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VULNERABILITY ANALYSIS OF GUAMS DEFENSE POSTURE

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VULNERABILITY ANALYSIS OF GUAM'S DEFENSE POSTURE

by

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December 2022

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Since the end of the Second World War, Guam has served as a linchpin of U.S. military power in the Indo-Pacific. As the United States' westernmost territory in the world, Guam has been lauded as the place where America's day begins. However, with its strategic importance and abundance of military combat power, Guam may be where America's next war begins. Following decades of reform and modernization, the People's Liberation Army presents a significant threat to the preeminence of U.S. military power in the region. This study uses a structured vulnerability analysis based on the principles of risk analysis, reliability engineering, adversarial analysis, and safety engineering to identify Guam's critical vulnerabilities and formulate recommendations that enhance the territory's defense posture. This study finds that Guam's missile defense posture constitutes the island's most significant vulnerability and recommends that congressional budgetary initiatives must remain focused on enhancing Guam's missile defense capability and hardening defense infrastructure throughout the Pacific territories. Should modern warfare reach the shores of Guam, the U.S. military will have to fight for Guam before it can fight from it.

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VULNERABILITY ANALYSIS OF GUAM'S DEFENSE POSTURE

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

Since the end of the Second World War, Guam has served as a linchpin of U.S. military power in the Indo-Pacific. As the United States' westernmost territory in the world, Guam has been lauded as the place where America's day begins. However, with its strategic importance and abundance of military combat power, Guam may be where America's next war begins. Following decades of reform and modernization, the People's Liberation Army presents a significant threat to the preeminence of U.S. military power in the region. This study uses a structured vulnerability analysis based on the principles of risk analysis, reliability engineering, adversarial analysis, and safety engineering to identify Guam's critical vulnerabilities and formulate recommendations that enhance the territory's defense posture. This study finds that Guam's missile defense posture constitutes the island's most significant vulnerability and recommends that congressional budgetary initiatives must remain focused on enhancing Guam's missile defense capability and hardening defense infrastructure throughout the Pacific territories. Should modern warfare reach the shores of Guam, the U.S. military will have to fight for Guam before it can fight from it.

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LIST OF ACRONYMS AND ABBREVIATIONS

A2AD	Anti-Access Area Denial
AEMRR	Annual Energy Management and Resilience Report
AFB	Air Force Base
AOR	Area of Responsibility
ARL	Army Research Laboratory
ASBM	Anti-Ship Ballistic Missile
ASW	Anti-Submarine Warfare
BFOL	Bomber Forward Operating Location
BMD	Ballistic Missile Defense
C2BMC	Command, Control, Battle Management, and Communications
CERL	Construction Engineering Research Laboratory
CNMI	Commonwealth of the Northern Marianas Islands
CNO	Chief of Naval Operations
CG	Ticonderoga-Class Guided Missile Cruiser
CSG	Carrier Strike Group
DDG	Arleigh Burke-Class Guided Missile Destroyer
DOD	Department of Defense
DOI	Department of the Interior
DPRI	Defense Policy Review Initiative
DSCA	Defense Support for Civil Affairs
ESG	Expeditionary Strike Group
FEMA	Federal Emergency Management Agency
GAO	Government Accountability Office
GPA	Guam Power Authority
HADR	Humanitarian Assistance Disaster Relief
HGV	Hypersonic Glide Vehicle
IAMD	Integrated Air and Missile Defense

IRBM	Intermediate Range Ballistic Missile
LHD	Wasp-Class Amphibious Assault Ship
LSD	Whidbey Island-Class Dock Landing Ship
MAGTF	Marine Air-Ground Task Force
MDA	Missile Defense Agency
MEU	Marine Expeditionary Unit
NAVFAC	Naval Facilities and Engineering Command
NBG	Naval Base Guam
NBGTS	Naval Base Guam Telecommunications Site
NDAA	National Defense Authorization Act
PACAF	Pacific Air Forces
PDI	Pacific Deterrence Initiative
PLA	People's Liberation Army
PLAAF	People's Liberation Army Air Force
PLAN	People's Liberation Army Navy
PLARF	People's Liberation Army Rocket Force
PRC	People's Republic of China
PSM	precision-strike missile
RAP	Reliable Acoustic Path
SASC	Senate Armed Services Committee
SM	Standard Missile
SSF	Strategic Support Force
SSL	Space Sensory Layer
SSN	Fast-Attack Nuclear Powered Submarine
THAAD	Terminal High Altitude Area Defense
TFCC	THAAD Fire Control and Communications System
USACE	U.S. Army Corp of Engineers

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I. INTRODUCTION

A. RESEARCH QUESTION

For decades, Guam has been considered a linchpin of American military power in the Indo-Pacific—a bastion for power projection in the United States' priority theatre of operations. However, with the expanding reach of adversarial capabilities by China and North Korea, Guam's strategic location within the second island chain[1] is under constant threat. More alarmingly, senior military leaders have indicated that the growth of our adversaries' capabilities have outpaced our ability to defend the island territory. Considering today's era of Great Power Competition, how would Guam and U.S. military assets in the region be vulnerable in a conflict with China? Furthermore, how can the U.S. military improve its defense posture on and around Guam? Should hostilities escalate in the Indo-Pacific, the U.S. military may have to fight for Guam before it can fight from it. This thesis analyzes the implications and vulnerabilities of Guam for U.S. Homeland Security and Defense and offers recommendations for how to better defend it.

B. SIGNIFICANCE OF THE RESEARCH

Since the end of the Second World War, the United States' Indo-Pacific strategy has depended on the military's forward-deployed forces to deter adversaries, reassure regional allies and partners, and project power from overseas bases—especially Guam. In *Comparative Strategy,* James Johnson asserts that Washington needs to address the threat to U.S. overseas bases in the Indo-Pacific from "China's rapidly maturing precision-strike missile (PSM) regime."[2] Security experts as well as senior U.S. officials have characterized China's rapid military modernization as an aggressive move to reassert their hegemony in

[1] The first island chain encloses the East Asian coastline arcing southward from mainland Japan through the Ryukyu Islands, Taiwan, and the Philippine archipelago. The second island encompasses the island chain formed by Japan's Bonin and Volcano Islands, the Mariana Islands (most notably Guam), the western Caroline Islands (Yap and Palau), and extends to Western New Guinea. For a diagram, see Annual Report to Congress: Military and Security Developments Involving the People's Republic of China 2021 (Washington, DC: Department of Defense, 2021), 40.

[2] James Samuel Johnson, "China's 'Guam Express' and 'Carrier Killers': The Anti-Ship Asymmetric Challenge to the U.S. in the Western Pacific," *Comparative Strategy* 36, no. 4 (August 8, 2017): 319–32.

the region. During China's 2015 Victory Day Parade, Beijing showcased two new Anti-Ship Ballistic Missiles (ASBMs): the *Dongfeng* DF-21D labeled by Chinese media as the "Carrier Killer" and the Intermediate Range Ballistic Missile (IRBM) *Dongfeng* DF-26 capable of reaching Guam and subsequently labeled the "Guam Express" or "Guam Killer".[3] The emergence of more advanced and capable conventional weapons from the People's Republic of China (PRC) undoubtedly challenges the existing balance of power in the Indo-Pacific. Consequently, China's rise as a military power in the region tests Washington's ability to project power in its priority theater of operations.

To counter China's rise in the region, Washington has responded with the Pacific Deterrence Initiative (PDI), a federal funding effort to bolster the United States' deterrence in the Indo-Pacific and maintain a competitive advantage against China. In May 2021, a report from the Office of the Under Secretary of Defense stated that the FY2022 PDI incorporated a $5.1 billion subset of the Department's annual Presidential Budget request.[4] Afterwards, on December 27, 2021, President Biden signed the FY2022 National Defense Authorization Act (NDAA), authorizing $770 billion in defense spending to include $7.1 billion for the PDI.[5] As the first NDAA signed into law following the U.S. withdrawal from Afghanistan, the FY2022 NDAA projects a more aggressive stance in the Indo-Pacific region specifically—allocating an additional $2 billion to the Pentagon's original request. From a budgetary standpoint, Washington is not allowing China's rise to power to go unchecked. The annual NDAA effectively demonstrates and reaffirms the United States' commitment to the Indo-Pacific region.

This thesis analyzes the current threats and vulnerabilities affecting Guam and the broader Marianas Archipelago. Additionally, this thesis evaluates the homeland security and defense implications of Guam to further justify the importance of defending the island stronghold. According to the former Indo-Pacific Commander, Admiral Phil Davidson,

[3] Johnson, "China's 'Guam Express' and 'Carrier Killers.'"

[4] Office of the Under Secretary of Defense (Comptroller), "Department of Defense Budget Fiscal Year (FY) 2022: Pacific Deterrence Initiative," May 2021, https://comptroller.defense.gov/Portals/45/Documents/defbudget/FY2022/fy2022_Pacific_Deterrence_Initiative.pdf.

[5] "President Biden Signs $770 Billion Defense Bill," CNBC, December 27, 2021.

Guam is "home to over 170,000 Americans and 20,000 active servicemembers and the defense of Guam is a matter of Homeland Security and Defense" and must be evaluated as such.[6] As the United States' westernmost territory in the world, Guam has been lauded as the place where America's day begins. However, with its strategic geographic importance and abundance of military combat power, Guam can potentially be where America's next war begins.

1. Defining Homeland Security and Homeland Defense

Guam's defense is critical for both homeland security and homeland defense. As such, clearly defining both distinct areas of national security is important prior to the beginning of this vulnerability analysis. Christopher Bellavita of the Naval Postgraduate School's Center of Homeland Defense and Security characterizes homeland security as "an element of national security that works with the other instruments of national power to protect the sovereignty, territory, domestic population, and critical infrastructure of the United States against threats and aggression."[7] Comparatively, while homeland security is domestically focused, homeland defense is primarily a DOD activity defined as "the protection of U.S. sovereignty, territory, domestic population, and critical defense infrastructure against external threats and aggression."[8]

C. LITERATURE REVIEW

Significant research considers the implications and vulnerabilities of Guam for U.S. homeland security and defense and the existing recommendations for how to better defend the island. This review covers two general areas of research relevant for determining Guam's current and future defensive posture. First, canonical work from 19th century naval theorists Alfred Thayer Mahan and Julian Corbett establishes the significance of Guam in

[6] "Statement of Admiral Philip S. Davidson, U.S. Navy, Commander, U.S. Indo-Pacific Command, Before the Senate Armed Services Committee on U.S. Indo-Pacific Command Posture," March 9, 2021, https://www.armed-services.senate.gov/imo/media/doc/Davidson_03-09-21.pdf.

[7] Christopher Bellavita, "Changing Homeland Security: What Is Homeland Security?," *Homeland Security Affairs* 4, no. 2 (June 1, 2008), https://www.hsaj.org/articles/118.

[8] U.S. Department of Defense, "Homeland Defense," *Joint Publication 3-27*, April 2018, https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_27.pdf.

the Indo-Pacific. Although historically in contrast with one another, the teachings of both theorists justify a heavy military presence on Guam. Despite current defensive posture informed by these theorists, the same 19th century naval strategies that cement Guam's importance are no longer adequate to defend against 21st century threats from China. Second, I review literature centered on current recommendations for how to improve Guam's defense posture—missile defense. Most regional security experts and senior defense officials agree that the greatest threat to Guam is China's advancing missile capability. In addressing Guam's vulnerabilities in missile defense, I define adversarial missile capabilities as the enemy's ability to destroy military assets. Although missile threats certainly endanger Guam's civilian population, I consider that the primary missile threat is to U.S. military forces. Conversely, to address the vulnerabilities in Guam's critical infrastructure, I define attacks on infrastructure as the enemy's ability to cripple military and civilian infrastructure systems. Examining both the missile defense and the critical infrastructure views of vulnerabilities is important in conducting a thorough analysis of Guam's defense posture. For the critical infrastructure perspective, I review literature from Nicole Starolieski, an infrastructure analyst specializing in undersea communication cables. Adding to Sarolieski's perspective and examining the ongoing debate over Guam's defense posture, the literature review concludes with differing perspectives from two former Indo-Pacific Combatant Commanders, retired Admirals Phil Davidson and Harry Harris.

1. Historical Perspectives: Mahan and Corbett

The guidance of 19th century naval theorists Mahan and Corbett is examined because the maritime domain underpins military competition between the U.S. and China in the Indo-Pacific. A study of both classical theorists suggests that they would advocate for a strong military presence on Guam to better defend it. From Mahan and Corbett, two distinct naval schools of thought have emerged and each one justifies the strategic significance of an island stronghold such as Guam in their own respective ways.

Strategists in favor of Mahan's doctrine emphasize the importance of amassing a large superior naval force to overwhelm the enemy[9] and Guam's strategic location in the Indo-Pacific is critical to the U.S. Navy's ability to establish command of the seas in the second island chain (see Figure 1). Mahan held command of the seas as the epitome of achieving victory in war. As such, Mahan's doctrine emphasized the importance of far-sighted thinking, amassing naval forces superior in number to the enemy, and controlling critical maritime choke points to ultimately gain command of the seas.[10] Furthermore, Mahan also stressed the strategic implications of overseas bases of operations because of their ability to allow naval forces to advance on the enemy. According to Mahan, "the geographical position of a country may not only favor the concentration of its forces but give the further strategic advantage of a central position and a good base for hostile operations against its probable enemies."[11] Consequently, Mahan's strategy demonstrates how achieving command of the seas can begin in Guam, a strategic location where naval forces can be amassed to encroach on the enemy.

[9] Alfred Thayer Mahan, *The Influence of Sea Power Upon History, 1660–1783*, Revised ed. edition (New York: Dover Publications, 1987).

[10] Alfred Thayer Mahan, *The Influence of Sea Power Upon History, 1660–1783*, Revised ed. edition (New York: Dover Publications, 1987), 25–89.

[11] Mahan, The Influence of Sea Power Upon History, 1660–1783, 29.

Figure 1. Map of First and Second Island Chains[12]

In contrast, strategists in favor of Corbett's doctrine advocate for the dispersal of smaller groups of naval forces across critical sea lines of communication.[13] Here, Guam is vital to U.S. military operations in the Indo-Pacific because it provides the U.S. and its Allies a forward logistical and operating base in the region from which they can project forces. Guam fortifies the critical sea lines of communication within the second island chain and between U.S. allies and partners. Corbett conceptualizes sea lines of a communication as a critical component of naval strategy: "by 'Naval Strategy' we mean

[12] Source: Office of the Secretary of Defense, "Annual Report to Congress: Military and Security Developments Involving the People's Republic of China 2012" (Washington, DC, May 2012), https://dod.defense.gov/Portals/1/Documents/pubs/2012_CMPR_Final.pdf.

[13] Julian Corbett, *Some Principles of Maritime Strategy* (The Project Gutenburg), accessed November 23, 2021, https://www.gutenberg.org/files/15076/15076-h/15076-h.htm.

the art of conducting the operations of the Fleet. Such operations must always have for their object 'passage and communication'; that is, the Fleet is mainly occupied in guarding our own communications and seizing those of the enemy."[14] Corbett emphasized the importance of securing sea lines of communication between strategic strongholds as a broader part of naval strategy. The American presence on Guam completes the vital network of logistics and communications coming from the U.S. mainland to the entire Indo-Pacific Area of Responsibility (AOR).

Although Mahan's and Corbett's theories justify the strategic importance of an island like Guam, the naval strategies they each present are difficult to apply in a war with China today. Specifically, the 21st century threats of nuclear weapons, hypersonic missiles, and cyber warfare challenge 19th century strategy for defending Guam. China's nuclear weapons make any kinetic action against the Chinese mainland exceedingly risky. For example, if a naval blockade imposes severe costs to China's economy and military, Chinese leaders may find cause to abandon their "no first use" policy and engage in a limited nuclear strike against U.S. warships. Furthermore, China has advanced their capabilities to deny enemy access into their regional waters, effectively making the idea of U.S. naval blockade obsolete. In his final testimony to the Senate Armed Services Committee, Admiral Davidson stated that China "continues to field advanced Anti-Access Area Denial (A2AD) systems, aircraft, ships, space, and cyber capabilities that threaten the U.S. ability to project power into the region."[15] Having written their respective theoretical frameworks in an age where neither nuclear weapons nor cyber warfare had existed, neither Mahan nor Corbett could have addressed the implications of such complex methods of warfare. Although Mahan and Corbet solidify the importance of the United States' forward presence on Guam, modern security challenges call for more advanced and applicable strategies.

[14] Corbett, Some Principles of Maritime Strategy,307.

[15] "Statement of Admiral Philip S. Davidson, U.S. Navy, Commnader, U.S. Indo-Pacific Command, Before the Senate Armed Services Committee on U.S. Indo-Pacific Command Posture."

2. Shifting the Focus to Missile Defense Strategy

Surveys of the Chinese and American military rivalry often lead to the conclusion that the United States must shift its current framework in challenging the growing threats from China. James Johnson argues that the "current passive and static conceptualizations of Chinese approaches to nuclear and conventional deterrence are no longer appropriate. Recent evidence indicates that these postures are far more integrated, flexible, and dynamic than Beijing's official rhetoric suggests."[16] Similarly, Jonathon Solomon argues that "the United States will need to focus its declining resources over the next decade on developing the force-level capabilities, postures, and doctrinal precepts that deterrence theory suggests are most likely to be effective." Solomon further outlines how a "viable and credible U.S. conventional deterrence policy of multi-domain denial" should be configured to meet the demands of a future Sino-American conflict.[17]

While Johnson's article focuses on the current and emerging threats from China, Solomon's article outlines how to improve the force posture in the Pacific to counter Chinese threats. Johnson and Solomon both agree that a doctrinal shift in American defense posture in the Pacific is needed to counter the growing Chinese military capability in the region. However, both authors neglect to explain how to defend and ultimately project power from existing American military strongholds in the Indo-Pacific such as Guam. The absence of this analysis is important because the PDI proposes $7.1 billion to bolster the U.S. military posture throughout the region to deter Chinese aggression.[18] Specifically, the bill includes a proposal of $77 million "for a permanent and persistent land-based integrated air and missile defense system and associated weapon delivery system on Guam."[19]

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[16] James Samuel Johnson, "Chinese Evolving Approaches to Nuclear 'Warfighting': An Emerging Intense US–China Security Dilemma and Threats to Crisis Stability in the Asia Pacific," Asian Security 15, no. 3 (September 2, 2019): 215.

[17] Jonathan F. Solomon, "Demystifying Conventional Deterrence: Great-Power Conflict and East Asian Peace," Strategic Studies Quarterly 7, no. 4 (2013): 118.

[18] Indo-Pacific Deterrence Initiative, H.R. 6613, 116th Cong., 2nd Sess. § (2021).

[19] Indo-Pacific Deterrence Initiative.

Arguments like the ones Solomon and Johnson presented have collectively led security experts and policy makers to support the PDI and advocate for an improved missile defense system on Guam. Henry Obering argues that it is imperative for the United States to "adapt its missile defense policy and strategy and leverage new technology to increase the capability of U.S. missile defenses, and it must do so with a sense of urgency and purpose."[20] Obering claims that adapting existing U.S. missile defense systems in the Indo-Pacific to the emerging threats from the People's Liberation Army (PLA) is not only a matter of improving American defense posture, but a matter of Great Power Competition. According to Obering, the inception of the PLA Rocket Force (PLARF) from the PLA's traditional missile forces signifies a crucial step in China's ultimate vision of becoming the dominant military power in the region.[21] Similar to most Indo-Pacific security experts, Obering recognizes the Chinese missile capability as the preeminent threat to Guam and American strongholds in the region. Obering states that "approximately 95 percent of the missiles in the PLARF are in the 500 to 5,500 km range, meaning that critical U.S. bases throughout Japan are within range of thousands of advanced ballistic and cruise missiles and are vulnerable to attack."[22] Consequently, Obering's risk analysis of the regional security concerns for Guam are consistent with those in his field; however, he introduces a viable missile defense strategy that seeks to leverage new technology in a familiar domain—space.

Exploring opportunities for integrating Guam's missile defense system with the space domain presents an innovative and viable opportunity for defense of Guam and also entire Indo-Pacific region. Obering claims that the space domain will be vital in deterring and combatting the advanced and capable threats the U.S. faces today. He states that "the missile defense architecture must thoroughly incorporate the space domain by using not only space sensors to track ballistic and non-ballistic missile threats and to enable a shorter intercept time but also a space-based intercept platform to complement—not replace—the

[20] Henry Obering and Rebeccah L. Heinrichs, "Missile Defense for Great Power Conflict: Outmaneuvering the China Threat," *Strategic Studies Quarterly: SSQ* 13, no. 4 (Winter 2019): 37.

[21] Obering and Heinrichs, "Missile Defense for Great Power Conflict," 37.

[22] Obering and Heinrichs, "Missile Defense for Great Power Conflict," 38.

spectrum of ground and sea-based systems."[23] One promising concept that Obering advocates for is the development of the Space Sensory Layer (SSL):

> The SSL would give the United States "eyes" necessary to see our enemy's missiles from launch and track them until the missiles' destruction in one form or another… With the right sensors, the SSL would immediately leverage the full potential of current U.S. missile defense interceptors, greatly improving the capability of current defense systems against traditional ballistic missiles.[24]

Incorporating the space domain with Guam's defense system may also improve the island territory's defense against China's growing hypersonic missile capability. Obering claims that the SSL combined with the concept of a Space Enabled Interceptor (SEI) will be effective in combatting against the emerging threat of Hypersonic Glide Vehicles (HGVs).[25] He states that SEIs would "allow interceptors to engage at much longer ranges since course corrections can be made beyond the line of sight of ground stations and reduce the time from tracking to intercepting." The speed and ability of HGVs to change course enroute to its target make hypersonic weapons exceptionally challenging so defend against. As such, SEIs and SSLs "would be valuable in the case of defending against HGVs since interceptors could engage in the HGVs' glide phase and continuously correct for their fast maneuvers."[26] Consequently, while Obering recognizes the vulnerability of Guam to China's rapidly advancing missile capabilities, he also presents viable solutions and strategies to combat them.

3. Perspectives of Guam's Vulnerabilities Beyond Missile Defense

Although Obering presents a strong argument for the need to develop a more robust missile defense strategy in the Indo-Pacific, he fails to recognize other threats that could also compromise American positions overseas. Like most Indo-Pacific security experts, Obering accepts China's missile threat as the preeminent threat to Guam. Obering does not

[23] Obering and Heinrichs, "Missile Defense for Great Power Conflict," 38.

[24] Obering and Heinrichs, "Missile Defense for Great Power Conflict," 49.

[25] Obering and Heinrichs, "Missile Defense for Great Power Conflict," 49.

[26] Obering and Heinrichs, "Missile Defense for Great Power Conflict," 51.

recognize the possibility that China may not immediately resort to a kinetic engagement or a nuclear strike against U.S. forces in the region. Most regional security experts do not assess Guam's vulnerabilities further than the umbrella of Chinese missiles. Security analysts provide insight into the vulnerability of U.S. forces to adversarial missile threats; however, they do not address the vulnerabilities to critical infrastructure systems that affect both military and civilian assets. Like other densely populated islands in the Indo-Pacific, Guam's critical infrastructure is uniquely positioned to serve the civilian population in conjunction with the military installations on the island. With any complex infrastructure system, there are critical nodes where a failure of a component could result in damaging effects for the entire system. The critical nodes throughout Guam's infrastructure, such as the electric grid or broadband communications network, are vulnerable to adversarial attack just as much as U.S. military assets are vulnerable to China's missile threats.

While security experts and senior military leaders focus on the future of Guam's missile defense, infrastructure analyst Nicole Starosielski draws attention to a vulnerability often overlooked—undersea communication cables. In discussing Guam's importance as an interconnection of transpacific communication cables, Starosielski asserts that "the island's militarization, the interests of private telecommunications companies, and general infrastructure development have all contributed to the establishment of Guam as a critical node for transpacific circulations and exchanges."[27] Starosielski further adds that "if the island's networks were disconnected, it would not only disrupt military operations and transpacific Internet traffic, but also the operation of the island's port, the flights that land on Guam… and the weather reporting for much of the region."[28] According to Starosielski, the undersea communications cables in Guam carry almost all transpacific internet traffic and historically, "more cables have been landed on Guam than in Hawaii or California, two other major hubs for signal exchange."[29] Consequently, Starosielski's provides the perspective of a critical infrastructure analysts rather than a regional security export. In

[27] Nicole Starosielski, "Critical Nodes, Cultural Networks: Re-Mapping Guam's Cable Infrastructure," *Amerasia Journal* 37, no. 3 (January 1, 2011): 26.

[28] Starosielski, "Critical Nodes, Cultural Networks,".

[29] Starosielski, "Critical Nodes, Cultural Networks," 19.

addition to establishing another case for the importance of defending Guam, Starosielski brings forward a vulnerability concern uncommon among security experts.

As an infrastructure analyst specializing in the study of undersea communications, Starosielski identifies the environmental, social, and economic factors that create vulnerabilities in Guam's undersea communications network. Starosielski claims that "due to the relative immobility of this infrastructural geography, Guam forms a pressure point where environmental friction arises between cable infrastructure and the local environment, as well as those who are invested in it." In recognizing the friction between environmental stakeholders such as conservationists and fishermen competing for access to shorelines, "environmental friction, rather than overt attacks or contestation, will be the more likely challenge to infrastructure development."[30] Although Starosielski acknowledges the national security significance of Guam's undersea cable system, she automatically rules out the possibility of a direct adversarial attack on undersea cables. As a result, a study of China's undersea warfare capabilities to intercept or destroy underwater cable systems may fill the gap in Starosielski's analysis.

4. The Current Debate over Missile Defense

Notwithstanding identified infrastructure vulnerabilities, current research on the defense of Guam remains centered on missile defense. There is an ongoing debate among security experts and senior military officials about what the future of Guam's missile defense should look like. In his final testimony to the Senate Armed Services Committee, former U.S. INDO-PACOM Commander, Admiral Phil Davidson, identified the establishment of Aegis Ashore on Guam as his top priority.[31] According to Bradley Bowman, "Aegis Ashore is an existing land-based version of the Navy's system. Aegis Ashore provides a capable and persistent 360-degree initial solution that is cost-efficient compared to the cost of keeping three ballistic missile destroyers nearby indefinitely."[32] In

[30] Starosielski, "Critical Nodes, Cultural Networks," 26.

[31] Bradley Bowman and Maj Shane Praiswater, "Guam Needs Aegis Ashore," Defense News, August 25, 2020, https://www.defensenews.com/opinion/commentary/2020/08/25/guam-needs-aegis-ashore/.

[32] Bowman and Praiswater, "Guam Needs Aegis Ashore."

contrast, Admiral Davidson's predecessor, Admiral Harry Harris, claims that Aegis Ashore in Guam will fall short of providing adequate defense. After recognizing Admiral Davidson's success in raising the importance of "up-gunning" Guam's defense system, Admiral Harris argued that "an Aegis Ashore modeled after the ones in Romania and Poland would have limited capability against air-breathing cruise missiles." Admiral Harris further added that "An advanced Integrated Air and Missile Defense Aegis Ashore could succeed, but it would need an advanced and joint command and control architecture to bring other platforms into the fight."[33]

Both perspectives from the former Indo-Pacific Combatant Commanders raise compelling arguments. While Admiral Davidson's solution advocates for an existing solution with a record of success seen in Europe, Admiral Harris' solution calls for a more diversified portfolio of weaponry drawing from all services' missile defense systems. Aegis Ashore offers a quicker and more cost-effective solution to a rapidly emerging threat from China. However, an integrated command and control system for a range of missile defense systems, to include Aegis Ashore, presents the potential for greater survivability and leverages the strengths from all current missile defense systems. Consequently, there is an ongoing debate over what the next steps should be for the defense of Guam. As Congress continues to back the PDI, analyzing the viability of all available options for defending Guam could not be more important.

D. POTENTIAL EXPLANATIONS AND HYPOTHESES

Current research identifies missile defense and telecommunications vulnerabilities and provides strategic proposals to improve defensive posture and prevent communication outages. Overall, current research suggests that improving Guam's defense posture will involve the development of new systems to address the key areas of Guam's vulnerabilities.

However, a lack of integration across studies suggests that implementing each proposed strategy on its own may not result in an effective defensive posture. Importantly,

[33] Harry Harris, "Aegis Ashore Too Limited For Guam: Former INDO-PACOM Head," Breaking Defense (blog), July 9, 2021, https://breakingdefense.sites.breakingmedia.com/2021/07/aegis-ashore-too-limited-for-guam-former-indo-pacom/.

strategies to improve missile defense ignore telecommunications vulnerabilities and strategies to prevent internet outages ignore potential for adversarial disruption. At minimum, an integrated approach that considers both is necessary to counter future attacks. Moreover, there is limited consideration of additional factors that influence an effective defensive posture, such as the current quality and condition of Guam's military systems, the ability to provide emergency resources (e.g., manpower, equipment) to the island if current capabilities are deemed insufficient, or rapidly advancing Chinese capabilities that may outweigh the timeline for the U.S. to fund, develop, and implement proposed strategies.

The goal of this work is to identify all areas of Guam's vulnerabilities and integrate recommendations into a comprehensive plan to improve defense posture. Following a structured vulnerability analysis of Guam's defense posture, I argue that the primary course of action is a combination of existing proposals that factor in the development pace of the most prevailing Chinese threats. This study takes a broad approach to Guam's defense strategy and argues that the key areas of focus should include missile defense and the security of critical infrastructure. Considering the advancing pace of offensive Chinese capabilities, I expect to conclude that implementing Aegis Ashore in conjunction with improving the reliability of existing communications infrastructure should be the primary course of action, rather than developing new defense systems altogether.

In summary, this work aims to answer the following research questions and associated hypotheses:

- Research Question 1: How would Guam and U.S. military assets in the region be vulnerable in a conflict with China?
- Hypothesis 1: Guam's missile defense capabilities and critical infrastructure are the island's principal vulnerabilities. There is no study that integrates vulnerabilities across military and infrastructure perspectives.
- Research Question 2: How can the U.S. military improve its defense posture on and around Guam?

- Hypothesis 2: An integrated defense strategy that combines recommendations from multiple, disparate vulnerability studies will produce a more effective defense posture for Guam.

E. RESEARCH DESIGN

The primary method of analysis for this thesis is a structured vulnerability assessment of Guam's defense posture focused on four principal tenets: risk analysis, reliability engineering, adversarial analysis, and safety engineering. Each tenet will explore distinct areas of Guam's defense posture and critical in forming resilience recommendations. This thesis focuses on vulnerability assessment because Guam's vulnerabilities must first be identified before any defense posture recommendations can be made.

Risk analysis identifies the predictable threats to Guam. Analyzing risk evaluates known threats and assesses their likelihood and consequence of occurrence. Together, this thesis evaluates the capabilities and limitations of the Chinese weapons systems within the range of Guam and the second island chain. Furthermore, this work summarizes reports of PLA weapon system testing throughout the Indo-Pacific region to analyze the likelihood and consequence of PLA weapons systems.

Reliability engineering identifies predictable flaws in Guam's defense posture. In engineering, reliability is informed by the maintenance and management of the system and evaluating the conditions for potential failure. This study evaluates current U.S. defense systems on Guam and assesses their capabilities against the threats identified during risk analysis. Furthermore, reliability reports of Guam's infrastructure are used to analyze the current condition of Guam's critical infrastructure systems and identify potential areas of weakness.

Adversarial analysis identifies where the most catastrophic loss of military capability will be in the event of an attack on Guam. The goal of adversarial analysis is to identify critical nodes that enable power projection from the island. This work uses reports and surveys on areas of military concentration on the island such as the airfields at Andersen Air Force Base and deep-water port of Apra Harbor. Furthermore, consulting

reports of communication infrastructure provide important context for identifying critical nodes of services.

For safety engineering, this work discusses a historical case study where a typhoon event led to the loss of critical systems and capabilities on Guam. Analyzing recent natural disasters provides insight for how personnel on Guam responded to surprise events and reacted to severe disruptions. Specifically, this work evaluates the events that took place on Guam and the Commonwealth of the Northern Marianas Islands (CNMI) following super typhoon Mangkhut in September 2018. Through this case study, this work addresses how the military and civilian responders reacted to a catastrophic event and loss of critical assets. In assessing the redundancy and extensibility of the island's assets, safety engineering evaluates the human response to future crises, including war.

A structured vulnerability assessment of Guam's defense posture provides the framework for developing thorough recommendations for improving Guam's defense posture. This research consults the following publicly available reports (UNCLASS // Distro A) to provide real data and insight: reports on the capabilities of PLA and U.S. military assets in the Indo-Pacific, critical infrastructure surveys of Guam, and the Defense Support for Civil Services (DSCA) report for Typhoon Mangkhut. Additionally, this work consults testimonies from senior military officials and security experts and applies their proposed strategies and recommendations to the identified vulnerabilities. Altogether, these sources provide the necessary perspectives to support the framework of vulnerability analysis of Guam's defense.

The following assumptions underlie this research design:

- Assumption 1: Current research and reports identify all key vulnerabilities for Guam and make appropriate recommendations to improve the protection and defensive posture of the island. This broad assumption embeds several related assumptions:

- Assumption 1.1: Current research and reports identify all future capabilities of the Chinese military that are relevant to Guam's defense.

- Assumption 1.2: Current research and reports identify all current vulnerabilities of Guam's civilian and military infrastructure systems relevant to risk, reliability, adversarial attack, and surprise events.
- Assumption 1.3: Current research and reports identify all vulnerabilities from interdependent and related systems that could influence Guam's vulnerabilities.
- Assumption 2: Vulnerabilities identified from historical events or case studies are transferrable to current needs on Guam. This broad assumption embeds several related assumptions:
- Assumption 2.1: Data and studies from similar military systems and islands (e.g., installations on other Pacific islands) can provide insight into the vulnerabilities and defense posture needs on Guam.
- Assumption 2.2: Proposed recommendations based on past events have not yet been addressed and should be included in current plans.

F. THESIS OVERVIEW AND CHAPTER OUTLINE

This study will conduct a comprehensive vulnerability assessment and provide subsequent recommendations for Guam's defense posture in the following seven chapters:

1. Introduction
2. The Historical and Present Strategic Significance of Guam
3. Risk Analysis
4. Reliability Engineering
5. Adversarial Analysis
6. Safety Engineering
7. Conclusion and Recommendations

The chapter on strategic significance will overview of U.S. military assets and capabilities on Guam. The purpose of this second chapter is to establish the overall military value and significance of the island's role in regional power projection. As outlined in the preceding research design, chapters three through six are dedicated to the four perspectives that underpin the study's vulnerability assessment—risk, reliability, adversaries, and safety. Lastly, the study concludes with a summary of the principal vulnerabilities to Guam's defense posture as well as recommendations for improving Guam's resilience in the Indo-Pacific.

II. THE HISTORICAL AND PRESENT STRATEGIC SIGNIFICANCE OF GUAM

As the westernmost U.S. territory in the same AOR as the nation's pacing threat of the PRC, Guam's strategic location creates critical and immediate implications for both homeland security and defense. As such, this chapter begins with a historical assessment of Guam's military significance and conducts a survey of the island territory's current strategic value to national security.

A. HISTORICAL SIGNIFICANCE

Following the Spanish-American War in 1898, Guam became a U.S. territory and immediately presented itself as an asset to American naval strategy.[34] The U.S. Navy was initially tasked with governing the new island territory. In 1905, Admiral Luke McNamee, the Naval Governor of Guam, described the island's location as being "in the center of the Western Pacific, about equally distant from Manila to Yokohama on the direct route from Hawaii to the Philippines and the fact of its possessing a fine harbor make it of great and recognized strategic value to the U.S., as a point to be occupied and held for naval purposes alone."[35] Guam's strategic location and operational feasibility was ultimately put to the test during the Second World War. After losing the island to Imperial Japanese forces in December 1941, U.S. forces regained their foothold of Guam in July 1944 and immediately turned the island into a "critical logistics base" to support American efforts against the Japanese throughout the Pacific campaign.[36] Throughout WWII, U.S. military presence on Guam grew as the island proved to be a critical enabler for the overall military strategy in the Pacific theater.[37]

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[34] Andrew Erickson and Justin Mikolay, "A Place and a Base: Guam and the American Presence in East Asia," in *Reposturing the Force: U.S. Overseas Presence in the Twenty-First Century: Naval War College Newport Papers 26* (CreateSpace Independent Publishing Platform, 2012), 65–95.

[35] Arnold H. Leibowitz, *Defining Status: A Comprehensive Analysis of United States Territorial Relations* (Dordrecht ; Boston : Norwell, MA, U.S.A: Nijhoff ; Sold and distributed by Kluwer/ Academic Publishers, 1989), 306–7.

[36] Erickson and Mikolay, "A Place and a Base," 67.

[37] Leibowitz, *Defining Status*, 312.

Following the Second World War, Guam's strategic role for the U.S. military continued to flourish during the Cold War. Determined to maintain dominance in the Western Pacific and to deter Soviet influence, the U.S. began to develop critical defense infrastructure on Guam such as missile bases, communication centers, and intelligence collection assets.[38] In 1950, President Truman signed into law the Guam Organic Act formally transitioning Guam from a naval colony to a U.S. territory under the U.S. Department of Interior (DOI) who administers the island today.[39] However, although the U.S. military turned over responsibility of the island to the DOI, the military significance of Guam endured. By the end of the Cold War, Guam was home to a substantial U.S. Air Force base, a deep-sea port capable of hosting U.S. Navy aircraft carriers and submarines, a communications base, and advanced weather station.[40]

During the post-Cold War years, the closure and downsizing of overseas U.S. military bases further amplified Guam's strategic significance. The closure of the U.S. naval base in Subic Bay, Philippines combined with the political pressure to downsize U.S. troop presence in Japan had once again highlighted the feasibility of pivoting to Guam.[41] In December 1996, the U.S. and Japan released the Final Report of the Special Action Committee on Okinawa recommending the substantial reduction of U.S. troop presence on Okinawa.[42] According to the U.S. Government Accountability Office (GAO), the U.S.-Japan agreement would unquestionably result in a considerable military buildup of Guam.[43]

The GAO reported on the DOD's initial plan to shift U.S. military troop presence from Okinawa to Guam in a 2008 report:

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[38] Erickson and Mikolay, "A Place and a Base," 67.

[39] "Office of Insular Affairs: Guam," U.S. Department of the Interior, June 11, 2015, https://www.doi.gov/oia/islands/guam.

[40] Leibowitz, *Defining Status*, 335–336.

[41] Erickson and Mikolay, "A Place and a Base," 66.

[42] Mark Gebicke, "Overseas Presence: Issues Involved in Reducing the Impact of the U.S. Military Presence on Okinawa" (Washington, DC: United States General Accounting Office, March 1998), https://www.gao.gov/assets/nsiad-98-66.pdf.

[43] Gebicke, "Overseas Presence."

> As a part of this initiative, DOD plans to move 8,000 Marines and their estimated 9,000 dependents from Okinawa, Japan, to Guam by the 2014 goal. At the same time, the other military services are also planning to expand their operations and military presence on Guam. For example, the Navy plans to enhance its infrastructure, logistic capabilities, and waterfront facilities; the Air Force plans to develop a global intelligence, surveillance, and reconnaissance strike hub at Andersen Air Force Base; and the Army plans to place a ballistic missile defense task force on Guam. As a result of these plans and the Marine Corps realignment, the total military buildup on Guam is estimated to cost over $13 billion and increase Guam's current population of 171,000 by an estimated 25,000 active duty military personnel and dependents (or 14.6 percent) to 196,000.[44]

However, a 2017 report from the GAO stated that the DOD scaled back its initial plans citing increasing security concerns in the Indo-Pacific and questions over Guam's infrastructure capacity being able to support a large military influx on the island.[45] As a result, the U.S. and Japanese governments agreed to a new plan requiring the Marines to "consolidate bases in southern Okinawa and relocate 4,100 Marines to Guam, 2,700 to Hawaii, 800 to the continental United States, and 1,300 (on a rotational basis) to Australia."[46] The agreement was solidified in the Defense Policy Review Initiative (DPRI), a jointly funded U.S.-Japan initiative to redistribute U.S. forces across the Indo-Pacific. Consequently, the initiatives behind the DPRI will have lasting military, diplomatic, and economic implications for both governments.

The controversial but strategic value of overseas military bases further demonstrates the importance of Guam. As an American territory in the Indo-Pacific, senior leaders can exercise Guam as an option for shifting U.S. troop presence around the region. In the case with Japan, shifting Marines from Okinawa to Guam allowed U.S. senior leaders to address the concerns of the Japanese government while also maintaining a strong regional presence. Furthermore, as U.S. troops in Guam are operating on American soil, international pressures to reduce U.S. military presence are not limiting factors for the

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[44] Brian J. Lepore, "Defense Infrastructure: Planning Efforts for the Proposed Military Buildup on Guam Are in Their Initial Stages, with Many Challenges Yet to Be Addressed," GAO-08-722T (Washington, DC: Government Accountability Office, 2008), 1, https://www.hsdl.org/?view&did=486058.

[45] Lepore, "Marine Corps Asia Pacific Realignment."

[46] Lepore, "Marine Corps Asia Pacific Realignment."

island. Consequently, Guam's status as an overseas U.S. territory affords the U.S. government an element of diplomatic flexibility that enables to U.S. to respect the sovereignty of allied nations while also maintaining the U.S. military's forward presence in the Indo-Pacific.

B. GUAM'S MILITARY SIGNIFICANCE TODAY

From its beginnings as a critical logistics stronghold in the Western Pacific, Guam has developed into a bastion of 21st century joint military power. The U.S. military encompasses nearly one-third of the island's territory with Naval Base Guam and Andersen Air Force Base as the island's largest military installations.[47] Naval Base Guam's Apra Harbor is a deep-water port capable of accommodating nuclear powered aircraft carriers, amphibious assault ships, and the home port of five nuclear fast attack submarines.[48] Andersen Air Force Base houses the Air Force's Bomber Task Force as well as F-22 squadrons.[49] Activated in October 2020, Camp Blaz is the Marine Corp's newest installation and hosts a Marine Air-Ground Task Force (MAGTF) of 5,000 Marines.[50] Lastly, Guam's supporting joint elements include the Naval Computer and Telecommunications Station Finegayan, and the Guam Army National Guard.[51]

For the U.S. Air Force, the 36th Wing is a major unit of the Pacific Air Forces (PACAF) and host wing for Andersen Air Force Base. Over 8,000 military personnel, and civilians call Andersen home, along with their 2,500 dependents.[52] Andersen currently has two runways, two landing zones, and 7.5 million square feet of ramp, all of which can

[47] Kimberly Underwood, "The Growing Importance of Guam," SIGNAL Magazine, January 25, 2021, https://www.afcea.org/content/growing-importance-guam.

[48] "Apra Harbor," Global Security, accessed January 18, 2022, https://www.globalsecurity.org/military/facility/apra.htm.

[49] Kimberly Underwood, "The Growing Importance of Guam," SIGNAL Magazine, January 25, 2021, https://www.afcea.org/content/growing-importance-guam.

[50] Underwood, "The Growing Importance of Guam."

[51] Underwood, "The Growing Importance of Guam."

[52] "Andersen Air Force Base (AAFB)," U.S. Air Force, accessed April 26, 2022, https://www.andersen.af.mil/Units/.

support all U.S. and allied aircraft.[53] Furthermore, the fuel and munitions storage capacity at Andersen is the largest in the United States Air Force. Since Andersen's inception as a B-29 bomber base in the Second World War, the air base has remained a strategic platform for the U.S., its allies, and partner nations.[54]

For the U.S. Navy, hosting several commands, Naval Base Guam is a pivotal point of strength and sea power in the Indo-Pacific. Apra Harbor at Naval Base Guam is one of the world's largest protected deep-water ports capable of berthing the largest of naval ships to include nuclear-powered aircraft carriers.[55] Naval Base Guam serves as the home port of five Los Angeles class fast attack submarines as well as two submarine tenders.[56] Permanently stationed submarines and submarine tenders in Guam increases the U.S. Navy's ability to conduct faster and more prolonged undersea operations in the Indo-Pacific. Additionally, Guam's shipyard at fi provides critical repair and maintenance facilities for visiting U.S. Navy ships and features the only deep-water ammunition port in the western pacific.[57]

Senior leaders recognize the dynamic strategic environment of the Indo-Pacific and have already begun taking requisite measures to fortify Guam's defenses. In his first testimony to the Senate Armed Services Committee (SASC) in March 2022, Admiral John Aquilino, Commander of U.S. Indo-Pacific Command, reaffirmed Guam's strategic importance:

> Guam's strategic importance is difficult to overstate. The Department has committed more than $11B for military construction projects on Guam in FY22-FY27 to meet our commitment with Japan under the Defense Policy Review Initiative (DPRI), highlighting the importance of the island for

[53] U.S. Air Force, "Andersen Air Force Base (AAFB)."

[54] U.S. Air Force, "Andersen Air Force Base (AAFB)."

[55] "Apra Harbor," Global Security, accessed January 18, 2022, https://www.globalsecurity.org/military/facility/apra.htm.

[56] "Naval Base Guam (NBG)," Government, Commander Naval Installations Command (CNIC), accessed April 20, 2022, https://www.cnic.navy.mil/regions/jrm/installations/navbase_guam/about.html.

[57] Global Security, "Apra Harbor,"

> sustaining the joint force as our main operating base and home to 130,000 Americans.[58]

Admiral Aquilino's testimony further strengthens the argument for both Guam's diplomatic and military significance. As a jointly funded venture between Japan and the U.S., expanding Guam's military capacities represents the interests of both governments and further strengthens the U.S.-Japan alliance. Furthermore, in acknowledging the 130,000 American citizens living on the U.S. territory, Admiral Aquilino reaffirms the moral imperative of strengthening the island's defenses while also preserving the U.S. ability to project power in the Indo-Pacific.

C. CONCLUSION

In the decades after WWII, Guam has steadily developed into America's strategic military stronghold in the Indo-Pacific region. The vital utility Guam has provided over the years has solidified the island territory's role in the military's operational and contingency planning. Consequently, Guam is undoubtedly an invaluable asset for U.S. national security. The next chapter introduces the vulnerability analysis of Guam and begins with a risk analysis of the island's defense posture.

[58] John Aquilino, "Statement of Admiral John Aquilino, U.S. Navy, Commander, U.S. Indo-Pacific Command Before the Senate Armed Services Committee on U.S. Indo-Pacific Command Posture," § Senate Armed Services Committee, accessed April 26, 2022, https://www.armed-services.senate.gov/imo/media/doc/INDOPACOM%20Statement%20(ADM%20Aquilino)%20_SASC2.PDF.

III. RISK ANALYSIS

In today's geopolitical environment of strategic competition, the defense and security of Guam has never been more important. The DOD's Annual Report to Congress on Military and Security Developments Involving the PRC has officially identified China as America's most strategic and pacing threat.[59] Furthermore, the Biden administration's Interim National Security Strategic Guidance emphasized that the PRC is the sole nation that can combine its "economic, diplomatic, military, and technological power to mount a sustained challenge to a stable and open international system."[60] Meanwhile, modernizing and strengthening the People's Liberation Army (PLA) is deeply rooted in China's "national strategy to achieve the great rejuvenation of the Chinese nation by 2049."[61] While U.S.-China relations become increasingly tense under the framework of strategic competition, two of the world's nuclear-armed militaries are at continual odds against one another. As such, understanding the risk of military confrontation between the U.S. and China in the Indo-Pacific has important implications for the security and defense of Guam.

A comprehensive risk analysis of Guam's defense posture aims to identify the predictable threats to the island. Analyzing risk evaluates the known threats to Guam and assesses the likelihood and consequence of occurrence. In this chapter, I first define risk and contextualize the definition within the subject of Guam's security and defense strategy. Next, I discuss how strategic competition between the U.S. and China has influenced the PLA's modernization efforts and subsequently fueled the prospect of a future large-scale war. In evaluating the PLA's evolving capabilities and wartime strategies, I discuss the likelihood of a PLA attack on Guam and the broader second island chain. Lastly, I consult studies from both U.S. and Chinese regional security experts as well as official defense

[59] Office of the Department of Defense. "Annual Report to Congress on Military and Security Developments Involving The People's Republic of China (PRC)." Accessed April 11, 2022. https://media.defense.gov/2021/Nov/03/2002885874/-1/-1/0/2021-CMPR-FINAL.PDF.

[60] Office of the Department of Defense, "Annual Report to Congress on Military and Security Developments Involving The People's Republic of China (PRC).".

[61] Neill, Alexander. "Xi Offers Bold Vision for PLA at 19th Party Congress." International Institute for Strategic Studies, October 17, 2017. https://www.iiss.org/blogs/analysis/2017/10/china-19th-party-congress.

publications from both countries to further analyze the likelihood and consequences of PLA threats to Guam.

A. DEFINING RISK

Prior to undergoing a thorough risk analysis of Guam's defense posture, it is important to first define risk in terms of probable threats, likelihood of occurrence, and potential consequences. More importantly, applying risk analysis terms within the context of this study is critical to understanding the first of the four tenets of vulnerability analysis. Risk management expert Douglas Hubbard defines risk as "the probability and magnitude of a loss, disaster, or other undesirable event."[62] Broken down even further, Stanley Kaplan and B. John Garrick characterize risk as the following triplet: "what can happen [scenario]…, how likely is it that it will happen [likelihood], if it does happen, what are the consequences?"[63]

In applying the technical definition of risk to the security and defense strategy of Guam, the principal scenario is a military conflict between the U.S. and the PRC. In a kinetic war between the U.S. and China, Guam will undoubtedly play a key role for the U.S. and will likely be a valuable target for the PLA. What are the assets in the PLA's arsenal that are capable of striking Guam and how would they be employed? Next, the likelihood piece of the risk triplet pertains to the broader prospect of a U.S.-China war and the likelihood that the PLA will launch an attack on Guam. In a war between the U.S. and China, how likely will Guam be a target? Lastly, the consequences piece pertains to the outcomes of a potential PLA strike on Guam. If the PLA were to deliver a devastating blow to U.S. forces on Guam, what would be the strategic implications for the broader war for both sides?

62 Douglas W. Hubbard, *The Failure of Risk Management: Why It's Broken and How to Fix It*, 1st edition (Hoboken, N.J: Wiley, 2009), 8.

63 Stanley Kaplan and B. John Garrick, "On The Quantitative Definition of Risk," *Risk Analysis* 1, no. 1 (1981): 13.

B. THE GENERAL THREAT OF WAR

Among other international security factors, strategic competition between the U.S. and China has largely framed PLA modernization over the last two decades and has subsequently fueled the prospects for future conflict. Historically, strategic competition with the U.S. has provided the PLA with insight on what the future of the regional security environment holds. In *International Security*, M. Taylor Fravel provides his assessment of China's perspective on U.S. military competition:

> Overall, China will continue to monitor closely other wars that occur in the international system, especially those involving U.S. forces. China will focus on the United States and its allies not just because of the potential for greater competition with the former in the Western Pacific, but also because the United States possesses the most advanced military power in the world, whose operations could signal a shift in the conduct of warfare.[64]

While military competition with the U.S. influences the PLA's platform and strategy for modernization, competition also provides Beijing with the framework for building a military that can withstand the future of warfare. Figure 2 depicts how the PRC's modernization and platform buildup has vastly eclipsed the U.S. force posture in the Indo-Pacific.[65] Consequently, the security dilemma that inevitably unfolds from the action and reaction dynamic of Sino-U.S. competition serves to embolden the PLA to take on more challenging roles and missions in the international security environment.

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[64] M. Taylor Fravel, "Shifts in Warfare and Party Unity: Explaining China's Changes in Military Strategy," *International Security* 42, no. 3 (2017): 82.

[65] Rebecca L. Heinrichs et al., "Defending Guam" (Washington, DC: *Hudson Institute,* July 2022), http://www.hudson.org/research/17933-defending-guam. Numerical figures are consistent with DOD estimates according to the DOD's 2021 Annual Report to Congress: Military and Security Developments Involving the People's Republic of China.

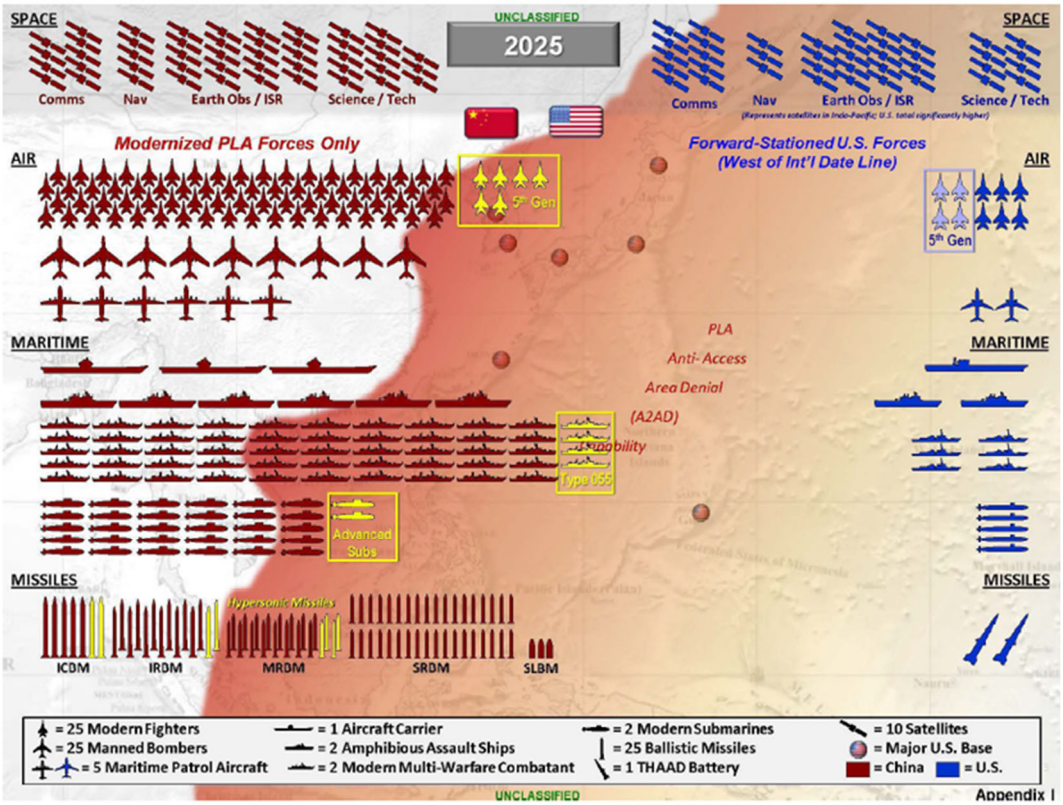

Figure 2. Projected 2025 PLA and Forward Deployed U.S. Forces[66]

Sino-U.S. military competition is especially apparent in the strategic domains of space and cyberspace where both American and Chinese security experts view the future of warfare to be. In a chapter from *Reshaping the Chinese Military*, authors Phillip Saunders and Julia Bowie highlight the significance of strategic domains to U.S. and China competition:

> The U.S. military regards the ability to operate in the space and cyber domains as critical to its ability to fight and win wars. Chinese military strategists share the assessment that space and cyber are critical battlegrounds for the information dominance necessary to fight and win 'limited wars under conditions of informationization.' PLA strategists have

66 Source: Heinrichs et al., "Defending Guam," 12.

> viewed U.S. space and cyber superiority as a critical foundation for U.S. military power, which they wish to both emulate and exploit.[67]

China's pursuit to dominate the cyber and space domains demonstrates how competition with the U.S. is a critical driver for the PLA's modernization. In 2015, the PLA established the Strategic Support Force (SSF) as its fifth branch of service to lead efforts in the space, cyber, and electronic warfare domains.[68] According to Saunders and Bowie, the creation of the SSF "highlights the centrality of space and cyber in China's efforts to build a military that can fight and win informationized wars."[69] Similar to how the PLARF was established with the aim of bolstering China's active defense strategy, the SSF is a part of a modern wave of reforms created within the context of strategic competition with the U.S. As a result, competition with the U.S. has substantially guided PLA modernization and has significantly influenced institutional reform over the past decades.

Finally, the PRC has also officially proclaimed that strategic competition with the U.S. constitutes a critical driver for the PLA's expansion. In discussing the international strategic landscape, China's 2019 Defense White Paper first pointed to the U.S. as the principal disruptor to China's regional security:

> International strategic competition is on the rise. The U.S. has adjusted its national security and defense strategies and adopted unilateral policies. It has provoked and intensified competition among major countries, significantly increased its defense expenditure, pushed for additional capacity in nuclear, outer space, cyber and missile defense, and undermined global strategic stability… The U.S. is strengthening its Asia-Pacific

[67] Phillip C. Saunders and Julia G. Bowie, "US–China Military Relations: Competition and Cooperation in the Obama and Trump Eras," in *Reshaping the Chinese Military* (Routledge, 2018), 101.

[68] John Costello and Joe McReynolds, "China's Strategic Support Force: A Force for a New Era" (National Defense University Press, October 2, 2018), https://ndupress.ndu.edu/Media/News/News-Article-View/Article/1651760/chinas-strategic-support-force-a-force-for-a-new-era/.

[69] Saunders and Bowie, "US–China Military Relations," 102.

> military alliances and reinforcing military deployment and intervention, adding complexity to regional security.[70]

Beijing's distinct threat perception of the U.S. provides insight on the PRC's motivation to carry out its own internal balancing of military hard power aimed to counter the U.S. and its allies. According to Saunders and Bowie, China's latest investments in "domestic and Russian conventional submarines, warships armed with advanced anti-ship cruise missiles, improving aircraft, and a formidable array of increasingly accurate ballistic missiles will make it more difficult and costly for the U.S. military to project power near and into Chinese territory."[71] This display of internal balancing portrays how strategic competition with the U.S., across all domains of warfare, has fueled the rapid modernization of the PLA over recent decades. In summary, strategic competition with the U.S. provides Beijing with the framework to build a modern and capable military and justifies the need to increase its own hard power to internally balance against the U.S. and its allies.

C. THE THREAT TO GUAM AND THE LIKELIHOOD OF CONFLICT

The principal threat to Guam is how the PLA's platform and strategy modernization directly supports their Anti Access Aerial Denial (A2/AD) objective. In *The Chinese Navy: Expanding Capabilities, Evolving Roles*, retired U.S. Navy Admiral Michael McDevitt characterizes A2/AD as the PLA's "attempts to prevent the U.S. military from intervening should China elect to attack Taiwan. The basic idea is to prevent approaching U.S. Navy aircraft carrier strike groups from getting within tactical aircraft operating ranges."[72] McDevitt recognizes that while A2/AD is a term coined by U.S. defense officials, Chinese military leadership refers instead to a strategy of "active defense."[73] McDevitt references the PLA's published text, *The Science of Military Strategy*, where authors Peng Guangqian

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[70] The State Council Information Office of the People's Republic of China, "China's National Defense in the New Era," 3–4.

[71] Saunders and Bowie, "US–China Military Relations," 102.

[72] Michael McDevitt, "The PLA Navy's Antiaccess Role in a Taiwan Contingency," in *The Chinese Navy: Expanding Capabilities, Evolving Roles* (Washington, DC: CreateSpace Independent Publishing Platform, 2012), 191.

[73] McDevitt, "The PLA Navy's Antiaccess Role in a Taiwan Contingency," 191.

and Yao Youzhi describe active defense as "the essential feature of China's military strategy" and assert that it is "the keystone of the theory of China's strategic guidance."[74] According to Peng and Yao, the PLA sees "active defense" as a "strategic counterattack," because if an enemy "offends our national interests, it means the enemy has already fired the first shot" and the PLA must "do all we can to dominate the enemy by striking first."[75] Peng and Yao continue to state that the PLA "should try our best to fight against the enemy as far away as possible, to lead the war to the enemy's operational base …and to actively strike all the effective strength forming the enemy's war system."[76] Consequently, the perspectives of both American and Chinese security experts reflect how an active defense, or A2/AD strategy, is a critical PLA objective. In designing an active defense strategy which aims to limit an adversary's ability to intervene militarily, no forward operational base would be a more valuable target to the PLA than Guam.

Guam directly plays an important role for the PRC's counter-intervention and active defense strategy. Peng and Yao's description of what the PLA's active defense strategy looks like reflects how Guam would be a vital node to U.S. military operations and therefore be a likely target. As a forward base distant from China's shores, a strategic preemptive attack on Guam would hinder the U.S. military's ability to intervene in Beijing's broader military ambitions, such as an invasion of Taiwan.

The PLA's platform and strategy modernization over recent decades are consistent with China's counter intervention doctrine extending well beyond China's periphery. While recent PLA operations have been largely focused on fighting wars near China's own shores, a study from the National Defense University found that some "Chinese writings advocate extending the PLA's 'defensive perimeter' to challenge intervening U.S.

74 Peng Guangqian and Yao Youzhi, *The Science of Military Strategy*, 1st ed. (Beijing: Military Science Publishing House, 2005).

75 Guangqian, Peng, and Yao Youzhi. The Science of Military Strategy. 1st ed. Beijing: Military Science Publishing House, 2005.

76 Guangqian and Youzhi, The Science of Military Strategy.

forces."[77] In his 2009 book *Strategic Air Force*, Chinese military strategist Zhu Hui argued that the People's Liberation Army Air Force (PLAAF) should pursue capabilities to "carry out lethal damage to core enemy targets" out to the second island chain, to include Guam.[78] More recently, a 2015 article from *China Military Science* advocated for the PLAAF to develop "knockout warfighting forces" and "accelerate the formation of credible combat power" beyond the first island chain.[79] To put the PLA's striking capability into perspective, Figure 3 shows the capable ranges of the PLA's current aircraft and missile inventory and their proximity to U.S. and allied bases in the Indo-Pacific.[80] Consequently, the vision of extending military combat capability beyond China's periphery has fueled the development of advanced medium to long range ballistic and cruise missiles as well as more advanced land-based aircraft.

The PLA aspires to modernize its military hardware in tandem with the development of its joint warfighting capabilities. The Chinese military journal *Science of Strategy* declares that the joint integration of all PLA branches enables the PLA to "effectively cover the First and Second Island Chains in the near future and gradually expand to cover part of the area of the Indian Ocean and Western Pacific Ocean in the mid to long term."[81] Since 2007, the PLAAF and the People's Liberation Army Navy (PLAN) have conducted joint exercises in the South China Sea, executing live fire exercises close to Taiwan's eastern shoreline.[82] The PLA's continual efforts to develop joint command and control (C2) capabilities that integrate air power over the far seas reaffirms China's aim to extend its military reach well beyond its periphery.

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[77] Joel Wuthnow, Phillip Saunders, and Ian McCaslin, "PLA Overseas Operations in 2035: Inching Toward a Global Combat Capability," *National Defense University Press*, Strategic Forum, no. 309 (May 2021), https://inss.ndu.edu/Media/News/Article/2619733/pla-overseas-operations-in-2035-inching-toward-a-global-combat-capability/.

[78] Wuthnow, Saunders, and McCaslin, "PLA Overseas Operations in 2035."

[79] Wuthnow, Saunders, and McCaslin, "PLA Overseas Operations in 2035."

[80] Heinrichs et al., "Defending Guam." The Hudson Institute data is consistent with DOD estimates according to the DOD's 2021 *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China.*

[81] Wuthnow, Saunders, and McCaslin, "PLA Overseas Operations in 2035."

[82] Christopher Sharmin, "China Moves Out: Stepping Stones Toward a New Maritime Strategy" (National Defense University, April 2015), https://apps.dtic.mil/sti/pdfs/ADA617178.pdf.

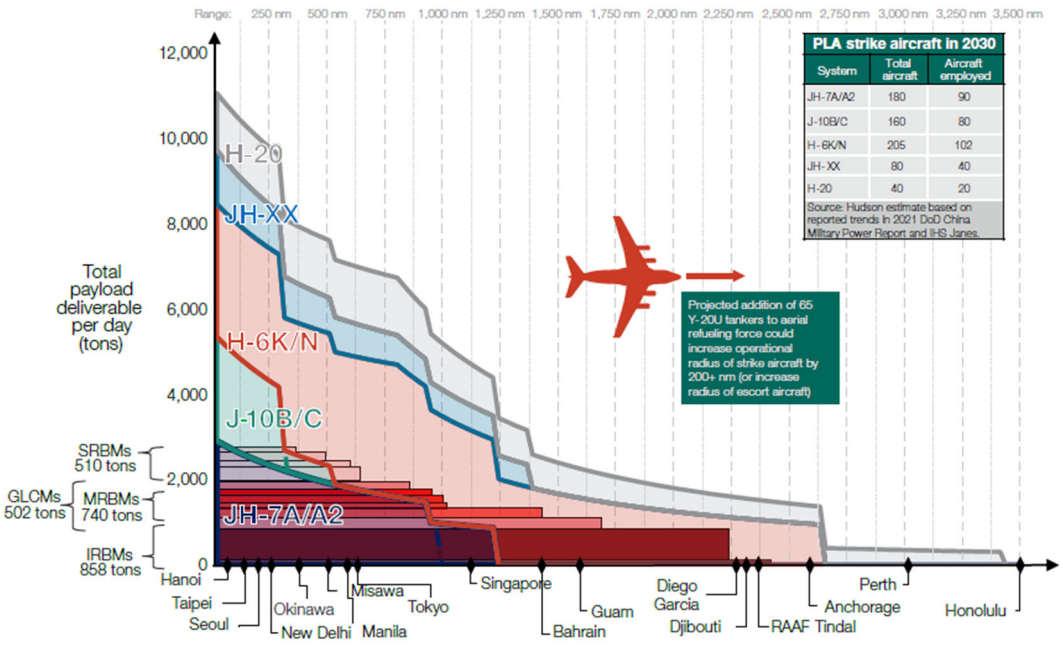

Figure 3. Notional Ranges of PLA Aircraft and Missiles[83]

Furthermore, the newest arm of the PLA, the PLA Rocket Force (PLARF), has also appeared in joint operations showcasing the prospective role of China's anti-ship ballistic missiles (ASBMs) and long-range ballistic missiles, namely the DF-26 "Guam killer," in counter intervention scenarios.[84] Figure 4 from the DOD's 2021 annual report to Congress on the PLA depicts the regional missile threats in the PLARF's arsenal as well as their reported effective ranges.[85] Consequently, the trajectory of China's platform and strategy development extend well beyond Beijing's proclaimed "informationized local wars." Continued joint doctrine development and platform modernization will further bolster the PLA's ability to strike U.S. military assets deep into the Western Pacific.

[83] Source: Heinrichs et al., "Defending Guam," 14.

[84] Defense Intelligence Agency, "China Military Power: Modernizing a Force to Fight and Win" (Washington, DC: Defense Intelligence Agency, January 2019), https://apps.dtic.mil/sti/citations/AD1066163.

[85] Office of the Secretary of Defense, "Annual Report to Congress on Military and Security Developments Involving The People's Republic of China (PRC)," 62.

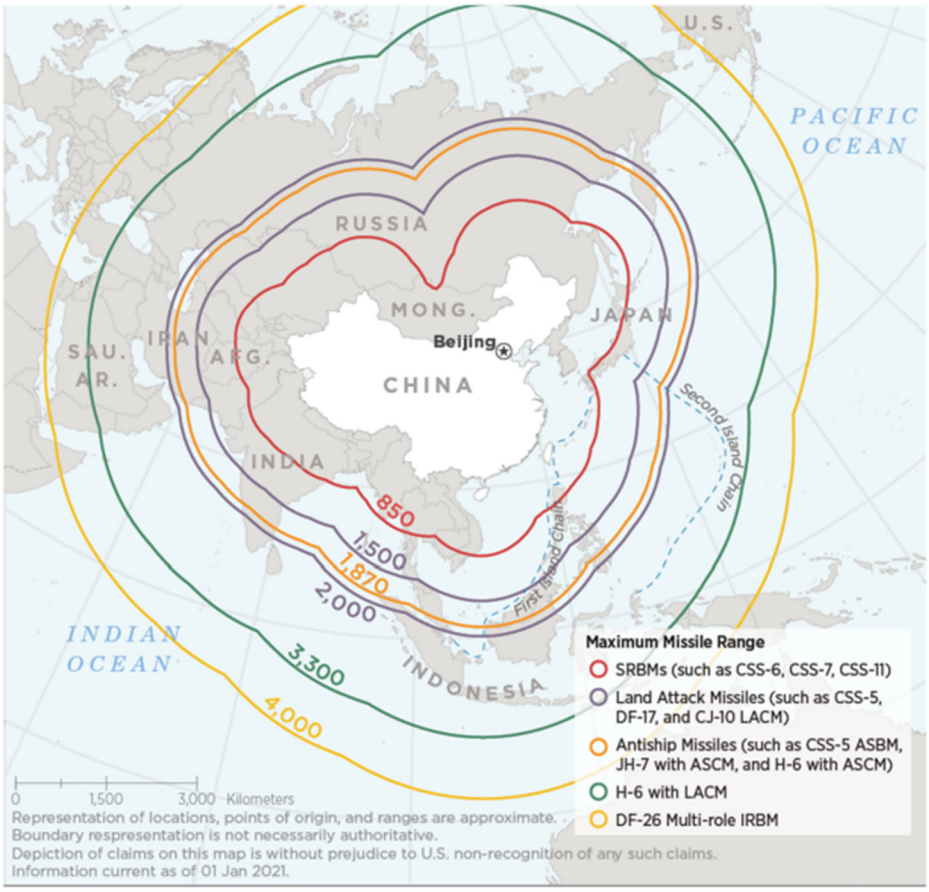

Figure 4. PLARF ICBM Ranges[86]

In addition to the PLA's ballistic missile capability, the PLAAF's long-range strategic bomber fleet has proven to be a vital component to Beijing's counter-intervention and active defense strategy. According to a 2018 study from the RAND Corporation, the PLA's latest long-range bomber platforms, the H-6K and H-20, mark the PLAAF's most "remarkable strategic transformations over the last two decades."[87] The study also found that China's military thinkers regard strategic bombers as the premier asset for "bringing the first and second island chains within striking range to counter perceived efforts to contain China, deploying long-range flights to threaten Taiwan's vulnerable eastern flank,

[86] Office of the Secretary of Defense, "Annual Report to Congress: Military and Security Developments Involving The People's Republic of China (PRC) 2021," 65.

[87] Derek Grossman et al., "China's Long-Range Bomber Flights: Drivers and Implications" (RAND Corporation, November 14, 2018), https://www.rand.org/pubs/research_reports/RR2567.html, 27.

and leveraging long-range offensive capabilities to defend interests in the South China Sea"[88] This vision among China's military strategists are consistent with the PLAAF's actions over the past decade. In May 2015, the PLAAF conducted its first long-range blue water bomber flights; today, PLAAF bombers routinely conduct operations around the second island chain near Guam, over the South China Sea, and around Taiwan.[89]

In summary, the PLA's platform and strategy modernization over the past decades demonstrate Beijing's commitment to an active defense and counter-intervention strategy. Beijing's active defense and counter-intervention framework aims to disable forward bases such as Guam to blunt the ability of U.S. forces to intervene in the PLA's combat operations. Moreover, recent PLA demonstrations outside of the first island chain illustrate how the PRC has the capability to reach U.S. forward bases and is a strong indicator of the likelihood that China will employ the same counter-intervention tactics in a future war. While China focuses most of its military effort around its periphery, the PLA continues to rapidly develop the platforms and strategies it needs to expand its reach and prevent foreign intervention into Beijing's regional military strategy.

D. LOSING GUAM: THE CONSEQUENCES

A Chinese attack on Guam is a strategic attack to the U.S. military's center of gravity in the Indo-Pacific. Prussian General Carl von Clausewitz famously coined the term center of gravity in the 18th century describing it as "the hub of all power and movement, on which everything depends… A center of gravity is always found where the mass is concentrated most densely. It presents the most effective target for a blow."[90] In a report from the *Hudson Institute*, Dr. Peppi Debiaso describes how Guam has become the center of gravity for the U.S. in the Indo-Pacific:

> The U.S. has shifted its forces and power projection center of gravity southward, with Guam increasingly encompassing the most significant capabilities within the region. Andersen Air Force Base located on Guam hosts B-52s, B-1s, and B-2s to support the continuous long-range bomber-

[88] Grossman et al., "China's Long-Range Bomber Flights," 31

[89] Grossman et al., "China's Long-Range Bomber Flights," 31

[90] Carl von Clausewitz, *On War* (Princeton University Press, 2008), 489–490.

> presence mission in the western Pacific, and Naval Base Guam is home to Navy submarines. In addition to providing storage for substantial amounts of ammunition and fuel, Guam contains all-domain communication nodes for operations across the Pacific theater and serves as an air/surface/submarine training and a logistical staging platform for joint force operations.[91]

A critical consequence of a strike on Guam would be to blunt the combat capability of U.S. forces. Consistent with Chinese military strategists' counter-intervention doctrine, an attack on Guam would disrupt and deter the U.S. military's power projection capabilities, operational sustainment, and the support for regional security commitments with allies and partners. Without Guam, the PLA would be able to advance their reach well beyond the second island chain unimpeded and hinder the U.S. ability to launch a retaliatory strike or intervene in the PRC's broader military operations.

A second consequence of a PLA strike on Guam would be the loss of Guam as a strategic deterrent in the region. In a study for the *Hudson Institute*, Matthew Costlow evaluates Guam's important contribution to regional deterrence during a Taiwan-invasion scenario. Costlow reports that "the presence of U.S. forces and facilities in Guam would enable a drawn-out conflict—precisely the sort of scenario the CCP would wish to avoid. Without Guam, CCP officials might have greater confidence that an initial setback could be overcome at acceptable cost."[92] Presently, U.S. troop presence on Guam complicates the PRC's calculus of a potential invasion of Taiwan because Beijing must consider the prospect of U.S. intervention rushing to Taiwan's defense. In addition to U.S. forces forward deployed to Japan, South Korea, and Australia, the PLA is forced to consider the abundance of U.S. military power concentrated on Guam. As a consequence, a preemptive strike on Guam could eliminate this consideration and may embolden the PRC to take a more aggressive position towards Taiwan. The loss of Guam therefore implicates a loss of a strategic position in the Indo-Pacific for the U.S.

Lastly, the most significant consequence of an attack on Guam would be to invoke what one analyst has called a "moral imperative" for the United States to defend Guam—

[91] Heinrichs et al., "Defending Guam," 40.

[92] Heinrichs et al., "Defending Guam," 28.

the insurmountable loss of American lives.[93] Patty-Jane Geller argues that the failure to defend Guam risks the lives of over "170,000 U.S. citizens who live on Guam, as well as over 20,000 American servicemembers, civilians, contractors, and their families."[94] Guam's significance goes well beyond its existence a strategic hub critical to U.S. security and regional deterrence. As a vital part of the U.S. homeland, an attack on Guam would result in a devastating blow to the American psyche unseen since the likes of September 11. Consequently, an attack on Guam would undoubtedly propel the U.S. and treaty allies into a war with China. The gravest consequence of a PLA attack on Guam would inevitably result in global conflict.

In some ways, Guam today resembles Pearl Harbor prior to World War II. In *Pacific Crucible*, WWII historian Ian Toll recounts how the attack on Pearl Harbor was viewed as "Mahan's worst nightmare" as Pacific Fleet battleships were concentrated in one location "moored in double file in the East Loch of Pearl Harbor, bow to stern and beam to beam."[95] Toll also describes how Imperial Japanese Admiral Isoroku Yamamoto, the orchestrator of the Pearl Harbor attack, believed that Japan's best chance in forcing the United States into a more vulnerable position was with a decisive attack on the U.S. Navy's most strategic concentration of forces in Hawaii.[96] While generations of military modernization, strategies, and doctrines have passed since December 7,1941, Guam today parallels the same strategic concentration of military combat capability as Pearl Harbor did in WWII. Guam today is the U.S. military's center of gravity in the Indo-Pacific as Hawaii was prior to WWII. As such, just as Japan's attack on Pearl Harbor launched the U.S. into WWII, a PRC attack on Guam would inevitably thrust the U.S. into a large-scale global war with China.

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[93] Patty-Jane Geller, "Missile Defense for Guam Needed to Improve Deterrence in the Indo–Pacific," *The Heritage Foundation*, no. 5203 (n.d.): 8.

[94] Geller, "Missile Defense for Guam Needed to Improve Deterrence in the Indo–Pacific."

[95] Ian W. Toll, *Pacific Crucible: War at Sea in the Pacific, 1941–1942*, 1st edition (New York: W. W. Norton & Company, 2011), xxxvi.

[96] Toll, *Pacific Crucible*, 64–65.

While present-day analysts and historical accounts resonate the moral and strategic concerns of an attack on Guam, senior U.S. military leaders also recognize the same consequences. In his final testimony before the Senate Armed Services Committee as the Commander of U.S. Indo-Pacific Command, Admiral Davidson stated that Guam is the "most important American operating location in the western Pacific. America's day begins in Guam, and it is not only a location we must fight-from, but one we must also fight-for given the threats we face in the near term and the foreseeable future."[97] Senior U.S. defense officials recognize the strategic consequences of an attack on Guam and have advocated for significant measures to counter the present threats. As a result, Admiral Davidson's testimony sounds the alarm of dangerously repeating history if the risks to Guam are not adequately addressed.

E. CONCLUSION

A comprehensive risk analysis of Guam's defense posture addresses the likelihood and consequences of how a large-scale war between the U.S. and China would affect Guam. Analyzing risk involves evaluating the known threats to Guam and addressing the likelihood and consequences of existing threats. Risk analysis has demonstrated how strategic competition between the U.S. and China has influenced the PLA's modernization and has subsequently fueled the prospect of a future global conflict. An analysis of the PLA's evolving capabilities and wartime strategies illustrates the strong likelihood of a PLA attack on Guam and the broader second island chain in the case of a South China Sea conflict or Taiwan invasion. Both U.S. and Chinese regional security experts as well as official defense publications from both countries further affirm the threats to Guam. Conclusions based on risk analysis found that the most significant threat to Guam comes from advancing PLA ballistic missile capabilities and evolving Chinese Anti-Access Area Denial strategies that aim to prevent U.S. military intervention in a Taiwan invasion or South China Sea conflict.

97 "Statement on U.S. Indo-Pacific Command Posture" (Washington, DC, March 9, 2021), https://www.armed-services.senate.gov/hearings/21-03-09-united-states-indo-pacific-command, 5.

IV. RELIABILITY ENGINEERING

Considering the existing threats to Guam addressed in the preceding risk analysis chapter, the DOD has already begun taking actions to harden Guam's defense posture. In recent years, efforts to bolster Guam's active and passive defenses have been marked by increased deployments of missile defense assets and improvements to the reliability of Guam's critical infrastructure. However, the current efforts to bolster Guam's defenses are not without their drawbacks. While missile defense alone constitutes a top priority for senior military officials in the Indo-Pacific, the problem set of countering the volume of threats remains complex. Furthermore, analysts outside of traditional security and defense policy circles have also highlighted how elements of Guam's critical infrastructure could be exploited or compromised during a potential conflict.

The goal of reliability engineering is to identify the capabilities of Guam's defense posture and estimate the potential for them to fail to protect the island. In engineering, reliability is informed by the design, maintenance, and management of a system and evaluating the conditions for potential failure. Even highly engineered systems with multiple back-ups, fail-safes, and other mechanisms to ensure reliable operation (e.g., nuclear power plants) have some likelihood of failure, even if very small, irrespective of external threats. Simply put, all systems are unreliable in some way and may fail even when designs, maintenance, and management of systems appears sufficient. The purpose of this chapter is to identify similar failure modes within Guam's defense posture and highlight those that are more likely than others to identify vulnerability gaps.

The rest of the chapter is organized as follows: first, the academic definition of reliability is given and then contextualized within the subject of Guam's defense posture. Next is an evaluation of the current U.S. missile defense systems available on Guam and an assessment of their capabilities against the threats identified during risk analysis. Lastly, to provide a comprehensive reliability analysis of Guam's defense posture and identify potential areas of weakness, reports of the current conditions of Guam's critical infrastructure systems are consulted.

A. DEFINING RELIABILITY

Prior to conducting a reliability analysis of Guam's defense posture, it is important to first define reliability engineering and contextualize how it applies to this study. According to engineering experts Kailash C. Kapur and Michael Pecht, "reliability is the ability of a product or system to perform as intended (i.e., without failure and within specified performance limits) for a specified time, in its life cycle conditions."[98] To better understand the reliability of a system, Kapur and Pecht outline the following reliability concepts and how they relate to a particular system:[99]

- Quality: What is the intended function of the system? What are the requirements that determine quality?
- Environmental Conditions: What is the system subjected to?
- Failure: When does the system has fail?
- Time: How does time affect decisions? What "time" matters?

This study applies Kapur and Pecht's reliability concepts to define reliability for Guam's defense posture and to identify the critical vulnerabilities within the overall system.

First, this study defines the *system* as Guam's current defense posture which encompasses existing subsystems in missile defense and critical infrastructure. Guam's missile defense capabilities include two primary systems: the sea-based Aegis Ballistic Missile Defense (BMD) and the land-based Terminal High Altitude Area Defense (THAAD) systems. Furthermore, the state of Guam's critical infrastructure must also be considered to inform the survivability of important capabilities such as communications during wartime. In particular, the state of Guam's defense posture is dependent on electricity and telecommunications infrastructure systems that ensure the functioning and

[98] Kailash C. Kapur and Michael Pecht, *Reliability Engineering* (Somerset, UNITED STATES: John Wiley & Sons, Incorporated, 2014), 4.

[99] Kapur and Pecht, *Reliability Engineering*, 2-16.

command and control capabilities necessary to operate on-island installations and defense systems.

Regarding *environmental conditions*, greater attention is focused on threats posed by the Chinese military. Whereas additional adversaries may view Guam as a target, this study focuses on U.S. defense systems deployed to Guam meant to deter and defend against known PLA threats. Moreover, environmental conditions could consider changes in weather/climate, manpower, and missions that constitute different requirements for systems on Guam. For the purposes of this study, these additional environmental conditions that can affect reliability estimates are disregarded

Applying concepts of *quality, failure,* and *time* in this study requires their definition for both Guam's defense posture as a whole and associated subsystems individually. This is important as the failure and success of individual subsystems may not constitute failure and success for Guam's defense posture. For example, a missile defense system may be expected to protect against a specified threat within a prescribed range and time frame. The failure of a missile defense system would be its inability to perform as expected (e.g., only providing partial protection), or not performing at all (failure to protect entirely). However, as Guam's defense posture comprises multiple missile defense systems, this failure of a single subsystem may not constitute a failure of overall Guam's defense posture. Moreover, its capacity to protect against designed threats may not be sufficient to ensure Guam's defense posture.

For Guam's defense posture, quality, failure, and time are defined as:

- Quality: The ability of Guam to defend itself against adversary attack and continue serving as a forward base for wartime military operations.
- Failure: The complete loss of Guam as a forward military base.
- Time: The length of time Guam can sustain itself in conflict before the island is completely lost.

The rest of the chapter focuses on the following analysis for each defense subsystem to Guam's overall defense posture:

- What is the likelihood of failure of each individual defense subsystem?
- Are there common-mode failures between subsystems or are missile defense systems entirely independent of each other?
- What is the likelihood that Guam's overall defense posture will fail if certain subsystems fail?

Lastly, following an analysis of all subsystems, a failure modes and effect analysis is conducted to examine how the interconnections between missile defense and critical infrastructure impact Guam's defense posture. The purpose of conducting a failure modes and effect analysis is to account for system interdependencies when determining which subsystem poses the greatest likelihood of failure to Guam's overall defense.

B. GUAM'S INTEGRATED AIR AND MISSILE DEFENSE (IAMD) CAPABILITY

The following section examines the capabilities and limitations of the current IAMD platforms deployed to Guam and applies the preceding reliability questions to assess their significance to Guam's overall defense. The first system examined is the U.S. Army's land-based Terminal High Altitude Area Defense (THAAD) missile defense system. The other system examined is the U.S. Navy's sea-based Aegis Ballistic Missile Defense System (BMDS) on board the Ticonderoga-class cruisers (CG) and Arleigh Burke-class destroyers (DDG) routinely deployed in the vicinity of Guam. Figure 5 from the DOD's Missile Defense Agency (MDA) illustrates how Aegis BMDS and THAAD create a layered defense concept defending against ballistic missiles in their midcourse and terminal phases respectively.[100] The section further discusses the interconnections between the two missile defense systems and examines each system's current state of readiness. Lastly, this section assesses the significance of the two missile defense systems to Guam and analyzes the consequences of their potential failures to Guam's overall defense posture.

[100] Missile Defense Agency. "The Ballistic Missile Defense System," Government, Missile Defense Agency, July 21, 2021, https://www.mda.mil/system/system.html.

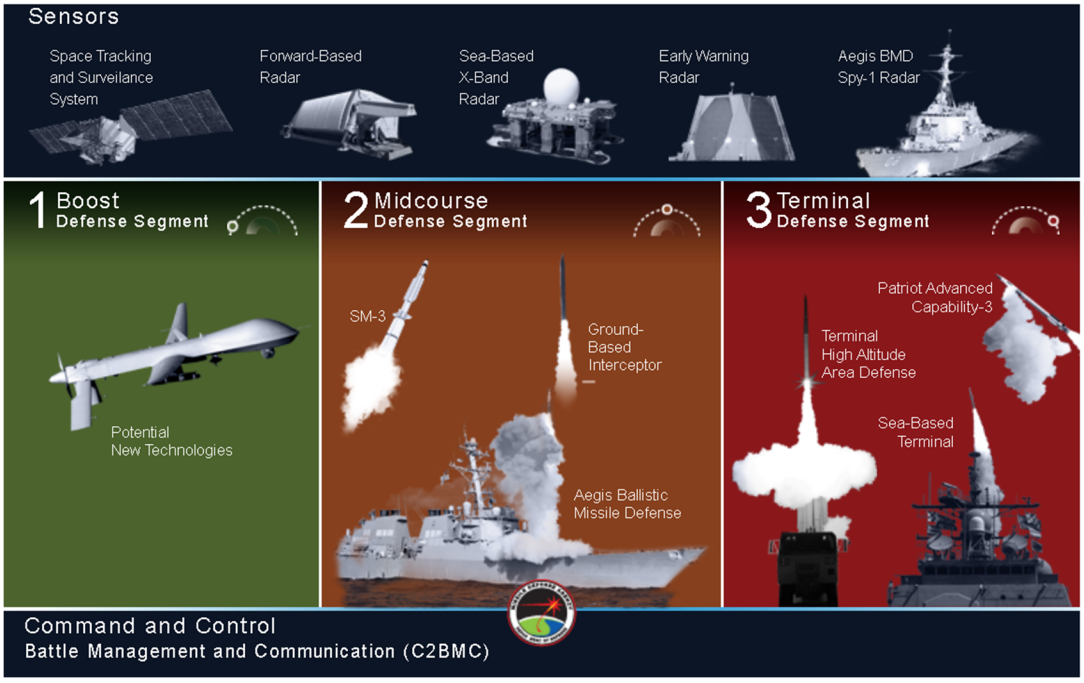

Figure 5. U.S. Ballistic Missile Defense Capabilities[101]

1. Terminal High Altitude Area Defense (THAAD)

The U.S. Army's THAAD system is a highly capable platform in Guam's missile defense arsenal. First deployed to Guam in 2013 in response to North Korean aggression in the region, THAAD is a mobile platform designed to intercept ballistic missiles.[102] According to the MDA, "THAAD provides the Missile Defense System (MDS) with a globally-transportable, rapidly-deployable capability to intercept and destroy ballistic missiles inside or outside the atmosphere during their final, or terminal, phase of flight."[103] In describing the THAAD interceptor, the CSIS Missile Defense Project states that THAAD's kill vehicle "uses a gimbaled infrared seeker to track targets in the terminal phase" and is capable of defending against targets "at ranges of 150 – 200 km (90 – 125

101 Source: Missile Defense Agency, "Aegis Ballistic Missile Defense (BMD)."

102 "CSIS Missile Defense Project: Terminal High Altitude Area Defense (THAAD)," Missile Threat, June 21, 2021, https://missilethreat.csis.org/system/thaad/.

103 "MDA - Terminal High Altitude Area Defense (THAAD)," Government, Missile Defense Agency, accessed August 23, 2022, https://www.mda.mil/system/thaad.html.

mi).”[104] There is currently one THAAD battery on Guam and according to military analyst Blake Herzinger from the *Hudson Institute*, “one THAAD battery includes at least six mobile launchers carrying up to eight interceptors each, along with mobile operations centers and long-range radar.”[105] Overall, the deployment of THAAD to Guam has significantly expanded the island’s lethality and hardened its missile defense capability. Providing a terminal layer of defense after the sea-based Aegis BMD system, THAAD is a critical subsystem withing Guam’s overall defense posture.

While THAAD’s capabilities have provided Guam a significant missile defense layer, further analysis of THAAD’s limitations and potential failures demonstrate that the lone THAAD battery only provides partial protection against the present threats to the island. During a Pentagon budget briefing in March 2022, MDA comptroller Dee Dee Martinez stated that “current forces are capable of defending Guam against today’s North Korean ballistic missile threats… However, the regional threat to Guam, including from China, continues to rapidly evolve.”[106] In *Defending Guam*, Geller more specifically asserts that “the THAAD battery was originally deployed to respond to the lower-end North Korean ballistic missile threat and is inadequate to pace the more sophisticated Chinese arsenal.”[107] Furthermore, while expert analysis points to THAAD’s capability gap against more advanced Chinese threats, DeBiaso argues in *Defending Guam* that the “need to scale up the initial defense for more effective protection can be achieved through additional THAAD deployments.”[108] Consequently, expert analysis suggests that THAAD falls short in both the quality of protection and quantity of existing batteries against the current threats to Guam. As a result, when faced with a barrage of advanced Chinese ballistic missiles in their terminal phase, such as the DF-26 IRBM, THAAD’s likelihood of failure significantly

104 “CSIS Missile Defense Project: THAAD.”

105 Heinrichs et al., “Defending Guam,” 50.

106 Jen Judson, “MDA’s Plan to Protect Guam Relies on Field-Proven Systems,” *Defense News*, March 31, 2022, https://www.defensenews.com/congress/budget/2022/03/30/mdas-plan-to-protect-guam-relies-on-field-proven-systems/.

107 Heinrichs et al., “Defending Guam,” p.23.

108 Heinrichs et al., “Defending Guam,” p.41.

increases. In a scenario against a more robust PLA threat, THAAD will rely on its integration with other missile defense systems to improve its ability to defend Guam.

THAAD's integration with Aegis BMD system partially improves Guam's overall defense posture. According to the CSIS Missile Defense Project, THAAD's Fire Control and Communications System (TFCC) works to "control battery launch operations and transfer fire control information from the AN/TPY-2 radar to the larger Command, Control, Battle Management, and Communications (C2BMC) network. By connecting with C2BMC, THAAD can exchange tracking data with Aegis."[109] Applying the scenario of a barrage of DF-26 IRBM's heading towards Guam, THAAD's ability to integrate with the broader layered defense system improves the system's overall survivability but still relies on the success of a sea-based Aegis BMD ship to counter ballistic missiles in their mid-course phase. Consequently, if the volume of enemy missiles were significant enough to penetrate through to their terminal phase, the limited capability of Guam's single THAAD battery would still only partially protect the island. As a result, THAAD's capabilities, limitations, and integration with other missile defenses illustrates the importance of the system and demonstrates how the failure of THAAD would adversely affect Guam's overall defense posture.

In summary, the reliability concepts and associated failure analysis specific to THAAD are the following:

- Quality: Ability to defend Guam against ballistic missiles in terminal phase of flight.
- Failure: Inability to provide Guam sufficient missile defense and/or not coordinate effectively with other missile defense systems (i.e., Aegis BMD) for effective layered defense protection.
- Time: The amount of time before the lone THAAD battery is expended and/or is destroyed during conflict.

109 "CSIS Missile Defense Project: THAAD."

- Most likely failure modes: Failed operability with sea-based Aegis BMD and a lack of capability to protect against more sophisticated PLA threats.

- Assessment: Given the identified failure modes, THAAD is likely to provide partial protection (i.e., experience partial failure) when missile strikes occur at inopportune times and/or consist of more sophisticated missile threats.

2. U.S. Navy Aegis Ballistic Missile Defense (BMD) System

The second critical component that completes Guam's current missile defense capability is the sea-based Aegis BMD system on board deployed guided missile cruisers and destroyers in the Indo-Pacific region. Aegis BMD capable ships employ the AN/SPY-1 air search radar and "variants of Standard Missile-3 (SM-3) or Standard Missile-6 to intercept ballistic missiles during their midcourse or terminal phases of flight."[110] DeBiaso further adds that some Aegis BMD ships are equipped with the "more advanced SM-3 IIA interceptor designed to counter longer range regional ballistic missiles in the mid-course phase of flight; these weapons are capable of engaging ballistic, cruise, and hypersonic missiles in the terminal phase." According to the MDA, in 2020, "an Aegis BMD-equipped destroyer successfully intercepted a simple intercontinental ballistic missile (ICBM)-threat representative target with a SM-3 Block IIA missile, illustrating how the system could be used in a layered missile defense architecture, enhancing U.S. homeland missile defense."[111] Aegis BMD is the U.S. Navy's premier missile defense platform and brings forth a robust layer of defense beyond the capability of THAAD. While analysts have demonstrated that THAAD alone may be insufficient to defend against more advanced Chinese threats, Aegis BMD ships provide a broader and more sophisticated layer of protection that further bolsters Guam's defense posture.

110 "CSIS Missile Defense Project: Aegis Ballistic Missile Defense BMD)," Missile Threat, August 4, 2021, https://missilethreat.csis.org/system/aegis/.

111 "MDA - Aegis Ballistic Missile Defense (BMD)," Government, Missile Defense Agency, accessed August 25, 2022, https://www.mda.mil/system/aegis_bmd.html.

Although the quality and capability of the sea-based Aegis BMD serves as a strong complement to the land-based THAAD, experts have expressed their concerns over the quantity and overall readiness of the Navy's BMD fleet. According to an April 2022 report from the Congressional Research Service, a considerable area of concern for the Navy is "the burden that BMD operations may be placing on the Navy's fleet of Aegis ships, particularly since performing BMD patrols requires those ships to operate in geographic locations that may be unsuitable for performing other U.S. Navy missions".[112] A 2018 press report from the office of the Chief of Naval Operations (CNO) highlighted the consequences of the increased burden the BMD mission was placing on the readiness of ships in the U.S. 7th Fleet:

> Amid the nuclear threat from North Korea, the BMD mission began eating more and more of the readiness generated in the Japan-based U.S. 7th Fleet, which created a pressurized situation that caused leaders in the Pacific to cut corners and sacrifice training time for their crews, an environment described in the Navy's comprehensive review into the two collisions that claimed the lives of 17 sailors in the disastrous summer of 2017.[113]

Consequently, given the tremendous capability that Aegis BMD provides for regional missile defense, the requirements to man, train, and equip a fleet of BMD ships in the Indo-Pacific have proven to have taken their toll on the Navy's operational readiness. In an address to the Naval War College's Strategy Forum in 2018, former CNO Admiral John Greenert addressed this area of concern best:

> Right now, as we speak, I have six multi-mission, very sophisticated, dynamic cruisers and destroyers—six of them are on ballistic missile defense duty at sea… You have to be in a tiny little box to have a chance at intercepting that incoming missile. So we have six ships that could go anywhere in the world, at flank speed, in a tiny little box, defending land… We've got exquisite capability, but we've had ships protecting some pretty static assets on land for a decade. If that [stationary] asset is going to be a

[112] Ronald O'Rourke, "Navy Aegis Ballistic Missile Defense (BMD) Program: Background and Issues for Congress" (Washington, DC: Congressional Research Service, April 1, 2022), 16.

[113] O'Rourke, "Navy Aegis Ballistic Missile Defense (BMD) Program: Background and Issues for Congress," 17.

> long-term protected asset, then let's build something on land and protect that and liberate these ships from this mission.[114]

Admiral Greenert's testimony brings forth a significant area of concern for the broader concept of sea-based Aegis BMD. While providing a robust capability that is relied upon worldwide, assigning a sole BMD mission to a versatile multi-mission capable ship presents a considerable opportunity cost for senior military leaders. For Guam, a sea-based Aegis BMD capability is critical for the island's overall defense posture; however, competing operational priorities in the region could reduce the ability of a multi-mission Aegis ship to provide the persistent missile defense that Guam needs.

The failure of Aegis BMD ships to defeat an incoming attack on Guam will lead to the failure of Guam's overall defense. Guam's overall defense posture has become increasingly dependent on Aegis BMD as the system's capabilities have evolved over time. In relation to THAAD, analysis has demonstrated that the limited THAAD batteries on Guam place an even greater reliance on Aegis BMD to be successful against enemy missile attacks. More importantly, Aegis BMD ships are not dedicated assets for Guam's defense. The Navy's BMD capable ships are tasked with providing regional missile defense for the entire Indo-Pacific and are also responsible for a myriad of other operational requirements. As a result, the absence of a dedicated Aegis BMD asset providing persistent coverage for Guam increases the likelihood of failure of Guam's overall defense posture. The potential failure of Aegis BMD to defend Guam places a greater burden on THAAD's limited batteries to defeat ballistic missiles in their terminal phase. Consequently, if Aegis BMD ships failed to defend against incoming ballistic missiles, the island's overall defense posture is more likely to fail overall.

In summary, the reliability concepts and associated failure analysis specific to Aegis BMD are the following:

- Quality: Ability to defend Guam against ballistic missiles in midcourse and terminal phases of flight.

[114] O'Rourke, "Navy Aegis Ballistic Missile Defense (BMD) Program: Background and Issues for Congress," 18.

- Failure: Unavailability of Aegis BMD ship to serve as dedicated missile defense platform for Guam. Inability to provide Guam sufficient missile defense and/or not coordinate effectively with THAAD for effective layered protection.
- Time: The amount of time available Aegis BMD ships can sustain their current BMD posture at sea.
- Most likely failure modes: The absence of an Aegis BMD ship adequately positioned to defend Guam due to operational availability or constraints.
- Assessment: Given the identified failure mode, Aegis BMD is likely to provide partial protection (i.e., experience partial failure) when missile strikes occur at inopportune times.

C. GUAM'S CRITICAL INFRASTRUCTURE

The following section follows a similar method of analysis from the previous section and examines two subsystems of Guam's critical infrastructure: undersea communications and Guam's electric power grid. The two subsystems were specifically chosen for evaluation as they were assessed to have more implications to Guam's defense and security than other infrastructure systems. First, the section discusses the respective services each subsystem provides for Guam and provides an assessment of their significance to the island's overall defense. Next, the section provides an overview of the current state of both infrastructure systems and the external factors that are affecting their ability to provide services. Lastly, in line with the previous section, an assessment of the consequences of potential failures for each system is provided.

1. Undersea Communications

Guam's robust network of undersea communications cables have transformed the island territory into a critical node of trans-pacific internet traffic for the Indo-Pacific region. Figure 6 is a cartographic representation of the global tele-geography cable map

from 2009 and highlights Guam's strategic location.[115] Infrastructure analyst Nicole Starosielski assesses that Guam's "undersea communication cables are durable and cost-effective infrastructures supporting the interconnection of America, Asia, and Australia… Historically, more cables have landed on Guam than in either Hawaii or California."[116] Further discussing the background of how Guam's undersea fiber optic cable infrastructure has developed, Starosielski states that "the island's militarization, the interests of private telecommunications companies, and general infrastructure development have all contributed to the establishment of Guam as a critical node for transpacific circulations and exchanges."[117] The further development of Guam's broader communications infrastructure only expanded the importance and subsequent dependence on undersea fiberoptic cables. As Starolieski notes, "despite the shift in the 1970s to satellite communication, cables continued to be laid and operated throughout this period, in part because they offered secure alternatives to wireless transmission. It was not until fiber-optic cables were developed that Guam's cable infrastructure significantly advanced."[118] Consequently, the benefits drawn from both military and commercial applications of undersea fiber optic cables have significantly influenced the expansion of the broader communications sector in Guam.

[115] Starosielski, "Critical Nodes, Cultural Networks," 18.

[116] Starosielski, "Critical Nodes, Cultural Networks," 19.

[117] Starosielski, "Critical Nodes, Cultural Networks," 26.

[118] Starosielski, "Critical Nodes, Cultural Networks," 22.

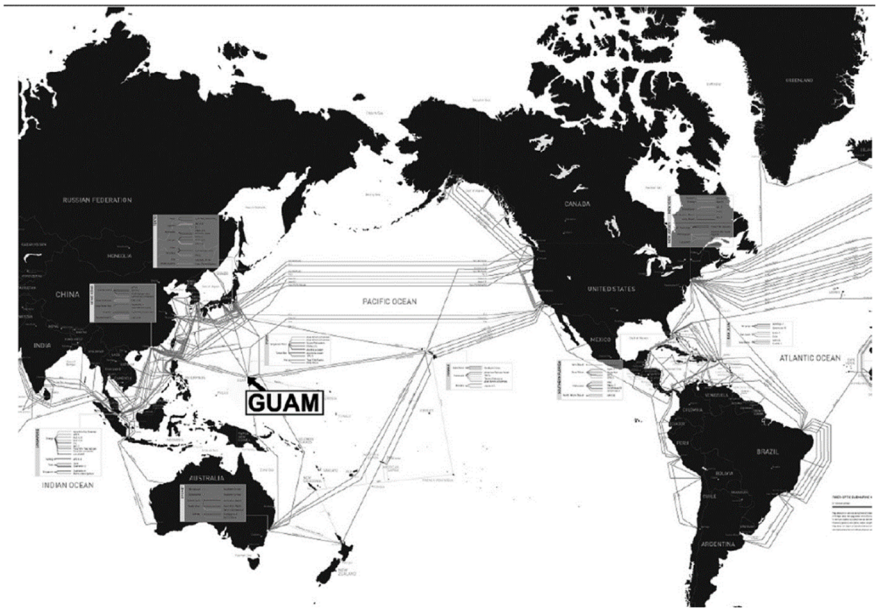

Figure 6. Map of International Undersea Cable Network[119]

In addition to expanding the island's communications sector and providing an important hub for trans-pacific broadband internet, undersea cables also have strategic military applications in anti-submarine warfare (ASW). While exact capabilities of undersea cables and ASW applications are beyond the classification of this study, international security analysts have made their assessments on the ASW applications drawn from integrating undersea fiberoptic cables with Reliable Acoustic Path (RAP) sensors. In *International Security,* Brendan Rittenhouse Green and Caitlin Talmadge describe RAP sensors as ASW barriers and networks of "bottom-mounted, upward-looking hydrophones using underwater fiber optic cables that come ashore for data processing. RAP sensors can detect even very quiet submarines because there is very little background noise in these small vertical areas."[120] Furthermore, Green and Talmadge assess that given the geographic circumstances of pacific islands such as Guam within the global network of undersea cables,

[119] Source: Starosielski, "Critical Nodes, Cultural Networks," 18.

[120] Brendan Rittenhouse Green and Caitlin Talmadge, "Then What? Assessing the Military Implications of Chinese Control of Taiwan," *International Security* 47, no. 1 (2022): 18.

> The United States likely deploys multiple ASW barriers against Chinese submarines… U.S. control of Guam, plus friendly control of other islands in the second island chain, likely enables the United States to use deep sound channel sensors to surveil the whole Philippine Sea basin. Deploying redundant arrays in this manner makes it very likely that the United States would not only detect any Chinese submarines attempting to reach the open ocean, but also be able to track these nuclear submarines while on station in the Philippine Sea.[121]

In addition to providing Guam with a robust communications infrastructure system, analysis has demonstrated that the island's network of undersea fiber optic cables is well suited for expanding the military's ASW capability. Given the immense value of fiber optic cables and Guam's dependence on undersea communications infrastructure, the development of this sector has proven to be significant to Guam's overall defense posture and has consequently been developed with defense in mind.

As a critical node of both military and commercial significance, Guam's undersea communication infrastructure has been hardened against potential threats. Discussing the environmental factors that affected the development of communications infrastructure, Starosielski states that "due to the frequency of natural disasters on the island, [engineers] attempted to design the station so that it would be completely self-contained with its own water, sewer, cold storage, and power systems, as well as to be fire, earthquake, and typhoon proof."[122] According to Starosielski, decades of typhoons and natural disasters have led network engineers and operators to fortify the important nodes within the Guam's communications infrastructure and today "cable infrastructures are now built to sustain such storms with numerous backup generators and battery systems."[123] Invoking the military and commercial importance of this infrastructure system, Starosielski further states that both military and civilian engineers "formed a united front protecting the island's communications infrastructure and ensuring that Guam remained a secure landing point."[124]

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[121] Green and Talmadge, "Then What," 19-20.

[122] Starosielski, "Critical Nodes, Cultural Networks," 24.

[123] Starosielski, "Critical Nodes, Cultural Networks," 24.

[124] Starosielski, "Critical Nodes, Cultural Networks," 24.

As a result of its strategic significance across a wide range of applications, Guam's undersea communications infrastructure has been developed with redundancies to mitigate the effects of potential failures or attacks. With adequate passive defenses, such as hardened fortifications for the critical junctions in the system and embedded system redundancies, the likelihood of failure of Guam's undersea communications infrastructure is assessed to be low. Consequently, as a well-defended and vital component to Guam's defense, the risk of undersea communications causing Guam's overall defense posture to fail is assessed to be low.

In summary, the reliability concepts and associated failure analysis specific to Guam's undersea communications cable infrastructure are the following:

- Quality: Ability to provide all defense assets on Guam the required communications capability to sustain itself during a conflict.
- Failure: Inability to function as designed leading to a significant loss of communications capability on Guam.
- Time: The length of time Guam's undersea cable network can function during a conflict before all critical junctions are destroyed or no longer function.
- Most likely failure modes: An adversarial attack on undersea cables or their critical junctions on land resulting in a significant loss of communications services on Guam.
- Assessment: Given the existing conditions (i.e., fortified junctions, redundancies), this failure mode is assessed to be of low significance.

2. Electric Power Grid

A second important infrastructure subsystem directly contributing to Guam's defense posture is the island's electric power grid. According to Guam Power Authority (GPA), the territory's electricity provider since 1968, GPA is responsible for providing "electrical service to 50,000 residences, businesses, the local government, and federal

agencies of [the] U.S. territory."[125] In *Transmission and Distribution World,* GPA Engineers John Cruz and Roel Cahinhinan report that "like most island utilities, GPA has no conventional energy resources and relies primarily on petroleum products shipped in by tanker to meet most energy needs. Operating as both a generation and distribution utility, GPA maintains 663 miles of transmission and distribution lines and 29 substations."[126] Considering the wide scope of interconnections between the power grid and all other infrastructure systems (both commercial and military), Guam's electric power grid undoubtedly plays a critical in the island's overall defense and security. As such, several studies have been undertaken to evaluate the power grid's overall resilience.

The quality of electric power from GPA's grid has been an area of considerable concern on DOD installations in Guam. In late 2018, the Naval Facilities and Engineering Command (NAVFAC) Pacific commissioned the U.S. Army's Research Laboratory (ARL) and Construction Engineering Research Laboratory (CERL) to "perform a comprehensive power quality study at selected electrical distribution locations on Guam."[127] Over the span of a six-week measurement period, the study's purpose was to "perform a detailed power quality study at Naval Base Guam (NBG)" and was designed to "detect, characterize, and quantify the frequency and degree of power quality disturbances at specific points of electrical service at NBG."[128] Following the measurement period, the study's principal finding was that "ubiquitous power quality events without changing current levels suggest sustained incoming instability from the electrical service provider. This instability has a high statistical variability with respect to baseline systems including CONUS grids."[129]

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[125] John J. Cruz Jr. and Roel A. Cahinhinan, "Grid Upgrades Deliver for Guam Power Authority," *Transmission & Distribution World* 70, no. 2 (February 2018): 30.

[126] Cruz Jr. and Cahinhinan, "Grid Upgrades Deliver For Guam Power Authority," 30

[127] Brandon Parks et al., "Power Quality Study for NAVFAC Marianas" (Naval Facilities and Engineering Command Pacific, December 2018), 5.

[128] Parks et al., "Power Quality Study for NAVFAC Marianas," 5.

[129] Parks et al., "Power Quality Study for NAVFAC Marianas," 5.

While the study was only carried out for a limited six-week measurement period confined to a single DOD installation, the concluding findings reveal another area of vulnerability for Guam's security. However, in assessing the study's implications for NBG specifically, the impact to overall defense posture is not as severe. From a strategic defense perspective, the most critical assets available on NBG that use electricity from the GPA grid are the nuclear-powered submarines homeported on Guam and the occasional nuclear-powered aircraft carrier routinely deployed to the region. If the most severe outcome of power instability from the grid is a loss of electrical power, backup shipboard power is immediately available onboard operational ships that are not in extended maintenance periods and entirely dependent on the grid. Consequently, the most operationally significant assets at NBG are less at risk from potential power quality instability. Furthermore, senior military officials have not indicated immediate concerns about the potential unreliability of Guam's grid. In late 2021, Rear Admiral Jefferey Jabalon, Commander of the Pacific Submarine Force, announced that a fifth nuclear fast attack submarine (SSN) was going to be homeported to Guam by the end of 2022.[130] According to Admiral Jabalon, "as the Navy starts moving the subs to Guam, there will be increased infrastructure to support it. There is a pier plan to support the Virginia-class Block 5 submarine that will eventually come to Guam in the future."[131] As a result, while grid power instability is an area of important concern for Guam, the risk to operational forces is limited. Consequently, the ability of forces to provide redundant backup power and the Pentagon's approach to scale up infrastructure based on the needs of Guam's growing military presence all contribute to mitigating the risks of unreliable power quality from the grid.

There is also ongoing work to modernize and further develop Guam's electric power grid that benefit the island's overall security and defense posture. In 2009, the U.S. Department of Energy awarded a grant of $16.7 million to GPA as part of the American

[130] Audrey Decker, "Five Navy Subs to Be in Guam by the End of 2022," *Inside the Pentagon's Inside the Navy* 34, no. 46 (November 22, 2021), ProQuest..

[131] Decker, "Five Navy Subs to Be in Guam by the End of 2022."

Recovery and Reinvestment Act. According to GPA engineers Cruz and Cahinhinan, the grant has funded 50% of an ongoing grid modernization project:

> The project involved a territory wide deployment of advanced metering infrastructure (AMI) and integration of the AMI with an outage management system (OMS). GPA also implemented substation automation equipment, including voltage regulators, fault indicators, smart relays and transformer monitors. An energy management system was deployed to leverage the new automation assets.[132]

While problems in grid reliability persist as an area of concern for NBG and ships in port, it is important to acknowledge that grid modernization efforts are improving island-wide reliability. Furthermore, advancements in microgrid technology on Guam have directly benefited important DOD installations on the island. In June 2020, the DOD's Annual Energy Management and Resilience Report (AEMRR) highlighted Guam for its "long-established and successful microgrids at Naval Base Guam Telecommunications Site (NBGTS) Finegayan."[133] The Department of Energy defines microgrids as "a group of interconnected loads and direct energy resources (DERs) within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid"[134] According to Janice Mallery of the Naval Postgraduate School's Systems Engineering Department, in having their own "power generation sources, electrical loads, energy storage, and interfaces," microgrids on DOD installations "increase energy resilience for a local area as an independent source of power when the city grid is interrupted."[135] Continued grid modernization efforts throughout the entire island as well as concentrated efforts to harden localized electrical infrastructure on key DOD installations both demonstrate how the Guam's electric power system has a low likelihood of failure. While the power grid is not without its imperfections, the overall risk of the island's electric power grid causing Guam's overall defense posture to fail is assessed to be low.

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[132] Cruz Jr. and Cahinhinan, "Grid Upgrades Deliver for Guam Power Authority."

[133] Office of the Undersecretary of Defense for Sustainability, "FY 2019 Annual Energy Management and Resilience Report" (Department of Defense, June 2020), 23.

[134] Janice Mallery et al., "Defense Installation Energy Resilience for Changing Operational Requirements," *Designs* 6, no. 2 (2022): 4.

[135] Mallery et al., "Defense Installation Energy Resilience for Changing Operational Requirements."

In summary, the reliability concepts and associated failure analysis specific to Guam's electric power grid are the following:

- Quality: Ability to provide installations, ships, and submarines the electricity required to perform missions and maintenance activities.
- Failure: Inability to function as designed leading to a significant loss of electric power on DOD installations and/or entire island.
- Time: The length of time Guam's electric power grid can function during a conflict before all critical junctions are destroyed or no longer function.
- Most likely failure modes: An adversarial attack on electrical infrastructure (i.e., substations, power generation plants) resulting in a significant loss of electricity on Guam.
- Assessment: Given the existing conditions (i.e., redundancies, microgrids), and ability for critical assets (i.e., ships and submarines) to switch to shipboard power, this failure mode is assessed to be of low significance.

D. FAILURE MODES AND EFFECT ANALYSIS

The purpose behind a failure modes and effect analysis is to account for system interdependencies when determining which subsystem poses the greatest likelihood of failure to Guam's overall defense. Figure 7 summarizes how each subsystem interacts to support Guam's defense posture and provides estimates for how their integrated reliability may lead to failure. In general, each subsystem is partially reliable (medium impact) or unreliable (high impact) to support Guam's missile defense. Specifically, THAAD is the least reliable missile defense system primarily due to lack of THAAD batteries and insufficient capability to protect against more advance Chinese systems. Aegis BMD is a more reliable missile defense capability, but its success depends on ship positioning and availability. Similarly, critical infrastructure supporting Guam's defense posture are only partially reliable. However, failure of these systems is determined to have low to no impact on Guam's defense posture. On-island and undersea telecommunications systems are

obvious targets that can be disrupted by an attack. Recent studies of the GPA power grid show it has power quality issues that can impact ships and submarines docked at NBG. Hence, all subsystems have a moderate likelihood of failure.

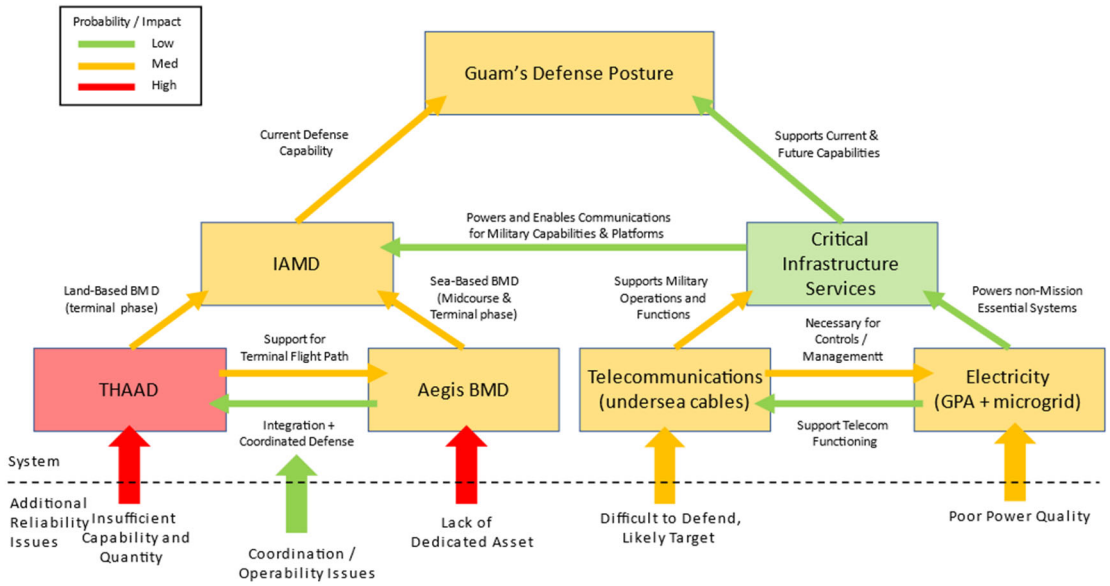

Figure 7. Summary of Failure Modes and Effect Analysis

When analyzing the interdependencies between missile defense and critical infrastructure, missile defense platforms depend on communications and energy infrastructure to perform their primary functions. Critical infrastructure is a key enabling factor that allows for missile defense to be possible. While this may indicate that critical infrastructure is the more important aspect of Guam's defense posture, the analysis has demonstrated that the risk and likelihood of failure of critical infrastructure is far less than that of missile defense. Guam's critical infrastructure has been largely reinforced over time and is continuing to undergo improvements that solidify its importance to Guam's defense posture. Meanwhile however, Guam's current missile defense posture lacks the capability and quantity to address today's more advanced Chinese threats. As a result, the likelihood of failure of missile defense systems constitutes a graver area of weakness within Guam's defense posture.

E. CONCLUSION

The purpose of this chapter was to conduct a comprehensive reliability analysis of the systems that contribute to Guam's overall defense posture to reveal critical areas of weakness. Breaking down Guam's defense posture into the two principal categories of missile defense and critical infrastructure has provided a wholistic approach of evaluating the potential vulnerabilities of each subsystem and conducting a failure modes and effect analysis examined the interdependencies between the two. In summary, the reliability of Guam's defense posture is determined to be moderate. There are likely modes of failure, yet none constitute complete failure to protect Guam from an attack. However, existing missile defense capabilities and critical infrastructure systems are insufficient to ensure a highly reliable defense posture. Overall, the most likely scenario is only partial protection of the island. The failure of missile defense systems the greatest area of weakness and should therefore be the focus of future defense initiatives.

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V. ADVERSARIAL ANALYSIS

The goal of adversarial analysis is to identify which disruptions to a system result in the worst-case loss to system performance irrespective of how likely those failures are to occur. In a simple sense, to answer the question: "what is the worst that could happen?" The purpose of this chapter is to answer this question for Guam's defense posture and the island's role in the Indo-Pacific.

Historically, Guam has undoubtedly served as the lynchpin of American military power in the Indo-Pacific. For decades, Guam's large concentration of U.S. forces and combat capability has transformed the island into a springboard for forward military operations. However, with the complexities of today's modern threats as well as the reliability gaps in Guam's defense posture, the large concentration of forces on Guam creates a critical node that, if successfully targeted, can potentially remove a considerable amount of military power from the fight. As a result, security experts and defense officials have begun to explore various strategies of dispersing the combat capability from Guam around the region to improve the overall defense posture in the Indo-Pacific.

This dispersal of combat capability directly relates to the goals of adversarial analysis. Adversarial analysis is distinct from risk and reliability by recommending system improvements that minimize the maximum loss of system performance (i.e., worst case). Dispersing combat capability among Guam assets and across the Indo-Pacific achieves this goal by minimizing the impacts of losing any single element of Guam's defense posture. Toward this end, this chapter first identifies where the most catastrophic losses of military capability will be in the event of an attack on Guam. Furthermore, this chapter evaluates the present strategies of dispersing Guam's combat power and analyze the implications of force redistribution on the adversary's targeting calculus. The previous two chapters have demonstrated that Guam's most significant reliability gap is in missile defense while the gravest risk to the island is the threat of PLA ballistic missiles. As a result, the primary focus of this chapter's adversarial analysis will be on PLA missiles targeting the critical nodes of Guam's combat capability.

The chapter is organized as follows: first, the academic definition of adversarial analysis is given and then contextualized within the subject of Guam's defense posture. Next, the two largest military bases on Guam, Andersen Air Force Base and Naval Base Guam, are discussed to further analyze their roles as critical nodes of Guam's power projection capability. Additionally, this chapter analyzes the implications of a PLA attack on both critical nodes to Guam's overall defense and combat capability. Lastly, this chapter discusses the recent efforts to disperse Guam's combat capability to other U.S. territories in the Indo-Pacific such as the Commonwealth of Northern Marianas Islands (CNMI). The dispersal of combat capability from Guam to other parts of the second island chain is critical to understanding adversarial analysis for the broader defense posture of the Indo-Pacific.

A. DEFINING ADVERSARIAL ANALYSIS

Prior to conducting an adversarial analysis of Guam's defense posture, it is important to first define and contextualize how it applies to this study. According to Daniel Eisenberg from the Naval Postgraduate School's Center for Infrastructure Defense, "adversarial analysis deals with possible challenges to a system. While the likelihood of an adversarial attack can only be estimated with possibility, the consequences of an adversarial attack can be explicitly measured. Adversarial analysis is the language of military and security experts."[136]

One of the earliest studies in adversarial analysis was in the 1950s when T.E. Harris and F.S. Ross conducted a study for the RAND Corporation analyzing the flow of military material moving throughout the Soviet Union and Eastern Europe. The Harris-Ross study presented the Soviet rail system as a network flow model displaying the critical junctions in the overall system as well as the different carrying capacities of connecting railway lines.[137] In an effort to optimize target effectiveness and economize the resources for a potential U.S. attack on the Soviet rail system, Harris and Ross found that targeting should be focused on

[136] Daniel Eisenberg, "Resilience Corner: The Four Horsemen of Infrastructure Vulnerability," Government, Naval Postgraduate School Energy Academic Group, May 1, 2021, https://nps.edu/web/eag/The-Four-Horsemen-of-Infrastructure-Vulnerability.

[137] T.E. Harris and F.S. Ross, "Fundamentals of a Method for Evaluating Rail Net Capacities" (Santa Monica, California: The RAND Corporation, October 24, 1955), https://web.eecs.umich.edu/~pettie/matching/Harris-Ross-fundamentals-of-evaluating-rail-net-capacities-RAND-report-declassified.pdf.

the connecting rail lines with the largest carrying capacity to yield the largest cumulative service disruption on the broader aggregate system.[138]

Since the 1950s, adversarial analysis has become a common practice to assess the vulnerability of military and civilian systems. Adversarial analysis involves evaluating the quantifiable losses of a *potential attack* or disruption to a system via a combination of game theoretic and optimization techniques referred to as interdiction models[139] and/or attacker-defender models.[140] The results of this analysis are the sets of critical locations (e.g., critical nodes or hubs) that cause worst-case failures if lost.[141] An important distinction between adversarial analysis and other vulnerability methods is the results – the sets of critical nodes – will be the same *irrespective of why they fail*. (The title "adversarial" refers to the use of two-player, zero-sum games in model formulation and assessment, rather than the nature for why critical nodes fail.) Hence, adversarial analysis supports defending systems to all possible threats, not just those that deemed high likelihood via risk or reliability. Defense against adversarial attack focuses on minimizing the impact of maximum (worst-case) failures via system hardening, redundancy, and redesign.[142] This is often done by dispersing assets and functions across a system, rather than centralizing them and making them easier to simultaneously fail. Taken together, adversarial analysis asks the following questions to assess vulnerability and protect systems:

- What would constitute a worst-case disruption?
- How would an adversary conduct an attack to create such a disruption?

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[138] Harris and Ross, "Fundamentals of a Method for Evaluating Rail Net Capacities."

[139] J. Cole Smith and Yongjia Song. "A survey of network interdiction models and algorithms." European Journal of Operational Research 283, no. 3 (2020): 797–811.

[140] Gerald Brown, Matthew Carlyle, Javier Salmerón, and Kevin Wood. "Defending critical infrastructure." Interfaces 36, no. 6 (2006): 530–544.

[141] David L Alderson, Gerald G. Brown, and W. Matthew Carlyle. "Operational models of infrastructure resilience." Risk Analysis 35, no. 4 (2015): 562–586.

[142] David L Alderson, Gerald G. Brown, W. Matthew Carlyle, and R. Kevin Wood. Solving defender-attacker-defender models for infrastructure defense. Naval Postgraduate School Monterey CA Dept Of Operations Research, 2011.

- What are the critical nodes that, if disrupted, would cause significant losses in system performance?
- What are the consequences if realized?

Applying the concepts of adversarial analysis to this study, the *aggregate system* refers to the overall defense posture of Guam. Additionally, the ability to project combat power from Guam constitutes the *delivery of services* for the broader system. The areas evaluated as critical nodes of operation are Andersen AFB for air power capability and Naval Base Guam for maritime power projection. This study applies the concepts of adversarial analysis to the defense of Guam and asks the following questions:

- What makes Naval Base Guam and Andersen AFB critical nodes for military operations in the Indo-Pacific?
- While the loss of both bases drastically affects military operations in the region, what are the consequences of the loss of one base to overall warfighting efforts in the Indo-Pacific?
- Of the two critical nodes, which base is more critical to Guam's defense posture?

B. NAVAL BASE GUAM

The U.S. Navy's largest footprint on Guam is Apra Harbor and Naval Base Guam. Apra Harbor is one of the world's largest protected deep-water ports, capable of berthing nuclear-powered aircraft carriers.[143] As the largest deep-water harbor between Hawaii and the Philippines, Naval Base Guam serves as the home port of five nuclear-powered attack submarines as well as two submarine tenders.[144] Figure 8 depicts the location of Apra Harbor and Naval Base Guam and illustrates how the Orote Peninsula in the south and the Cabras

143 "Apra Harbor," Global Security, accessed January 18, 2022, https://www.globalsecurity.org/military/facility/apra.htm.

144 "Naval Base Guam (NBG)," Government, Commander Naval Installations Command (CNIC), accessed April 20, 2022, https://www.cnic.navy.mil/regions/jrm/installations/navbase_guam/about.html.

Island in the north create a naturally protected deep-water harbor.[145] The western edge of the Inner Apra Harbor contains the necessary pier facilities for navy ships and submarines while the Outer Apra Harbor has many deep-draft anchorages available for both military and commercial vessels.[146] Additionally, Guam's shipyard at Apra Harbor provides critical repair and maintenance facilities for visiting U.S. Navy ships and features the only deep-water ammunition port in the western pacific.[147] The bulk of the Navy's combat capability is delivered from Apra Harbor. Naval Base Guam and Apra Harbor directly support the Navy's most strategic maritime power projection assets to include aircraft carriers, submarines, and logistical support vessels. As a result, Naval Base Guam and Apra Harbor are critical nodes for naval operations on Guam for of their ability to support and deliver naval combat power in the Indo-Pacific.

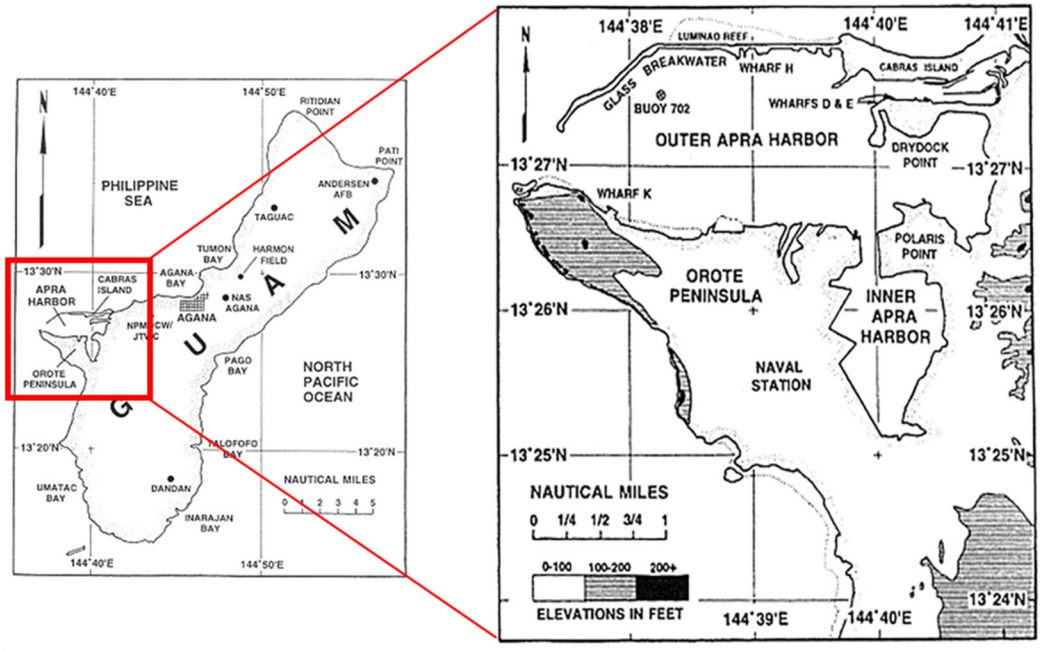

Figure 8. Map of Apra Harbor[148]

[145] Global Security, "Apra Harbor."

[146] Global Security, "Apra Harbor."

[147] Global Security, "Apra Harbor."

[148] Source: Global Security, "Apra Harbor."

A PLA attack on Apra Harbor and Naval Base Guam would have significant consequences for naval operations in the Indo-Pacific; however, the loss of Guam's naval facilities would have a limited effect on warfighting readiness in the region. With the loss of the naval facilities on Guam, the Navy's ships and submarines would lose a strategically important position in the region for logistical, maintenance, and replenishment support. Moreover, the worst-case disruption to naval operations on Guam would be an attack on the harbor while strategic maritime assets, such as an entire Carrier Strike Group (CSG) and multiple nuclear submarines, are moored at Naval Base Guam. However, while an attack on Naval Base Guam would significantly disrupt naval operations in the Indo-Pacific, the Navy's inherent ability to mobilize forces at sea and conduct sustained operations afloat, independent of supporting land bases, minimizes the cumulative impact to overall warfighting operations in the Indo-Pacific. In a 2015 RAND study analyzing the prospects of U.S.-China confrontation during a Taiwan Strait scenario, experts modeled the capability of U.S. naval forces against PLAN forces and found that "although U.S. capability against Chinese amphibious forces has declined somewhat, a combination of submarine, air, and surface attacks would nevertheless pose a serious threat to Chinese amphibious forces and their ability to conduct or sustain an amphibious invasion."[149] Consequently, while supporting land bases and harbors are essential to naval operations, the bulk of the Navy's combat capability comes from the sea and is not entirely dependent on land-based assets.

The Navy's most strategic advantage is the service's ability to replenish and sustain operational forces at sea for prolonged periods of time. Absent of Guam, naval forces could turn to the deep-water ports of allied partners such as Australia, Japan, and the Philippines for situations when ships and submarines are required to enter port for more critical repairs and maintenance. Additionally, Hawaii would also offer a more protected option for naval forces requiring significant port services. As a result, the elimination of Naval Base Guam and Apra Harbor will force the Navy to drastically shift logistical lines of support for navy assets in the Indo-Pacific, but the Navy's ability to project power from the sea will remain.

[149] Eric Heginbotham et al., "The U.S.-China Military Scorecard: Forces, Geography, and the Evolving Balance of Power, 1996–2017" (RAND Corporation, September 14, 2015), xxvi.

In summary, the following answers the adversarial analysis questions posed earlier in the chapter as they pertain to Naval Base Guam and Apra Harbor:

- The deep-water harbor, ship repair facilities, and logistical support network makes Naval Base Guam and Apra Harbor a critical node for military operations in the Indo-Pacific.

- The Navy's ability to sustain prolonged operations at sea as well as the availability of allied ports and naval bases in Hawaii minimizes the consequences of losing naval facilities on Guam.

C. ANDERSEN AIR FORCE BASE

The U.S. Air Force's most strategic footprint on Guam is Andersen AFB located at the northeast corner of the island. Andersen AFB is home to over 8,000 joint personnel, civilians, and military contractors along with 2,500 dependents.[150] Andersen currently has two aircraft runways, two landing zones, and 7.5 million square feet of ramp, all of which can support every aircraft in the DOD inventory.[151] Furthermore, Andersen has the largest fuel storage and largest munitions storage capacity in the Air Force.[152] Among Air Force commands, Andersen hosts the "Pacific Air Forces' 13th Air Force and the 36th Wing, Air Mobility Command's 634th Air Mobility Support Squadron and several other tenant organizations."[153] The base also serves as "one of four Bomber Forward Operating Locations (BFOL) in the Air Force" providing "forward support to bomber crews deploying overseas in Europe, Southwest Asia and in the Pacific."[154] Figure 9 is a satellite image of Guam and illustrates the considerable size and scale of Andersen AFB compared to entire island

150 "Andersen Air Force Base (AAFB)," Government, U.S. Air Force, accessed April 26, 2022, https://www.andersen.af.mil/Units/.

151 Global Security, "Andersen Air Force Base."

152 Global Security, "Andersen Air Force Base."

153 Global Security, "Andersen Air Force Base."

154 Global Security, "Andersen Air Force Base."

territory.[155] A large majority of the Air Force's air power capability is mustered on Andersen Air Force Base as well as the requisite amounts of supporting elements such as aircraft fuel, ammunition, maintenance, and logistical elements. Consequently, when compared to the Navy's footprint on Guam, the Air Force constitutes the bulk of military presence on the island territory. As a result, Andersen AFB delivers a host of considerable air power capability and is a critical node military operations in the Indo-Pacific.

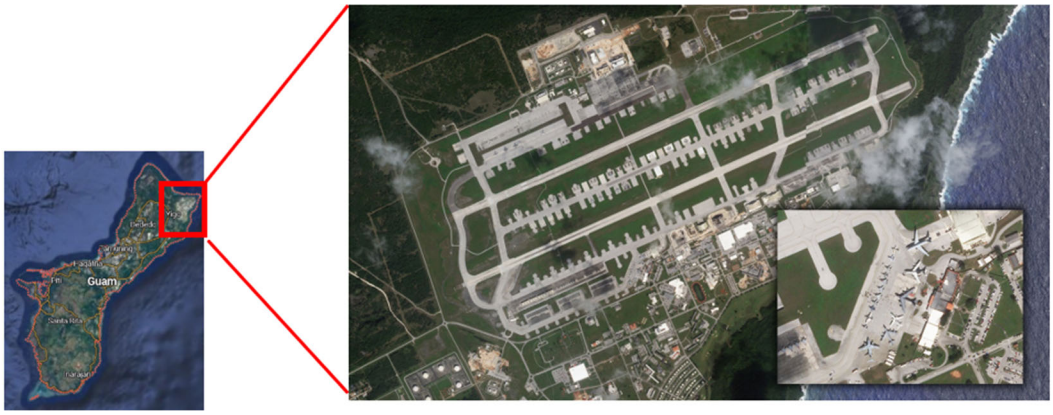

Figure 9. Satellite Image of Andersen Air Force Base[156]

A PLA attack on Andersen AFB would have detrimental consequences to U.S. and Allied air power in the Indo-Pacific. Unlike the Navy, the Air Force depends on the support from strategic air bases to conduct sustained combat air operations. Experts from the RAND Corporation modeled the effects of losing critical air bases and assessed that "as a larger proportion of U.S. aircraft are forced to fly from bases that are either susceptible to attack or farther from the scene of conflict, basing issues will greatly complicate U.S. efforts to gain air superiority over the battlefield."[157] Comparing the models of China and

[155] Tyler Rogoway, "Check Out All The Airpower On Guam For Exercise Cope North In This Exclusive Satellite Image," The Drive, February 16, 2020, https://www.thedrive.com/the-war-zone/32233/check-out-all-the-airpower-on-guam-for-exercise-cope-north-in-this-exclusive-satellite-image.

[156] Source: Rogoway, "Check Out All The Airpower On Guam For Exercise Cope North In This Exclusive Satellite Image."

[157] Eric Heginbotham et al., "The U.S.-China Military Scorecard: Forces, Geography, and the Evolving Balance of Power, 1996–2017" (RAND Corporation, September 14, 2015), xxiii.

U.S. military capabilities between 1996 and 2017, the RAND study also found that in a conflict today, "U.S. commanders would probably be unable to find the basing required for U.S. forces to prevail in a seven-day campaign. They could relax their time requirement and prevail in a more extended campaign, but this would entail leaving ground and naval forces vulnerable to Chinese air operations for a correspondingly longer period."[158] As a result, the loss of strategic air bases such as Andersen will drastically disrupt the Air Force's ability to achieve air superiority in the region. Without Andersen, U.S. air forces would not only lose a strategically vital support node in the Indo-Pacific but would also have to drastically extend aerial refueling routes to sustain air operations in the region during a conflict. Figure 10 is a notional map of the Air Force's tanker laydown in the Indo-Pacific and illustrates how central Guam and the broader Marianas Islands are to the Air Force's refueling capability.[159]

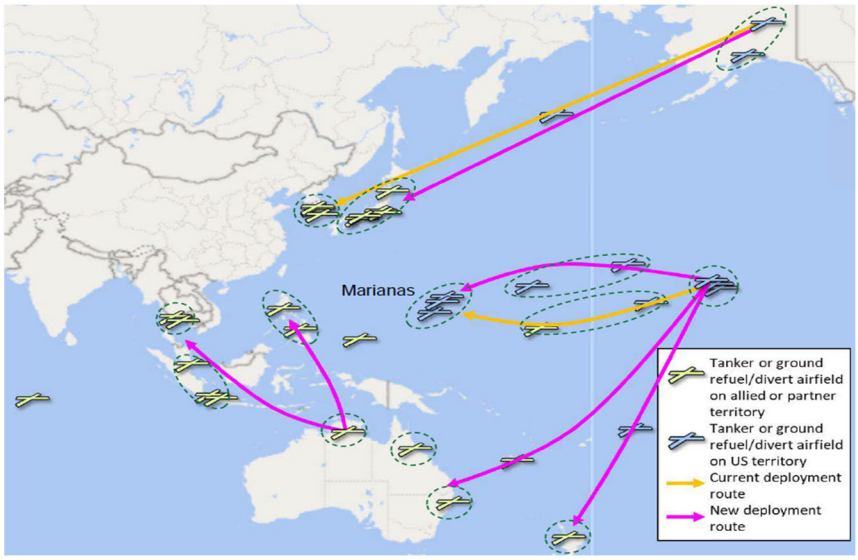

Figure 10. Notional Laydown of Air Force Tanker Airfields in Indo-Pacific[160]

158 Heginbotham et al., "The U.S.-China Military Scorecard," xxiv.

159 Timothy Walton and Bryan Clark, "Resilient Aerial Refueling: Safeguarding the U.S. Military's Global Reach - by Timothy A. Walton Bryan Clark" (Washington, DC: *Hudson Institute*, November 2021).

160 Source: Walton and Clark, "Resilient Aerial Refueling."

In summary, the following answers the adversarial analysis questions posed earlier in the chapter as they pertain to Andersen AFB:

- The concentration of air combat capability as well as the requisite supporting elements (aircraft fuel, ammunition, maintenance, and logistical elements) make Andersen a critical node for military operations in the Indo-Pacific.
- The vital importance of air bases and ground infrastructure on the Air Force's ability to achieve air superiority maximizes the consequences of losing Andersen as a strategic air base.
- Of the two bases, Andersen AFB is more critical to military operations in the Indo-Pacific due to the cumulative consequences that would be realized following an attack.

D. DISPERSING COMBAT CAPABILITY BEYOND GUAM

The realization of the dire consequences of losing Guam's strategic military bases have led to a tactical shift in the distribution of military combat capability in the areas beyond the island territory. Most notably, senior leaders have turned to another U.S. territory less than 200 miles north of Guam, the Commonwealth of Northern Marianas Islands (CNMI) (Figure 11). According to an Air Force press release, in May 2019, the local government of CNMI and the DOD "finalized and signed a 40-year lease agreement worth $21.9 million for the U.S. Air Force's divert airfield on Tinian Island."[161] Specifically outlining the construction of additional fuel pipelines and aviation infrastructure, Air Force officials stated that the divert airfield will be "designated to provide strategic operational and exercise capabilities for U.S. forces when needed and offer humanitarian assistance and disaster relief in times of natural or man-made disasters."[162] With construction expected to be completed in October 2025,[163]

[161] Pacific Air Forces Public Affairs, "CNMI Signs $21.9M 40-Year Lease with U.S. DOD," *Air Force*, May 8, 2019.

[162] Pacific Air Forces Public Affairs, "CNMI Signs $21.9M 40-Year Lease with U.S. DOD."

[163] Joanna Delfin, "NAVFAC Marianas Manages Tinian Divert Airfield Construction Projects," Government, DVIDS, February 25, 2022, https://www.dvidshub.net/news/415278/navfac-marianas-manages-tinian-divert-airfield-construction-projects.

the divert airfield in Tinian will provide U.S. commanders added operational flexibility beyond Andersen AFB. The DOD's investment in CNMI demonstrates a need for more than a single critical air operations node in the second island chain. With the added fuel storage and aviation-related infrastructure on Tinian, air force tankers will be better postured to support sustained air operations in the region. Moreover, from the PLA's threat perspective, distributing strategic air assets beyond Guam adds additional layers of redundancy and complicates the adversary's threat calculus about which targets to attack and where possible attacks could originate from. Consequently, the expansion of a divert airfield on Tinian serves to alleviate Andersen's vulnerability and provides U.S. commanders added operational flexibility.

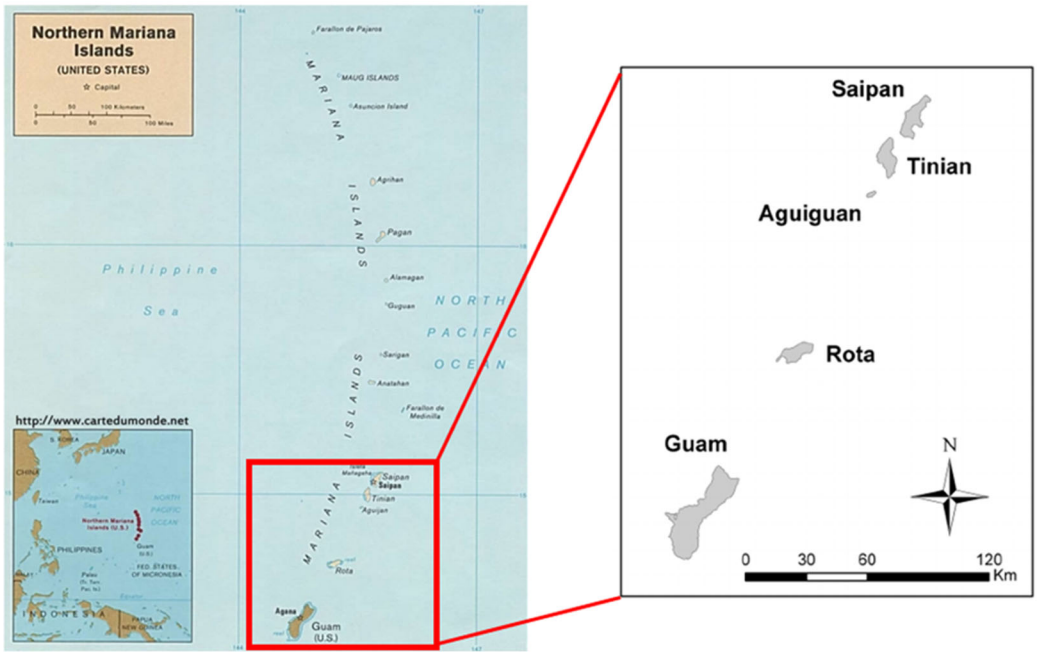

Figure 11. Map of Northern Marianas Islands[164]

In addition to expanding air operations on Tinian, the Army has also begun making strides in distributing air and missile defense capabilities throughout the second island

164 Source: Research Gate, "Map of Commonwealth of the Northern Marianas Islands (CNMI)," ResearchGate, accessed November 2, 2022, https://www.researchgate.net/figure/Map-of-CNMI-Source-US-Department-of-Interior-Office-of-Insular-Affairs_fig2_255243454.

chain. During an exercise in March 2022, soldiers from the E-3 Air Defense Battery deployed Guam's sole THAAD launcher to Rota, CNMI and conducted a successful THAAD launch on Rota from a control station in Guam using a newly developed remote launch kit.[165] According to an Army press release about the exercise, "this was the first use of the THAAD remote launch capability outside of testing and proved to be an outstanding addition to THAAD's already combat-proven effectiveness… The future perspective of what THAAD is capable of is still to be seen. For now, the ability to expand and better protect the chain of Marianas islands is what E-3 is focused on."[166] The recent deployment of THAAD to Rota and subsequent remote launch demonstration from Guam is an innovative capability that directly complements the expansion of air power capabilities to the broader CNMI region. Bolstering air combat capability to CNMI will require additional air defense units to ensure the adequate protection of strategic assets. As such, the ability to rapidly deploy multiple THAAD batteries throughout CNMI and execute command and control from remote locations will be crucial to the defense of Guam and the entire second island chain.

E. CONCLUSION

The purpose of this chapter was to conduct a comprehensive adversarial analysis of Guam's defense posture, identify the critical nodes of military operations for the island, and evaluate recent efforts to disperse Guam's combat capability throughout the region. The goal of adversarial analysis is to focus on the cumulative consequences of a disruptive event on an aggregate system when identifying the critical nodes of operation. Naval Base Guam and Andersen AFB are critical nodes of military operations for their ability to support and deliver naval and air combat capability throughout the Indo-Pacific. After assessing the consequences of a potential PLA attack on either of the two critical bases, the analysis has demonstrated that the elimination of Andersen AFB would have a more disruptive effect on overall military operations in the Indo-Pacific. The inherent ability of

[165] Nicholas Chopp and David Chapman, "Guam Air Defenders Deploy First THAAD Remote Launch Capability," www.army.mil, March 16, 2022, https://www.army.mil/article/254576/guam_air_defenders_deploy_first_thaad_remote_launch_capability.

[166] Chopp and Chapman, "Guam Air Defenders Deploy First THAAD Remote Launch Capability."

naval forces to mobilize forces at sea and conduct sustained naval combat operations independent of land bases alleviates the consequences of the potential loss of Naval Base Guam. Conversely, the concentration of air power on Andersen as well as the importance of air bases and ground infrastructure on the ability to achieve air superiority amplifies the consequences of losing Andersen as a strategic air base. As a result of this vulnerability, recent efforts to distribute combat capability beyond Guam have proven to be effective strategies in improving the overall defense posture of Guam and the broader CNMI. Following a comprehensive adversarial analysis, Andersen AFB is determined to be the most critical node for Guam's defense posture; however, recent strategic changes in military operations in the region have begun to alleviate the consequences of this important vulnerability.

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VI. SAFETY ENGINEERING

The final step in this vulnerability analysis is to evaluate the human response to a historical crisis using concepts of safety engineering. The goal of safety engineering is to evaluate the response to dangerous conditions and analyze the effects of human behavior during a crisis. Toward this end, safety and resilience concepts focus on identifying the factors that helped prevent or mitigate the effects of actual historical events to inform responses to future crises or surprises. While modern warfare has fortunately not reached the shores of Guam in recent history, Guam's location in the Indo-Pacific has made the island especially susceptible to natural disasters. Analyzing military response during natural disasters offers a case study to demonstrate what decision-making may occur when any crisis strikes.

Historically, typhoons have ravaged the Marianas Islands and have been known to cause territory-wide disruptions in both military and civilian sectors. While a natural disaster such as a typhoon does not exactly resemble the same effects as a deliberate PLA attack on Guam, the response to such an event is indicative of the U.S. military's current posture to respond to any regional crisis. Although natural disasters have undoubtedly led to unfortunate losses in human lives and physical infrastructure, the response to natural disasters greatly informs analysts about the resilience of military installations and their defense posture. Recent examples of military installations impacted by natural disasters, including Hurricane Florence and Marine Corps Base Camp Lejeune[167] or Hurricane Matthew and Tydall Air Force Base[168] revealed a lack of readiness and inability to quickly manage disaster impacts. An inability to successfully manage natural disasters translates into impacts on mission readiness and is considered a major driver of current DOD defense

[167] E. A. Pesicka and D.A. Eisenberg, "Resilience to Climate Surprise: Lessons from Hurricane Florence and Marine Corps Base Camp Lejuene," Sustainable and Resilient Infrastructure (in review).

[168] Michael T. Klare, *All Hell Breaking Loose: The Pentagon's Perspective on Climate Change* (New York: Metropolitan Books, 2019).

posture.[169] In the case of Guam, analyzing the effects of natural disasters provides a basis of understanding for how military forces, and emergency management organizations would respond following a potential attack on the island. In the broader context of Guam's defense posture, it is important to examine the human response that occurs following natural disasters and consider it as a critical factor in vulnerability analysis.

The principal case study used in this chapter is Typhoon Manghuk which devasted Guam and CNMI in September 2018.[170] Figure 12 depicts Typhoon Manghuk's path and its closest proximity to Guam and CNMI.[171] Typhoon Manghuk is a particularly important example as local military services were deployed to provide a Defense Support of Civil Authorities (DSCA) mission in response to the disaster. Given the recent response and impacts of Typhoon Manghuk, a key assumption in this chapter is that military and non-military response to this event is indicative of response to future events, including conflict.

This chapter is organized as follows: first, safety engineering is defined and applied within the subject of Guam's defense posture. Next, this chapter analyzes the effects of Typhoon Manghuk and the subsequent responses in both CNMI and Guam. As demonstrated in the previous chapter, CNMI is taking on a larger role in bolstering U.S. defense posture in the region. As a result, CNMI is included in this chapter's safety engineering analysis and is henceforth considered as an element of Guam's defense posture. After applying safety engineering concepts to the events following Typhoon Manghuk, this chapter concludes with an overall resilience assessment of Guam's defense posture.

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[169] Department of Defense, "2022 National Defense Strategy of the United States Including 2022 Nuclear Posture Review and 2022 Missile Defense Review," 2022, https://media.defense.gov/2022/Oct/27/2003103845/-1/-1/1/2022-NATIONAL-DEFENSE-STRATEGY-NPR-MDR.PDF.

[170] Center for Excellence in Disaster Management & Humanitarian Assistance, "An Introduction to Defense Support of Civil Authorities (DSCA): A Look at Recent DSCA Operations in Support of Disaster Relief in U.S. Territories in the Indo-Pacific," Case Study Series (Center for Excellence in Disaster Management & Humanitarian Assistance), accessed October 6, 2022, Center for Excellence in Disaster Management & Humanitarian Assistance.

[171] National Oceanic and Atmospheric Administration, "Typhoon Mangkhut Slams China and the Philippines," Government, National Environmental Satellite Data and Information Service, September 17, 2018, https://www.nesdis.noaa.gov/news/typhoon-mangkhut-slams-china-and-the-philippines.

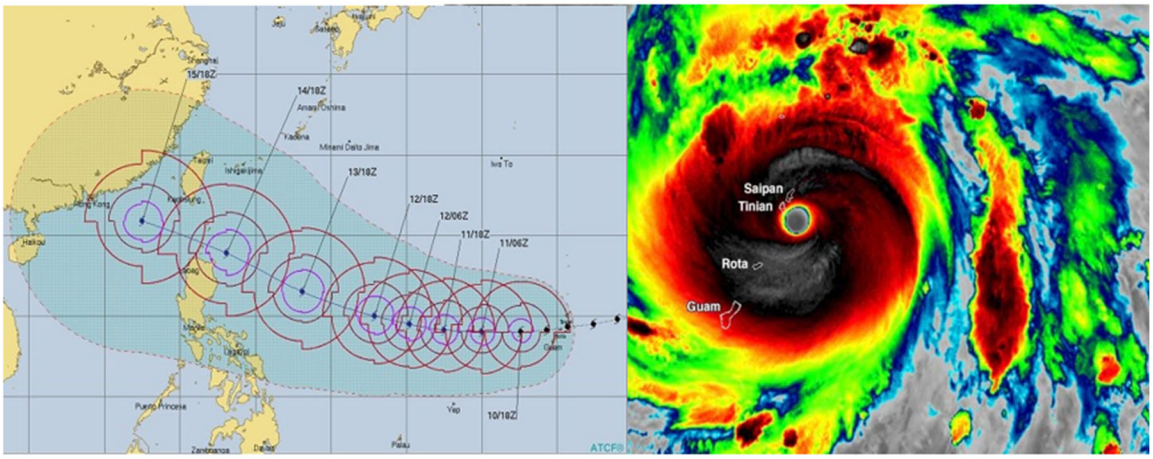

Figure 12. Path of Typhoon Manghuk[172]

A. DEFINING SAFETY ENGINEERING

Safety engineering allows analysts to account for human factors when evaluating an overall system's resilience. In the *Journal of Homeland Security and Emergency Management,* John E. Thomas et al. state that "human and technological resilience capacities are interconnected, interrelated, and interdependent to one another."[173] The authors further argue that "the affective dimension of human resilience may be more critical than tends to be acknowledged in resilience engineering literature… [the] cognitive, behavioral, and affective dimensions of human resilience contribute to the resilience of infrastructure essential to public health, safety, and well-being."[174] More specifically, in *Building Research and Information*, Erik Hollangel defines resilience as "the capacity to sustain operations under both expected and unexpected conditions. The unexpected conditions are not only threats but also opportunities."[175] While these authors were

[172] Source: National Oceanic and Atmospheric Administration, "Typhoon Mangkhut Slams China and the Philippines."

[173] John E. Thomas et al., "A Resilience Engineering Approach to Integrating Human and Socio-Technical System Capacities and Processes for National Infrastructure Resilience," *Journal of Homeland Security and Emergency Management* 16, no. 2 (2019), 11.

[174] Thomas et al., "A Resilience Engineering Approach to Integrating Human and Socio-Technical System Capacities and Processes for National Infrastructure Resilience," 11.

[175] Erik Hollnagel, "Resilience Engineering and the Built Environment," *Building Research & Information* 42, no. 2 (2014): 1.

primarily discussing human decisions and resilience in critical infrastructure systems like electric power and telecommunications, their analysis is also relevant for military systems, including missile defense and power projection capabilities. In summary, safety engineering analyzes how human factors affect the overall system's ability to continue operations during routine activity and especially during an unexpected crisis. In infrastructure system analysis, safety engineering asks the following questions:

- What is a historical example of a surprise event affecting system operations and emergency response?
- How did operators respond?
- Did operator action prevent losses or exacerbate them?
- Do systems remain vulnerable to those same or different surprises?

Applying safety engineering concepts to Guam's defense posture aims to analyze how U.S. military and emergency management services responded in the wake of Typhoon Manghuk. More specifically, this analysis evaluates how well CNMI and Guam were able to sustain military operations and defense readiness following disruptive events brought by the typhoon. Applying safety engineering concepts, Guam's defense posture focuses on answering the following question:

- How did U.S. military and emergency management services respond to Typhoon Manghuk?
- How did Typhoon Manghuk affect the overall military readiness and defense posture in the region?
- How vulnerable is Guam and CNMI to future natural disasters?

B. CNMI'S RESPONSE

Typhoon Manghuk considerably damaged CNMI and significantly disrupted every facet of the territory's day-to-day operations. According to the Center for Excellence in Disaster Management & Humanitarian Assistance,

> Typhoon Mangkhut hit CNMI as a Category 2 typhoon on September 10, 2018, affecting all three main islands, however CNMI's southernmost island of Rota suffered the worst of the damages, with the storm passing directly overhead. Typhoon Mangkhut was the strongest storm to hit [Rota] since 2002. Rota's main village of Songsong suffered widespread damage. The storm toppled trees and caused power poles and transformers to fall across the island's roads.[176]

As CNMI's southernmost island and the island closest to Guam, the damage Manghuk left behind on Rota provided responders a glimpse of the degree of destruction that was to be expected throughout the Marianas archipelago. With the degree of damage to the entire territory and the insufficient capacity of local emergency management services, CNMI heavily depended on the Federal Emergency Management Agency (FEMA) and the DOD through the military's DSCA mission.

The DOD response to Typhoon Manghuk is a case study of the how swift and immediate actions make remote U.S. territories more resilient. Home to over 50,000 American citizens,[177] CNMI was in great need of federal assistance following the typhoon. The first on scene to assist FEMA were naval ships from Expeditionary Strike Group 7 (ESG 7) and their embarked Marines from the 31st Marine Expeditionary Unit (31st MEU) who were already at sea operating in the Indo-Pacific region when the typhoon landed on CNMI.[178] The amphibious assault ship USS WASP (LHD 1) and the amphibious dock landing ship USS ASHLAND (LSD 48) carried a complement of helicopters and ship-to-shore vehicles organically outfitted to conduct Humanitarian Assistance Disaster Relief (HADR) missions.[179] According to FEMA and DOD officials, the air mobility capability from the sea was notably significant during initial damage assessments as "Navy and Marine Corps aircraft from the ESG [conducted] aerial surveys of the islands of Rota,

[176] Center for Excellence in Disaster Management & Humanitarian Assistance, Introduction, 36.

[177] Center for Excellence in Disaster Management & Humanitarian Assistance, "An Introduction to DSCA,," 29"

[178] Center for Excellence in Disaster Management & Humanitarian Assistance, Introduction, 37.

[179] Center for Excellence in Disaster Management & Humanitarian Assistance, Introduction, 37.

Saipan and Tinian" allowing decision makers to prioritize relief efforts.[180] Additionally, the ability to rapidly deploy personnel to the shore proved to be critical as "more than 100 Marines and Sailors assisted with debris removal from roads and provided logistical help throughout Rota. The troops cleared roadways using chainsaws and axes along nine miles of the island's main road"[181] Furthermore, the U.S. Army Corp of Engineer's (USACE) played a considerable role in relief efforts deploying subject matter experts to assist local, state, and federal agencies with restoring critical infrastructure systems such as electrical power.[182] Overall, relief efforts in CNMI were robust in capability and demonstrated the capacity of joint interagency HADR efforts.

As the islands of CNMI become increasingly significant to the region's defense posture, the ability to respond to a crisis in the U.S. territory becomes ever more important. While the military does not have a considerable footprint on CNMI, the territory's proximity to Guam and the islands' proven military utility makes the resilience of the territory critical to regional defense. The Navy and Marine Corps' swift response in CNMI demonstrated the critical capability of effectively integrating with emergency management personnel during disaster relief operations. In particular, the ability of the Navy to rapidly deploy an expeditionary strike group, specifically outfitted for HADR missions, proved to enhance the overall resilience of CNMI. Ultimately, the military's support in the quick restoration of the island's basic necessities such as food, water, shelter, and electricity was quintessential in demonstrating CNMI's resilience.

The following summarizes the answers to the safety engineering questions posed earlier in the chapter as they pertain to CNMI's response to Typhoon Manghuk:

- The speed and effectiveness of Navy and Marine Corps assets during HADR operations were critical for CNMI's recovery

[180] Center for Excellence in Disaster Management & Humanitarian Assistance, Introduction, 38.

[181] Center for Excellence in Disaster Management & Humanitarian Assistance, Introduction, 38-39.

[182] Center for Excellence in Disaster Management & Humanitarian Assistance, Introduction, 39.

- Although the military defense posture in the region was momentarily occupied with HADR operations versus combat readiness, the speed of restoring CNMI's necessities allowed for a quicker return to normal operations.

- Accounting for CNMI's geographic location and ongoing efforts to build more typhoon-resistant infrastructure,[183] CNMI remains vulnerable to future typhoons and natural disasters.

C. GUAM'S RESPONSE

While Typhoon Manghuk took a greater toll on CNMI, the disruption on Guam was significant nonetheless. According to the Center for Excellence in Disaster Management and Humanitarian Assistance,

> Although the eye of the storm did not pass over Guam, the island still reportedly experienced hurricane-force winds, causing widespread flooding and power outages in Guam. More than 2,000 people in Guam stayed in emergency shelters overnight as the typhoon passed close to the island. The powerful typhoon damaged or destroyed homes on the island…damaged the power infrastructure, disrupted water services, and caused agricultural damages. Around 80 percent of Guam was without power.[184]

Like CNMI, the scale of the typhoon's destruction throughout Guam would require substantial federal assistance, especially from the organic military capability already on the island. Furthermore, the quick restoration of Guam would also allow military forces to better support simultaneous recovery efforts going on throughout the broader Marianas archipelago.

The case study of Guam's response to Manghuk is another thorough demonstration of how effective DSCA missions can be in a region. Just as in the case for CNMI, Sailors and Marines from ESG 7 and the 31st MEU were deployed throughout Guam to directly

[183] Pacific Island Times News Staff, "CNMI Soon to Launch $244 Million Worth of Disaster-Recovery Projects," *Pacific Island Times*, October 17, 2020, https://www.pacificislandtimes.com/post/2020/10/17/cnmi-soon-to-launch-244-million-worth-of-disaster-recovery-projects.

[184] Center for Excellence in Disaster Management & Humanitarian Assistance, Introduction, 45.

support FEMA with aerial surveys, search and rescue operations, debris removal, and emergency supply distribution.[185] However, something unique to Guam was the presence of the U.S. Coast Guard in Apra Harbor which "began making assessments and clearing debris from the port so that it could reopen while DOD and other federal teams headed to CNMI to assess the situation."[186] Another critical enabler for relief operations in both territories but especially Guam was the presence of the Ronald Reagan Carrier Strike Group which flew in additional supplies and served as a "floating refueling point for helicopters moving between the islands."[187] Consequently, the DSCA mission in Guam following Typhoon Manghuk leveraged the robust capability of Navy and Marine Corps' forward deployed assets. The recovery efforts were not only important for the restoration of Guam, but they were especially crucial in enabling Guam to support broader relief efforts throughout CNMI. In cooperation with FEMA and local emergency management organizations, the military's HADR efforts greatly contributed to Guam's overall resilience.

While the Air Force played a crucial role in managing air operations during Guam's recovery efforts, the service also contributed to preserving the island's most strategic combat capability in the wake of the typhoon. Prior to the typhoon making landfall in Guam, the Air Force sortied their strategic bombers from the 96th Expeditionary Bomb Squadron to Alaska to evade the storm.[188] According to DOD officials in an interview with the *Air Force Times*, only two B-52 bombers were deemed unflyable at the time and were subsequently loaded with fuel and carefully secured; following the typhoon, the aircraft were assessed to have sustained minimal damages.[189] Despite the priority of the ongoing relief efforts, the Air Force's mitigating actions prior to the typhoon serve to

[185] Center for Excellence in Disaster Management & Humanitarian Assistance, Introduction, 46.

[186] Center for Excellence in Disaster Management & Humanitarian Assistance, Introduction, 46-47.

[187] Center for Excellence in Disaster Management & Humanitarian Assistance, Introduction, 47.

[188] Tara Copp, "Guam B-52s Left Behind to Face Typhoon as B-2s, C-17s Scramble From 2 Other Major Storms," Air Force Times, September 11, 2018, https://www.airforcetimes.com/news/your-military/2018/09/11/guam-b-52s-left-behind-to-face-typhoon-as-b-2s-c-17s-scramble-from-2-other-major-storms/.

[189] Copp, "Guam B-52s Left Behind to Face Typhoon as B-2s, C-17s Scramble From 2 Other Major Storms."

preserve the island's strategic military assets in the wake of disastrous events. As a result of the Air Force's ability to anticipate the potential effects of the typhoon, the service's actions greatly improved Guam's overall resilience as the island's combat capability was not entirely compromised.

The following summarizes the answers to the safety engineering questions posed earlier in the chapter as they pertain to Guam's response to Typhoon Manghuk:

- The speed and effectiveness of Navy and Marine Corps assets during HADR operations were critical for Guam's recovery and further enabled relief efforts throughout the region.
- The Air Force's mitigating actions prior to the storm as well as the presence of a Carrier Strike Group ensured that Guam's combat capability and overall defense posture was unabated during relief efforts.
- Guam's location in the Indo-Pacific will always make it vulnerable to future typhoons; however, military and emergency management organizations are well postured to address future vulnerabilities.

D. CONCLUSION

The goal of this chapter was to apply safety engineering concepts to assess the resilience of Guam's defense posture using Typhoon Manghuk as a case study for Guam and CNMI. While modern warfare has fortunately not reached the shores of U.S. territories in the Indo-Pacific, analyzing the response to natural disasters provides a basis of understanding for how forces would respond following a catastrophic attack. While a natural disaster such as a typhoon does not exactly resemble the same effects as a deliberate PLA attack on Guam, the response to such an event is indicative of the U.S. military's current posture to respond to any regional crisis. Safety engineering analyzes the human response to disruptive events and accounts for human factors when determining the resilience of an entire system. In the case of both CNMI and Guam, the prompt and effective response efforts of military forces and emergency management agencies enabled the safe restoration of the island territories. Moreover, the military's HADR and DSCA

operations proved to be a critical component of the federal government's response efforts to disasters in the Indo-Pacific. Furthermore, proper anticipation and planning efforts ahead of the disaster allowed for minimal impacts to the region's overall defense posture and combat readiness. Overall, the human response to Typhoon Manghuk was robust and greatly contributes to the resilience of U.S. territories.

VII. CONCLUSION AND RECOMMENDATIONS

Since the end of the Second World War, Guam has served as a linchpin of American military power in the Indo-Pacific. As the United States' westernmost territory in the Indo-Pacific, Guam has been lauded as the place where America's day begins. However, with its strategic geographic importance and abundance of military combat power, Guam can potentially be where America's next war begins. The rise of China as the United States' most strategic competitor has led senior military officials and defense experts to reevaluate U.S. defense posture in the Indo-Pacific. Following decades of reform and modernization, the People's Liberation Army presents a clear and significant threat to the preeminence of U.S. military power in the region. From the threat against advanced Chinese ballistic missiles to the vulnerabilities of Guam's critical infrastructure, Guam is no longer the safe haven it once was during the decades of U.S. military hegemony following the Cold War. As a result, using a structured vulnerability analysis built around risk analysis, reliability engineering, adversarial analysis, and safety engineering, this thesis identifies all areas of Guam's vulnerabilities and integrates recommendations into a comprehensive plan to improve defense posture.

A. SUMMARY OF FINDINGS AND RECOMMENDATIONS

A comprehensive risk analysis of Guam's defense posture addresses the likelihood and consequences of how a large-scale war between the U.S. and China would affect Guam. Analyzing risk involves evaluating the known threats to Guam and addressing the likelihood and consequences of existing threats. Risk analysis has demonstrated how strategic competition between the U.S. and China has influenced the PLA's modernization and has subsequently fueled the prospect of a future global conflict. An analysis of the PLA's evolving capabilities and wartime strategies illustrates the strong likelihood of a PLA attack on Guam and the broader second island chain in the case of a South China Sea conflict or Taiwan invasion. Both U.S. and Chinese regional security experts as well as official defense publications from both countries further affirm the threats to Guam. Conclusions based on risk analysis found that the most significant threat to Guam comes

from advancing PLA ballistic missile capabilities and evolving Chinese Anti-Access Area Denial strategies that aim to prevent U.S. military intervention in a Taiwan invasion or South China Sea conflict.

Following an identification of the most significant risk to Guam's defense posture, reliability analysis identified Guam's most critical areas of weakness. Breaking down Guam's defense posture into the two principal categories of missile defense and critical infrastructure, reliability analysis provided a holistic approach of evaluating the potential vulnerabilities of each subsystem and a failure modes and effect analysis examined the interdependencies between the two. In summary, the reliability of Guam's defense posture is determined to be moderate. There are likely modes of failure, yet none constitute complete failure to protect Guam from an attack. However, existing missile defense capabilities and critical infrastructure systems are insufficient to ensure a highly reliable defense posture. Overall, the most likely scenario is only partial protection of the island. The failure of missile defense systems is the greatest area of weakness and should therefore be the focus of future defense initiatives.

Adversarial analysis identified the critical nodes of military operations for the island and evaluated the recent efforts to disperse Guam's combat capability throughout the region. In identifying the critical nodes of operation, the focus of adversarial analysis was on the cumulative consequences of an attack on Guam. Naval Base Guam and Andersen AFB are determined to be critical nodes of military operations for their ability to support and deliver naval and air combat capability throughout the Indo-Pacific. After assessing the consequences of a potential PLA attack on either of the two critical bases, the analysis has demonstrated that the elimination of Andersen AFB would have a more disruptive effect on overall military operations in the Indo-Pacific. The inherent ability of naval forces to mobilize forces at sea and conduct sustained naval combat operations independent of land bases alleviates the consequences of the potential loss of Naval Base Guam. Conversely, the concentration of air power on Andersen as well as the importance of air bases and ground infrastructure on the ability to achieve air superiority amplifies the consequences of losing Andersen as a strategic air base. As a result of this vulnerability, recent efforts to distribute combat capability beyond Guam have proven to be effective

strategies in improving the overall defense posture of Guam and the broader CNMI. Following a comprehensive adversarial analysis, Andersen AFB is found to be the most critical node for Guam's defense posture; however, recent strategic changes in military operations in the region have begun to alleviate the consequences of this important vulnerability.

Safety engineering assessed how well local military and emergency managers are poised to adapt to unforeseen threats by analyzing the resilience of Guam's defense posture after Typhoon Manghuk in 2018. While a natural disaster such as a typhoon does not exactly resemble the same effects as a deliberate PLA attack on Guam, the response to such an event is indicative of the U.S. military's current posture to respond to any regional crisis. Safety engineering analyzes the human response to disruptive events and accounts for human factors when determining the resilience of an entire system. In the case of both CNMI and Guam, the prompt and effective response efforts of military forces and emergency management agencies enabled the safe restoration of the island territories. Furthermore, the military's HADR and DSCA operations proved to be a critical component of the federal government's response efforts to disasters in the Indo-Pacific. Furthermore, proper anticipation and planning efforts ahead of the disaster allowed for minimal impacts to the region's overall defense posture and combat readiness. Overall, the human response to Typhoon Manghuk was robust and suggests CNMI and Guam are resilient to extreme events.

Following a structured vulnerability analysis of Guam's defense posture, this study fundamentally recommends that budgetary plans, such as the Pacific Deterrence Initiative, be prioritized for the development and enhancement of Guam's missile defense capabilities. This recommendation is based on several conclusions that integrate each analysis presented. Based on reliability and adversarial analysis, loss of Guam's critical infrastructure is determined to have a limited impact on defense posture. Based on safety engineering, successful HADR and DSCA missions in the region suggest that Guam and CNMI are prepared for extreme events. Recommendations based on adversarial analysis suggest dispersing combat capability from Andersen AFB to other regions in the Pacific. Yet, safety engineering shows that natural disasters like Typhoon Manghuk can impact

CNMI and Guam simultaneously, suggesting the need for more analysis of where effective dispersal should happen. Hence, funding to improve Indo-Pacific defense should not yet be directed towards efforts to upgrade infrastructure, disperse combat capability, or improve emergency response.

In contrast, Guam's current missile defense posture is the island territory's greatest vulnerability. Based on risk and reliability analysis, this study shows that Guam does not currently have an organic means of defending itself against sophisticated Chinese ballistic missile threats and that the loss of Guam's combat capability could jeopardize U.S. military power in the region. Specifically, risk analysis revealed that the PLA's advanced missile capability may outperform current missile defense systems. Then, reliability analysis showed that current IAMD systems are not reliable enough for Guam's comprehensive defense. As a result, the Pacific Deterrence Initiative should continue to fund efforts in Guam's missile defense systems. The short-term recommendation to immediately counter the PLA's expanding capabilities would be to leverage existing missile defense systems and establish an Aegis Ashore site on Guam and provide the island territories with additional THAAD batteries. To further bolster Guam's defense posture in the coming decades, the Pentagon must continue to develop a missile defense system that incorporates an integrated command and control system that will improve survivability and leverage the strengths from missile defense systems across all services. Lastly, budgetary plans for the Indo-Pacific should continue to support defense infrastructure efforts throughout Guam and CNMI. The expansion of combat capability in both Guam and CNMI will allow for greater redundancy and operational agility throughout the Indo-Pacific. Hardening the combat capability throughout the second island chain mitigates the risk of an attack when forces are concentrated in a single location.

B. LIMITATIONS

The basis of this study's research design underlies several assumptions and subsequent limitations. First, the current research and reports identify all key vulnerabilities for Guam and make appropriate recommendations to improve the protection and defensive

posture of the island. This broad assumption further assumes that current research and reports identify the following:

- Future capabilities of the Chinese military that are relevant to Guam's defense.
- Current vulnerabilities of Guam's civilian and military infrastructure systems relevant to risk, reliability, adversarial attack, and surprise events.
- Vulnerabilities from interdependent and related systems that could influence Guam's vulnerabilities.

A second assumption of this research design is that the vulnerabilities identified from historical events or case studies are transferrable to the current needs of Guam. This broad assumption further assumes that data and studies from similar military systems and islands (e.g., installations on other Pacific islands) can provide insight into Guam's vulnerabilities and defense posture needs. Lastly, the proposed recommendations based on past events have not yet been addressed and should be included in current plans.

C. AREAS OF FUTURE RESEARCH

The overall goal of this study was to present a broad understanding of the vulnerabilities in Guam's defense posture and to provide general recommendations to better enhance the security and defense of U.S. territories. As such, a limitation of this study was the absence of greater quantitative detail and sensitivity analysis within each subset of vulnerability analysis. Critical areas of further research beneficial to this study may include modeling for the areas addressed throughout this vulnerability analysis to provide quantitative comparisons for funding decisions. Moreover, sensitivity analysis that shows the impacts of uncertainty among threats and decisions support a more robust course of action for improving missile defense. As an example, quantitative modeling may help prioritize the amount and/or types of missile defense systems that Guam would need to effectively counter an initial PLA attack. Likewise, mathematical models may also serve as a measure of effectiveness to prove or disprove the recommendations within this study.

Furthermore, the principles of vulnerability analysis used in this study may be applied to other strategic locations for the U.S. military. While commonly used to analyze engineering and infrastructure systems, this study has demonstrated how a structured vulnerability analysis can be utilized on a larger scale to inform the strengths and weaknesses of a strategic military location. In the context of the Indo-Pacific, vulnerability analysis can inform the defense readiness and posture of U.S. forces deployed throughout Allied nations such as Japan, South Korea, and Australia. Consequently, conducting a vulnerability analysis for the broader Indo-Pacific region that incorporates the network of U.S. allies constitutes a significant area of future research.

D. SUMMARY

The defense of Guam is paramount. The island territory in the heart of the Pacific Ocean is home to tens of thousands of American citizens and is the U.S. military's stronghold in the nation's priority theater of operations. After years of U.S. military hegemony following the end of the Cold War, the rise of China and the expanding reach of the PLA's capabilities put Guam's strategic location within the second island chain under constant threat. More alarmingly, senior military leaders have indicated that the growth of China's capabilities have outpaced the United States' ability to defend the island territory. While congressional initiatives are well underway to bolster the defense and security of U.S. forces in the Indo-Pacific, budgetary efforts must remain focused on enhancing Guam's missile defense capability and hardening defense infrastructure throughout the Pacific territories. Should the strategic competition between the United States and the People's Republic of China escalate to global war, modern warfare will inevitably reach the shores of Guam and the U.S. military will have to fight for Guam before it can fight from it.

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