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The View from Beijing: An Alternate Perspective on Cross-Straits Invasion

March 2024

Capt Fidencio S. Gonzalez, USMC

Thesis Advisors: Harrison C. Schramm, Senior Lecturer
Dr. Chad W. Seagren, Senior Lecturer

Department of Defense Management

Naval Postgraduate School

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ABSTRACT

The so-called Taiwan Strait crises will likely continue until Taiwan is reunified or China abandons its claim. Currently, China has a few options for reunification; this research takes the novel approach of looking at the problem from China's perspective, specifically: What factors would give China's command pause when considering an amphibious invasion of Taiwan? What is China's threshold for loss?

The analysis uses straightforward analytic methods to examine several vignettes of a single beach landing of Taiwan. Results are delivered in terms of combat losses and the time it could take for China to establish a lodgment on Taiwan. We have found that loss of the PRC's landing forces early in the invasion or no longer having the capability of conducing anti-access/area denial (A2/AD) would give its invasion pause and constitute a strategic loss for Beijing. Furthermore, it is crucial for Beijing to first determine whether it has a fait accompli over Taiwan before committing to forceful reunification. Understanding the history of the China-Taiwan tensions and the worries China may have during an invasion may help determine military and political actions necessary for Taiwan and the United States to revoke or suspend its potential fait accompli in the near future.

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LIST OF ACRONYMS AND ABBREVIATIONS

A2/AD	Anti-Access/Area Denial
APC	Armored Personnel Carrier
CCP	Chinese Communist Party
JSDF	Japanese Self Defense Force
KMT	Kuomintang
LHD	Landing Helicopter Dock
LPD	Landing Platform Dock
LSM	Landing Ship, Medium
LST	Landing Ship, Tank
PLA	People’s Liberation Army
PLAA	People’s Liberation Army Army
PLAN	People’s Liberation Army Navy
PLARF	People’s Liberation Army Rocket Force
PRC	People’s Republic of China
ROC	Republic of China
RO-RO	Roll-on/Roll-off
SCS	South China Sea
SP	Self-propelled
TRA	Taiwan Relations Act

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I. INTRODUCTION

The research questions examine China's perspective in a cross-strait invasion of Taiwan initiated by the People's Republic of China (PRC). We ask, what would constitute a strategic 'loss' in a cross-strait invasion? What factors would give China's command pause when considering an amphibious invasion of Taiwan? We have found that loss of the PRC's landing forces early in the invasion or no longer having the capability of conducing anti-access/area denial (A2/AD) would give its invasion pause and constitute a strategic loss for Beijing. Furthermore, we have discovered why it is crucial for Beijing to first determine whether it has a fait accompli over Taiwan before committing to forceful reunification. Understanding the history of the China-Taiwan tensions and what worries China during an invasion would help determine military and political actions necessary for Taiwan and the United States to revoke or suspend its fait accompli.

A. OVERVIEW

This narrative begins with the Century of Humiliation. Which in essence, was China's suffering from wars and treaties from foreign nations. Key countries contributing to this were the United Kingdom (UK) and Japan. It was not until 1912 that China abandoned the old style of government the Qing Dynasty and the Republic of China (ROC) was established lead by the Kuomintang (KMT) (Wang, 2012).

The establishment of the ROC was to reunify China's separately territories and prevent further humiliation from foreign nations. Not many agreed with the KMT, particularly the China's Communist Party (CCP). The CCP's founding was a result of Russia's October in 1917. The CCP unlike the KMT believed that their country suffered because of their Confucius and traditional culture of doing things (Wang, 2012). They believe communism was the new brand needed to bring back China.

Rivalry between the CCP and KMT continued since the CCP's inception. It was not until after WWII that this rivalry intensified into a civil war. The civil war ended in 1949 with the CCP emerging victorious and as a result led to the exile of the KMT, led by Chaing Kai-Shek, to continue the ROC in Taiwan. This also led to the creation of the PRC.

The CCP found its new narrative of the communist party being the only modern party to fend off foreign nations (*China's narratives regarding national security policy*, 2011).

Although the Century of Humiliation was considered to have ended in 1949, the Chinese believed actions to rectify their country's humiliation was necessary. The PRC's belief to completely rectify its humiliation was to return all lost lands to the mainland. Taiwan is the final piece. Since 1949, we have seen three Taiwan crises, which likely will continue until Taiwan is reunified with the mainland or the PRC abandons its claim.

Post China civil war, the United States have been pivotal in deterring China from invaded and forcefully reunifying Taiwan. Defense pacts such as the Formosa Act was a key contributor to stopping China from invading. An example of the United States intervening is seen during the second Taiwan Crises. This is chiefly do with China's belief of being incapable of fighting both Taiwan and the United States.

With the Cold War at its peak, the U.S. and China viewed the Soviet Union as a common foe. This common threat was a gateway to normalizing relations between the China and the United States. Both countries shared three Joint Communique which is referred to as the One-China Policy. To improve relations with China, the United States repealed the Formosa Act leaving Taiwan vulnerable for the time being. The One-China Policy was craftly navigated by the U.S. and lead to the Taiwan Relations Act in 1979 and the Six Assurances. Both these actions would continue supporting Taiwan unofficially while allowing the United States to improve and maintain relations with China.

Despite U.S. interference since 1949, China's mission remains strong and unwavering today as highlighted in President Xi Jinping speech at the 20th National Congress of the Communist Party of China on 16 October 2022. Xi Jinping stated, "resolving the Taiwan question and realizing China's complete reunification is, for the Party, a historic mission and an unshakeable commitment" (Nikkei Asia, 2022, sec. XIII). Xi Jinping's remarks are an echo of the PRC rectifying the wrongs they perceived committed to them during the Century of Humiliation.

China's goal is under a time constraint. China's shrinking demographics is a result of the legacy of the "One-Child Policy." The shrinking demographics is reducing the

PRC's working class, and by extension, its military force. These factors limit Beijing's military reunification option to the short to medium term. Failure to reunify Taiwan could be devasting for the legitimacy of the CCP if they do not act at all. Legitimacy is also at stake should the PRC fail during an amphibious campaign as well.

As the dynamics in the Taiwan Strait remain fluid, understanding China's concerns, thresholds, and preparations is paramount. For Taiwan and the United States, an informed and strategic response is essential, balancing diplomatic, economic, and military considerations to navigate the complexities of the cross-strait relationship and maintain regional and global stability. Such understanding will help the U.S. and allies broaden our consideration of this problem from simply a military one to an integrated, whole of Government approach.

B. METHODOLOGY

With Beijing believing the time to reunify is soon, this thesis examines the aftermath of an amphibious cross-strait invasion of Taiwan under one strategic scenario and two vignettes leveraging deterministic and stochastic Lanchester equations and a circulation model.

An amphibious invasion is complex in nature, and we discuss the grand campaign strategy and then scope it down to a single notional beachhead within a multipronged assault. This methodology considers previous studies and reports investigating what a Chinese invasion of Taiwan may look like and how they may leverage their military capabilities to develop a scenario with key assumptions for a combat model. Success is determined when the PRC landing force achieves a force buildup of 3:1 within a 72-hour period. During this period, we assume major military action by Japan and United States is delayed. This analysis implicitly assumes that China has sufficient lift and experience to conduct an amphibious landing; this assumption is not obvious.

The combat model applies a deterministic and stochastic Lanchester equation and circulation model which accounts for 13 parameters that may affect the outcome of the battle. These parameters are based on expert literature and what is estimated to be in PRC's inventory in 2023 provided by the International Institute for Strategic Studies (2023) and

Department of Defense (2023) as well as estimated PRC future production. The PRC has four of the thirteen parameters within their sole ability to influence: combat effectiveness, number of landing vessels, number of fighters, and the speed of the landing vessels. For the purposes of this model, we use Engel's (1954) and Samz (1972) Iwo Jima study to apply combat effectiveness to China and Taiwan. A key parameter of interest in this study is transit risk of the landing ship which both China and Taiwan have the ability to influence.

Further analysis is made to examine China's tradeoff options on combat effectiveness and transit risk. 4,900 cases are simulated which examine vignette one and two under differing combat effectiveness and transit risks. Results are recorded and the hours it took for the PRC to achieve a 3:1 force ratio are plotted.

Findings from this methodology may provide insight into what the PRC would be faced with in terms of attrition, its center of gravity for an amphibious assault, and investments it may consider for bolstering capability. It would also provide insight into what China could be worrying about the most during an amphibious invasion and actions available to the U.S. and allies.

C. ORGANIZATION

Chapter II elaborates on the history of China and Taiwan, Taiwanese relations with the United States, Chinese relations with the United States, China's future challenges, and Lanchester equations studies. This provides understanding into the China-Taiwan tensions and technical insight on the methodology used in this thesis.

Chapter III discusses the methodology used to answer the research question. It describes a potential strategy scenario China may consider and two vignettes it may experience. This chapter also provides explanations of the combat model used, assumptions, and figure of merit.

Chapter IV analyzes and discusses the findings from the models used. Discussion points focus on what keeps China from attempting an invasion of Taiwan, capabilities China can try to bring to bear, and ultimately the potential threshold for loss and what would give China's assault pause.

Chapter V summarizes the findings and result of the thesis and provides recommendations for future work.

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II. LITERATURE REVIEW

This chapter is broken down into three sections as follows: section one discusses the history of China and Taiwan since 1839. The second section looks to China's future challenges with an eye toward what may enable—or inhibit—a forced reunification with Taiwan. These two sections are to provide a background of China and Taiwan. The third section focuses on the technical aspects of deterministic and near-deterministic combat models, specifically, Lanchester Equations and extensions.

A. HISTORY OF CHINA AND TAIWAN

This section discusses the history of China and Taiwan. Understanding the history of these two countries provides explanations to China and Taiwan's tensions today. Specifically, it sheds light on China's claim and unwavering commitment to reunifying Taiwan. The section is broken up into two time periods. It begins with the Century of Humiliation covering 1839–1949. From 1949 to the present, it discusses relationships between Taiwan with the United States, and China with the United States.

1. The Century of Humiliation, 1839–1949

China's claim to Taiwan has historical ties. Our consideration of Chinese history begins in 1839, with the so-called "Century of Humiliation" and China's narrative to justify reunification of Taiwan.

The humiliation felt by China begins with the British in 1839. China analyst from the Center for Naval Analyses, Alison Kaufman, highlights this in her testimony before the 112th Congress. The British compelled the Chinese to open ports and markets to the import of opium from the British East India Company and culminated in the forced cession of Hong Kong and other territories from the First Opium War, 1839–1842 (*China's narratives regarding national security policy*, 2011). Chinese native and professor of international relations at Seton Hall University, Zheng Wang, in his book *Never Forget National Humiliation*, explains the impact felt by China. Wang explains, the Opium War was the start point in which China began to degenerate and recognized that the Celestial Empire of

China had already been left behind. This was the beginning of many more wars and treaties humiliating China (Wang, 2012).

The next country to greatly humiliate China was Japan, a former tributary and vassal state of China. China and Japan engaged in the Sino-Japanese War in 1895 and concluded with the Treaty of Shimonoseki. The treaty included China's recognition of Korea as an independent state, which ceased payments of tribute to China; cession of the Penghu Group, Formosa (now Taiwan), and the eastern portion of the bay of Liaodong Peninsula; and war indemnity to Japan (Wang, 2012). This sparked an anti-foreign and anti-imperialist movement known as the Boxer Rebellion, although it was halted by the Eight National Alliance.

The impact of the Western nations and Japan led to the eventual collapse of the Qing Dynasty in 1912. This led to the founding of the Republic of China (ROC) on January 1, 1912. The collapse of the Qing Dynasty divided China into several territories ruled by different warlords. The ROC was propelled by the Kuomintang (KMT) party, with a goal to unify the government.

In 1915 and with the Western Powers distracted by WWI, Japan saw an opportunity to expand its influence on China with the infamous "Twenty-One Demands." Chinese historians and academics Zhitian Luo (1993) and Zheng Wang (2012) explained that these demands resulted in the Chinese people coining the term "National Humiliation." The Twenty-One demands were viewed by the Chinese as essentially transferring sovereignty to the Japanese, Wang emphasized. Although, this was not China's first humiliation, it was the first time it was used as a vehicle to arouse people's patriotism and to stress its distrust for Japan and western powers (Luo, 1993). The net effect is that China felt culturally disrespected by both the West and Japan, as well as having a keen desire never to be subjected by a foreign power again.

The KMT was not the only political party trying to rectify the humiliations felt by China. In 1917, Russia's October Revolution, which highlighted Marx's class struggle and Lenin's anti-imperialist theories, sparked the founding of the Chinese Communist Party (CCP) in 1921 (Wang, 2012). Both parties claimed a patriotic role to "save the country."

Differences between the parties were due to what they perceived as the reason for China's humiliation and the ideology that should govern China.

The differences in both the KMT and CCP led to an intense rivalry. Wang (2012) explained that where the two parties differ is in their view of traditional Chinese culture and view towards foreign powers. The CCP perceived the Confucian orthodoxy and Chinese tradition as the cause of their weakness and wanted to use Communism as a brand-new ideology. On the other hand, KMT viewed China's culture as elite and their foundation, and that China's deterioration of national culture was caused by imperialism and unequal treaties. These two conflicting views set the political discourse and led to the eventual civil war.

Before the Chinese Civil War, the KMT and CCP united on two occasions. The first occasion was in 1926, to fight against the warlords in China. The second occasion was to fight off the imperialist actions and full-scale invasion of Japan from 1937–1945 (Wang, 2012). At the conclusion of WWII, the KMT and CCP, with the help of western allies, defeated Japan and had their lost territories returned, which included Taiwan and Manchuria.

After WWII, the rivalry manifested as the Chinese Civil War. The civil war was to settle which party's ideology would govern China. The war concluded with the CCP's victory over the KMT and establishment of the People's Republic of China (PRC) on October 1, 1949. This also resulted in the KMT's, led by Chaing Kai-Shek, exile to Taiwan and continuation of the ROC. The CCP's victory also shifted its legitimacy from a national humiliation narrative to the victories of the revolution (Wang, 2012). Specifically, it allowed the CCP to portray itself as "the only modern Chinese political party that was able to successfully stand up to foreign aggression" (*China's narratives regarding national security policy*, p. 140). The end of the civil war solidified the PRC's narrative of no longer being a nation subjected to insult and humiliation.

Although the Century of Humiliation concluded in 1949 with the CCP's victory, the PRC has not viewed its humiliation as rectified. Kaufman (*China's narratives regarding national security policy*, 2011) stated,

> China is often portrayed as having suffered three kinds of loss during the Century of Humiliation: a loss of territory; a loss of control over its internal and external environment; and a loss of international standing and dignity. Each of these represents an injustice to be rectified. (p. 141)

In order to rectify these humiliations, China seeks to be co-equal with its former oppressors, chiefly the United Kingdom, and by extension, the United States.

From China's view, to consider their humiliation rectified, recovery of their lost territories during the Century of Humiliation is necessary. Taiwan is the only territory still not under China's control. Kaufman explains that reunification of Taiwan is considered a non-negotiable policy and cites a passage within China's 2005 Anti-Secession Law written as this is a "sacred duty of all the Chinese people" (*China's narratives regarding national security policy*, 2011, p. 141). This stance is still strongly held by China today as highlighted in Xi Jinping's 2022 speech: "We will continue to strive for peaceful reunification with the greatest sincerity and the utmost effort, but we will never promise to renounce the use of force, and we reserve the option of taking all measures necessary" (Nikkei Asia, 2022, sec. XIII). There have been three Taiwan-PRC crises since 1949, which may likely continue until the PRC reunifies Taiwan or abandons its claim.

2. Taiwanese Relations with the United States, 1949-Present

After the ROC reestablished itself in Taiwan in 1949, the PRC made continued efforts to reunify Taiwan but was deterred by Taiwan relations with the United States. In late 1949 and early 1950, the United States was prepared to let PRC forces invade and retake Taiwan. This view quickly changed with the outbreak of the Korean War. The U.S. disrupted the PRC by placing its Seventh Fleet in the Taiwan Strait in order to prevent Korean conflict from spreading south (Lawrence, 2023). This action was the first time the United States conflicted with PRC policies.

The U.S. continued diplomatic actions to deter the PRC from reunifying Taiwan. In 1954, the creation of the Southeast Asia Treaty Organization by the U.S. sought to unify the region against its perceived Communist Threat (Lawerance, 2023). U.S. relations with the ROC regime solidified the alliance with Taiwan through the Mutual Defense Treaty to support Taiwan if engaged in broad conflict with the PRC. This defense treaty, however, excluded the defense of Taiwan's offshore islands. This quickly changed with the Formosa Resolution in 1955, which gave the U.S. president total authority to defend Taiwan and its offshore islands during a PRC conflict (Lawrence, 2023). The U.S. support for Taiwan has been an issue for the PRC as it did not have the capabilities to fight both Taiwan and the U.S.

U.S. policies and treaties were effective as long as the U.S. had capabilities to support Taiwan's defense. Despite the Formosa Resolution, in 1958, the PRC took advantage of U.S. involvement in Lebanon and began bombarding ROC garrisons in Kinmen and Matsu, cutting off the garrisons' ability to resupply. This was considered the second Taiwan Strait Crisis. President Eisenhower perceived the loss of Taiwan's islands as potentially hurting Taiwan nationalist morale. This prompted a U.S.-led resupply of the ROC garrisons, which also eased tensions between the ROC and PRC (Lawrence, 2023). This however did not stop the PRC and ROC from bombarding each other for the next 20 years until relations between the PRC and United States normalized.

In light of the PRC and United States relations improving, the U.S. was careful to ensure that Taiwan was not left defenseless. In part of normalizing relations between the U.S. and China, the Formosa Resolution was repealed in 1974. Although this meant that the United States would not be obligated to defend Taiwan during a PRC conflict, the U.S. continued defense support. This was highlighted in the Taiwan Relations Act (TRA) in 1979. The TRA allows the U.S. to interact with an unrecognized state while also building relations with Beijing. The importance of the TRA is to help Taiwan "maintain peace, security, and stability" with promises of arms sales and other assistance to help Taiwan resist the PRC (Rigger, 2019, p. 12).

After the 1982 U.S.-PRC Joint Communique, which became known as the One-China Policy, President Reagan provided Taiwan with what is referred as the six assurances (Lawrence, 2023). These assurances were meant to show the U.S. support for Taiwan despite to agreeing to China's policy. The six assurances are that the U.S.

> (1) has not agreed to set a date for ending arms sales to Taiwan, (2) has not agreed to consult with the PRC on arms sales to Taiwan, (3) will not play mediation role between Taipei and Beijing, (4) has not agreed to revise the

Taiwan Relations Act, (5) has not altered its position regarding sovereignty over Taiwan, and (6) will not exert pressure on Taiwan to enter into negotiations with the PRC. (American Institute in Taiwan, 2023)

The United States' policies with Taiwan dating back to 1949 to the present have been pivotal to preventing and deterring PRC's reunification attempts.

3. Chinese Relations with the United States

Relations between the PRC and United States started to normalize in 1972. The PRC and the U.S. had three joint communiques, which eventually became known as the One China Policy. The Shanghai Communique, the first, documents that the U.S. "acknowledges that all Chinese on either side of the Taiwan Strait maintain there is but one China and Taiwan is a part of China. The United States Government does not challenge that position" ("Current Documents: The Shanghai Communique, 1972," 1972, p. 132).

The next communique in 1978 improved relations further by setting terms on PRC-U.S. diplomatic relationship. The 1978 U.S.-PRC Normalization Communique states the agreed terms of diplomatic relations beginning January 1, 1979. This led to the termination of the U.S.-ROC defense treaty effective January 1, 1980, and the withdrawal of U.S. military personnel from Taiwan (Lawrence, 2023).

In light of the termination of the U.S.-ROC treaty, the U.S. began unofficial relations with the Taiwan Relations Act in 1979, which stated the U.S. would provide "defense articles and defense services in such quantity as may be necessary to enable Taiwan to maintain sufficient self-defense capability" (Taiwan Relations Act, 1979, p. 2). Unofficial support from the U.S. to Taiwan ensured that Taiwan would not be at the mercy of the PRC.

To address the TRA and further disconnect the U.S. from Taiwan, the U.S. and PRC had another communique. The 1982 U.S.-PRC Joint Communique addressed the issue of the U.S. arms sales to Taiwan, which impeded China's policy for peaceful reunification. To appease the PRC, the U.S. stated that "it does not seek to carry out a long-term policy of arms sales to Taiwan," and "intends gradually to reduce its sale of arms to Taiwan, leading, over a period of time, to a final resolution" (American Institute in Taiwan, 2022,

p. 1). The U.S. also declared it has no intentions of pursuing a policy of "two Chinas" (Lawrence, 2023, p. 2).

The rationale behind the need for improved U.S.-China relations was due to a common foe: the Soviet Union. China attempted to separate relations between the U.S. and Taiwan, however, it was unsuccessful due to the TRA. With the collapse of the Soviet Union in 1991, the relations between China and the U.S. weakened.

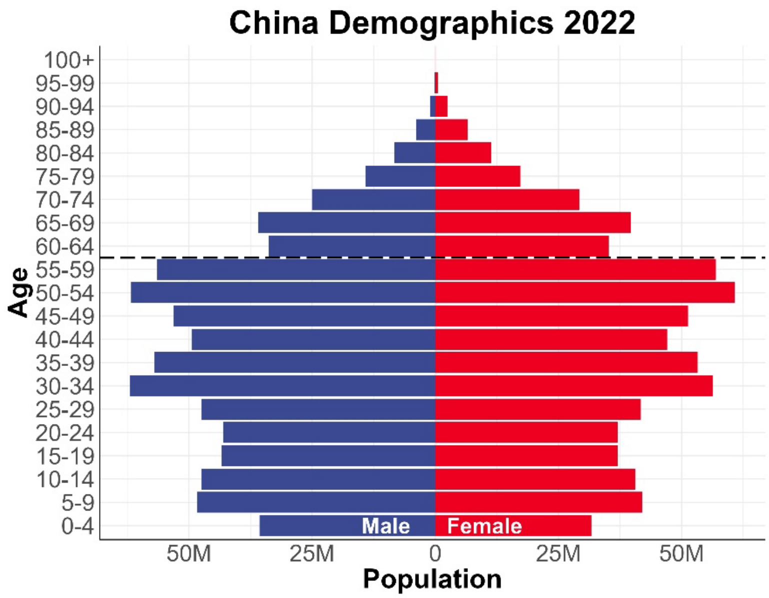
B. CHINA'S OUTLOOK: CHALLENGES

In this section we examine China's future in terms of challenges that inhibit a military solution to reunify Taiwan with the mainland and actions to increase its capability. The challenges discussed are China's population decline and military corruption. The capabilities discussed are military training. While Western thinkers find China to be a juggernaut, the world is not as simple looking from Beijing.

1. Demographics

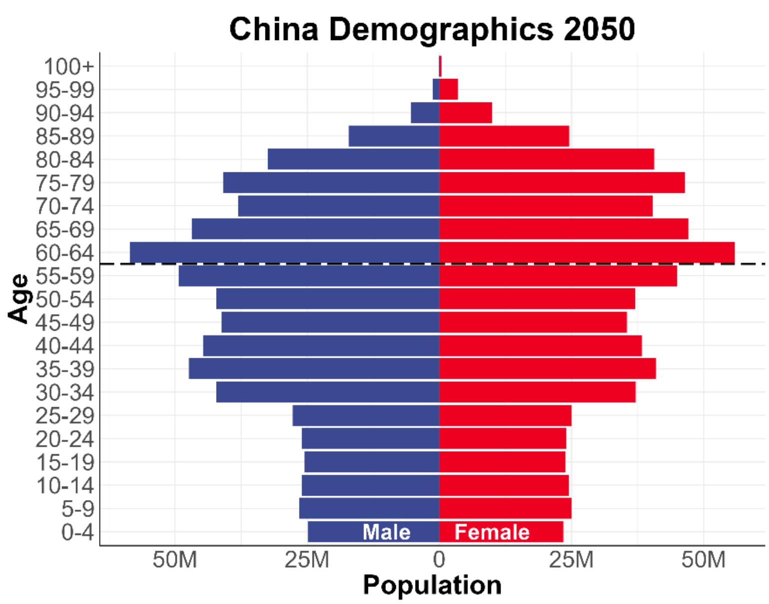
China's ability to act with a military solution for the reunification of Taiwan is dwindling due to the decline of its population. In an article published by Michael O'Hanlon in 2000, O'Hanlon mentions that China's action is constrained to the short- and medium-term due to its workforce population expected to decline to 700 million and having to care for 500 million Chinese aged 60 and over by 2050. 22 years later the United Nations 2022 World Population Prospects confirm O'Hanlon's 2000 estimates. By 2050 China is estimated to have a working population of approximately 650million and Chinese aged over 60 above 500 million, refer to Figures 1 and 2.

The demographics issue is a result of the legacy of the so-called "One-Child Policy" (Chang, 2015). The One-Child Policy was a level of government control of births to overcome China's large population and rapid growth rate (Feng et al., 2012). Feng and his associates noted that the policy has prevented some 400 million Chinese births.



This graph displays China’s 2022 population age demographics by gender. The horizontal line depicts the age 60 threshold. Data is pulled from the United Nations 2022 World Population Prospects. Chinese population aged above 60: Approx. 265 million.

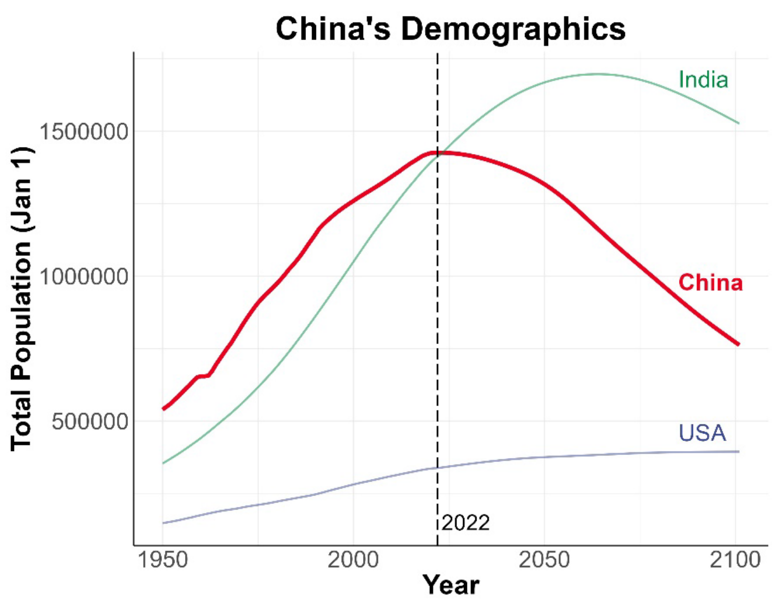
Figure 1. Chinese Age Demographics, 2022



This graph displays China’s estimated 2050 population age demographics by gender. The horizontal line depicts the age 60 threshold. Data is pulled from the United Nations 2022 World Population Prospects. Chinese population aged above 60: Approx. 509 million.

Figure 2. Chinese Age Demographics, 2050

China's demographic decline hinders its military capabilities. The decline of its population is depicted in Figure 3 with data provided by the United Nations 2022 World Population Prospects. As time goes on, China will be faced with a disproportionate population that cannot risk the loss of their younger workforce. This among other factors encourages China's leaders to think that now is the time for a major military action.



This plot shows a peak for China's population in the year 2022, with a return to parity with the United States by the end of the Century. This among other factors encourages China's leaders to think that 'now' is the time for a major military action.

Figure 3. Chinese Demographics (1950-2100)

2. Rooting Out Military Corruption

Xi Jinping announced to the People's Liberation Army (PLA) to be ready for a Taiwan-Strait invasion by 2027. Military corruption within the PLA would contribute to the delay or failure of a Taiwan-Strait invasion.

Corruption is an ongoing issue that the PRC has been grappling with to ensure the PLA is ready for a military action such as a Taiwan Cross-Straight invasion. Senior International Defense Researcher of RAND corporation, Timonthy Heath addresses this in his testimony before the 116th congress. He mentions that Xi Jinping inherited the corruption issue when he took reign in 2012 which was perpetuated from Jiang and Hu's tenures (*What keeps Xi up at night*, 2019). Recently unveiled in 2023 is a military corruption with the People's Liberation Army Rocket Force (PLARF). Based on U.S. assessments, PLA military officials found water instead of fuel in their missiles, as well as defective missile silo lids in western China that would inhibit the effective launching of missiles (Martin & Jacobs, 2024). With the PLARF degraded, China's ambition for a successful military-forced reunification with Taiwan is hindered.

China must now address and assess how this recent discovery will impact its 2027 readiness. Martin and Jacobs (2024) report that the U.S. has assessed that corruption within the PLA has shaken the confidence in its overall capabilities. This impact led to the purge of nine military officials with the Chinese military's official newspaper, signaling for more purges as they crack down on corruption (Martin & Jacobs, 2024). The PRC with the negatively trending demographics has a few decades left to act while its military strength is still capable. Although they face a setback with flushing out their military corruption, it will allow them to improve readiness and become a more capable force within the next decade.

3. Military Training

It is important to consider China's efforts in military training and education to better understand the combat effectiveness they may bring to bear. China looks to improve the PLA through learning from foreign military experiences and realistic training to undertake a military action approach to reunifying Taiwan.

China is often perceived as a force of quantity but lacks quality. This is mentioned by Lyle Goldstein (2023), a visiting professor at Watson Institute for International and Public Affairs at Brown University, regarding the PRC's lack of major and recent experience. The PRC has attempted to remedy this through intensive and systematic investigations of historical battles and campaigns from wars such as WWII, the Korean War, and the Falklands War.

Goldstein critiqued the PLA's analyses of foreign military history recorded in its 2020 doctrine *The Science of Military Strategy*. Goldstein accessed that the Chinese strategists extracted high fidelity key lessons that have been applied to their doctrine. If the PLA can successfully incorporate these lessons into their training and force design, they may be able to overcome their military inexperience. Goldstein compared this PRC possibility with WWII Germany. Even though it was the British who introduced tank warfare, the Germans excelled in it despite never having experienced armored combat.

An amphibious assault on Taiwan would be considered one of the most challenging and complex military operations for the PLA. To prepare for such an operation, the PLA continually hosts training events to refine crucial tactics. Tactics include "rapid loading, long distance transport and beach assault under complicated sea situations, and logistical support capabilities" (Department of Defense [DOD], 2023, p. 145). The DOD has also assessed that the People's Liberation Army Army (PLAA) has shifted towards realistic, large-scale amphibious operations that are aimed at supporting a cross-strait invasion of Taiwan. In 2019, China conducted a month-long training event involving its navy, air force, and rocket force, which incorporated some of the PLA's newest warships (Zuo & Warsh, 2019). To ensure realism of the training and prevent commands and actions from being rehearsed, the PLA gave no pre-brief of the scenarios and no advanced notices. Hong Kong-based military analyst, Song Zhongping, noted that the exercise was to test the combined force command and the capabilities at their disposal.

A majority of military analysts believe that China lacks the appropriate lift capability for a Taiwan invasion. Professorial Lecturer at George Washington University, Lonnie Henley, in a testimony hearing to the 117th congress, stressed that in terms of lift capability, "the PLA believes it has built enough for at least the initial landing capability" but would be supplemented with civilian vessels (*Deterring the People's Republic of China Aggression toward Taiwan*, 2021, p. 15). Henley (2022), in *China Maritime Report No. 21*, described how the PLA would leverage its civilian vessels to support large transport to the Taiwan beachhead following the initial landing. He also pointed out that the civilian ships would provide other capabilities to the PLAN such as at-sea support, medical support, reconnaissance, surveillance, early warning, and helicopter platform relays. This is not without its challenges as the civilian vessels and crew would need to be outfitted to augment the military equipment as well as training of the crew to better support the PLA.

A civilian training integration was reported by J. Michael Dahm (2023) in *China Maritime Report No. 25*. Dahm noted that the PLA incorporated civilian vessels into its amphibious assault exercises in 2022. Successfully integrating the civilian vessels into a Taiwan amphibious assault could likely bridge the gap of its perceived lack of lift capabilities.

An avenue that the PRC can use during an amphibious operation over Taiwan is a decapitation strategy. Evan Montgomery and Toshi Yoshihara (2022) from the Center for Strategic and Budgetary Assessments, describes a decapitation strategy as:

> The PLA would kill or capture national and local leaders who could otherwise maintain command and control of forces, serve as a symbol of organized resistance, galvanize international support, and lead the transition from conventional conflict to insurgency, should it become necessary. (para. 23)

The Chinese could consider Russia's leadership targeting strategy of Ukrainian President Volodymyr Zelenskyy. Beijing's consideration for a decapitation strategy can be found in PLA's *Science of Military Strategy* (Tianlian et al., 2020) military doctrine and in simulations conducted by the PLA. Montgomery and Yoshihara highlight, "PLA writings have held up 'decapitation operations' as an important element of a larger campaign to subdue Taiwan" which would result in quicker negotiations with Beijing (Montgomery and Yoshihara, 2022, para. 22). Lo Tien-pin and Jake Chung (2015) of the *Taipei Times* write about China successfully simulating a "decapitation" strategy using a mockup resembling Taiwan's presidential office building. With realistic training and doctrinal support, the PLA could very well attempt to remove Taiwan's head to increase pressures on a reunification negotiation.

C. TECHNICAL BACKGROUND

This section covers the high points of our technical approach, which we leverage in subsequent chapters of the thesis. Many excellent references for deterministic cohort-based combat models exist (e.g., McCue, 2022).

1. Lanchester Equations

This thesis leverages the use of the Lanchester Equations as first presented by Frederick W. Lanchester, whose original motivating example came from air-to-air combat. There have been several studies conducted since then to either validate his equation or build upon it.

Frederick W. Lanchester in 1916 presented a method for determining attrition loss using a system of ordinary differential equations known as the Lanchester Equations. Specifically, he developed his linear law and square law, which offer a mathematical method of how an engagement may result. Lanchester's studies were to stress the importance of the concentration of forces and their ability to employ weapons.

M. Osipov (1915), during the same time period as Lanchester, also worked on differential equations. Unlike Lanchester, M. Osipov used quantitative historical data and recognized that historical examples of battles seldom do not last until the annihilation of one side, also known as a "fight to the finish." Based on historical evidence, he concluded that a force would abandon the battle at roughly 20% casualties.

In 1954, Joseph H. Engel conducted a study that validated Lanchester's square law attrition model. Engel's method was unique by using time-series data from the Battle of Iwo Jima. This battle, unlike most battles, was rare as it was a true fight to the finish with Japan facing 100% attrition. It is important to note that the study was corrected by Robert Samz (1972). The issue was with the number of troops and how landings occurred. Samz found a more accepted number of 71,425 versus Engel's 73,000. With this he also provided a more accurate landing sequence, which accounts for low ship-to-shore transportation, uncertainty of the enemy situation, and beach congestion (Samz, 1972). Samz's analysis mentions a difference between the island declared secured and the end of the battle. This difference is hypothesized to be the difference in rate and intensity as the battle continues.

In 1962, S. J. Deitchman used the Lanchester Equations to examine guerrilla warfare. He wanted to observe if a defending regular army force could turn the attack on guerrilla forces by using the same guerilla methods. Deitchman noted that despite Lanchester's models being ineffective at predicting the course of a military engagement, they are still useful in eliciting general principles regarding the study, which can be discussed and addressed. Important points from his study include numerically inferior guerrilla forces' ability to win engagements by maintaining local numerical superiority; it is a heterogeneous approach to Lanchester's Equations and adds the element of surprise metric, which the guerilla forces have to substantially reduce opposing forces before they can return fire. He concluded by stating a defending regular army can counter guerrilla actions by using guerrilla tactics themselves due to the significantly large local force ratios or extremely effective weapons.

In 1977, Janice B. Fain conducted a study to investigate 60 World War II engagements, which lasted two to three days. She noted that the Lanchester Equations would "be poor descriptors for large battles extending over periods during which the forces were not constantly in combat; they may be adequate for predicting losses while the forces are actually engaged in fighting" (Fain, 1977, p. 34). She highlighted that during an offensive assault on fortified defensive positions, attackers are shown by the Lanchester equations to suffer casualties by the square law while defenders suffer casualties by the linear line. This difference is attributed to the defender identifying the attackers' positions more precisely than the attackers knowing the defenders' position. However, Fain noted that this finding is reversed when the assaulting force is in prepared positions as well as an assault on hasty defenses. In delaying situations, using the square law was the case for both the attacker and defender. She concluded that "Tactics appear to be an important determinant of combat results" (Fain, 1977, p. 40). She added that this hasn't been the case for analysts studying the effects of "varying force levels and force mixes" (Fain, 1977, p. 40).

Jerome Bracken (1995) used the Lanchester Equations on the Ardennes Campaign. Out of the 33 days of data, Bracken chose to examine 10 days of the campaign. Specifically, he focused on days 2 to 6, where the Germans were attacking, and days 7 to 11, where the Allies were attacking. In Bracken's model, he introduced the d parameter, called a tactical parameter, which factors for attrition to the defender or the inverse of d for attrition to the attacker. When d is less than 1, then the defender has an advantage. If d is greater than 1, then the defender has a disadvantage. Bracken introduced four models that focused on the combat forces with and without the use of the tactical parameter and total forces with and without the use of tactical parameters.

In Bracken's four models, he assigned "reasonable, but subjective, weights to tanks, armored personnel carriers, artillery, and manpower" (p. 575) which he assigned as 20, 5, 40, and 1, respectively. The purpose of the weights was because his models only examined manpower, so a weight must be assigned to convert commonly used equipment on the battlefield to manpower. Bracken concluded that the Lanchester linear equation fit the Ardennes Campaign when examining the four proposed models. He also concluded that in regard to combat forces, the Allies were considered to have better combat effectiveness over the German forces but were the same when looking at the total force. With this result, Bracken stated, both sides had similar "individual capabilities but were organized differently–the Allies chose to have more manpower in the support forces, which yielded greater individual capabilities in the combat forces" (p. 559). A limitation of his study was he did not include the effects of air forces.

2. Contemporary Criticism of Lanchester Equations

In 1987, Trevor N. Dupuy criticized using Lanchester Equations to assess attrition loss. He argued that Lanchester's ideas were focused on the Principle of Concentration, which discussed the strength and concentration of forces, rather than with force attrition, a by-product. Dupuy also pointed out that it is impossible to make Lanchester's Equations fit actual historical statistical data with the exception of the Iwo Jima Study by Engel (1954). However, he pointed out the Engel still misrepresented the historical data, although Samz (1972) corrected and validated Engel. He argued that for Lanchester equations to estimate attrition loss, there must be an all-else-equal environment, which is unrealistic in war due to human factors.

In 2022, Brain McCue examined the difficulties of applying Lanchester's equations to data from historical battles. These difficulties included getting good data, forces being inhomogeneous, fighting being inhomogeneous, and targeting between the different types of units on the battlefield. McCue also reminded readers that the Lanchester Equations are a continuous and deterministic model based on a law of averages where it should really be looked at as a discrete and probabilistic model.

After review of these studies, this thesis still employs the use of Lanchester's Equations. Criticism as mentioned by Deitchman (1962), Dupuy (1987), and McCue (2022) are noted and as Deitchman (1962) points out, the Lanchester model can be useful to elicit general principles of an engagement. The combat effectiveness variables from Samz (1972) will be used for Taiwan and PRC's combat effectiveness. The weights created from Bracken's (1995) study is used to convert tanks, APCs, and artillery pieces to manpower as they are still employed by the PLA and Taiwan militaries. Lessons from Fain's (1977) study are considered to scope the model's timeline to eliminate the phenomenon of fighting intensity slowing down over time. This model aims to examine the forces in constant engagement.

D. CONCLUSION

The tension between China and Taiwan is historically rooted and its claim over Taiwan does not appear to be abandoned in the near future. China has many options in attempting reunification; however, its forceful military option is dwindling due to its shrinking demographics. China may deem the time is 'now' to forcefully reunify Taiwan. This thesis aims to capture one scenario's outcomes out of many using Lanchester equations. Results from this analysis would potentially shed light into what China's losses and centers of gravity are, what China may want to consider in preparing for a cross-strait invasion, and what the United States may need to prepare and counter for either through diplomatic or military means.

III. METHODOLOGY

This chapter discusses a scenario used to simulate a PRC forced reunification attempt with a simple model. The scenario's focus examines a PRC cross-strait invasion of Taiwan, executing its forced reunification option. The combat model leverages deterministic models such as the Lanchester Equations and circulation method to compute combat losses for the PLA and ROC Armed Forces. This chapter concludes with a discussion on the assumptions and data inputs for the model.

A. DEFINITIONS

We assume that PRC's military Taiwan reunification begins with amphibious assault and a very short warning timeline. Use of the terms amphibious assault and termination of an amphibious assault are defined by 2019 Joint Publication 3-02 Amphibious Operations. Amphibious Assault as "the rapid buildup of combat power ashore, from an initial zero capability to full coordinated striking power as the attack progresses toward AF [amphibious force] objectives. In the Amphibious assault, combat power is progressively phased ashore" (Joint Chiefs of Staff [JCS], 2019, p. xii). Termination of an amphibious assault is "predicated on either the accomplishment of the mission set out in the initiating directive or a change in the situation that renders mission objectives no longer achievable or operationally necessary" (p. I-9).

B. STRATEGIC CONSIDERATIONS

The PRC has multiple options for a forceful reunification of Taiwan. These options include seizing Taiwan's outlying islands, quarantine, blockade, and invasion of Taiwan. Studies taken into consideration for the scenario build are Cancian et al. (2023), O'Hanlon (2000), Lague and Murray (2021), Blackwill and Zelikow (2021), Dougherty et al. (2021), and Henley (2022) which all investigated outcomes and courses of action during a Chinese cross-strait invasion of Taiwan.

Many of these studies on examining a Chinese cross-straits invasion of Taiwan have investigated the seizing Taiwan's outlying islands, quarantine, blockade, and invasion of Taiwan individually or as a combination. China appears to have the capability to invade Taiwan now; however, what constitutes success is a different question. As time goes on, the PLA continues to advance its capabilities, which strengthens its ability to exercise options.

Most scenarios assume China would take Taiwan's periphery islands. The PRC has four to choose from: Spratly Island, Pratas Island, Penghu Islands, and Kinmen. Robert Blackwill and Philip Zelikow (2021) believe the most advantageous option for China is the Pratas Island, which provides the Chinese outlets to the deep Pacific. China can exercise this option with high confidence that their military will be successful. Taiwan would then be faced with the decision to extend this fight. This would of course increase the blood loss from both sides but most likely end with the PLA succeeding due to distance of the island from Taiwan and the PLA's military superiority over Taiwan. The U.S. and allies would be reluctant to participate in this fight due to not willing to risk a major war over such a small territory. Although seizure of this island can prove advantageous for China, the simple model presented excludes this option to prevent further attrition of their landing ships.

Another option discussed by Lague and Murray (2021) is that China could impose a customs quarantine. The quarantine would not impede Taiwan's vital imports and exports of energy and food. The purpose of such action is to limit and ultimately prevent threatening weapons into their "territory." This action would also be followed with Beijing demanding Taipei to negotiate reunification with the mainland.

If Taipei refuses reunification negotiations with Beijing, China could then change its quarantine to a full blockade. This would increase pressures on Taipei to accept negotiations. Given Taiwan's reliance on exports for energy and food, Taiwan would have to call for assistance from the United States and its allies to intervene. For the purposes of the model's scenario, a blockade has been executed.

The final option that China could exercise is a full-scale complex invasion of Taiwan. China would most likely launch an air and missile campaign to degrade Taiwan's defensive while also preemptively degrading U.S. capabilities in the region to delay a military response for a Taiwan Invasion (Shugart & Gonzalez, 2017).

This invasion would most likely be headed by the Eastern Theater Commander using forces from both the Eastern and Southern Theater Command (see Figure 4 for military balance of PRC and Taiwan).

TAIWAN STRAIT MILITARY BALANCE, NAVAL FORCES			
	CHINA		TAIWAN
	Total	Eastern and Southern Theater Command Navies	Total
Aircraft Carriers	2	1	0
Amphibious Assault Ships	3	3	0
Cruisers	8	4	0
Destroyers	42	30	4
Frigates	47	30	22
Corvettes	50	40	0
Medium Landing Ships/ Tank Landing Ships / Amphibious Transport Dock	57	50	50
Attack Submarines	47	31	4
Nuclear-Powered Attack Submarines	6	2	0
Nuclear-Powered Ballistic Missile Submarines	6	6	0
Coastal Patrol (Missile)	60	60	43
Coast Guard Ships	142	N / A	168

Note: The PLAN has the largest force of principal combatants, submarines, and amphibious warfare ships in Asia. In the event of a major Taiwan conflict, the Eastern and Southern Theater Command Navies would participate in direct action against the Taiwan Navy. The Northern Theater Navy (not shown) would be responsible primarily for protecting the sea approaches to China, but could provide mission-critical assets to support other fleets. In conflict, China may also employ CCG and CMM ships to support military operations.

Military force comparison between China's Eastern and Southern Theater Command and Taiwan. China's Eastern and Southern Theater Commands would likely be the forces used to participate in the invasion of Taiwan's beaches.

Figure 4. PRC-Taiwan Naval Forces. Source: DOD (2023)

In accordance with China's joint military doctrines, *Service and Arms Application in Joint Operations* (Rongren, 2010) and *Science of Military Strategies* (Tianlian et al., 2020), an amphibious invasion would begin with preparatory fires conducted by aviation and ship-directed fires to destroy obstacles. Fire support would also be conducted to cover the sailing force's advancement to Taiwan.

The sailing force would likely first send minesweeper units to clear landing lanes for the invasion force. Following this action, amphibious warships would likely get into position to provide further fire support and shield landing and transportation vessels. Transportation units would begin to form their landing arrays where they will launch their assault.

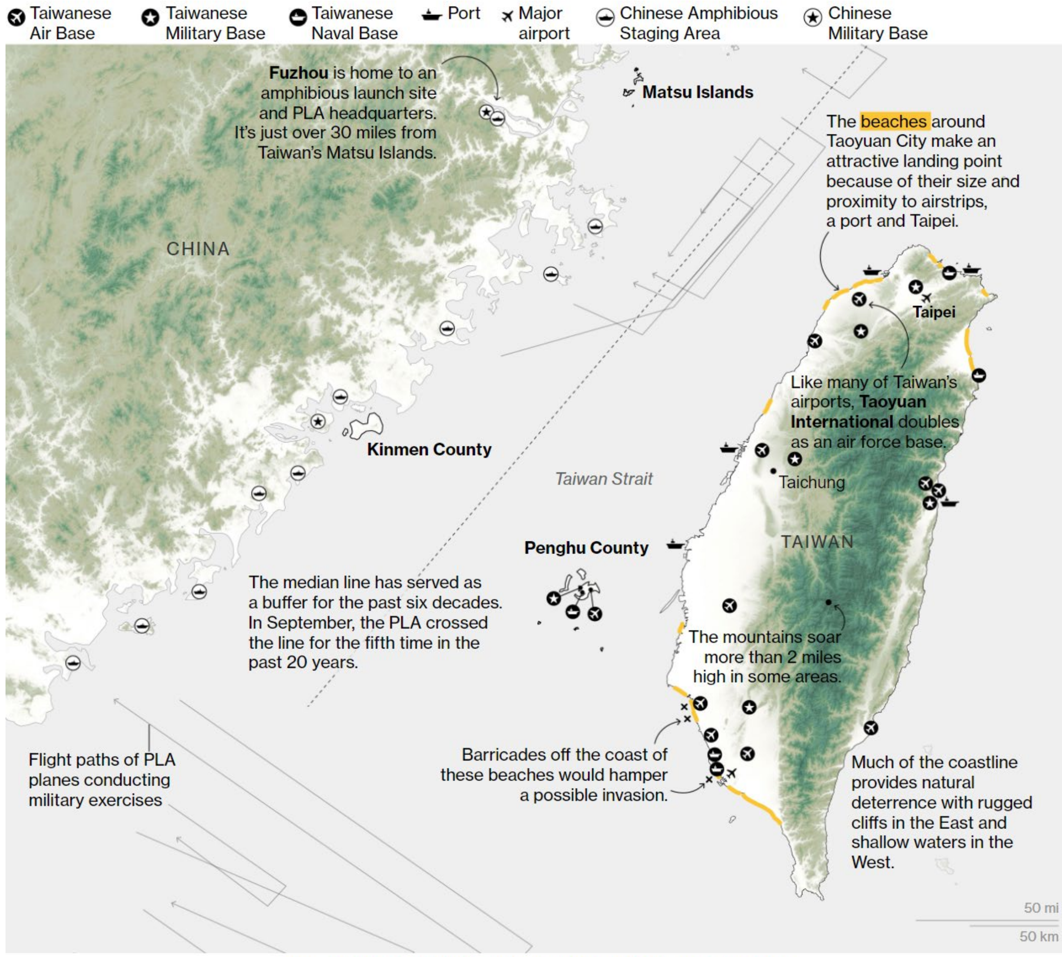
According to PLA doctrine, the PLA would also carry out air landings. The air inserted troops would be tasked with preventing enemy reserve forces from reinforcing the beachheads and attacking the enemy's in-depth defensive positions from the flank and rear. This action is meant to actively support and cooperate with landing troops' operations. Other operations for the air inserted troops are decapitation operations of key political and military leaders, which they have rehearsed and port/airfield seizures to facilitate follow on force landings. The scenario does not examine attrition of PRC air inserted forces but considers this for delaying a Taiwan reinforcement to the defending positions on the beachheads.

PRC doctrine notes the importance of surprise before the invasion. Given the technology and proximity of Taiwan and China, this would be difficult to obtain; however, it would not be impossible. The PRC could achieve surprise by masking mobilization under the cover of their military exercises. If a blockade strategy was first implemented in their campaign, then the use of deception would most likely be used. A deception strategy is available from their Maritime Militia. Given the large number of civilian ships available it has "the ability to hide its most valuable platforms among radar clutter" and emit false signals to "counterfeit ships, missiles, fighters and other targets on the sea" (Henley, 2022, p. 6). Civilian military integration is stressed within PRC doctrine recent doctrine, *Science of Military Strategies* (Tianlian et al., 2020). An effective deception strategy, especially through the use of their civilian militia force, has the potential to paralyze the Taiwanese military forces due to trying to identify the PRC's main effort assault. This delay could prove a pivotal step for the PRC to successfully establish a lodgment by delaying Taiwan reinforcements and strikes on the PRC fleet.

Finally, A PRC invasion would most likely involve a single pronged assault. The assault would most likely be the main effort and supporting forces facilitating the main effort until a lodgment is established. It is important to note the criticality of maintaining force flow. The PRC would need to use as many available vessels as possible to prevent a pause in the landing of its forces. Any pause during its amphibious assault would condemn the forces already on the beachhead. Once established other landing sites would be considered to bolster the PRC's capabilities in Taiwan. Given the PRC's doctrine on flexibility, they could shift the main effort and support the direction of attack with the most success.

C. SCENARIO DESCRIPTION

Given the complexity of a PRC cross-strait invasion of Taiwan, the scenario selected for the model examines a PRC amphibious assault across the Taiwan-Strait on one of few beachheads available (refer to the beaches highlighted in yellow in Figure 5). The PRC is likely to launch a main direction of attack with a multi-pronged assault on an identified beachheads collocated together similar to the Allied Forces in the Normandy landings in WWII.



Sources: The Chinese Invasion Threat, NASA, OpenStreetMap contributors, Natural Earth, Google Earth

This plot highlights the tenable beachheads for a PRC amphibious operation. It also draws our attention to the strategic resources, such as airports and port facilities, and Taiwan's military and naval bases which may affect PRC beach selection.

Figure 5. Taiwan Beachheads and Strategic Coastal Assets Source: (Ellis, 2020)

The PRC selection of beaches may share similarities to the WWII Normandy landings. On 6 June 1944, German defenders had approximately 50,000 defenders across a 50-mile stretch (Roos, 2019). Although the Allied forces had 50 miles to consider, they divided their landings into five beachheads. The beachheads were Utah, Omaha, Gold, Juno, and Sword which were 3, 6, 5, 6, and 5 miles wide, respectively (*D-Day: The Beaches*, n.d.). The PRC may take a similar approach when selecting the width of the beachhead and thus two collocated 6-mile stretches for a total of 12 miles is considered for the amphibious assault for this model.

The Taiwan defense structure for the initial assault conducted by the PRC for this model will consider the German defense forces in the Normandy landings and a remark from Michael Beckley (2017). Beckley mentioned that Taiwan could theoretically station 2,000 defenders per mile. Germany's 50,000 defenders protecting a 50-mile stretch could be interpreted as the German forces having 1,000 defenders per mile width. Fifteen-hundred defenders per mile width with two artillery battalions in support is used to determine the Taiwan force defense structure. The artillery battalion structure used contains 33 artillery pieces per battalion as used by Cancian's et al. (2023) war game. This consideration is made with an assumption that these forces have survived the PRC preparatory fires.

The risk inherent to an amphibious assault involves attrition of landing vessels and ships. The transit across the 100 miles puts the People's Liberation Army's Navy (PLAN) at risk due to Taiwan ground based anti-ship missiles and air force. PLAN is likely to face attrition of ships, which degrades the number of troops they can land per wave. This consideration is accounted for in the circulation model presented.

Once the first PRC wave lands, the Lanchester model accounts for attrition simulating the combat engagement between the PRC and Taiwan forces. The following section describes the characteristics of the Lanchester and circulation model in detail.

Finally, the model examines the painted scenario under two vignettes. The first vignette examines a contested beach landing with no Taiwan reinforcement. The second vignette considers the same PRC assault force but with the addition of a Taiwan reinforcement during the amphibious assault. With both vignettes, the model provides insight of attrition from both sides and the impact of a Taiwanese reinforcement to the PRC assault force.

D. CHARACTERISTICS OF THE LANCHESTER/CIRCULATION MODEL

This section discusses the characteristics of the Lanchester model, the parameters examined, the termination of the amphibious assault, and assumptions made.

1. Lanchester Equation

Lanchester's equation first presented by Lanchester (1916) examined fire power of two forces, ρ and β, and number of troops, *R* and *B*. Fire power or combat effectiveness is the percent rate at which the force can inflict a casualty shot.

$$\frac{dB}{dt} = -\rho R$$

$$\frac{dR}{dt} = -\beta B$$

A modification of this model is used to determine the attrition rates of battle on the beachhead with a time step.

Determining the PLA's forces for each time step we subtract PLA's force on the a given time step by the combat effectiveness of the Taiwanese fighters multiplied by Taiwanese fighters and time interval.

$$B_{t+h} = B(t) - \rho \cdot R(t) \cdot h \tag{1}$$

$$R_{t+h} = R(t) - \beta \cdot B(t) \cdot h \tag{2}$$

Equations (1) and (2) are used to determine the force total remaining during the 72-hour amphibious assault. This then provides us with the ability to determine when China's forces are three times greater than Taiwan's forces by dividing R_{t+h} by B_{t+h}.

2. Circulation Method

The circulation model factors likely risk associated with the 100-mile transit to and from Taiwan. The inbound transit risk used is 10% while outbound transit risk is 5%. The model attrites the PLAN landing ships by the associated risk during ingress and egress. The model will use a deterministic and stochastic approach to attrition rates.

The first wave is calculated differently because landing ships would only be subjected to inbound risk. Delivery of troops to the beachhead is then determined by the number of landing ships that survived multiplied by the capacity of troops per landing ships.

$$Vessels_{t+5} = Vessels_{t} \cdot (1 - InboundRisk)$$

$$Delivered_{t} = Vessels_{t+5} \cdot NumTroops$$

For the waves following the first, an outbound risk is injected with the timeline also increased to iterations of 10 hours to account for the total 200-mile round trip.

$$Vessels_{t+10} = Vessels_{t} \cdot (1 - OutboundRisk) \cdot (1 - InboundRisk)$$

3. Model Parameters

Our model accounts for 13 parameters that affect the outcome (refer to Table 1). These parameters values are established based on expert literature and what is estimated to be in the PRC's inventory in 2023 and their future production. It is important to note that the PRC has four parameters directly under its control. The four parameters they can influence are combat effectiveness, number of landing vessels, number of fighters, and the speed of the landing vessels. Combat effectiveness is based on the Engel (1954) and Samz (1972) studies on the battle of Iwo Jima. The Taiwan forces take on the Japanese defender's combat effectiveness while the PLA take on the U.S. invading force's combat effectiveness.

Table 1. Model Variables

Variables	Description
Bo	Taiwan Starting Force
beta	Taiwan Combat Effectiveness
rho	China Combat Effectiveness
StartBoats	Initial Number of Chinese Boats
FightersPerBoat	Chinese Boat Capacity
Dist	Distance Traveled (miles)
Speed	Chinese Boat Speed (mph)
InboundRisk	Attrition of Boats (%) Heading toward Taiwan
OutboundRisk	Attrition of Boats (%) Leaving Taiwan
tmax	Total Hours Observed in the Model
h	Time intervals (in hours) observed
Brein	Taiwan Reinforcement Size
Brein_T	Taiwan Reinforcement Time of Arrival

4. Termination of the Amphibious Assault

An important consideration of this model is knowing the termination of the amphibious assault. The metric for a successful PRC landing is a PRC force build up that has a force ratio of 3:1 over the Taiwan defenders. A timeline of the amphibious assault is provided to identify when PRC has succeeded in establishing a force ratio of 3:1. If the force is unable reach the ratio within a 72-hour period the amphibious assault is considered a failure.

a. 3:1 Force Ratio

Success of the invasion is achieved when the PRC has a force ratio of 3:1 over the Taiwan defenders in a 72-hour period. The 3:1 Force Ratio is historically based on as far as antiquity (Sun Tzu), which states that an attacker needs a three-to-one strength superiority over the defender in order to win (Davis 1995; DuPuy, 1987). From expert literature, the 3:1 is a useful planner tool. Davis (1995) points out a 2:1 ratio might seem acceptable for the attacker; however, to win decisively, an even larger force ratio might be needed. The model's use of the 3:1 ratio goes beyond comparing sheer numerical advantage by leveraging the Lanchester Equations and incorporating combat effectiveness.

b. Timeline

Given the assumption that the PRC has preemptively struck the U.S. military bases in the region, this model assumes that strong U.S. military retaliation is not conducted for the first 72 hours. As for the Japanese Self Defense Force (JSDF), reactions times could be longer than that of the United States due to Japanese defense structure. Japan may not be keen to involve itself until attacked by the PRC. The time taken to establish its lodgment thus determines the PRC's success or failure of its amphibious assault. If the U.S. and other allies, such as Japan, intervenes with the PRC amphibious assault, this could severely degrade its capabilities to continue with the operation to the point of futility.

5. Assumptions

The model used does not consider the other variables for a complex amphibious invasion. First, the PLAN has different types of methods for landing troops onto a beachhead, such as air and sea lift. The model views only the PRC's medium amphibious ship capabilities and disregards its Type 071 Amphibious Transport Dock, which has ship-to-shore connectors and airlift capabilities. The Type 072 and Type 072A medium Landing Ship, Tanks (LST) and Type 073A Landing Ship, Medium (LSM) are the only consideration for the amphibious assault. The PRC also has roll-on/roll-off civilian ships that can assist with the transport of troops and sustain a continuous flow of forces but will not be considered.

The second assumption is on air superiority and capability. This model assumes that the PRC has enough air superiority that enables freedom of movement of their LSTs. Although the PRC has air superiority, no airlift or paratrooper capabilities are considered for the model results but are considered to increase the feasibility of the first vignette.

Third, the sea has the ability to impact any amphibious assault negatively. The sea state of an amphibious operation can terminate an amphibious operation before it begins. For this consideration, an assumption is made that the PRC has a favorable sea state that allows for an amphibious assault.

Fourth, it is likely that the PRC will have conducted preparatory fires before committing its LSTs to land. The scenario makes the assumption that the Taiwanese forces used in the model survived the bombardment.

Fifth, we examine the other variables that affect timeliness of the PRC landings. For the simplicity of the model, the PRC has instant disembark/embark time. It is also likely that the PRC would need to resupply troops on the beachhead, which would affect the number of troops in follow-on landings. An assumption is made that the number of troops will not be affected. Another assumption is made that the PRC ships follow a direct route to Taiwan, which keeps the distance traveled to the approximate distance of the Taiwan-Strait, 100 miles.

Finally, the PRC's amphibious operation can easily be disrupted by interference by Taiwan's allies. A final assumption made is the United States or neighboring country involvement does not occur for the first 72-hours due to the preemptive strikes conducted on U.S. bases in the region.

These assumptions are key to keep the model simple and analyze the PRC's amphibious assault capabilities in terms of its LSTs. This is to then understand what changes to these capabilities would affect an actual PRC cross-strait invasion of Taiwan.

E. SUMMARY

This methodology considers previous studies and reports investigating what a Chinese invasion of Taiwan may look like and how they may leverage their military capabilities to develop a scenario with key assumptions for a combat model. The combat model applies a Lanchester equation and circulation model to identify attrition rates for both forces and the time it would take to establish a PRC force ratio of 3:1. A successful PRC beach landing would be establishing a 3:1 force ratio on the beachhead within 72 hours. Findings from this methodology may provide insight into what the PRC would be faced with in terms of attrition, its center of gravity for an amphibious assault, and investments it may consider for bolstering capability.

IV. ANALYSIS

This section discusses the results of a deterministic Lanchester combat model with deterministic and stochastic landings under two vignettes. Next, the vignettes are examined through the same combat model but with varying combat effectiveness and transit risk to view PRC tradeoff. Another analysis is conducted to determine what the minimum Taiwanese reinforcement to prevent a successful PRC lodgment under the set parameters Finally, it includes a discussion for what this could mean for China.

A. VIGNETTE ONE

The strategic scenario is the PRC initiated a quarantine of Taiwan to pressure Taiwan to the negotiating table to discuss reunification back to the mainland. After Taiwan officials disagree to reunification talks, the PRC changes its quarantine into a full blockade and pressures Taiwan officials again to discuss reunification. Once again with Taiwan declining, the PRC begins its option to invade Taiwan through a cross-strait invasion. Vignette one is a PRC invasion of two six-mile beachhead within a single-pronged assault. Table 2 displays the constant parameters throughout the Vignettes.

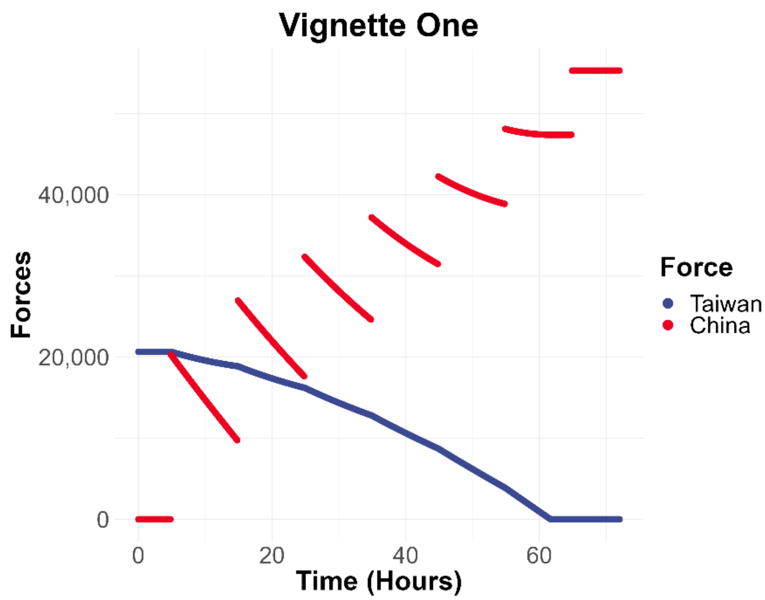
Table 2. Vignette One: Parameters

Variables	Description
Bo	20,640
beta	0.54
rho	0.01199
StartBoats	50
FightersPerBoat	450
Dist	100 miles
Speed	20mph
InboundRisk	10%
OutboundRisk	5%
tmax	72
h	0.1

Table 2 displays 11 of the 13 parameters within the Lanchester combat model. Excluded parameters are for Taiwan's reinforcement inject seen in Vignette Two.

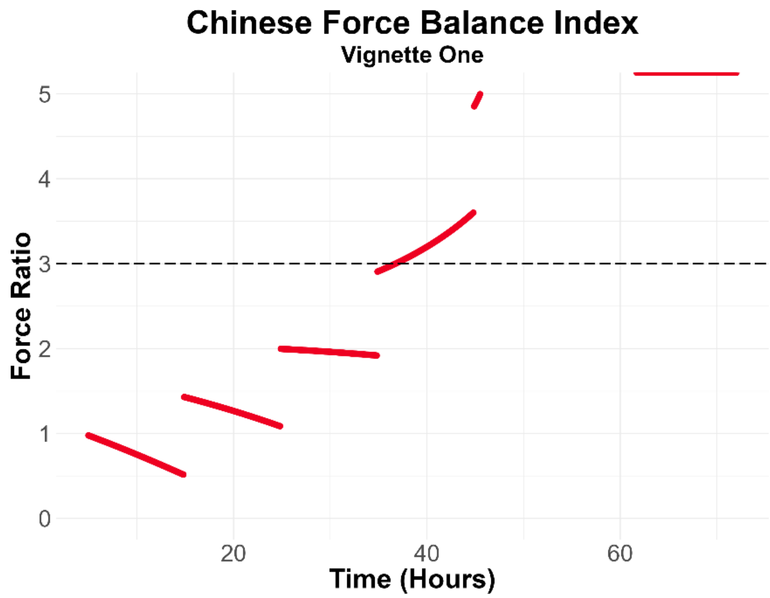
1. Deterministic Model

The vignette resulted in the PRC successfully establishing force superiority during the 37th hour and its fourth amphibious landing (see Figures 6 and 7 for graphical representation).



This graph depicts the level of forces ashore of Taiwan and China over the course of a 72-hour unwavering assault.

Figure 6. Vignette One: PRC Amphibious Assault



This graph depicts a PRC force ratio over Taiwan. The dash line represents a PRC 3:1 force ratio.

Figure 7. Vignette One: PRC Force Ratio Over Taiwan

It is important to note that personnel loss from the figures include loss of tanks and artillery units, which have been converted to personnel using the Bracken (1995) study. The result of the battle which includes inbound attrition rates for China in vignette one is as follows: 20,640 casualties for Taiwan and 48,044 casualties with 33 LSTs/LSMs destroyed for China. This is a 100% attrition of Taiwan's forces defending the beachhead compared to a 46.5% attrition of China's total assault force and 65% attrition of their landing ships. Refer to Table 3 for detailed PRC force attrition breakdown.

Table 3. Vignette One: PRC Force Attrition Breakdown, Deterministic

PRC Force		
Committed Forces	103,343	
Total Force Loss	48,044	
Transit Loss-Personnel		5,741
Transit Loss-Tanks		4,593
Combat Loss		43,770
Landing Ship Loss	33	

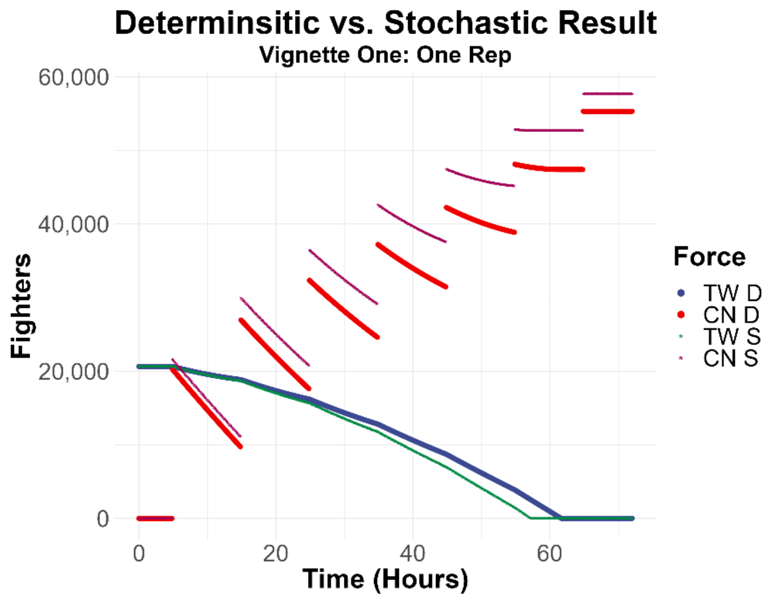
The number of Chinese forces attrited included the personnel aboard LSTs destroyed while inbound to Taiwan. An assumption made for this figure is that all troops aboard a destroyed LST would be considered as casualties.

2. Stochastic Model

The stochastic variation of vignette one considers the same deterministic parameters as listed above. The difference when it comes to the stochastic model is that it will vary the attrition of vessels by conducting a Bernoulli distribution with each vessel. Each vessel will be examined on whether they will survive the transit risk to and from Taiwan.

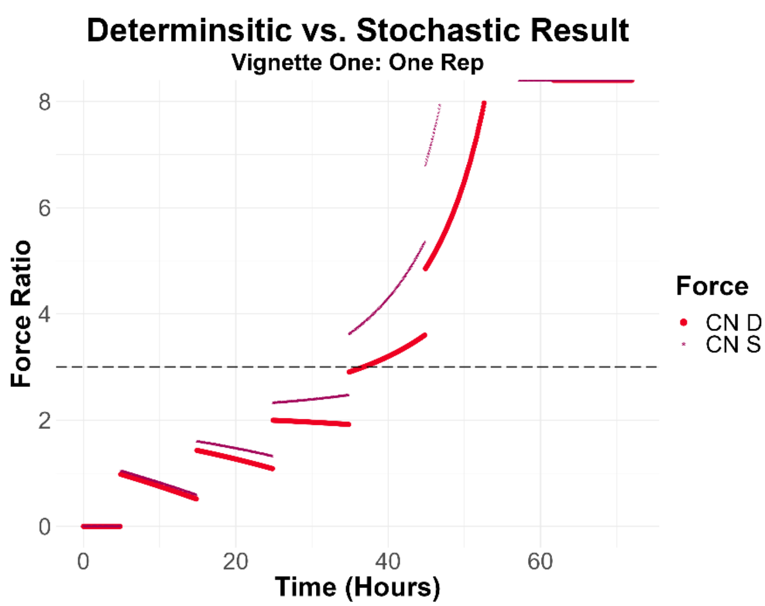
Unlike the deterministic model where a constant transit risk is applied, the stochastic model is different with each attempt. To ensure reproducibility of the model, a seed is set to allow for analysis for the 30 random events we tested for (Refer to Appendix B. Codes).

One replication of the stochastic model is graphically represented in Figure 8. This particular rep shows a significantly more favorable outcome for the PRC with their landing force suffering less loss than the deterministic model.



This graph depicts the stochastic and deterministic level of forces ashore of Taiwan and China over the course of a 72-unwavering assault.

Figure 8. Vignette One: Stochastic Result



This graph depicts the deterministic and stochastic PRC force ratio over Taiwan. The dashed line represents a 3:1 force ratio.

Figure 9. Vignette One: Stochastic PRC Force Ratio Over Taiwan

The result for the stochastic landing and deterministic battle had similar results to the deterministic model with the PRC obtaining a successful 3:1 force buildup on the 35th hour with its fourth landing. Examining only the dynamics of the land battle with the impacts of the stochastic loss of ships Taiwan suffered 20,640 casualties while China suffered 34,584 casualties and 39 landings ships destroyed. This is a 100% attrition rate for Taiwan and 37.5% attrition rate for China and 78% attrition rate for its landing ships.

Further examining the stochastic landing and deterministic battle, we ran through 30 iterations with the detailed findings listed in Appendix A and a visual representation in Figure 14. All 30 cases ended with the PRC successfully establishing a lodgment in Taiwan. The quickest success was in 35 hours, longest success was 54 hours, and an average of approximately 39 hours.

B. VIGNETTE TWO

The same scenario is applied to vignette two. This vignette mirrored the same PRC forces, however, a Taiwanese reinforcement of 10,000 fighters after 24 hours of fighting was injected. Refer to Table 4 for vignette two's parameters.

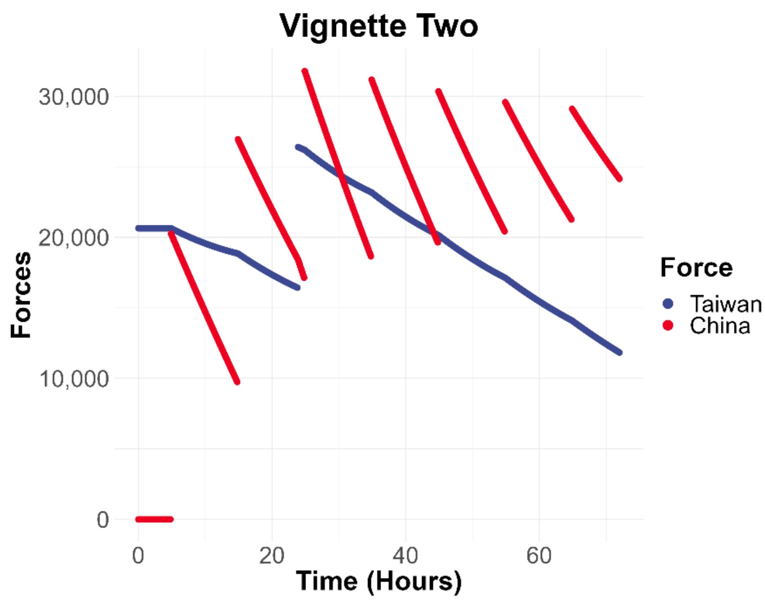
Table 4. Vignette Two: Parameters

Variables	Description
Bo	20,640
beta	0.54
rho	0.01199
StartBoats	50
FightersPerBoat	450
Dist	100 miles
Speed	20mph
InboundRisk	10%
OutboundRisk	5%
tmax	72
h	0.1
Brein	10,000
Brein_T	24

Table 4 displays all 13 parameters within the Lanchester combat model. The last two parameters are included to inject Taiwan's reinforcement for vignette two.

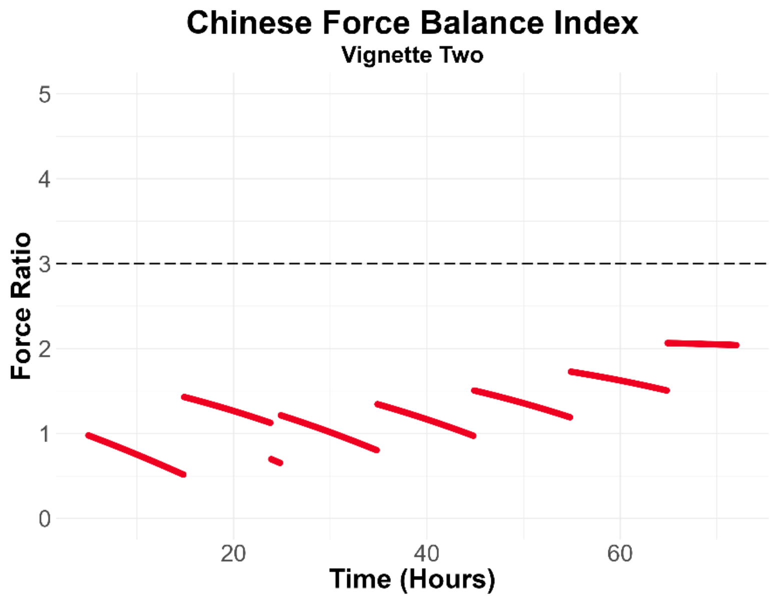
1. Deterministic Model

The result for the second vignette was a Chinese defeat although the PRC managed to average a force ratio of 1.28 and peaked at 2.07 during its seventh landing at hour 65 (see Figures 10 and 11 for graphical representation). Due to the attrition of the PLAN's LSTs/LSMs, the PRC's ability to land troops in mass degraded to a point of inability to match the Taiwanese reinforcement. Although the PRC did not meet the 72-hour window, it may have been able to reach the 3:1 force ratio during subsequent landings if the U.S. or Japan are unable to intervene.



This graph depicts the forces ashore of Taiwan and China over the course of a 72-hour unwavering assault.

Figure 10. Vignette Two: PRC Amphibious Assault with Taiwan Reinforcement



This graph depicts a PRC force ratio over Taiwan. The dash line represents a PRC 3:1 force ratio.

Figure 11. Vignette Two: PRC Force Ratio Over Taiwan

The result of the battle for vignette two is as follows: 18,811 casualties for Taiwan and 79,196 casualties with 33 LSTs/LSMs destroyed for China. Refer to Table 5 for detailed breakdown. This is a 61.4% attrition of Taiwan's forces defending the beachhead with reinforcements compared to a 76.6% attrition of China's total assault force and 65% attrition of their landing ships.

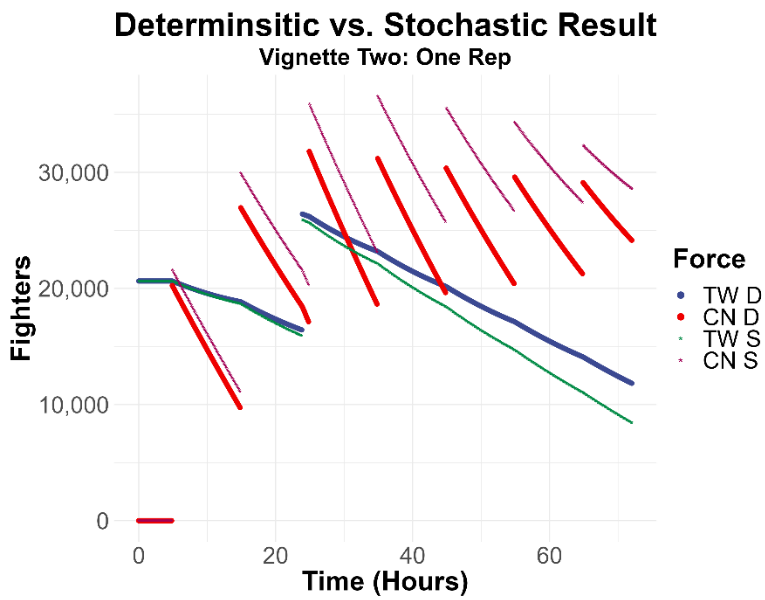
Table 5. Vignette Two: PRC Force Attrition Breakdown, Deterministic

PRC Force		
Committed Forces	103,343	
Total Force Loss	79,196	
Transit Loss-Personnel		5,741
Transit Loss-Tanks		4,593
Combat Loss		68,862
Landing Ship Loss	33	

Despite the PRC not being able to reach a 3:1 force ratio in time they were able to maintain a presence of approximately 24,000 troops on Taiwan during hour 72.

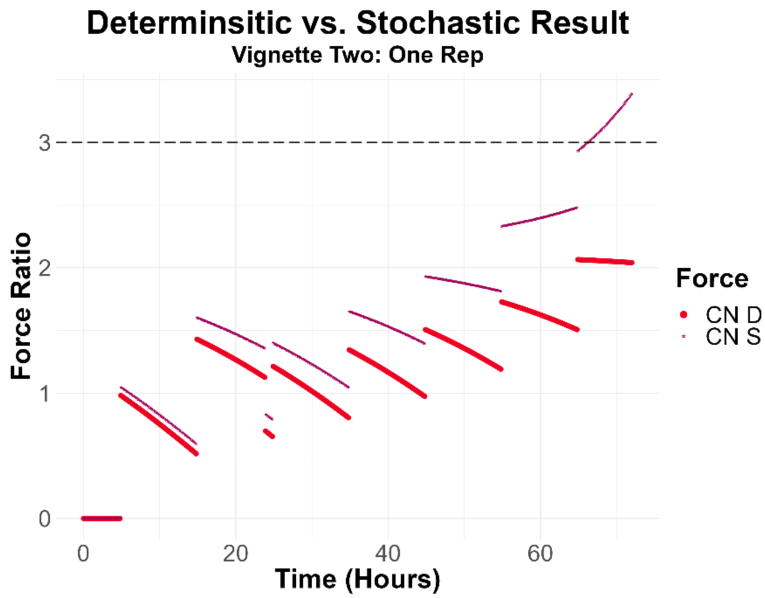
2. Stochastic Model

The stochastic model of vignette two considers the same deterministic parameters as listed above. One rep of the stochastic model for vignette two is graphically represented in Figure 12.



This graph depicts the stochastic and deterministic level of forces ashore of Taiwan's and China's forces the course of a 72-unwavering assault.

Figure 12. Vignette Two: Stochastic Result



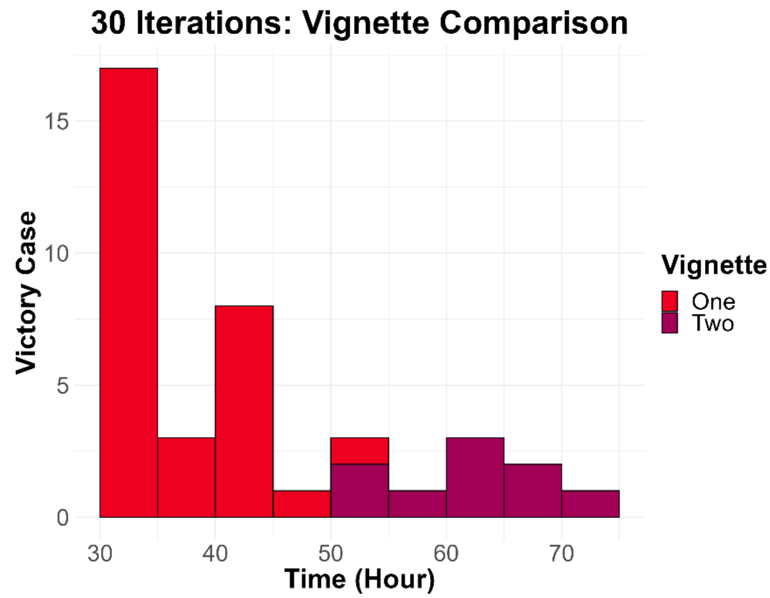
This graph depicts the deterministic and stochastic PRC force ratio over Taiwan. The dashed line represents a 3:1 force ratio.

Figure 13. Vignette Two: Stochastic PRC Force Ratio Over Taiwan

The results are as follows: Taiwan suffered 22,199 casualties for an attrition rate of 72.5% while China suffered 63,654 casualties at an attrition rate of 69%. Loss of their landing ship remains the same as vignette one stochastic results.

What is of note is that despite the PRC facing a Taiwanese reinforcement of 10,000 under the stochastic model they were able to still achieve a 3:1 force buildup due to the survivability of their landing ships.

Thirty iterations were run to further examine the stochastic landing and deterministic battle. Out of the 30 cases where Taiwan was able to reinforce with10,000 fighters at hour 24, we saw nine cases where the PRC was still able to achieve a successful lodgment, refer to Appendix A for breakdown and Figure 14 for a visual representation. The quickest success was at hour 55, the longest at hour 71, and the average at approximately 63 hours.



This graph plots the victory cases for vignette one and two under stochastic landings and deterministic combat to compare the impact a Taiwanese reinforcement has on a PRC amphibious assault.

Figure 14. Vignette Victory Comparison: Stochastic Landings with Deterministic Combat

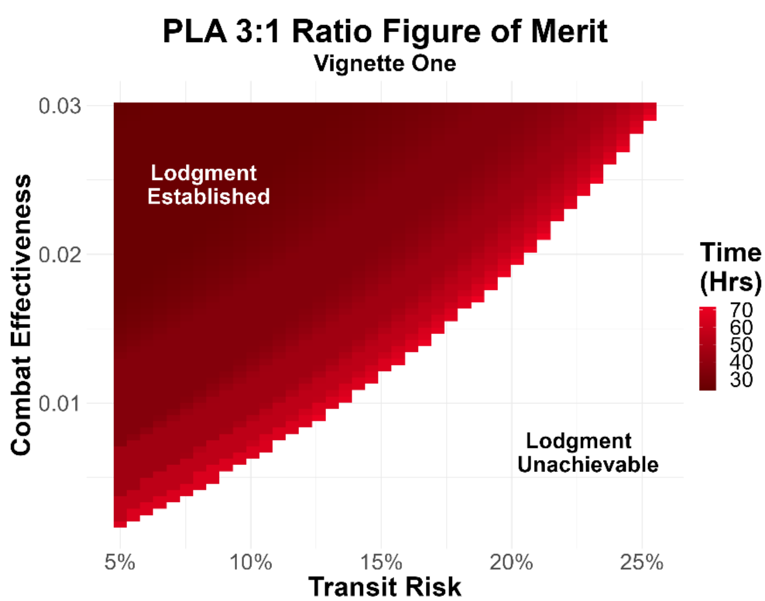
C. ANALYSIS

A separate analysis is done altering the PLA's troop combat effectiveness and landing ship transit risk to assess how these parameters affect the PRC's ability to obtain a 3:1 force ratio over Taiwan. The PLA has the ability to increase its troops' combat effectiveness and defenses for a transit of their landing ships, while Taiwan has the ability to increase its anti-ship capabilities.

To examine this, a model is built to examine 4,900 cases that alter the PLA's troop combat effectiveness from 0.001 to a max of 0.03 while looking at transit risk ranging from 5% to 40%. Any case in which the PRC achieves a 3:1 force ratio over Taiwan is recorded with the time it would take and then plotted. The figure of merit is a successful buildup of forces with a 3:1 ratio within 72 hours from the launch of the invasion.

Figure 15 displays cases under the conditions of vignette one under the deterministic combat model. Should the PRC reduce the transit risk of their LSTs to 5%, they can achieve a force ratio of 3:1 over Taiwan with a combat effectiveness or casualty hit rate of 0.18%. For reference, the deterministic model presented for both vignettes considered the PLA with a 1.2% combat effectiveness. This metric applied uses Engel (1954) and Samz (1972) combat effectiveness for the U.S. invading force during the battle of Iwo Jima. In other words, with a 5% transit risk, the PRC could find success if their troops match approximately a fifth of the combat effectiveness seen by the U.S. troops in the Battle of Iwo Jima. If the PRC can increase the survivability of its landing ships and maintain it, this can substitute a lack of combat effectiveness and potentially the number of ships required for an amphibious assault.

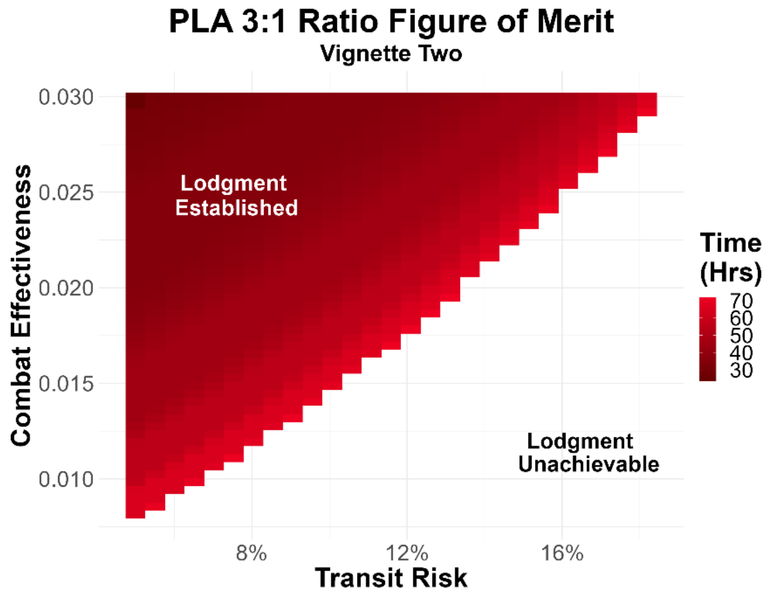
If the PRC is able to increase its combat effectiveness to approximately three times that of the U.S. troops in the battle of Iwo Jima, they can achieve a 3:1 force ratio with a maximum allowable transit risk of 25.3% to their landing ships. This implies that if the PLAA's soldiers can exhibit extreme proficiency, also three times of the U.S. in the battle of Iwo Jima, they can still succeed despite a strong Taiwan anti-ship defense.



This graph displays the PRC's ability and time to achieve a 3:1 force ratio over Taiwan under 4,900 cases, with PLA's combat effectiveness and transit risk varying. The figure of merit (FOM) highlights the time in hours the PRC achieved success. This model is based on vignette one's scenario.

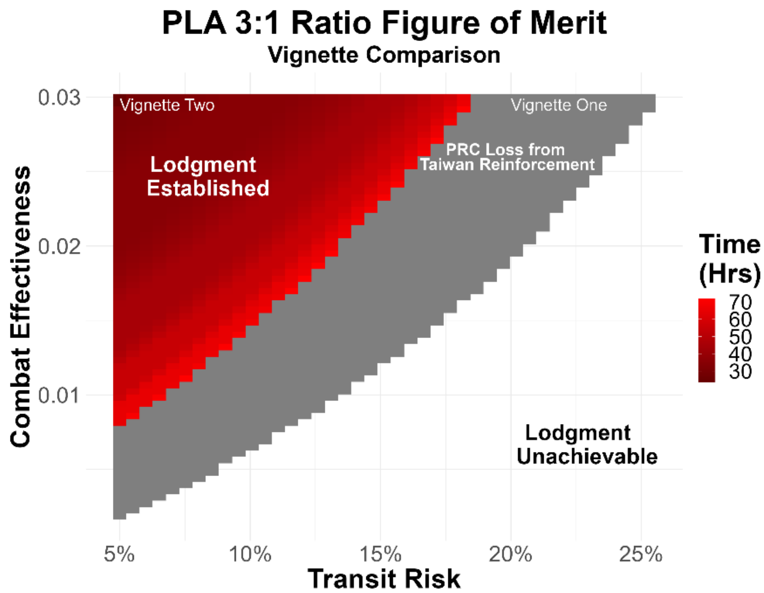
Figure 15. Vignette One: Figure of Merit

The same analysis was done for vignette two, where Taiwan reinforces the beachhead with 10,000 fighters, see Figure 16 and 17.



This graph displays the PRC's ability and time to achieve a 3:1 force ratio over Taiwan under 4,900 cases, with PLA's combat effectiveness and transit risks varying. The figure of merit (FOM) highlights the time in hours the PRC achieved success.. This model is based on vignette two's scenario.

Figure 16. Vignette Two: Figure of Merit



This graph displays the figure of merit comparison between both vignettes. The red highlights vignette two's FOM while the gray zone depicts vignette one. This difference highlighted in gray is the effect a Taiwanese reinforcement has on a PRC invasion under the vignettes' scenario.

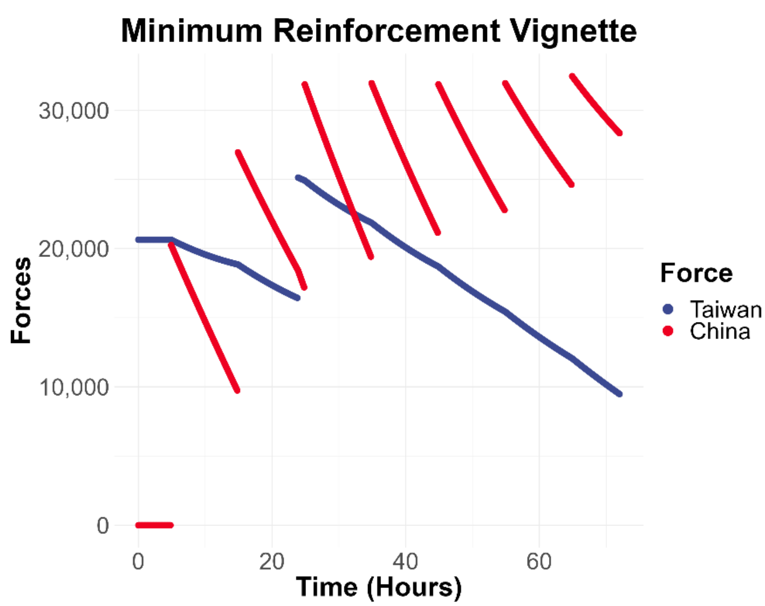
Figure 17. Figure of Merit Vignette Comparison

Figure 16's plot shows that a PRC invasion with 50 LSTs/LSMs can still achieve a 3:1 force ratio with a Taiwanese reinforcement of 10,000 at hour 24. However, the PRC would have to increase its troops' combat effectiveness and reduce their transit risk to and from the beachhead to negate the effects of a Taiwanese reinforcement.

For the PRC invasion to achieve a 3:1 force ratio while facing Taiwan reinforcement, they must have a minimum combat effectiveness of 0.8% while reducing their transit risk to 5%. This implies that the PRC could still achieve a lodgment under our scenario with combat effectiveness 4 percentage points less than the U.S. troops during the battle of Iwo Jima while significantly reducing Taiwan's anti-ship capabilities to a 5% effectiveness.

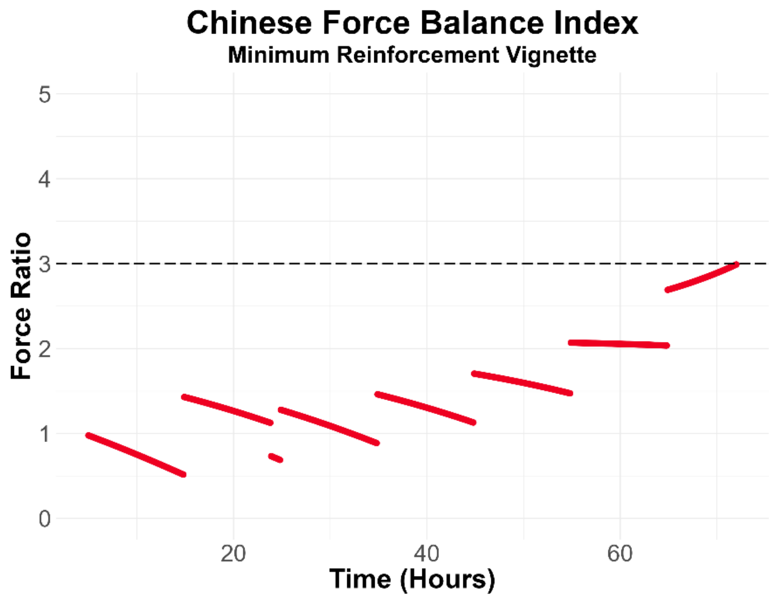
Examining transit risk under vignette two, the most allowable transit risk for the PRC's landing ships would have to be 18.8%. This, however, would require them to extensively train their troops to a 3% combat effectiveness. In other words, the PLA troops would have to be approximately three times more capable than the U.S. troops in the battle of Iwo Jima. Both cases could also be substituted through expanding the number of landing vessels employed for a cross-strait invasion.

A final analysis is presented on the minimum required reinforcement for Taiwan to prevent a successful PRC lodgment within 72-hours, refer to figures 18 and 19. For Taiwan to prevent a successful PRC lodgment under the scenario we have given, it would need approximately 8,725 fighters or equivalent to keep the PRC under a 3:1 force buildup. This would be equivalent to approximately two U.S. Marine Corps regimental combat teams.



This graph depicts the forces ashore of Taiwan and China over the course of a 72-hour unwavering assault.

Figure 18. Minimum Taiwan Reinforcement Vignette



This graph depicts a PRC force ratio over Taiwan. The dash line represents a PRC 3:1 force ratio.

Figure 19. Minimum Taiwan Reinforcement Vignette: Force Ratio

D. DISCUSSION

This section discusses the analysis further to address the results of the simple model and what it can mean for China. Specifically, it highlights weaknesses in China's capabilities during a cross-strait invasion of Taiwan, other actions China could likely incorporate, and other scenarios. It aims to speculate China's network point of failure. In other words, should a war between China over the forced reunification of Taiwan occur, where should Taiwan, the United States, and its allies prioritize targeting?

China's potential options to forcefully reunify Taiwan with military action are to take Taiwan's periphery islands, quarantine, blockade, invade Taiwan, or a combination of these. The model presented is a reunification attempt via amphibious assault and blockade.

The model examined the exclusive use of the PLA's LSTs/LSMs during the scenario's cross-strait invasion. Of course, the PLA has other landing ships to assist in its invasion campaign to include LSD, LHD, and their civilian militia force, which were not examined in this model. An inclusion of these methods would allow the PRC to bolster the number of troops landed with each wave and quickly achieve a favorable 3:1 force ratio over Taiwan. Something of note is that the PLA's civilian militia force could change the flow of force into a continuous insertion rather than in waves. Once the LSTs deposit their troops and return to mainland, the Roll-on/Roll-off (RO-RO) civilian ships would then insert their forces to avoid pause during the amphibious assault.

The PLA's use of the LSTs/LSMs under a vacuum shows a potential of succeeding in establishing a lodgment of Taiwan, given that Taiwan is unable to reinforce in time and have a fighting force of approximately 18,000 with the support of 2 artillery battalions. What can be derived from this result is that the PRC's amphibious assault can be quickly repelled if the PRC lost air superiority and Taiwan increases the PRC's inbound and outbound risk through increased anti-ship capabilities. This can be done through the expansion of asymmetric warfare using submarines, anti-ship missiles, and bomber aircraft.

Asymmetric warfare is what would perhaps worry China the most during an amphibious invasion of Taiwan. China would not have enough submarines to safeguard its naval fleet if the United States and Japan intervened. Another concern for China is if it lost air-superiority or was temporarily unable to prevent U.S. bombers from entering the Taiwan Strait air space. This would have China see mass destruction of its landing force through the lethality and accuracy of the U.S. B-52 bomber. To combat this China would need a fait accompli of Taiwan.

During the invasion, Taiwan would likely reinforce its beachhead defenses, especially if they have determined the PRC's main effort. However, should the PRC successfully and simultaneously insert troops via airlift capabilities, it is possible for a Taiwanese reinforcement to the beachhead to become delayed. Another situation in which a delay of forces can occur is through PLA feinting and deception operations its civilian militia force. A combination of the two could lead to the devastating situation found in scenario one. The use of the civilian militia force would most likely be seen as it would allow maximum use of PLA's military landing ships to assist in the invasion. It should once again be noted that both vignettes do not include other landing ships and ship-to-shore connectors from its LHDs and LPDs, which the PRC would most likely deploy in support of their beach landings allowing them to reach their force ratio of 3:1 over Taiwan's forces more quickly.

Successfully establishing a lodgment in Taiwan, the PRC can aggressively build up forces through many avenues due to the reduced attrition rate inherently available to an uncontested beachhead. The PRC would likely use already established ports or set up artificial ones while using nearby airports to flow in forces rapidly. This would position the PRC to begin follow on operations.

During an amphibious assault, the PRC would rely on the use of armored vehicles (tanks, tracked SP artillery, and tracked vehicles), which would increase the firepower at its disposal upon landing. The PRC would also likely execute special operations for decapitation operations with their special forces. If conditions favor the PRC, they would likely try to use their airlift capabilities to disrupt Taiwan's rear and flanks causing increased confusion. Based on a one-prong assault, the PRC could not fail their designated beachhead as they may not have enough military ships to attempt an establishment of another lodgment elsewhere. Given their doctrine, they would likely attempt to be flexible and consider other landings once their main effort has established a sufficient foothold.

Of last note, should a PRC invasion completely fail, its blockade is the biggest challenge for Taiwan, the United States, and allies to overcome. With vital resources such as food and energy depleting, Taiwan will be competing against time, testing their resolve. For a Chinese blockade to succeed, they must maintain their naval and air defense assets to prevent the United States and its allies from breaking the blockade. Of other note, geography would now be on China's side as the crucial ports that would need to be used are on the western edge of Taiwan. An amphibious invasion of Taiwan executed by the PRC would see an egregious loss on both sides.

E. CONCLUSION

A PRC amphibious landing with enough force build up may be possible in a campaign to reunify Taiwan to the mainland. This would, however, imply the PRC maintain air superiority, anti-area and anti-denial of the strait, and have a favorable sea and weather state. This is to counter what China is perhaps most afraid, U.S. submarines and bombers, but overall, the loss of its landing force and vessels.

What the models and analysis highlight is that the PRC can obtain a 3:1 force buildup with 50 LSTs/LSMs with no Taiwanese reinforcement. Should the Taiwanese successfully reinforce the beachhead, the PRC can still find success if they are able to prepare the individual soldiers with enough training to raise combat effectiveness, successfully reduce the transit risk of their landing ships, or expand the number of vessels at their disposal by either production or use of the civilian fleet.

It is important to reiterate that the results are from a simple model attempting to capture the complexities of a complicated joint amphibious operation. Although the model is not predictive in nature, it allows for talking points and considerations. Even if the PRC fails to establish a lodgment in Taiwan, they can still succeed in their overall Taiwan reunification campaign with a blockade. If deterrence fails, Taiwan is fighting for survival with a short clock if they are unable to maintain a flow of resources.

For the PRC to consider an attempt for forceful reunification is the likelihood it perceives it would succeed. What is key here is that the U.S. would need to continue to give the PRC doubt and uncertainty to consider a cross-strait invasion of Taiwan. High probably or uncertainty of losing the invasion of Taiwan would deter the PRC.

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V. CONCLUSION

This thesis brings insight to the questions: What is China's strategic threshold for loss during a Taiwan cross-strait invasion? and what factors would give China's command pause when considering an amphibious invasion of Taiwan?

A. RESEARCH SUMMARY

This research structured a scenario based on past research and analysis of the PRC. The painted scenario analyzed two vignettes, one with no Taiwanese reinforcement and a second with Taiwanese reinforcement. The vignettes were examined under a deterministic combat model which involved a Lanchester equation and a deterministic and stochastic circulation model. Results from these models offered talking points and consideration for what the PRC may want to consider when deciding to forcefully reunify Taiwan.

The first key factor to examine are the landing ships used for a Chinese amphibious assault of Taiwan. This is perhaps the biggest factor and most likely contribution for a successful PRC lodgment in Taiwan. The specific attributes of the landing ships involve carrying capacity, survivability, speed, and the number of landing ships available. All attributes are all within the PRC's ability to affect, however, there are tradeoffs that Beijing must consider in terms of production on the types of ships it wants pursue for its naval fleet.

Improving the landing ships carrying capacity and speed or increasing the number of landing ships would take a considerable amount of time and resources that could otherwise be suited elsewhere such as assets to improve anti-access/area denial (A2/AD). This then becomes a question of increasing the quantity of ships and troops employed facing a transit risk set by Taiwan and its allies or increasing the amphibious ships that would reduce the transit risk for the landing ships. The research determined that reducing the transit risk for the landing ships offers a significantly better advantage in terms of cost. Less PRC lives and costly transit ships would be lost.

If a favorable transit risk is something that the PRC cannot obtained, then increasing the number of ships for the amphibious assault is the next best thing despite the cost that would be incurred. This then begs the question of whether Beijing is willing to lose over 50,000 lives and 33 Landing Ships on a single beachhead like seen in vignette one which depicts a medium transit risk.

Combat effectiveness of the PLA's soldiers is another key factor to the success of a PRC lodgment in Taiwan. This would also allow for the PRC to reach a 3:1 force balance more quickly. Increasing the PLA's ability to attrite the Taiwanese fighters' faster, however, pales in comparison to increasing the number of ships available or improving survivability of the landing ships. Indeed, realistic training and implementing lessons learned from previous wars are key to achieving a PRC combat effective advantage, but the PLAA alone should not be Beijing's primary source for success as the PLAN can contribute much more.

For Beijing to fully support the PLAN it should focus on A2/D2. Investments in long range surface-to-air missiles, aircraft, submarines, destroyers, and carriers are needed to increase the survivability of their landing force and prevent pause in their invasion of Taiwan. The PRC have made strides in each of these areas; however, it is not enough once the United States, Japan, and allies become involved in the war. The PRC is overmatched when compared to the countries that would be involved in a cross-strait conflict. For as long as this overmatch exists, the PRC will have to plan for a rapid amphibious invasion and pressure Taipei to reunify with Taiwan. Beijing would not be able to sustain a blockade long enough for Taiwan to give in to Beijing's demands with the overmatch they would face.

During a cross-strait invasion of Taiwan, a reinforcement from the Taiwanese would severely impact Beijing's timing to establish a lodgment. For Beijing to overcome or even prevent this, they would have to execute effective deception strategies such as feints with their civilian militia force or insert troops via air transport. The former would be in Beijing's favor as it would equate to less lives lost when compared to air inserted troops. A reinforcement from Taiwan is perhaps not the biggest worry for the PRC as long as it is able to continue landing forces on the beachhead and have at least a 2:1 force buildup before the United States and its allies become involved.

B. SHORTFALLS

Due to the classification level of this research, only open-source documents were considered for the development and analysis of this model. Another shortfall is China has no war plan available to the public in order to fully investigate scenarios.

When creating a simple model many assumptions were made to allow for a PRC landing which also included scaling the combat scenario to only involve infantry, tanks, and artillery. Realistic combat could also include the use of naval surface fires and close air support.

The use of Lanchester equations. We used combat effectiveness values from the battle of Iwo Jima. PRC and Taiwan may not accurately reflect the respective U.S. and Japan's combat effectiveness from WWII.

C. FOLLOW ON RESEARCH

Improvements to answering the research question presented could include a using a design of experiments, considering other landing ships in PLA's arsenal, use of civilian militia, air power, naval battles, and unmanned vehicles.

D. CONCLUSION

Beijing's biggest worries summarized are the loss of its landing ships in the early stages of its invasion. Items that are specific to this worry are the PRC being overmatched in submarine warfare, U.S. bombers or other strike capabilities which have massive payloads that would degrade their landing ships and forces, and an integrated Taiwanese mobile ground anti-ship missile capability. Beijing's failure to establish a lodgment in Taiwan would result in severe losses to PRC lives, civilian ships, and amphibious fleet. The alternative option for a PRC successful forceful reunification of Taiwan is to continue the blockade although this would disrupt the global economy. With a blockade, Beijing would aim to destroy Taiwan's will to fight as crucial resources to their survival deplete.

If war between China and Taiwan broke out, the question now is what is the United States' end goal with regards to the PRC? The legitimacy of the CCP would be at stake should the PRC lose. The same can perhaps be said if the CCP does not invade Taiwan. Is there a policy that could satisfy the U.S., Taiwan, and China? With what happened to Hong Kong, the peaceful solution of two systems one country is hard for Taiwan to agree to. The PRC's attempt to fully redeem itself from the century of humiliation would also prevent the PRC from abandoning its claim. The PRC states that it is a sacred duty to its people, however, I would argue that attempting to fulfill this duty would do more harm than good due to the lives that would be lost but as well as China's standing with the rest of the world should it win or lose.

In closing, from a presentation by Dr. Andrew Erickson of China Maritime Studies Institute, Beijing would need to estimate a high probably of success and an acceptable level of loss to consider its military option for a Taiwan reunification. Once Xi Jinping feels they have reached the appropriate balance of success probability and level of loss, then they would execute as soon as the sea conditions allow it. For Taiwan, United States, and allies, duties to deter China from executing a cross-straits invasion is to increase uncertainty. Military options may include increased bilateral operational capabilities, force posturing in the Indo-Pacific area, or bringing new capabilities to bear. The United States should increase the uncertainty for China with military actions, but it should not be the only option it pursues to preventing a Chinese invasion of Taiwan. For as long as China is unsure of its success probability and loss of lives it would not favor its military option for a forceful reunification of Taiwan. China would not want to risk another humiliation.

APPENDIX A. STOCHASTIC LANDINGS – 30 ITERATIONS

Table 6. Vignette One: 30 Iterations – Stochastic Landing and Deterministic Battle, Figure of Merit

Rep	FOM (Hour)	Rep	FOM (Hour)
Victory – Rep: 1	34.9	Victory – Rep: 16	34.9
Victory – Rep: 2	34.9	Victory – Rep: 17	34.9
Victory – Rep: 3	44.9	Victory – Rep: 18	36.2
Victory – Rep: 4	34.9	Victory – Rep: 19	44.9
Victory – Rep: 5	34.9	Victory – Rep: 20	48.6
Victory – Rep: 6	34.9	Victory – Rep: 21	34.9
Victory – Rep: 7	34.9	Victory – Rep: 22	44.9
Victory – Rep: 8	34.9	Victory – Rep: 23	44.9
Victory – Rep: 9	44.9	Victory – Rep: 24	34.9
Victory – Rep: 10	34.9	Victory – Rep: 25	54.3
Victory – Rep: 11	34.9	Victory – Rep: 26	34.9
Victory – Rep: 12	38.4	Victory – Rep: 27	36.7
Victory – Rep: 13	34.9	Victory – Rep: 28	40.4
Victory – Rep: 14	34.9	Victory – Rep: 29	44.9
Victory – Rep: 15	34.9	Victory – Rep: 30	44.9

Minimum FOM: Hour – 34.9; Maximum FOM: Hour – 54.3; Average FOM: Hour – 38.74; Successful: 30

Table 7. Vignette Two: 30 Iterations – Stochastic Landing and Deterministic Battle, Figure of Merit

Rep	FOM (Hour)
Victory – Rep: 1	66.3
Victory – Rep: 2	71.2
Victory – Rep: 5	55.6
Victory – Rep: 10	64.9
Victory – Rep: 13	54.9
Victory – Rep: 17	64.9
Victory – Rep: 21	67.7
Victory – Rep: 24	54.9
Victory – Rep: 26	64.9

Minimum FOM: Hour – 54.9; Maximum FOM: Hour – 71.2; Average FOM: 62.8; Successful: 9

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APPENDIX B. CODE

A. LANCHESTER/CIRCULAR MODEL/FOM, DETERMINISTIC

```
library(ggplot2); library(ggsci);

library(magrittr); library(reshape2);library(dplyr)

theme_set(theme_minimal())


setwd(" ")


Combined = function(Bo = 20640,  #BLUE STARTING

            beta = .05400,  #Blue Combat Effectiveness

            rho = .01199, #PRC COMBAT EFFECTIVENESS

            StartBoats = 50, #PRC NO. OF BOATS

            FightersPerBoat = 450, #PRC NO. OF FIGHTERS

            Dist = 100, #DISTANCE BETWEEN CHINA MAINLAND AND TAIWAN/ MAY NEED TO
ADJUST

            Speed = 20, #PRC BOAT SPEED

            InboundRisk = .1, #PRC RISK INSERTING SHIP-TO-SHORE CONNECTORS

            OutboundRisk = .05, #PRC RISK WITHDRAWING SHIP-TO-SHORE CONNECTORS

            tmax = 72, #TIMELINE OF THE INVASION IN HOURS

            h = .1, #Time Step in 0.1 of an hour, or six minute increments

            Brein = 10000, #Blue Reinforcement Size

            Brein_T= 24){  #Blue Reinforcement Time

 FirstTrip = floor(Dist/Speed) #FIRST TRIP IS DIFFERENT

 RoundTrip = floor(2*Dist/Speed) #Floor rounds to previous hour. RoundTrip determines the time it takes
to send a boat and return


 T = seq(0, tmax, by = h) #T is increasing in intervals of h or .1

 n = length(T) #Taking the length of this value

 BT = rep(0, n) #Setting a vector of 0 for Blue Forces (T) to 0 for each iteration of h
```

```
RT = rep(0, n) #Same as BT for Red Forces

BT2 =rep(0,n)

RT2 = rep(0,n)


BT[1] = Bo #Sets the first vector for blue forces for the engagement.

RT[1] = 0 #Because they haven't shown up yet

BT2[1]=Bo #For Vignette 2

RT2[1]=0


#Figure out the delivery schedule first!


TT = vector() #creates an empty logical vector set to variable TT

Delivered = vector() #creates an empty logical vector set to variable TT

TripIncr = RoundTrip #TripIncr not sure but equal to round trip

i = 1


#First Trip is different

TT[i] = FirstTrip #bookkeeping #FIRST TRIP IS DIFFERENT

These.Boats = (1-InboundRisk)*StartBoats #Boat attrition for the inbound risk

# print(These.Boats)

Delivered [i] = These.Boats*FightersPerBoat #First wave of fighter delivered

# print(Delivered [i])

while(TT[i] <= tmax){ #Iteration increments of round trip time. Loop capped at 30

  i = i+1 #looks at next interval

  These.Boats = These.Boats*(1-OutboundRisk)*(1-InboundRisk) #attrition of outbound risk and inbound
risk

  TT[i] = TT[i-1] + TripIncr #shows the next iteration of wave deposit

  Delivered [i] = These.Boats*FightersPerBoat #Shows the number of fighers delivered with the remaining
boats available

  # print(These.Boats)
```

```
  # print(Delivered [i])
 }

del = data.frame(TT, Delivered) #creates a dataframe that shows the delivery schedule (iteration and no. of fighers)

#Vignette 1: No reinforcement
for(j in 2:n){
  #Check if a landing occurred
  if(T[j] %in% del$TT){
    # print(T[j])
    # print(del$Delivered [which(del$TT == T[j])])
    RT[j-1] = RT[j-1] + del$Delivered [which(del$TT == T[j])]
    #Arrivals happen at end of last turn
    # print(RT[j])
  }

  #Now, back to normal Lanchester
  BT[j] = max(0,
           BT[j-1] – rho*h*RT[j-1])
  RT[j] = max(0,
           RT[j-1] – beta*h*BT[j-1])
  # print(RT[j])
 }

#Vignette 2: Reinforcement
for(j in 2:n){
  #Check if a landing occurred
  if(T[j] %in% del$TT){
    # print(T[j])
```

```
    # print(del$Delivered [which(del$TT == T[j])])
    RT2[j-1] = RT2[j-1] + del$Delivered [which(del$TT == T[j])]
    #Arrivals happen at end of last turn
    # print(RT[j])
  }

  #THIS IS THE CODE FOR Reinforcement
  if(Brein_T == T[j]){
    BT2[j-1]=BT2[j-1]+Brein
    # print(BT[j-1])
  }

  #Now, back to normal Lanchester
  BT2[j] = max(0,
               BT2[j-1] – rho*h*RT2[j-1])
  RT2[j] = max(0,
             RT2[j-1] – beta*h*BT2[j-1])
  # print(RT[j])
}

ret <- data.frame(Time = T,
                  Blue = BT,
                  Red = RT,
                  Blue2=BT2,
                  Red2=RT2)

return(ret)
}
```

```
ret<-Combined(Bo = 20640, StartBoats = 50)

ret$`Force Ratio`<- ret$Red/ret$Blue

ret$`Force Ratio2`<- ret$Red2/ret$Blue2


####################################Vignette 1:

ret %>% select(-4,-5,-6,-7)%>%

 melt(id.vars = “Time”) %>%

 ggplot(aes(x = Time, y = value, color = variable)) +

 geom_point(size=2.5) +

 scale_y_continuous(name = “Forces,” labels = scales::comma) +

 labs(title=“Vignette One”,color = “Force”)+

 scale_color_manual(labels=c(“Taiwan”,”China”),values=c(‘#3B4992FF’,’#EE0021FF’))+

 xlab(“Time (Hours)”)+

 theme(title=element_text(size=28, face=‘bold’), plot.title = (element_text(hjust = 0.5)),axis.text.y =
element_text(size=24),

       axis.text.x = element_text(size=24),legend.text = element_text(size = rel(2.2)))+

 guides(color = guide_legend(override.aes = list(size = 4.5)))

# ggsave(“1_Vig One.png”,width = 11, height = 8.5,bg=“white”)


#####FORCE RATIO

ggplot(ret,(aes(x=Time,y=`Force Ratio`)))+

 geom_point(size=2.5,color=‘#EE0021FF’)+scale_y_continuous(limits=c(0,5))+

 scale_x_continuous(limits=c(5,72))+

 scale_size_manual()+

 labs(title=“Chinese Force Balance Index”,subtitle = “Vignette One”)+

 xlab(“Time (Hours)”)+

 geom_hline(yintercept = 3, size=.75,color=‘black’,linetype=‘longdash’)+

 theme(title=element_text(size=28, face=‘bold’), plot.title = (element_text(hjust = 0.5)),plot.subtitle =
(element_text(hjust=0.5,size=24)),

       axis.text.y = element_text(size=24),axis.text.x = element_text(size=24),legend.text = element_text(size
= rel(2.2)))
```

```
# ggsave("2_Vig One FR.png",width = 11, height = 8.5,bg="white")


#########################################Vignette 2

ret %>% select(-2,-3,-6,-7)%>%

 melt(id.vars = "Time") %>%

 ggplot(aes(x = Time, y = value, color = variable)) +

 geom_point(size=2.5) +

 scale_y_continuous(name = "Forces," labels = scales::comma) +

 labs(title="Vignette Two",color = "Force")+

 scale_color_manual(labels=c("Taiwan","China"),values=c('#3B4992FF','#EE0021FF'))+

 xlab("Time (Hours)")+

 theme(title=element_text(size=28, face='bold'), plot.title = (element_text(hjust = 0.5)),axis.text.y =
element_text(size=24),

       axis.text.x = element_text(size=24),legend.text = element_text(size = rel(2.2)))+

 guides(color = guide_legend(override.aes = list(size = 4.5)))


# ggsave("3_Vig Two.png",width = 11, height = 8.5,bg="white")


#####FORCE RATIO

ggplot(ret,(aes(x=Time,y=`Force Ratio2`)))+

 geom_point(size=2.5,color='#EE0021FF')+scale_y_continuous(limits=c(0,5))+

 scale_x_continuous(limits=c(5,72))+

 scale_size_manual()+

 labs(title="Chinese Force Balance Index",subtitle = "Vignette Two")+

 xlab("Time (Hours)")+ylab("Force Ratio")+

 geom_hline(yintercept = 3, size=.75,color='black',linetype='longdash')+

 theme(title=element_text(size=28, face='bold'), plot.title = (element_text(hjust = 0.5)),plot.subtitle =
(element_text(hjust=0.5,size=24)),

       axis.text.y = element_text(size=24),axis.text.x = element_text(size=24),legend.text = element_text(size
= rel(2.2)))
```

```
# ggsave("4_Vig Two FR.png",width = 11, height = 8.5,bg="white")

################################### Sim Driver
SimDriver = function(rhomin = .001,
                     rhomax = .1,
                     RiskMin = .05,
                     RiskMax = .5,
                     ncases = 10
){
 rho = seq(rhomin, rhomax, length.out = ncases)
 Risk = seq(RiskMin, RiskMax, length.out = ncases)

 DM = expand.grid(rho = rho,
                  Risk = Risk)
 DM$FOM = -1
 DM$FOM2 = -1

 for(i in 1:dim(DM)[1]){
   this.model = Combined(Bo = 20640,
                         beta = .054,
                         rho = DM$rho [i],
                         StartBoats = 50,
                         Dist = 100,
                         Speed = 20,
                         Brein = 10000,
                         Brein_T = 24,
                         InboundRisk = DM$Risk [i],
                         OutboundRisk = DM$Risk [i]*.75,
```

```
                    tmax = 72,
                    h = .1)
  RVicTime = this.model$Time [which(this.model$Red/this.model$Blue > 3)[1]]
  if(!is.na(RVicTime)){
   DM$FOM[i] = RVicTime
  }
  RVicTime2 = this.model$Time [which(this.model$Red2/this.model$Blue2 > 3)[1]]
  if(!is.na(RVicTime)){
   DM$FOM2[i] = RVicTime2
  }
 }
 return(DM)
}

z = SimDriver(rhomin = .001, rhomax = .03,
            RiskMin = .05, RiskMax = .4,
            ncases = 70)

z %>% dplyr::filter(FOM > 0) %>% ggplot(aes(x = Risk, y = rho, fill = FOM)) +
 geom_raster() + scale_x_continuous(name = 'Transit Risk',
                              labels = scales::percent) +
 scale_y_continuous(name = "Combat Effectiveness")+
 labs(title = "PLA 3:1 Ratio Figure of Merit," subtitle = "Vignette One",fill="Time\n(Hrs)")+
 scale_fill_gradient(low='#660000',high='#EE0021FF')+
 annotate("text",x=.0615,y=0.0255,label="Lodgment," size=8, hjust=0,color='white',fontface=2)+
 annotate("text",x=.0601,y=0.0239,label="Established," size=8, hjust=0,color='white',fontface=2)+
 annotate("text",x=.2052,y=0.0075,label="Lodgment," size=8, hjust=0,color='black',fontface=2)+
 annotate("text",x=.202,y=0.0059,label="Unachievable," size=8, hjust=0,color='black',fontface=2)+
 theme(title=element_text(size=28, face='bold'), plot.title = (element_text(hjust = 0.5)),plot.subtitle =
(element_text(hjust=0.5,size=24)),
```

```
      axis.text.y = element_text(size=23),axis.text.x = element_text(size=23),
      legend.text = element_text(size = rel(2)))

# ggsave("5_Vig One FOM.png",width = 11, height = 8.5,bg="white")

z %>% dplyr::filter(FOM2 > 0) %>% ggplot(aes(x = Risk, y = rho, fill = FOM2)) +
 geom_raster() + scale_x_continuous(name = 'Transit Risk',
                              labels = scales::percent) +
 scale_y_continuous(name = "Combat Effectiveness")+
 labs(title = "PLA 3:1 Ratio Figure of Merit," subtitle = "Vignette Two",fill="Time\n(Hrs)")+
 scale_fill_gradient(low='#660000',high='#EE0021FF')+
 annotate("text",x=.0615,y=0.0255,label="Lodgment," size=8, hjust=0,color='white',fontface=2)+
 annotate("text",x=.0601,y=0.0242,label="Established," size=8, hjust=0,color='white',fontface=2)+
 annotate("text",x=.1508,y=0.0120,label="Lodgment," size=8, hjust=0,color='black',fontface=2)+
 annotate("text",x=.1485,y=0.0108,label="Unachievable," size=8, hjust=0,color='black',fontface=2)+
 theme(title=element_text(size=28, face='bold'), plot.title = (element_text(hjust = 0.5)),plot.subtitle =
(element_text(hjust=0.5,size=24)),
      axis.text.y = element_text(size=23),axis.text.x = element_text(size=23),
      legend.text = element_text(size = rel(2)))

# ggsave("6_Vig Two FR.png",width = 11, height = 8.5,bg="white")

##########################################FORCE RATIO COMPARISON
z %>% dplyr::filter(FOM > 0) %>% ggplot(aes(x = Risk, y = rho, fill = FOM2)) +
 geom_raster() + scale_x_continuous(name = 'Transit Risk',
                              labels = scales::percent) +
 scale_y_continuous(name = "Combat Effectiveness")+
 labs(title = "PLA 3:1 Ratio Figure of Merit," subtitle = "Vignette Comparison",fill="Time\n(Hrs)")+
 scale_fill_gradient(low='#660000',high='#FF0000')+
 annotate("text",x=.0615,y=0.0255,label="Lodgment," size=8, hjust=0,color='white',fontface=2)+
```

```
 annotate("text",x=.0601,y=0.0239,label="Established," size=8, hjust=0,color='white',fontface=2)+

 annotate("text",x=.2052,y=0.0075,label="Lodgment," size=8, hjust=0,color='black',fontface=2)+

 annotate("text",x=.202,y=0.0059,label="Unachievable," size=8, hjust=0,color='black',fontface=2)+

 annotate("text",x=.20,y=0.0295,label="Vignette One",size=6,hjust=0, color='white')+

 annotate("text",x=.175,y=0.0265,label="PRC Loss from",size=6,hjust=0, color='white',fontface=2)+

 annotate("text",x=.165,y=0.0255,label="Taiwan Reinforcement",size=6,hjust=0,
color='white',fontface=2)+

   annotate("text",x=.05,y=0.0295,label="Vignette Two",size=6,hjust=0, color='white')+

 theme(title=element_text(size=28, face='bold'), plot.title = (element_text(hjust = 0.5)),plot.subtitle =
(element_text(hjust=0.5,size=24)),

       axis.text.y = element_text(size=23),axis.text.x = element_text(size=23),

       legend.text = element_text(size = rel(2)))


# ggsave("7_FR Compare.png",width = 11, height = 8.5,bg="white")


# setwd("")

# write.csv(ret, file="1_amphibious_assault.csv")

# write.csv(z, file="3_FOM.csv")
```

B. LANCHESTER, DETERMINISTIC & LANDING, STOCHASTIC

```
set.seed(2581)

library(ggplot2); library(ggsci);

library(magrittr); library(reshape2)

library(dplyr)

theme_set(theme_minimal())

setwd(" ")


Combined = function(Bo = 20640,

                beta = .054,

                rho = .01199,

                StartBoats = 50,
```

```
        FightersPerBoat = 450,
        Dist = 100,
        Speed = 20,
        Brein = 10000,
        Brein_T = 24,
        InboundRisk = .1,
        OutboundRisk = .05,
        tmax = 72,
        h = .1){
FirstTrip = floor(Dist/Speed) #FIRST TRIP IS DIFFERENT
RoundTrip = floor(2*Dist/Speed) #Floor rounds to previous hour

T = seq(0, tmax, by = h)
n = length(T)
BT = rep(0, n)
RT = rep(0, n)
BT2 = rep(0, n)
RT2 = rep(0, n)


BT[1] = Bo
RT[1] = 0 #Because they haven’t shown up yet

BT2[1] = Bo
RT2[1] = 0 #Because they haven’t shown up yet

#Figure out the delivery schedule first!

TT = vector()
```

```
Delivered = vector()
TripIncr = RoundTrip
i = 1

#First Trip is different
TT[i] = FirstTrip #bookkeeping #FIRST TRIP IS DIFFERENT
These.Boats = (1-InboundRisk)*StartBoats
Delivered [i] = These.Boats*FightersPerBoat
while(TT[i] <= tmax){
  i = i+1
  These.Boats = These.Boats*(1-OutboundRisk)*(1-InboundRisk)
  TT[i] = TT[i-1] + TripIncr
  Delivered [i] = These.Boats*FightersPerBoat
}

del = data.frame(TT, Delivered)
.GlobalEnv$del<-del

for(j in 2:n){
  #Chieck if a landing occurred
  if(T[j] %in% del$TT){
    #print(T[j])
    #print(del$Delivered [which(del$TT == T[j])])
    RT[j-1] = RT[j-1] + del$Delivered [which(del$TT == T[j])]
    #Arrivals happen at end of last turn
    #print(RT[j])
  }

  #Now, back to normal Lancheter
```

```
  BT[j] = max(0,
            BT[j-1] – rho*h*RT[j-1])
  RT[j] = max(0,
            RT[j-1] – beta*h*BT[j-1])
}

#FOR REIN
for(j in 2:n){
  #Chieck if a landing occurred
  if(T[j] %in% del$TT){
    #print(T[j])
    #print(del$Delivered [which(del$TT == T[j])])
    RT2[j-1] = RT2[j-1] + del$Delivered [which(del$TT == T[j])]
  }

  #THIS IS THE CODE FOR Reinforcement
  if(Brein_T == T[j]){
    BT2[j-1]=BT2[j-1]+Brein
    # print(BT[j-1])
  }

  #Now, back to normal Lancheter
  BT2[j] = max(0,
            BT2[j-1] – rho*h*RT2[j-1])
  RT2[j] = max(0,
            RT2[j-1] – beta*h*BT2[j-1])
}

ret = data.frame(Time = T,
```

```
            Blue = BT,
            Red = RT,
            Blue2=BT2,
            Red2=RT2)

}

Combined2 = function(Bo = 20640,
             beta = .054,
             rho = .01199,
             StartBoats = 50,
             FightersPerBoat = 450,
             Dist = 100,
             Speed = 20,
             Brein = 10000,
             Brein_T = 24,
             InboundRisk = .1,
             OutboundRisk = .05,
             tmax = 72,
             h = .1
){
 FirstTrip = floor(Dist/Speed) #FIRST TRIP IS DIFFERENT
 RoundTrip = floor(2*Dist/Speed) #Floor rounds to previous hour

 T = seq(0, tmax, by = h) #For the lanchester portion
 n = length(T)
 BT = rep(0, n)
 RT = rep(0, n)
 BT2 = rep(0, n)
```

```
RT2 = rep(0, n)

BT[1] = Bo
RT[1] = 0 #Because they haven’t shown up yet

BT2[1] = Bo
RT2[1] = 0 #Because they haven’t shown up yet

#Figure out the delivery schedule first!

TT = vector()
Delivered = vector()
TripIncr = RoundTrip
i = 1

#First Trip is different
TT[i] = FirstTrip #bookkeeping #FIRST TRIP IS DIFFERENT
These.Boats = rbinom(1, StartBoats, (1-InboundRisk))#(1-InboundRisk)*StartBoats
Delivered [i] = These.Boats*FightersPerBoat
while(TT[i] <= tmax){
  i = i+1
  TRisk = (1-OutboundRisk)*(1-InboundRisk)
  These.Boats = rbinom(1, These.Boats, TRisk) #These.Boats*(1-OutboundRisk)*(1-InboundRisk)
  TT[i] = TT[i-1] + TripIncr
  Delivered [i] = These.Boats*FightersPerBoat
}

del = data.frame(TT, Delivered)
.GlobalEnv$del2<-del
```

```
for(j in 2:n){
 #Check if a landing occurred
 if(T[j] %in% del$TT){
  #print(T[j])
  #print(del$Delivered [which(del$TT == T[j])])
  RT[j-1] = RT[j-1] + del$Delivered [which(del$TT == T[j])]
  #Arrivals happen at end of last turn
  #print(RT[j])
 }

 #Now, back to normal Lanchester
 BT[j] = max(0,
       BT[j-1] – rho*h*RT[j-1])
 RT[j] = max(0,
       RT[j-1] – beta*h*BT[j-1])
}

#FOR REIN
for(j in 2:n){
 #Chieck if a landing occurred
 if(T[j] %in% del$TT){
  #print(T[j])
  #print(del$Delivered [which(del$TT == T[j])])
  RT2[j-1] = RT2[j-1] + del$Delivered [which(del$TT == T[j])]
 }

 #THIS IS THE CODE FOR Reinforcement
```

```
  if(Brein_T == T[j]){
   BT2[j-1]=BT2[j-1]+Brein
   # print(BT[j-1])
  }

  #Now, back to normal Lancheter
  BT2[j] = max(0,
              BT2[j-1] – rho*h*RT2[j-1])
  RT2[j] = max(0,
              RT2[j-1] – beta*h*BT2[j-1])
 }

 ret = data.frame(Time = T,
                Blue = BT,
                Red = RT,
                Blue2=BT2,
                Red2=RT2)

}

##Let's see if there's a difference?

Determ = Combined(Bo = 20640,
                StartBoats = 50,
                FightersPerBoat = 450,
                InboundRisk = .1,
                OutboundRisk = .05)
Stoch = Combined2(Bo = 20640,
                StartBoats = 50,
```

```
            FightersPerBoat = 450,
            InboundRisk = .1,
            OutboundRisk = .05)

Stoch %<>% select(-Time)

mods = cbind(Determ, Stoch)

names(mods) = c("Time," "BD," "RD," "BD2," "RD2","BS","RS","BS2","RS2")

mods %>% select(-4,-5,-8,-9)%>% melt(id.vars = "Time") %>%
 ggplot(aes(x = Time, y = value, color = variable, shape=variable)) +
 geom_point(size=3) +
 scale_shape_manual(values=c(20,20,42,42),labels=c("TW D","CN D","TW S","CN S"))+
 scale_color_manual(values=c("#3B4992FF","#EE0000FF",'#008B45FF','#A20056FF'),labels=c("TW
D","CN D","TW S","CN S"))+
 labs(title="Determinsitic vs. Stochastic Result",subtitle = "Vignette One: One
Rep",color="Force",shape="Force") +
 xlab("Time (Hours)")+
 scale_y_continuous(name = "Fighters,"
             labels = scales::comma)+
 guides(color = guide_legend(override.aes = list(size = 4.5)))+
 theme(title=element_text(size=28, face='bold'), plot.title = (element_text(hjust = 0.5)),plot.subtitle =
(element_text(hjust=0.5,size=24)),
     axis.text.y = element_text(size=24),axis.text.x = element_text(size=24),legend.text = element_text(size
= rel(2.2)))

# ggsave("8_Vig One D v S.png",width = 11, height = 8.5,bg="white")

mods %>% select(-2,-3,-6,-7)%>% melt(id.vars = "Time") %>%
 ggplot(aes(x = Time, y = value, color = variable, shape=variable)) +
```

```
 geom_point(size=3) +

 scale_shape_manual(values=c(20,20,42,42),labels=c("TW D","CN D","TW S","CN S"))+

 scale_color_manual(values=c("#3B4992FF","#EE0000FF",'#008B45FF','#A20056FF'),labels=c("TW
D","CN D","TW S","CN S"))+

 labs(title="Determinsitic vs. Stochastic Result",subtitle = "Vignette Two: One
Rep",color="Force",shape="Force") +

 xlab("Time (Hours)")+

 scale_y_continuous(name = "Fighters,"

                   labels = scales::comma)+

 guides(color = guide_legend(override.aes = list(size = 4.5)))+

 theme(title=element_text(size=28, face='bold'), plot.title = (element_text(hjust = 0.5)),plot.subtitle =
(element_text(hjust=0.5,size=24)),

       axis.text.y = element_text(size=24),axis.text.x = element_text(size=24),legend.text = element_text(size
= rel(2.2)))


# ggsave("9_Vig Two D V S.png",width = 11, height = 8.5,bg="white")




####Force Ratio####

mods2=mods

mods2$`D FR`<-mods2$RD/mods2$BD

mods2$`S FR`<-mods2$RS/mods2$BS

mods2$`D FR2`<-mods2$RD2/mods2$BD2

mods2$`S FR2`<-mods2$RS2/mods2$BS2


mods2[, c(1,10,11)] %>% melt(id.vars = "Time") %>%

 ggplot(aes(x = Time, y = value, color = variable, shape=variable)) +

 geom_point(size=3) +

 scale_shape_manual(values=c(20,42),labels=c("CN D","CN S"))+

 scale_color_manual(values=c('#EE0021FF','#A20056FF'),labels=c("CN D","CN S"))+

 labs(title="Determinsitic vs. Stochastic Result",subtitle = "Vignette One: One
Rep",color="Force",shape="Force") +
```

```
 xlab("Time (Hours)")+

 geom_hline(yintercept = 3, size=.75,color='black',linetype='longdash')+

 scale_y_continuous(name = "Force Ratio",

                  labels = scales::comma,

                  limits=c(0,8))+

 guides(color = guide_legend(override.aes = list(size = 4.5)))+

 theme(title=element_text(size=28, face='bold'), plot.title = (element_text(hjust = 0.5)),plot.subtitle =
(element_text(hjust=0.5,size=24)),

      axis.text.y = element_text(size=24),axis.text.x = element_text(size=24),legend.text = element_text(size
= rel(2.2)))


# ggsave("10_Vig One D V S FR.png",width = 11, height = 8.5,bg="white")


mods2[, c(1,12,13)] %>% melt(id.vars = "Time") %>%

 ggplot(aes(x = Time, y = value, color = variable, shape=variable)) +

 geom_point(size=3) +

 scale_shape_manual(values=c(20,42),labels=c("CN D","CN S"))+

 scale_color_manual(values=c('#EE0021FF','#A20056FF'),labels=c("CN D","CN S"))+

 labs(title="Determinsitic vs. Stochastic Result",subtitle = "Vignette Two: One
Rep",color="Force",shape="Force") +

 xlab("Time (Hours)")+

 geom_hline(yintercept = 3, size=.75,color='black',linetype='longdash')+

 scale_y_continuous(name = "Force Ratio",

                  labels = scales::comma)+

 guides(color = guide_legend(override.aes = list(size = 4.5)))+

 theme(title=element_text(size=28, face='bold'), plot.title = (element_text(hjust = 0.5)),plot.subtitle =
(element_text(hjust=0.5,size=24)),

      axis.text.y = element_text(size=24),axis.text.x = element_text(size=24),legend.text = element_text(size
= rel(2.2)))


# ggsave("11_Vig Two D v S FR.png",width = 11, height = 8.5,bg="white")
```

```
# setwd("")
# write.csv(mods2, file="2_Stoch Land_Determin Battle.csv")
###########Variation############
variation=function(n=30){
 Min_FOM = 1000000
 Max_FOM = -100000

 Min_FOM2 = 1000000
 Max_FOM2 = -100000

 count<-list()
 count2<-list()
 out<-list()
 out2<-list()
 for(i in 1:30){
  this.model= Combined2(Bo = 20640,
                      beta = .054,
                      rho = .01199,
                      StartBoats = 50,
                      Dist = 100,
                      Speed = 20,
                      Brein = 10000,
                      Brein_T = 24,
                      InboundRisk = .1,
                      OutboundRisk = .05,
                      tmax = 72,
                      h = .1)
  FOM = this.model$Time [which(this.model$Red/this.model$Blue > 3)[1]]
  FOM2 = this.model$Time [which(this.model$Red2/this.model$Blue2 >3)[1]]
```

```
  if(!is.na(FOM)){
    if(FOM < Min_FOM){Min_FOM = FOM}
    if(FOM > Max_FOM){Max_FOM = FOM}
    count<-append(count,FOM)
    rep<-paste0("Victory – Rep: ",i)
    out<-append(out,rep)

  }
  if(!is.na(FOM2)){
    if(FOM2 < Min_FOM2){Min_FOM2 = FOM2}
    if(FOM2 > Max_FOM2){Max_FOM2 = FOM2}
    count2<-append(count2,FOM2)
    rep2<-paste0("Victory – Rep: ",i)
    out2<-append(out2,rep2)
  }
 }

 if(length(out)!=0){
 vig_1<-data.frame("Rep"=matrix(unlist(out)),"FOM"=matrix(unlist(count)))
 .GlobalEnv$vig_1<-vig_1
 }
 if(length(out2)!=0){
 vig_2<-data.frame("Rep"=matrix(unlist(out2)),"FOM"=matrix(unlist(count2)))
 .GlobalEnv$vig_2<-vig_2
 }
}

set.seed(2581)
```

```
variation(n=30)


#Vignette 1

sum(vig_1$FOM)/length(vig_1$FOM)

min(vig_1$FOM)

max(vig_1$FOM)


#Vignette 2 ####NO VICTORY CASES

sum(vig_2$FOM)/length(vig_2$FOM)

min(vig_2$FOM)

max(vig_2$FOM)


vig_c<-bind_rows(list(dat1=vig_1,dat2=vig_2),.id=“datasets”)


ggplot(vig_c,aes(FOM,fill=datasets,color=datasets))+

 scale_fill_manual(values=c(‘#EE0021FF’,’#A20056FF’),label=c(‘One’,’Two’))+

 geom_histogram(breaks=c(30,35,40,45,50,55,60,65,70,75),color=‘black’,position = “stack”)+

 labs(title = “30 Iterations: Vignette Comparison”,fill=“Vignette”)+

 xlab(“Time (Hour)”)+ylab(“Victory Case”)+

 theme(title=element_text(size=28, face=‘bold’), plot.title = (element_text(hjust = 0.5)),plot.subtitle =
(element_text(hjust=0.5,size=24)),

       axis.text.y = element_text(size=24),axis.text.x = element_text(size=24),legend.text = element_text(size
= rel(2.2)))


# ggsave(“11.5_Vig Compare FOM.png”,width = 11, height = 8.5,bg=“white”)


# setwd(““)

# write.csv(vig_1, file=“4_30Reps_Stochastic_FOM.csv”)

# write.csv(vig_2, file=“5_30Reps_Stochastic_FOM2.csv”)
```

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Acquisition Research Program
Naval Postgraduate School
555 Dyer Road, Ingersoll Hall
Monterey, CA 93943

www.acquisitionresearch.net