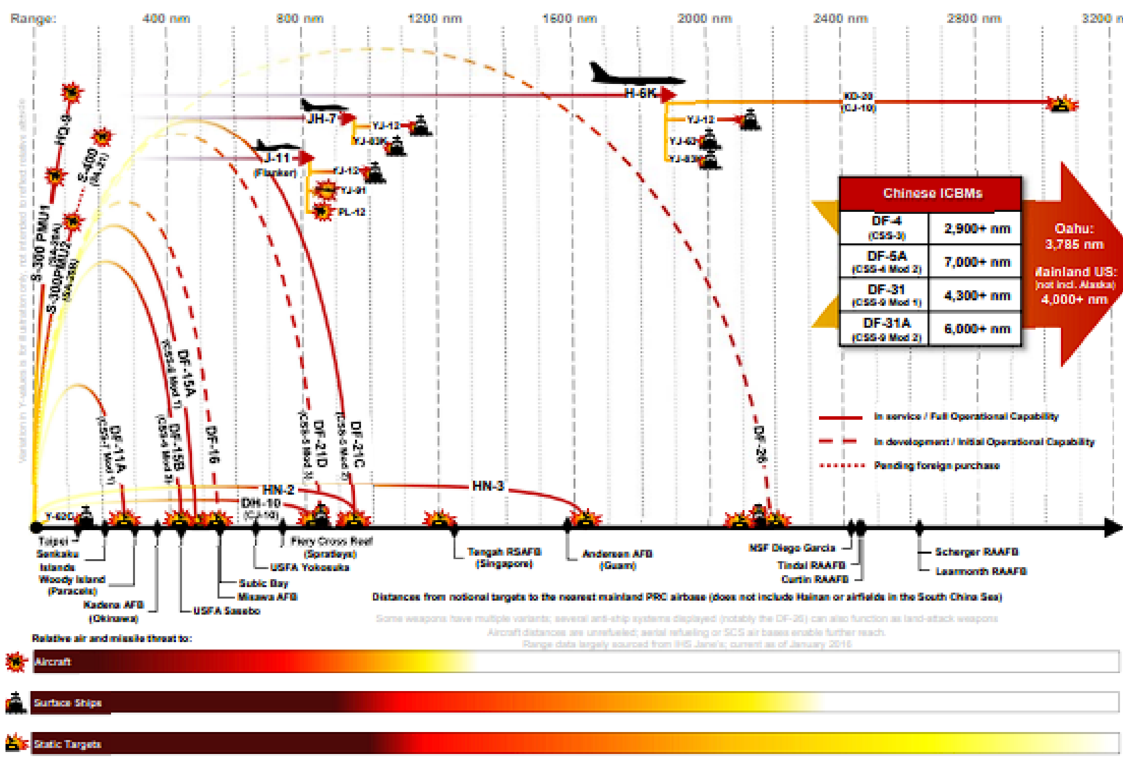
D. BACKGROUND

China’s significant investments in military capabilities, expansion, and global influence have become a threat to the United States as the lead nation for international world order. China considers the United States its primary competitor to achieve its goals and has developed a national strategy that outlines a path forward to becoming the next superpower (Department of Defense, 2021). As tensions increase between the two nations, the chance of potential conflict grows. The United States Navy and Marine Corps must reassess our ability to rapidly provide logistics support to forces in an environment where air and maritime superiority does not exist. Over the last several decades, China has performed thorough research to produce a counter logistics approach should China and the United States go to war (Walton et al., 2019). In order to prevent the U. S. from massing forces and supplies, Chinese campaign concepts will look to conduct preventive or preemptive strikes on U.S. large standing logistics bases and facilities to achieve strategic and operational surprise (Walton et al., 2019).

If the U.S. and China were to become entangled in conflict, there would likely be a tremendous number of casualties. Since Vietnam, the United States is sensitive to the loss of human life and severely impacts public opinion towards conflict. The loss of human life would cause the public opinion and civilian leadership to avoid a conflict by developing a defensive strategy through development of standoff weapons that are able to outrange the adversary. The CMC, General Berger, argues this type of approach plays right into China's strategy; "We have to be in there with troops, we have to be close-up and forward" (Doornbass, 2021, para 2). This requires an agile and unpredictable method to provide logistical support to forces operating forward. Standoff logistics will be available, but there should be multiple ashore and afloat nodes that are active and reactive reducing their chance of being targeted. As the Navy and Marine Corps continue developing their integrated operating concepts, this requires a multi-pronged solution.

1. China's Military Strategy and Capabilities

According to the DOD's report to Congress, "the People's Republic of China's (PRC) strategy is based on what it describes as 'active defense,' a concept that adopts the principles of strategic defense in combination with offensive action at the operational and tactical levels" (Department of Defense, 2021). The term "active defense" implies that China will seek to take the initiative in areas that advance their ability to use defense and offense in support of their national interests. As a result, China has developed significant standoff weapons for anti-access area-denial (A2/AD). This provides the Chinese with the ability to engage targets at distances over 2,000 nautical miles. Figure 1 is a depiction of these capabilities and assessed reach. Many of our standing forces and installations in the region can expect to be targeted in the event of preemptive strike from China.



Data to build this graphic was derived from IHS Jane's (2019); National Air and Space Intelligence Center (NASIC), Ballistic and Cruise Missile Threat (2017); and CSIS Missile Threat (2019).

Figure 1. China's Missile Capabilities.
Source: Walton et al. (2019)

2. Navy and Marine Corps Strategy

The Chinese are attempting to control access at key maritime locations to threaten the freedom of navigation and maneuver that the United States and international community has become accustomed to for many years (United States Navy, 2021). The Navy, Marine Corps, and Coast Guard developed the Tri-Service Maritime Strategy that outlines their vision and concepts to defeat any threats to our way of life. NAVPLAN 2021 states that should deterrence fail we stand ready to confront aggression and decisively win the fight (United States Navy, 2021). Additionally, the NAVPLAN 2021 discusses how the Navy and Marine Corps will use the joint concepts of Distributed Maritime Operations (DMO), Littoral Operations in a Contested Environment (LOCE), and Expeditionary Advanced Base Operations (EABO), to distribute forces and mass sea and shore-based fires (United States Navy, 2021).

The Marine Corps is prioritizing a recommitment to its naval roots by concentrating on supporting the Navy's ability to establish and maintain sea control and sea denial. In the CMC's planning guidance for 2019 he describes this shift "it is time to move beyond the Marine Corps Operating Concept itself, however, and partner with the Navy to complement LOCE and EABO with classified, threat-specific operating concepts that describe how naval forces will conduct the range of missions articulated in our strategic guidance" (Marine Corps, 2019). The CMC put into motion FD2030 as way to man, train, and equip the force to fight under these conditions. The outcome is the development of MLRs which are a multi-domain force designed to operate in the littorals within the contact and blunt layers of the enemy.

a. Distributed Maritime Operations

DMO is the Marine Corps concept to operate within an adversary's A2/AD umbrella. The concept is designed for small but highly lethal forces that are dispersed across the land and sea. DMO threatens the ability of adversary forces to concentrate from within their A2AD, changes their cost calculus, and buys time for flexible options and assembling a joint task force (Headquarters Marine Corps, 2021a).

b. Littoral Operations in a Contested Environment

LOCE is a Navy and Marine Corps concept that focuses on land and sea integration to establish and support sea control in the littorals. According to the Navy and Marine Corps Littoral Operations in a Contested Environment, "Today, the range of modern sensors and weapons extend hundreds of miles both seaward and landward, blurring the distinction between operations at sea and on land and necessitating an operational approach that treats the littorals as a singular, integrated battlespace" (Headquarters Marine Corps, 2017). Having the ability to operate and sustain forces is vital to successfully disrupt the adversary's ability to freely maneuver within the littorals.

c. Expeditionary Advanced Base Operations

EABO is the employment of small naval expeditionary forces in key maritime locations within the contested areas to support sea control and sustainment. The Tentative

Manual for EABO sates its purpose as "EABO seeks to address challenges created by potential adversary advantages in geographic location, weapons system range, precisions and capacity while creating opportunities by improving our own ability to maneuver and exploit control over key maritime terrain by fully integrating Fleet Marine Force (FMF) and Navy capabilities to enable sea denial and sea control, as well as support sustainment of the fleet" (Headquarters Marine Corps, 2021c). These small forces, with a low signature, distributed across the maritime domain creates a dilemma for the adversary. To support an integrated naval campaign, it's important to understand the types of missions and tasks expected in EABO. The Tentative Manual for EABO outlines the expected missions and tasks of the forces conducting these operations. These missions are

- Support sea control operations
- Conduct sea denial operations with the littorals
- Contribute to maritime domain awareness
- Provide forward command, control, communications, computers, combat systems, intelligence, surveillance, reconnaissance, targeting (C5ISRT), and counter- C5ISRT
- Provide forward sustainment (Headquarters Marine Corps, 2021, p. 1-4)

The EABO tasks are

- Conduct surveillance and reconnaissance
- Conduct operations in the information environment
- Conduct screen/guard/cover
- Conduct surface warfare operations
- Conduct air and missile defense
- Conduct strike operations
- Conduct antisubmarine warfare
- Conduct sustainment operations
- Conduct forward arming and refueling point (FARP) operations (Headquarters Marine Corps, 2021c, p. 1-4)

d. Stand-In Forces

Stand-in Forces are forward deployed and partnered with allied nations. These forces are at the forefront of any conflict and will be the first to operate with the adversary's contact layer. They will be the ones to initiate and integrate the concepts previously mentioned. This will immediately disrupt the adversary's freedom of maneuver and mobility as the joint force prepares for follow on forces. They will be the first to gain and maintain key maritime positions that supports sea denial. These forces are designed to be small, have a low signature, require minimal logistics, and dispersed across the area of operations. The sustainment of these forces must also be agile, dispersed, flexible, and survivable to allow the joint force to mass combat power and logistical support.

e. Marine Littoral Regiment

The MLR is a product of FD2030 to fight and operate in the littorals within the contact and blunt layers of the enemy. The MLR is still in development, but the anticipated strength is estimated to be between 1,800 – 2,000 Marines and sailors. The official Marine Corps website for the MLR describes their intended purpose as "designed as a naval formation, including capabilities to enable maneuver and operations in the maritime domain" (Headquarters Marine Corps, 2021b). The MLR is a "stand in force that is mobile, low-signature, persistent in the contact to blunt layers, and relatively easy to maintain and sustain as part of a naval expeditionary force" (Headquarters Marine Corps, 2021b). The official Marine Corps website for the MLR describes that the MLR will be capable of the following missions:

- Conduct Expeditionary Advanced Base Operations
- Conduct Strike
- Coordinate Air and Missile Defense Actions
- Support Maritime Domain Awareness
- Support Surface Warfare
- Support Operations in the Information Environment (Headquarters Marine Corps, 2021b)

f. Maritime Prepositioning Force

MPF provides rapid deployment of forces and capabilities to respond to a crisis or conflict. The MPF Operations doctrine offers a description of how the forces enable national military strategy, "it provides leaders with a range of preplanned options to clearly demonstrate U.S. resolve, deter potential adversaries, and deploy and employ forces to fight and win quickly and decisively" (Headquarters Marine Corps, 2016, p.1-4). Prepositioning is essential to Naval and Marine Corps concepts. Like in Iraq and Afghanistan, the United States will not have the ability for a large buildup of forces. MPF enables the sustainment of stand in forces who will be the first to operate within contested areas.

E. OVERVIEW OF CHAPTERS

This thesis is composed of five chapters. This chapter introduces the study along with relevant background. Chapter II reviews relevant literature. Chapter three describes the research approach in developing a facility location framework. Chapter four provides results based on an established scenario. Lastly, chapter five summarizes the thesis and its conclusions along with recommendations.

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II. LITERATURE REVIEW

This literature review is broken down into three themes. The first theme reviews the DOD's report to Congress on China's strategy. The second theme reviews FD2030 and how the Marine Corps is countering China's strategy. The final theme reviews research on prepositioning and associated models determined to provide Humanitarian Aid and Disaster Relief (HADR) organizations with optimal locations for prepositioning. This chapter links the relevant literature with our study to explore new ashore preposition sites to support FD2030.

A. CHINA'S STRATEGY

Prior to identifying a solution to a problem, it is important to first understand the problem. Understanding China's strategy influences decision makers at every level of government. The DOD publishes an annual unclassified report required by Congress to detail security developments involving China. The recent unclassified report to Congress was released in 2021.

According to the DOD's 2021 report to Congress, China's National Strategy is to displace the United States as the dominant influence in the region. The DOD report to Congress states the People's Republic of China's (PRC) strategy is "to achieve 'the great rejuvenation of the Chinese nation' by 2049 to match or surpass U.S. global influence and power, displace U.S. alliances and security partnerships in the Indo-Pacific region, and revise the international order to be more advantageous to Beijing's authoritarian system and national interests" (Department of Defense, 2021). To accomplish the great rejuvenation China is expanding the role and global presence of the People's Liberation Army (PLA) and People's Liberation Navy (PLN).

The DOD report continues by discussing the PLA's overseas basing and access. In an effort to expand their influence beyond their base located in Djibouti, the PLA is looking to establish bases in additional locations (Department of Defense, 2021). The report assesses the following locations the PLA is considering for future basing and access to project power:

- Cambodia
- Myanmar
- Thailand
- Singapore
- Indonesia
- Pakistan
- Sri Lanka
- United Arab Emirates
- Kenya
- Seychelles
- Tanzania
- Angola
- Tajikistan (Department of Defense, 2021)

If the PLA successfully establish basing and access in the report's assessed locations, the PLA will have the ability to disrupt and threaten U.S. operations beyond the first island chain. PLA expansion increases the significance of the U.S. to strengthen ties with nations in the Indo-Pacific region. Strengthening ties with partners and allies provides the U.S. with flexible basing and access options while maintaining the U.S. as the partner in choice.

Our research analyzes partner nations in the Indo-Pacific region through a facility location model to optimize the nations to be considered in support of FD2030. Our research includes nations with mutual interest from the DOD report and provides additional knowledge where the U.S. should consider its own basing and access expansion.

B. FORCE DESIGN 2030

FD2030 is the CMC's number one priority for the Marine Corps to meet the challenge of the next conflict while remaining cognizant of resource constraints. The Marine Corps is a forward deployed naval force. The CMC describes in his Planning Guidance (2019) how the recent ground wars separated the Marine Corps from its Naval roots "In subsequent years, the luxury of presumptive maritime superiority deluded us into thinking the Navy existed to support Marine operations ashore" (Headquarters Marine Corps, 2019). Much of the research surrounding FD2030 is focused on the maritime domain, but the CMC recognizes there are multiple solutions to FD2030. Although supporting the fleet and having Marines operating aboard ships is a priority, the Marine Corps should explore all ways and means of distributing its forces. With the advancement in the adversary's precision strike capabilities, the Navy and Marine Corps must consider solutions ashore and not concentrate forces on large ships (Headquarters Marine Corps, 2019). This is a signal that despite our presence abroad, the Marine Corps needs to identify and think about new ways and locations to position ashore.

The CMC's planning guidance for Marine Corps Prepositioning Network provides additional guidance to planners. The CMC's guidance outlines the requirement to transition the network that is based on current operating concepts to one that closely aligns with FD2030. The CMC's intent in his guidance for the Marine Corps Prepositioning Network (2022) is "over the next ten years we will transform the existing prepositioning programs into an integrated afloat and ashore network that enables the execution of both naval campaigns in support of sea control/sea denial and global crisis response" (p. 4). This guidance shows the need for further research into ashore locations that can integrate with maritime logistics.

To fight and win in the contested environment, the Navy and Marine Corps will need to develop and acquire next generation logistic ships (NLGS). Loseke and Yarnell (2020) explore the NGLS required to support DMO and EABO. They developed a transshipment model to determine the optimal NGLS composition that minimizes the number of deliveries. Loseke and Yarnell broke down the NGLS families into two distinct subgroups: The platform supply vessel (PSV)/ fast supply vessel (FSV) and the light amphibious warship (LAW) (Loseke et al., 2020). Loseke and Yarnell found the PSV to be the better option and should receive prioritization of effort and resources to reduce risk while conducting logistics within the WEZ.

Our research extends the knowledge of conducting logistics to support FD2030 and future concepts by analyzing locations ashore that can be used to distribute forces and equipment.

C. PREPOSITIONING

Most research regarding prepositioning is in support of HADR, maritime prepositioning, the public and private sectors of business, and bulk fuel in support of military operations.

There are many types of models that can be used to determine a facility location. Owens and Daskins (1998) provide an overview of strategic facility location and review the literature related to the facility location problems. In this study they review static and deterministic location problems. Owens and Daskins define each model, their purpose, and basic formulations.

Fuel will be a major resource required to sustain operations within the contested environment. Kasdan (2020) researches a bulk fuel distribution network. He developed a facility location model that optimizes where to store bulk fuel. Specifically, he focused on the areas within the first and second island chain. Kasdan uses Kline's (2019) Naval Postgraduate School unclassified scenario Global War 2030. The scenario provides a description of the events and actions leading up conflict and event once the conflict begins. His research uses the scenario to stochastically determine the locations based on friendly courses of action.

HADR is one of the most widely studied topics in in prepositioning and facility location. Duran et al. (2011) developed and performed a study for Cooperative for Assistance and Relief Everywhere (CARE) international. Their study explores the optimized number and location of prepositioning warehouses. Duran et al. developed a mixed-integer programming inventory-location model with an objective function to minimize the average response time over 240 demand instances. Their study included "22 demand points, 12 candidate warehouse locations, seven relief items, and 240 demand instances" (Duran et al. 2011, 227). Their results included optimized locations from 1 to 9 with the expectation of gradual funding to support establishment of the warehouses.

D. SUMMARY

Our research closely aligns with Duran et al. (2011). Specifically, we find the optimal number and location of prepositioning locations in the INDO-PACOM theater that supports FD2030. However, the difference is we look at prepositioning in support of military operations in a time of war in an un-permissive environment. Another difference from previous research is our supply includes equipment that supports future operating concepts and units. We aim to identify locations the Marine Corps can consider in future planning to preposition equipment that facilitates the sustainment and readiness of MLRs operating within the first island chain.

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III. DATA AND METHODOLOGY

Our model intends to provide future planners with a prepositioning framework that results in the optimal location to preposition assets that supports the Navy and Marine Corps' future operating concepts within the contact and blunt layer.

A. GENERAL FRAMEWORK

This report is unclassified, therefore, the parameters we use within the model are hypothetical and meant to estimate values. Specifically, supply from the preposition sites and demand from the MLR are placeholders because the MLR is still considered a concept in development.

Sustaining stand in forces in a contested environment will require a dynamic and flexible logistics network that incorporates afloat and ashore prepositioning. With limited resources in mind a new approach is required to identify optimal locations ashore to support Marine Corps forces operating in the WEZ. The underlying notion is that the current large standing logistics bases will be among the first locations targeted by the enemy. Establishing additional ashore prepositioning sites that supports operating forces provides resilient and flexible options. The area of focus is demand sites located within the first and second island chain. Figure 2 is a graphical depiction of the region and outlines the first and second island chain. Our study uses a linear programming facility location model that we implemented in Excel.

Figure 2. First and Second Island Chain. Source: Apte et al. (2020)

To determine the countries to include in the model, we used the members of the Indo-Pacific Economic Framework. The Indo-Pacific Economic Framework involves countries that are committed to growth, peace, and prosperity (White House, 2022). Although this study does not include geo-politics, the Indo-Pacific Economic Framework provides potentially viable options. The Indo-Pacific Framework outlines the following nations who have committed to the Indo-Pacific Economic Framework.

- United States
- Australia
- Brunei Darussalam
- India

- Indonesia
- Japan
- Republic of Korea
- Malaysia
- New Zealand
- Philippines
- Singapore
- Thailand
- Vietnam (White House, 2022)

B. NODES

The nodes consist of supply nodes and demand nodes. The supply nodes represent the respective countries while the demand nodes represent self-generated forces operating EABs. We include ten of the thirteen countries committed to the Indo-Pacific Economic Framework. The countries not included are: United States, Australia, and Republic of Korea. Each EAB locations are randomly assigned islands within the first island chain and represent forces distributed and operating within the area of responsibility (AOR). Additionally, the supply and demand of each node was self-generated and designed as a placeholder. Country locations are origin nodes where the equipment will be drawn from. The EABs are destination nodes where equipment will be demanded.

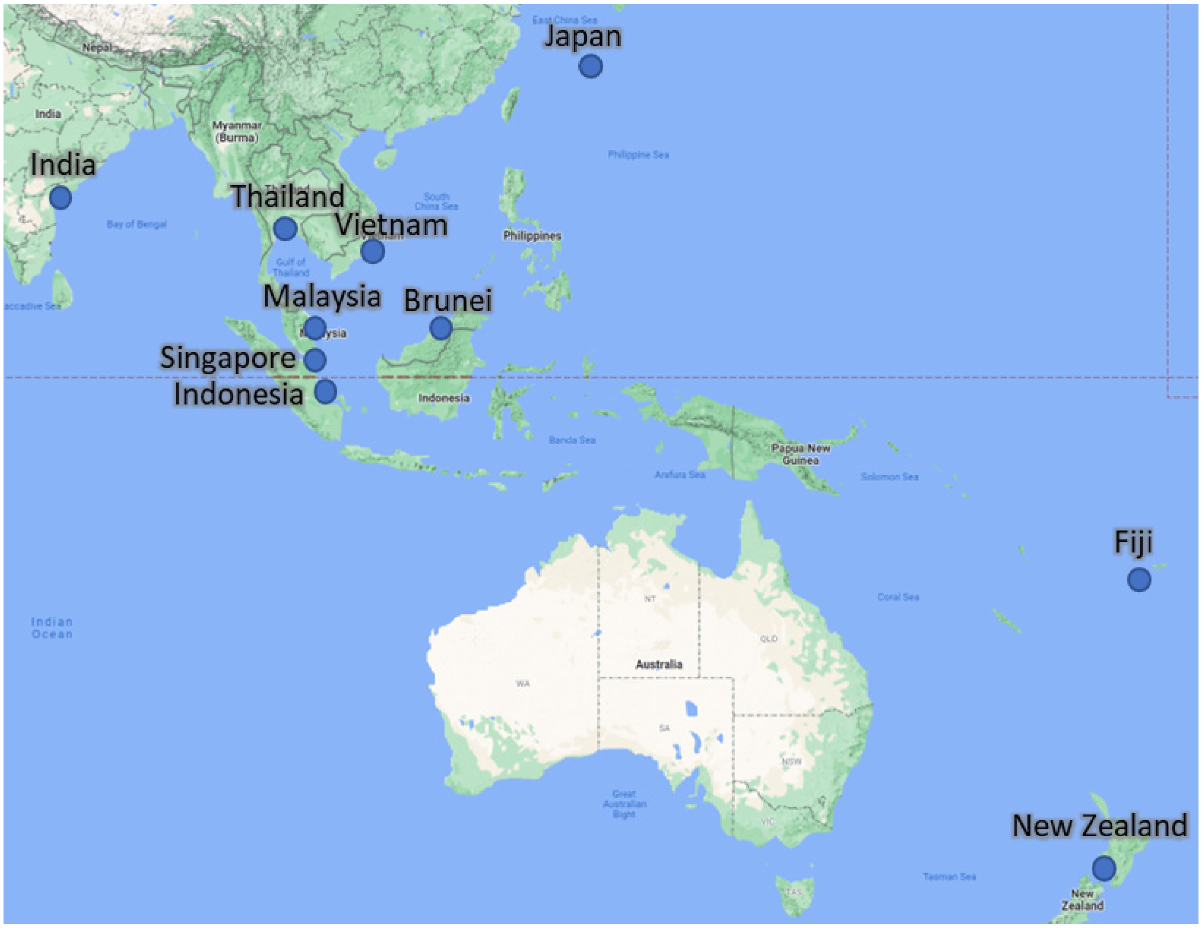

Figure 3. Graphic Depiction of the Supply Nodes (Preposition sites) Presented as a Map Overlay.

C. ARCS

The arcs in our model connect the prepositioning location to the EAB demand locations. Each arc is considered unrestricted meaning capacity along the routes are not limited. The length of each arc connecting the nodes are considered the cost measured in kilometers.

D. MODEL FORMULATION

1. Indices and Sets

i Preposition locations (i = 1, 2, 3…I)

j EAB locations (j = 1, 2, 3…J)

2. Data [units]

$Demand_j$ Demand for equipment by EAB locations *j*

$Supply_i$ Supply of equipment by preposition locations *i*

$Distance_{ij}$ Distance from preposition locations *i* to EAB locations *j* [kilometers]

3. Decision Variables

Y_i If a site *i* is selected (1 = selected, 0 = otherwise)

X_{ij} Number of trucks transported from site *i* to EAB *j*

4. Model Formulation

min

$$\sum_{i=1}^{I}\sum_{j=1}^{J} X_{ij} \times DISTANCE_{ij} \tag{01}$$

Subject to:

$$\sum_{j=1}^{j} X_{ij} \leq Supply_i Y_i \quad \forall i \in I \tag{1}$$

$$\sum_{i=1}^{I} X_{ij} \geq Demand_j \quad \forall j \in J \tag{2}$$

$$Y_i \in \{Int\} \tag{3}$$

$$X_{ij} \geq 0 \tag{4}$$

5. Model Description

The prepositioning model identifies the optimal location to preposition assets that assesses the cost (distance, km) between the site and potential EAB sites in a competitive and conflict environment.

The objective function (01) minimizes the distance between locations which represents a gained advantage and responsiveness. The model selects a predetermined number of locations ranging from one to three based on the assumption that funding will be available, and the geo-political environment permits the establishment of a site while investing in mutual interests between the United States and the country selected.

The supply constraint (1) ensures each preposition site can deliver the required amount of supply (vehicles) to augment and support EAB locations. Each preposition site is given a level of supply constraint that can support all five randomly generated EABs. As the number of preposition sites change, the model reflects flexibility in the amount of supply at each site. For example, if the required vehicles to support five EABs is 60, then the preposition site at a minimum should have the capacity to support 60 vehicles.

The demand constraint (2) ensures the readiness and strength of each EAB location is sustained through their demand. Since each preposition site can support five EABs, the demand constraints remain constant. The model is populated with notional demand data that is a placeholder for actual demand data when known.

The number of location constraint (4) ensures, at a minimum, one site is selected. The model reflects how the locations change as the number of sites selected is changed from a constrained selection of one to three.

E. OPERATIONAL SCENARIO

Fictional scenario, (Kline 2019) Global War of 2030, provides valuable background information and context to our study. The scenario provides background for the road to war and the events following a declaration of war. The scenario describes the actions of friendly and opposing forces within the first and second island chain which is used to determine the locations of the supported forces. A summary is provided.

1. Road to War

China in 2020 is expanding political, fiscal, economic, and military influence by continuing to trade infrastructure between Asia and Europe. The relationship between China and Russia is strengthening with the increase in trade agreements centered on energy. Their common interest to challenge United States national power is the cause for increased cooperation.

China is adding to their terra-formed islands populated with military installations. According to Kline (2019), "China are now building facilities on the western end of the Scarborough Shoal reef which is being protested by the Philippines and the United States."

In response to the China's expansions, the United States is working to establish closer ties with Indo-Pacific nations. Specifically, building closer ties with Singapore and the Philippines. Additionally, the United States is expanding its presence and activity at Diego Garcia and Darwin, Australia.

2. Conflict

Tension begins to build in 2027 when several countries along the "Belt and Silk" road de-faulted on Chinese loans to build ports, roads, pipelines, and other infrastructure. Violent civil protests against Chinese workers occurred in Malaysia, Pakistan, Djibouti, Vietnam, and Indonesia.

Following civil protests, in the spring of 2029, a Chinese deep-sea exploration ship exploded without warning. China claims either Vietnam, Indonesia, or the Philippines were responsible. As a result of the Chinese ship explosion, the Chinese mobilized their fleet in the region and demanded the three countries accept responsibility, or they would "secure their sea." After a month the Chinese responded by dinking a patrolling Vietnamese ship with their land-based surface to surface missile. Additionally, they announced maritime traffic throughout the South China Sea would be subject to inspection and control by Chinese forces.

Following the events in 2029, the war starts in early in 2030. China begins by successfully occupying Natuna Besar, Indonesia and Palawan, Philippines. The United States, operating under mutual agreement, began to respond by stopping and inspecting Chinese flag ships operating throughout the world. Additionally, the United States begins to mobilize its forces for a potential conflict. While conducting an inspection in the Indian Ocean, a U.S. DDG is torpedoed, and war is declared.

For our study, we consider the various locations of the USMC forces conducting sea control operations within the first and second island chains. We focus on the build-up to conflict and specifically how prepositioning supports the rapid response to augment stand-in forces with additional resources to begin sea control operations. Our study determines the demand and locations of each unit to decide the optimal locations to preposition assets to support the operating units and ensures a rapid and timely shipments of vehicles that minimizes transportation costs.

F. DETERMINING THE EAB LOCATIONS

To determine the EAB locations, we conduct an analysis of the first and second island chains. We select 15 random islands located throughout the AO. Using the "as the crow flies" method, we measure the distances between each EAB location and the potential prepositioning sites to determine the shipment costs. During each random sample draw of EAB locations, all islands are considered with replacement. For example, if EAB location 4 is selected during the first sample draw, EAB location 4 is not removed for selection from subsequent sample draws. This randomized method is used since actual EAB locations are unknown. Additionally, this randomized the distances to allow the model to provide optimized solutions based on random EAB selection. This framework can be adapted and applied to a real-world scenario where the users input known EAB locations. Table 1 provides the latitude and longitude of each EAB locations along with their associated distances (km) to each preposition location, respectively.

Table 1. EAB Locations and Distance (km) from Preposition Sites

Distances between preposition sites and EAB locations (km)										
EAB/Preposition Site	Vietnam	Brunei	Fiji	India	Indonesia	Japan	Malaysia	New Zealand	Singapore	Thailand
1 (8.036067728187579, 110.60908507405959)	462	581	7864	3383	1585	2684	1164	8148	1220	1263
2 (7.655871572400383, 113.99824305320634)	717	312	7507	3560	1703	2400	1283	8227	1306	1310
3 (8.375019748944458, 115.20865661718733)	771	371	7409	3780	1831	2295	1340	8310	1412	1419
4 (8.912058167131585, 116.28326768374608)	844	454	7327	3840	1954	2284	1460	8380	1520	1520
5 (10.819985349844558, 117.77709515539091)	949	710	7269	3960	2264	2017	1670	9517	1839	1717
6 (0.1079836258240376, 107.22644404751344)	1325	1016	7927	3299	366	3646	592	8166	394	1685
7 (4.722870470843564, 107.97815865504322)	811	803	8021	3181	803	3204	514	8407	567	1284
8 (9.547849496789865, 112.8888538155875)	480	571	7726	3588	1532	2432	1237	8420	1338	1438
9 (19.525294186327336, 121.94816980746829)	1600	1766	7336	4523	3025	975	2677	8660	2809	2379
10 (19.096651360820452, 121.23150855902743)	1514	1595	7387	4450	2933	1049	2587	8650	2735	2298
11 (3.6328449080804615, 125.49944025484876)	2014	1159	6154	5096	2411	2551	2464	7018	2396	2979
12 (11.053014722805093, 114.28529620646646)	559	678	7646	3733	1766	2222	1458	8456	1566	1519
13 (11.497298535918373, 119.68123881513466)	1139	875	7125	4324	2209	1856	1997	8094	2059	2102
14 (4.088425188572142, 108.2198185611883)	896	792	7953	3244	731	3252	532	8372	536	1369
15 (2.9454147455415365, 108.87012127478081)	997	740	7846	3348	690	3290	624	8240	574	1503

The key takeaways are that the model selects the optimal locations to establish a preposition site when the EAB locations are random. The demand constraint for each EAB is binding meaning the preposition sites must be able to meet the EAB's demand. While the model minimizes the distance between the preposition sites, the assumption is the shorter distances reduce response time and demand can be satisfied faster.

G. SUMMARY

In summary, our model is designed to provide a standard framework that results in the optimal location to preposition assets that supports the Navy and Marine Corps' future operating concepts within the contact and blunt layer. We generate preposition sites by focusing on countries who are committed to future economic and development ties to the United States. The context for our model is provided by a fictional scenario, (Kline 2019) Global War of 2030. The scenario outlines a fictional conflict between the United States, and China and Russia. Within the context of the scenario, and our study, we generate fifteen EAB sites to be randomly drawn from as EAB sets for the model. Following the formulation of the model, we generate three random EAB sets composed of five EABs to produce optimized locations for further analysis.

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IV. ANALYSIS

The goal of our model is to provide a transparent, data driven recommendation for the optimal locations the USMC can preposition assets that supports FD2030 operating concepts. The results are presented across three scenarios. Additionally, we ran constrained models which restricts the model to only include specific locations based on risk.

- Scenario 1 finds the solution if one preposition site is selected (constrained vs. unconstrained)
- Scenario 2 finds the solutions if two preposition sites are selected (constrained vs. unconstrained)
- Scenario 3 finds the solutions if three preposition sites are selected (constrained vs. unconstrained)

The decision to include scenarios 1–3 accounts for the assumption that over time the USMC may perhaps expand from an initial preposition site to multiple preposition sites.

A. INTERPRETING COST RESULTS

The intention of our framework is to minimize the cost of locating a preposition site when randomly generated EABs are sampled. In this framework we use distance between the preposition site and the EAB. Since the preposition site must be capable of meeting the demand of the five EABs selected, the capacity of each preposition must have the capacity to meet the total demand of the five EABs. The scope of the framework is not intended to determine the number of vessels required to meet the demand. Therefore, the total cost is the sum product of the cost and the amount of demand. For example, if four vehicle deliveries are required at Node X at a cost of 300km along Arc X, the total cost would be 1,200.

B. EAB SETS

Before executing the model, we randomly select three EAB sets composed of five EABs. EAB set 1 are locations 1, 5, 12, 9, and 2. EAB set 2 are locations 13, 7, 14, 11, and 3. EAB set 3 are locations 11, 8, 9, 4, and 12, respectively. The EAB sets are used in each iteration of the model. The purpose for randomly selecting EABs is to perform a sensitivity analysis of the model since we do not know the locations of potential locations of EABs. Our model provides a framework for decision makers and operational planners to utilize when potential locations are identified or in the event of uncertainty.

C. SCENARIO ONE RESULTS

In the first iteration of the model, we consider a scenario in which only one preposition site is selected. The model is updated with the corresponding values to each EAB set. When the model is constrained to selecting one location, the optimized location is Brunei across all three EAB sets. Table 2 summarizes the results from scenario one.

Table 2. Selection Results for Scenario One

	EAB set 1	EAB set 2	EAB set 3
Vietnam			
Brunei	X	X	X
Fiji			
India			
Indonesia			
Japan			
Malaysia			
New Zealand			
Singapore			
Thailand			

Results of each EAB set with unconstrained preposition sites are shown in Table 3.

Table 3. Total Cost of Single Site Selection, Unconstrained

Preposition Site	EAB	Cost (Kilometers)					Total Cost (km)
Sample 1							
Brunei	1, 5, 12, 9, 2	581	710	678	1766	312	70153
Sample 2							
Brunei	13, 7, 14, 11, 3	875	803	792	1159	371	103478
Sample 3							
Brunei	11, 8, 9, 4, 12	1159	571	1766	454	678	110567

D. SCENARIO TWO RESULTS

In the second iteration of the model, we consider a scenario in which two preposition sites are selected. The model is updated to reflect the constraint of selecting two preposition sites. When the model is constrained to selecting two locations, the optimized locations vary based on the sample. The one constant location selected across all three EAB sets remains Brunei. However, the second location for each EAB set are as follows: set one selected Vietnam, set two selected Malaysia, and set three selected Japan. Table 4 summarizes the results from scenario two.

Table 4. Selection Results for Scenario Two

	EAB set 1	EAB set 2	EAB set 3
Vietnam	X		
Brunei	X	X	X
Fiji			
India			
Indonesia			
Japan			X
Malaysia		X	
New Zealand			
Singapore			
Thailand			

Results of each EAB set with unconstrained preposition sites are shown in Table 5.

Table 5. Total Cost of Two Sites, Unconstrained

Preposition Site	EAB	Cost (Kilometers)					Total Cost (km)
Sample 1							
Vietnam	1, 5, 12, 9, 2	462	949	559	1600	717	
Brunei	1, 5, 12, 9, 2	581	710	678	1766	312	
							63755
Sample 2							
Brunei	13, 7, 14, 11, 3	875	803	792	1159	371	
Malaysia	13, 7, 14, 11, 3	1997	514	532	2464	1340	
							92488
Sample 3							
Brunei	11, 8, 9, 4, 12	1159	571	1766	454	678	
Japan	11, 8, 9, 4, 12	2551	2432	975	2284	2222	
							90792

E. SCENARIO THREE RESULTS

In the third iteration of the model, we consider a scenario in which three preposition sites are selected. The model is updated to reflect the constraint of selecting three preposition sites. When the model is constrained to selecting three locations, we also see variability in the results. Across all three EAB sets the model selects: Brunei and Vietnam, respectively. The third site selection produces variability across all three sets. The first set selects Thailand, second set selects Malaysia, and the third set selects Japan. Table 6 summarizes the results for scenario three.

Table 6. Selection Results for Scenario Three

	EAB set 1	EAB set 2	EAB set 3
Vietnam	X	X	X
Brunei	X	X	X
Fiji			
India			
Indonesia			

	EAB set 1	EAB set 2	EAB set 3
Japan			X
Malaysia		X	
New Zealand			
Singapore			
Thailand	X		

Results of each EAB sets with unconstrained preposition sites are shown in Table 7. These parameters resulted in set one selecting Vietnam, Brunei, and Thailand; set two selecting Vietnam, Brunei, and Malaysia; set three selecting Vietnam, Brunei, and Japan.

Table 7. Total Cost of Three Sites, Unconstrained

Preposition Site	**EAB**	**Cost (Kilometers)**					**Total Cost (km)**
Sample 1							
Vietnam	1, 5, 12, 9, 2	462	949	559	1600	717	
Brunei	1, 5, 12, 9, 2	581	710	678	1766	312	
Thailand	1, 5, 12, 9, 2	1263	1717	1519	2379	1310	
							63755
Sample 2							
Vietnam	13, 7, 14, 11, 3	2014	811	896	2014	771	
Brunei	13, 7, 14, 11, 3	875	803	792	1159	371	
Malaysia	13, 7, 14, 11, 3	1997	514	532	2464	1340	
							92188
Sample 3							
Vietnam	11, 8, 9, 4, 12	2014	480	1600	844	559	
Brunei	11, 8, 9, 4, 12	1159	571	1766	454	678	
Japan	11, 8, 9, 4, 12	2551	2432	975	2284	2222	
							83897

F. UNCONSTRAINED COMPARISON

Evaluating the results of a single site selection across all three EAB sets showed Brunei selected in all three scenarios. Assuming initial investments in establishing future preposition sites, we would recommend Brunei be strongly considered.

Moving from a single site selection to selecting two sites results in the greatest gains in terms of cost. For example, when comparing the single site to the two site selections in EAB set one we show a decrease in cost of 6,398. Moving from a two site to three site constraint nets zero savings in cost. EAB sets two and three provide similar results that when moving beyond two sites to three sites produces marginal gains. This indicates that if appropriate funding is available, the USMC should consider the establishment of two preposition sites. Across all three scenarios, Brunei and Vietnam were selected. The third site selected varied in each EAB set with Thailand, Malaysia, and Japan, respectively. If funding is available to establish up to two preposition sites, the recommendation is Vietnam be strongly considered. The third site selections variability is due to the random selection of the EABs in each EAB set. Considering the marginal gains when adding a third site suggests that an optimal consideration would likely be two. The future location of potential EABs significantly impacts the selection of a preposition site.

G. EFFECTS OF RISK LEVELS ON PREPOSITION SITE SELECTION

As discussed earlier, due to threats and capabilities posed by the PLA, risk is an important measure in selecting a preposition site. To evaluate risk in the selection of potential preposition sites, we bin each site into categories; high, medium, low, and no risk. To determine the category a preposition site belongs to we use the estimated threat rings associated with China's missile capabilities. Figure 4 is a graphical representation of the threat rings.

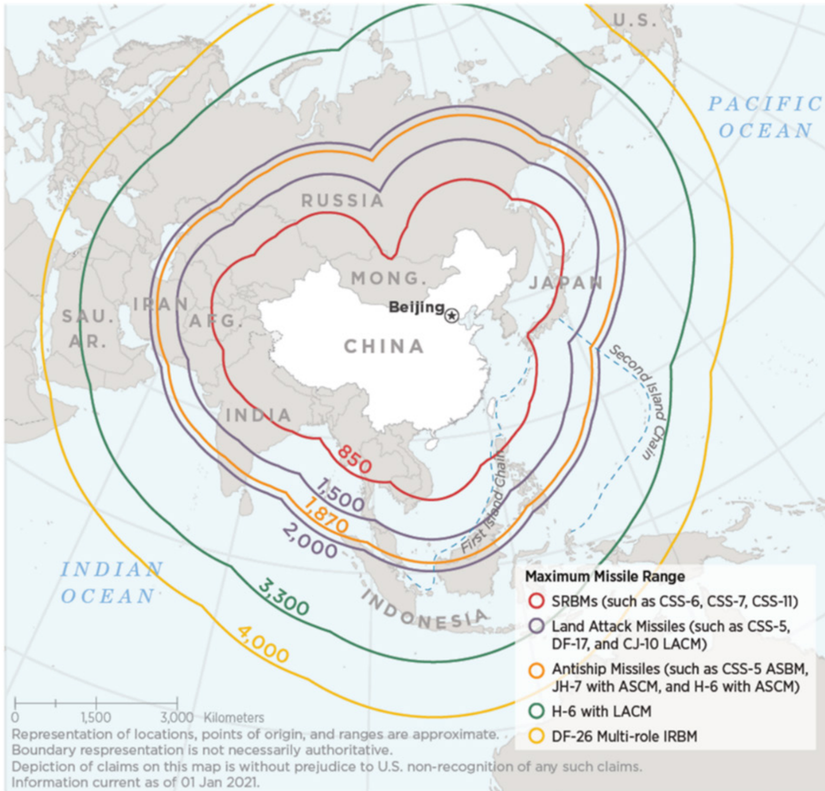

Figure 4. China's Missile Range Rings.
Source: Department of Defense (2021).

A preposition site located within 850 kilometers was determined to be high risk. Preposition sites located between 851 to 2,000 kilometers were assigned to medium risk. Preposition sites between 2,001 and 4,000 kilometers were assigned to low risk and anything beyond 4,001 kilometers were assigned to no risk. Following the assignment of each preposition site to a risk category, we constrain the model to the medium and no risk categories. Table 8 shows each country and their respective risk categories.

Table 8. Preposition Site Risk Assignments

Risk Based on China Capabilities			
High Risk	**Med Risk**	**Low Risk**	**No risk**
Vietnam	India	Indonesia	Fiji
Thialand	Malaysia		New Zealand
Japan	Brunei		
	Singapore		

H. WITH RISK SITE SELECTION COMPARISON, CONSTRAINED

As mentioned, we want to evaluate the model's optimized preposition site when constrained based on risk. The intent is to identify a preposition site that may have a higher a cost, or distance, to reduce the risk associated with China's missile capabilities. To accomplish this, we remove the preposition sites considered as high risk and constrained the model to only include medium risk followed by no risk. Since Indonesia is the only preposition site within the low-risk threshold, the total cost was calculated by using the sum-product excel function between the distances of each EAB set and the demand at each EAB.

1. Medium Risk

Since Brunei is medium risk and was selected in all instances when one preposition site is selected, we evaluated the model based on the selection of two preposition sites. As expected, Brunei was selected in each iteration of the model. The second site selected under the medium risk threshold varied. However, in each iteration, the total cost was not affected. In EAB set one and EAB set three, the model selected a second preposition site (Fiji) but the site did not supply equipment to the EABs. With the randomly generated EABs in set one and set three, Brunei is the optimized preposition site and additional sites have negligible impacts on total cost. In the unconstrained model, EAB set two selected Brunei and Malaysia. Brunei and Malaysia are both considered medium risk. Therefore, the optimized preposition sites selected, and total cost are unchanged.

2. Low Risk

As previously mentioned, we calculated the total cost for the low-risk threshold by taking the sum-product of each EAB set's distances and the demand at each EAB. Table 9 shows the total cost results.

Table 9. Low-Risk Total Cost

	Preposition Site	Total Cost (km)
EAB set 1	Indonesia	225831
EAB set 2	Indonesia	171983
EAB set 3	Indonesia	254732

3. No Risk

The no risk category included two preposition sites: Fiji and New Zealand. In all scenarios Fiji is the preposition site selected. As expected, the total cost varies and is dependent on the location of the EABs. Table 10 displays the results for each EAB set and the associated total cost.

Table 10. No Risk Category Selection Results

Preposition Site	EAB	Cost (Kilometers)					Total Cost (km)
Sample 1							
Fiji	1, 5, 12, 9, 2	7864	7269	7646	7336	7507	927803
Sample 2							
Fiji	13, 7, 14, 11, 3	7125	8021	7953	6154	7409	895263
Sample 3							
Fiji	11, 8, 9, 4, 12	6154	7726	7336	7327	7646	906986

4. Effects of Risk on Preposition Site Selection

As discussed, we wanted to measure the effect risk has on the selection of a prepositioning site. To do this, we compared the average total cost across three risk thresholds: Medium, Low, and No Risk. This analysis showed that establishing a preposition site closer to the area of operations results in greater risk but at a much lower cost. The reverse is also true that if the risk appetite is low, then the expectation is that cost will be significantly higher. These tradeoffs between risk and total cost (distance, km) are depicted in Figure 5.

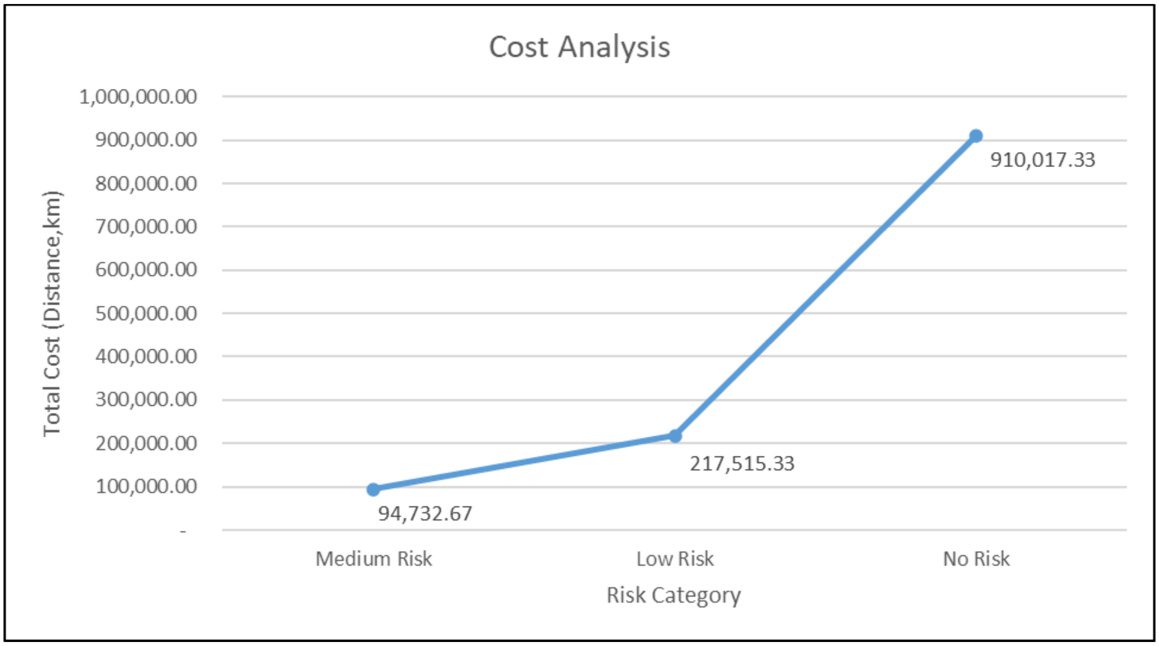

Figure 5. Tradeoff of Risk and Total Cost (Distance, km)

I. SUMMARY OF FINDINGS

Our findings show that in every scenario Brunei is an optimal country for a prepositioning site to include the selection of multiple sites. When additional prepositioning sites are available, the second and third site selections varies based on the locations of the EABs. Figure 6 shows the total number of times Brunei was selected in each iteration was 9. As the model was expanded to include two and three preposition sites, additional sites were selected dependent on the location of the EABs.

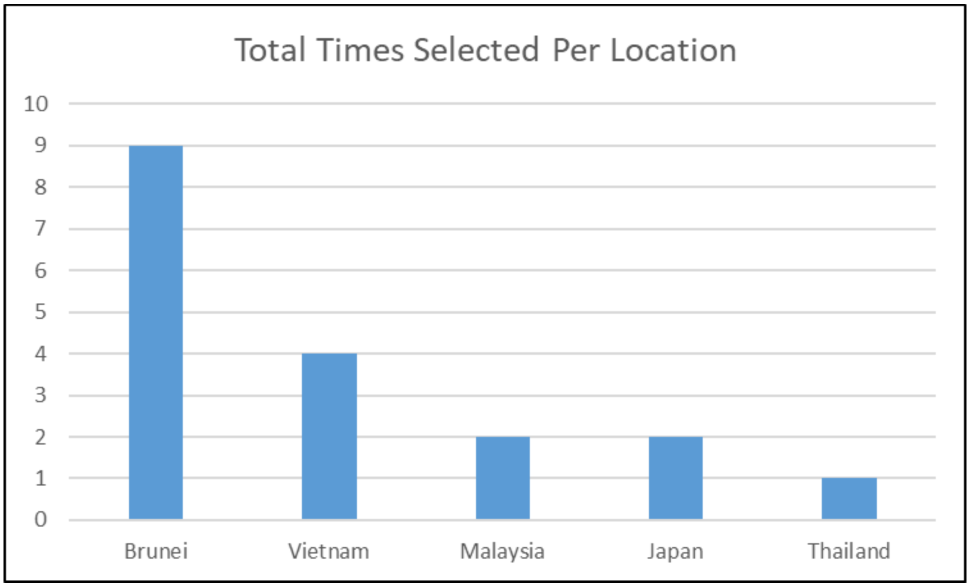

Figure 6. Total Times Selected per Scenario

Analysis Summary

Summary of our main analysis:

- In all instances Brunei is the optimal location to place a prepositioning site in the event funding is only available for one site.

- Considering the area of operations, the optimal number of prepositioning sites is two. When the number of prepositioning sites increased from two to three the gain in total cost was negligible.

- When we consider risk based on the missile capabilities of China, we see that a tradeoff exists between the risk tolerance and the total cost. As a prepositioning site is located to reduce the amount of risk, the total cost in distances to the EABs becomes greater.

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V. CONCLUSIONS AND FUTURE WORK

Future Navy and Marine Corps operating concepts require thorough analysis on current concepts to be validated. The Marine Corps Global Positioning Network (MCGPN) is a program designed for large scale mobilization to support Cold War operating concepts. The global landscape and the growth of China as a competitor ignited the Marine Corps to initiate Force Design 2030 (FD2030). FD2030 is a future operating concept designed for expeditionary forces to operate within contested environments in a competitive environment and capable of transitioning to conflict. In order to support FD2030 operating concepts the Navy and Marine Corps need to evaluate and expand MCGPN to meet the demands of the forces operating in the contested environments.

China's standoff missile capabilities and aggressive expansion in the Indo-Pacific region results a re-evaluation of our current large standing logistical nodes as potential targets and their ability to support stand in forces. This requires us to consider potential new locations to preposition assets in the region that can support forces operating in the contested environment that meets the challenges of competition and conflict. Additional benefits of identifying new preposition assets allows the United States to capitalize on its advantage of building and expanding its allies and partnerships.

A. CONCLUSION

Our model is designed as a framework to provide future planners with a recommendation on the optimal locations to preposition assets capable of supporting FD2030 concepts. We develop a facility location model to minimize the distance to support randomly generated Expeditionary Advanced Bases (EAB) within the contested environment. The end state was to provide recommendations on where to preposition assets through the minimization of the distance between the preposition sites and the randomly generated EABs. We used countries identified in the U.S. led Indo-Pacific Economic Framework to preposition assets. Specifically, the countries used in our model were Vietnam, Brunei, Fiji, India, Indonesia, Japan, Malaysia, New Zealand, Singapore, and Thailand.

Our findings show that when considering an investment in a single preposition site, Brunei was the only location selected in our model. When considering an investment in more than one preposition site, the location of follow-on sites varies significantly dependent on the location of the EABs. Besides Brunei, Vietnam was the most selected site location in our model. To benefit the most from prepositioning, our model shows that two preposition sites optimize the minimum total cost (distance). When moving beyond two preposition sites, the objective function value is often unchanged or minimal cost reduction is achieved. On average, we saw a 15% reduction in total cost when increasing our preposition site from 1 to 2 while increasing from 1 to 3 preposition sites resulted in a 18% reduction in total cost. We identified that a risk threshold significantly impacts the total cost in our model. When selecting sites further away from the missile capabilities of China to reduce risk our total cost was significantly higher.

These findings provide a framework for future planners to consider and incorporate into their decision-making process. As the Marine Corps continues to evaluate the future of its prepositioning network, it needs to consider the potential locations of the EABs and the optimal locations to support them. By minimizing the distance between the EABs and preposition sites, the demand of the forces operating within the contested environment can be satisfied quicker.

B. FUTURE WORK

This research intends to provide the optimum locations to preposition assets to support FD2030 concepts, specifically, the Marine Littoral Regiments. Since FD2030 is a developing concept, we deliberately kept our framework broad while providing context from an academic scenario. Upfront investment associated with opening a preposition site would be value added if included within the model. This would create an objective function that minimizes the cost of establishing a prepositioning site while still constrained to meeting an associated demand for the EABs that is financially reasonable.

This study incorporated user generated capacity at each location to ensure each site was capable of meeting demand. The capacity at each potential location is a variable that needs future consideration. If the inventory levels at each capacity is known, it could significantly affect the results of the model. For example, if only one site can be considered and Brunei is not able to meet the demand for a designated amount of EABs, then Brunei would no longer be the optimized location under a single site constraint. Therefore, continued research and review into the potential demand and supply requirements of the EABs would be required to determine the optimal location of prepositioning sites.

A final area of future research is a qualitative assessment of each prepositioning site location. This study used the Indo-Pacific Framework to determine the locations to guide this research in a direction as a future priority that each government has agreed to future cooperation. The Indo-Pacific Framework does not include future military cooperation and each potential location would require a qualitative assessment to determine it is a viable location to preposition military equipment.

C. SUMMARY

This study assesses the optimal locations to preposition equipment to support FD2030 operating concepts. It focuses on locations within the WEZ on randomly generated EAB locations to determine the best locations that minimizes the total distance. We created a facility location model to provide a general framework for determining the optimized prepositioning locations to support the demand of EABs. As planners continue to analyze legacy programs and adapt them to future operating concepts, our model provides an adaptive framework capable of providing inputs to a tailoring cycle.

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APPENDIX. MODEL FORMULATION

Decision Variables:

Yi = 1 if site selected, 0 otherwise (For i = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
i= Vietnam, Brunei, Fiji, India, Indonesia, Japan, Malaysia, New Zealand, Singapore, Thailand

Xij = Amount of equipment transported from preposition site i to EAB site j. (j= 1, 2, 3...15)

LP Model

Minimize (462 X11 + 717 X12 + 559 X112 + 480 X19 + 949 X15 + 581 X21 + 312 X22 + 678 X212 + 579 X29 + 710 X25
+ 7864 X31 + 7507 X32 + 7646 X312 + 7726 X39 + 7269 X35 + 3383 X41+ 3560 X42 + 3733 X412 + 3588 X49 + 3960 X45
+ 1585 X51 + 1703 X52 + 1766 X512 + 1532 X59 + 2264 X55 + 2684 X61 + 2400 X62 + 2222 X612 + 2432 X69 + 2017 X65
+ 1164 X71 + 1283 X72 + 1458 X712 + 1237 X79 + 1670 X75 + 8148 X81 + 8227 X82 + 8456 X812 + 8420 X89 + 8517 X85
+ 1220 X91 + 1306 X92 + 1566 X912 + 1338 X99 + 1839 X95 + 1263 X101 + 1310 X102 + 1519 X1012 + 1438 X109 + 1717 X105)

Subject to Constraints:

-125Yv + X11 + X12 + X112 + X19 + X15 <= 0 (Vietnam Supply)
-150Yb + X21 + X22 + X212 + X29 + X25 <= 0 (Brunei Supply)
-200Yf + X31 + X32 + X312 + X39 + X35 <= 0 (Fiji Supply)
-150Yi + X41 + X42 + X412 + X49 + X45 <= 0 (India Supply)
-175Yin + X51 + X52 + X512 + X59 + X55 <= 0 (Indonesia Supply)
-125Yj + X61 + X62 + X612+ X69 + X65 <= 0 (Japan Supply)
-150Ym + X71 + X72 + X712 + X79 + X75 <= 0 (Malaysia Supply)
-200Ynz + X81 + X82 + X812 + X89 + X85 <= 0 (New Zealand Supply)
-150Ys + X91 + X92 + X912 + X99 + X95 <= 0 (Singapore Supply)
-125Yt + X101 + X102 + X1012 + X109 + X105 <= 0 (Thailand Supply)

X11 + X21 + X31 + X41 + X51 + X61 + X71 + X81 + X91 + X101 >= 15 (Site 1 Demand)
X12 + X22 + X32 + X42 + X52 + X62 + X72 + X82 + X92 + X102 >= 30 (Site 2 Demand)
X112 + X212 + X312 + X412 + X512 + X612 + X712 + X812 + X912 + X1012 >= 25 (Site 12 Demand)
X19 + X29 + X39 + X49 + X59 + X69 + X79 + X89 + X99 + X109 >= 18 (Site 9 Demand)
X15 + X25 + X35 + X45 + X55 + X65 + X75 + X85 + X95 + X105 >= 35 (Site 5 Demand)

Only one warehouse
Y1....Y10 = 1
Xij >= 0, Y binary

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