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The Strait of Hormuz:
Political-Military Analysis of Threats to Oil Flows

Lyndon B. Johnson School of Public Affairs
Policy Research Project Report

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Executive Summary

The Strait of Hormuz, a narrow waterway between Oman and Iran, is a sensitive global oil supply chokepoint. Each day, about 17 million barrels of oil, or 20 to 30 percent of the world's oil supply, is exported by oil tankers through the Strait. The maintenance of secure oil throughput in the Strait is a central U.S. foreign policy issue and Iran is positioned as the key player of concern in a potential disruption in the Strait.

There are extreme political contexts in which Iran could find it strategically advantageous to disrupt the flow of oil through the Strait. For example, an aggressive adversary could push Iran to take a methodical or hurried action in response to economic sanctions or an adversary may take preventative military action against a perceived threat, Iranian nuclear facilities, prompting an Iranian response.

Since the key to affecting the global oil market is to reduce the available supply of the valuable commodity, stopping tanker transits seem like the most effective way for Iran to operate. Our analysis identifies very large crude carrier (VLCC) oil tankers traversing the Strait as the most likely targets of an attack. These tankers operate in high volume and concentration through the Strait and would likely be targets for an intended oil market disruption. Our research assesses that small boats, missiles, and mines would serve as the most effective weapons for damaging VLCCs. We selected these three weapons based on their historical use, explosive capabilities when facing a VLCC, and the propensity of Iran to use them to achieve their goal.

Our military campaign analysis estimates that in the best case for Iran, it could significantly damage 33 percent of the tanker traffic on a given day, about seven VLCC tankers. Most of the tankers could be repaired after a period of time and can be returned to the tanker fleet. This damage estimate compensates for any abnormalities in the data calibration and awards Iran the benefit of the doubt in every case including doubling the estimate for the limiting variable. If they were to use missiles, they could expect to significantly damage about 25 percent of the tanker traffic on a given day, about five VLCC tankers. If Iran lays a minefield, only six or seven tankers would be affected during the entire time that the minefield is active, assuming tankers continue to complete their routes. The estimate of significant damage to tankers due to small boat suicide attacks translates into 14 million barrels of oil prevented from going through the Strait in one day. This shortage could be compensated for through the Strategic Petroleum Reserves (SPR) or increased production in other oil producing countries. Most likely the shortage will create some panic among the public and possibly increase oil prices for a limited time. These oil prices would drop when oil transport returns to normal shortly after the attack.

Therefore, short-term disruption of oil flow, even if it accounts for as much as 14 million barrels in one day, is not going to be enough. Initial effects of disruption can be relieved through the Arabian Peninsula pipelines which can serve as alternatives to sea routes; slack capacity in the market that can alleviate the effects for a period of time; and the

Strategic Petroleum Reserves that can replace the daily consumption rate in the United States for almost two months.

In order to actually affect the market, Iran would have to stop six million barrels of crude oil a day for at least two weeks. There is no need, however, to panic about a long-term disruption that could lead to an energy crisis. Assuming that Iran is successful on the first day of the campaign, several defensive measures could go into place, reducing the possibility of a second successful Iranian attack. Depending on the severity of these attacks, defensive measures could range from tanker captains turning off their radar and varying their routes to a U.S naval strike against Iran. In any case, the most significant damage will be done on the first day.

The bottom line is that if a disruption to oil flows were to occur, the world oil market retains built in mechanisms to assuage initial effects. And since the long-term disruption of the Strait, according to our campaign analysis, is highly improbable, assuaging initial effects might be all we need. Panic, therefore, is unnecessary.

Chapter 1. Project Description

Given the focus on the U.S.-Iran relationship in contemporary policy discussions and the explicit threats from Iran to respond to U.S. military pressure with attacks on oil flows, the project's core effort focuses on analysis of a possible Iranian effort to close the strait. Such an effort would presumably capitalize on Iranian geographic and military advantages: Iranian access to the strait from its coastline and from nearby islands and the Iranian arsenal of small boats, anti-ship cruise missiles, and mines suited to attacks on shipping. The project conducts a military campaign analysis of Iran's capability to use these various tools to disrupt oil flows.

Many experts fear that an accident, terrorist attack, or military effort to close the Strait of Hormuz, even temporarily, could threaten the global economy. To calm fears in energy markets, the American military's current posture in the Persian Gulf emphasizes a forward American presence, including patrolling the waters with U.S. Navy warships. Some have even referred to the recently issued U.S. Navy Maritime Strategy as designed to provide military protection to globalization: America's active leadership provides a key global public good, the protection of international commerce and especially the oil trade.

American strategic thinkers also add the auxiliary assumption that international business is likely to panic and run from the first sign of conflict. Our study suggests that this strategic analysis substantially exaggerates the dangers of a political-military disruption to oil supply that would be large enough to have a significant effect on the market. Any attack is likely to produce short-term panic: traders in the global market will naturally fear that more attacks are coming, and they will take a few days to assess the actual level of supply disruption.

The international oil market has built-in compensation mechanisms that can readily handle the loss of up to a couple of million barrels a day. On the other hand, cutting off all 17 million barrels of oil a day that transits the strait would indeed overwhelm private inventories, slack production capacity outside the Persian Gulf, and even public inventories like the U.S. Strategic Petroleum Reserve. To consider an effort to close the Strait dangerous beyond the initial panic stage, the attack would have to threaten to stop six million barrels a day of crude oil from getting out to the Indian Ocean (and then on to consumers' ports around the world).

But stopping six million barrels a day is not an easy task, even given the resources of a state-based threat with a relatively large military (like Iran). Oil tankers (specifically, very large crude carriers, or VLCC's, the type of ship that normally carries crude oil in the Persian Gulf) are difficult targets. Historically, most attacks on tankers have failed to stop their transits even when they succeed in hitting their targets because of the resilient architecture of this kind of vessel, and the geographic and bathymetric conditions in the southern Persian Gulf and the Strait of Hormuz severely constrain the ability to hit tankers with missiles, mines, or small suicide boats. Iran's current arsenal is at least a generation more sophisticated than the arsenal used in the 1980's Tanker War between

Iran and Iraq, when hundreds of oil tankers were attacked with little effect on global markets, but systematic campaign analysis shows that even the new weapons cannot achieve a sustained disruption.

Chapter 2. Strategic Importance of the Strait

The Strait of Hormuz is strategically important to the United States (U.S.) given the significance of oil to the global economy. Analysts often fear that a terrorist attack or military operation in the strait would threaten the global economy. Oil throughput in the Strait of Hormuz continues to be a central U.S. foreign policy issue, and the U.S. maintains its role as the "protector" of Middle Eastern oil because in the event that oil cannot pass through, few alternative routes exist. This role was reinforced by the Iraq War in 2003 and the ongoing tensions between the U.S. and Iran over Iran's nuclear capabilities. Hostile U.S.-Iranian relations have increased concerns about the vulnerability and sensitivity of oil flow through the strait.

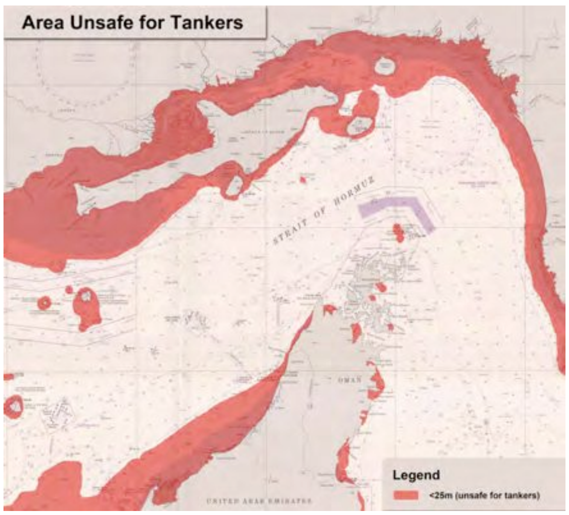

Figure 1. Map of the Strait of Hormuz

Geography

Connecting the Persian Gulf to the Gulf of Oman, the warm waters of the Strait of Hormuz reach depths of 330 feet.[1] Over 33,000 ships traverse the Strait each year.[2] At its

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[1] Colbert C. Held, *Middle East Patters: Places, Peoples, and Politics* (Boulder, CO: Westview Press, 2006), p. 27.

narrowest point, 21 miles across, the Strait can become dense and congested as thousands of smaller fishing boats, sea vessels and water craft join dry cargo, container, passenger ships and liquid natural gas, chemical, and oil tankers.

The physical geography of the area illustrates why the Strait of Hormuz is a chokepoint. In peacetime, ships enter and exit the strait through a six-mile wide traffic separation scheme (TSS) recognized by the International Maritime Organization (IMO). Each lane is two miles wide with a two-mile buffer in between. Due to high temperatures, thick haze tends to cloak the area, and pervasive sand storms in the Persian Gulf add to the strenuous conditions in which transport flows in and out of the Persian Gulf.[3]

Iran claims seven strategically located islands inside or near the Strait. Qeshm, Larak, Hormuz, Hengam, Abu Musa and Greater and Lesser Tumb all lay in or near the TSS. The islands are mostly barren with small populations, but their location and potential for military bases makes them strategically valuable.[4]

Military Presence in the Region

U.S. and Coalition Forces

The United States also maintains a formidable presence in the area around the Strait of Hormuz. Fifth Fleet is the naval component of U.S. Central Command and exercises operational control over maritime forces in the area around the Strait. It is headquartered in Manama, Bahrain, and bears responsibility for areas including the Persian Gulf, Red Sea, Gulf of Oman, and parts of the Indian Ocean. Fifth Fleet provides a variety of services and security measures in the Gulf region including mariner assistance, protection of infrastructure, piracy deterrence, and combat operations. It operates under international maritime law to maintain secure and safe international waters for all commercial shipping vessels. Combined Task Force (CTF) 150 is a multinational force with the Strait of Hormuz in its area of responsibility. The nations of Pakistan, Canada, France, Germany, the United Kingdom, and the United States all contribute to the approximately 15 vessels in CTF 150. Command of the CTF is shared among participating nations and rotates every four to six months. This force would likely respond first to any scenario involving the Strait.

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[2] Interview by Colin Murphy and John Losinger with Daryl Williamson and Wally Mandryk, Lloyd's Marine Intelligence Unit, London, United Kingdom, February 18, 2008.

[3] "OSS Dust, Sunglitter," NASA Visible Earth. Online. Available: http://daac.gsfc.nasa.gov/oceancolor/shuttle_oceanography_web/oss_58.shtml. Accessed: March 18, 2008.

[4] Pirouz Mojtahed-Zadeh, *Security and Territoriality in the Persian Gulf* (Cornwall: Curzon Press, 1999), p. 30.

In addition to the Naval base, the U.S. Coast Guard has maintained a presence in the Gulf since November 2002. Though first established as a part of Operation Iraqi Freedom, the Coast Guard presence became permanent in 2004. This force conducts maritime patrols and is responsible for oil platform security in the Persian Gulf. U.S. military presence in the Persian Gulf makes any sustained Iranian attack difficult. Iran's first-mover advantage would be limited by superior U.S. air and naval forces, which would respond quickly to any significant Iranian provocation in the strait.

Regional Partners

The Gulf Cooperation Council (GCC) is a trade bloc with shared defense responsibilities. Founded in 1981, its member nations are Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates. The GCC's immediate objective was to provide a common defense against the threat of the Iran-Iraq War. Further, GCC members felt that their organization would be a good counterbalance to Iranian-inspired Islamic fundamentalism. They believe that an act of aggression toward one of them is an act of aggression toward all of them, and thus the GCC can be construed as a collective security organization.

If there is an armed conflict in the Strait of Hormuz, it is likely that GCC member states would respond immediately to protect their shared commercial interests. Therefore, it is important to assess the military capabilities of GCC members. Saudi Arabia and Kuwait (under the auspices of the GCC) have bolstered the sea and air defense around the Strait of Hormuz.

In conclusion, the Strait of Hormuz is a vital world oil chokepoint. Any threat to the Strait raises concerns not only in the U.S., but in the larger international community as well. However, the U.S. and coalition forces in the region posture to counter potential threats to the strategic waterway. The physical characteristics of the Strait make it difficult to navigate. This means that defending the Strait from potential threats is difficult. On the other hand, the same characteristics make targeting the Strait difficult as well.

Chapter 3. Political Contexts in which Iran would take Action

Knowledge of world affairs, the U.S.-Iran dynamic, and the Iranian military structure provide the foundation for understanding the possible scenarios that might lead to conflict in the Strait of Hormuz. Depending on how the conflict evolves, Iran might activate a variety of military plans designed to address changes or shifts in international politics. If Iran strikes first in a conflict, it could do so with the full force of its military assets. If Iran strikes second in response to an initial U.S. or Israel strike, then its options will likely be limited by the damage to infrastructure or military assets. In either case, a methodical attack on the part of Iran would look different from a rushed, short-term attack. The working group conceptualized these four scenarios to frame military analysis. These four scenarios are not intended to be detailed forecasts of U.S.-Iran relations or predictions about Iranian behavior. They are informed generalizations about how a conflict in the Strait of Hormuz might occur.

Iran Initiates with a Methodical Attack

Tehran has a healthy respect for the U.S. military, particularly air and naval capabilities. This respect stems from the decisive U.S. victory in Operation Praying Mantis during the Tanker War. In 1988, Tehran drastically underestimated the U.S. Navy and lost half of its naval assets in a matter of hours.[1] Since this victory, Iran has demonstrated a tendency to back down when faced with a military confrontation with U.S. forces. In spite of this prudence, it is not unreasonable to imagine a scenario where Iran might initiate a methodical first strike against the U.S.[2]

Under the Iranian constitution, political power and military command are shared between the President and the Supreme Religious Leader. Despite the fact that the president is popularly elected, the Supreme Leader can remove the president from office with the support of the Parliament. In addition, the Supreme Leader maintains control over the Iranian military.[3] It is not unreasonable to imagine that the existing tension between the religious and political leaders could result in a regime change that puts either the religious leader or a more extremist political leader in control. Under these circumstances, it is plausible to imagine that the new leadership would choose to engage the U.S. and the West on ideological grounds.

If this were to happen, then Iran could implement a methodical and strategic planned attack against U.S. economic interests by disrupting the flow of oil through the Strait of Hormuz. Iran could, for example, lay a large, well-designed minefield in a strategic area

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[1] "Nine Hours that sank Iran's Navy: The Gulf," The London Times. April 24, 1988.
[2] Meeting with Kenneth Pollack, March 20, 2008, Austin, TX.
[3] Wilfried Buchta, *Who Rules Iran?* Washington, D.C.: Washington Institute for Near East Policy, 2004, xi.

of the strait over a matter of months. Such an attack would likely be the most disruptive to U.S. interest in the region, because Iran would have time to execute a large-scale military disruption through surreptitious deployment and readiness of military assets.

Iran Initiates with a Rushed Attack

Response to Sanctions

Since the Bush administration took office, Iran has faced increased international scrutiny concerning the objectives of its nuclear program. The U.S. has approached the United Nations Security Council on numerous occasions to pursue economic and diplomatic sanctions to deter Tehran and demand greater transparency and more rigorous inspections for its nuclear installations. If the UN voted to impose sanctions on Iran, there are at least two plausible ways that Tehran might respond.

First, Iran might pursue a limited response to antagonize the U.S. and the West, ultimately leading to a tit-for-tat escalation of the conflict in the Persian Gulf. Iran could combat the increase in international pressure with an isolated missile attack on one ship in the Gulf, or a quick deployment of a few mines to cause alarm in the shipping community. Under this scenario, it is reasonable that the U.S. would execute a limited response, and that the cycle might escalate into a larger conflict in the Strait of Hormuz.

Second, Iran could use a disruption in the Strait as leverage to create a quick crisis in order to pressure the international community to lift sanctions or negotiate. This crisis might result from a deployment of Iranian military assets over a matter of a few weeks. In either case, the Iranian response would likely be limited because of U.S. military superiority and the need for a swift and timely response to sanctions.

Iranian Revolutionary Guard (IRGC) Entrepreneurship

IRGC entrepreneurship could also lead to a conflict in the Strait of Hormuz. The IRGC functions as an independent source of power within the Iranian government structure. IRGC members are recruited based on their religious and nationalist ideology and then trained in Islamic and Iranian ideological thought.[4] This kind of indoctrination within system of merit could reasonably create the perception among IRGC members that aggression against U.S. or Western targets in the Gulf region would be rewarded by the regime.

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[4] Mehdi Moslem, "Factional Politics in Post-Khomeini Iran," Syracuse, New York: Syracuse University Press, 2002.

If an IRGC leader or some group of IRGC members took the opportunity to demonstrate their ideological fervor by harassing or attacking commercial traffic or a U.S. military vessel in the Gulf, it is plausible that the regime would take responsibility for the incident. Denying responsibility for such an attack could be perceived by Tehran as a signal to the international community that the regime is weak lacks coordination, or experiences command-and-control problems.

Recent history suggests that this is a reasonable assumption. On March 23, 2007, after IRGC craft seized 15 members of the British Royal Navy and Marine Corps, Tehran took responsibility for the incident. The Iranian government claimed that the sailors were arrested for entering Iranian territorial waters, but the sailors were soon released unharmed without further explanation from Tehran.[5] In similar fashion, IRGC speedboats swarmed a U.S. Naval ship in the Persian Gulf in January 2008.[6] While these events received a good deal of media attention, this type of confrontation is not unusual in the Persian Gulf. It is reasonable to imagine that not all interaction between Iranian and U.S. forces in the region are instructed by Tehran.

Iran Responds

The Bush administration has consistently stated that "all options remain on the table" when dealing with Iran, particularly on the issue of nuclear proliferation. Both the U.S. and Israel have articulated a commitment to preventing Iran from developing a nuclear weapon. If Washington or Jerusalem had reason to believe that Iran was getting close, a preventive strike against Iran's nuclear facilities is one possibility.[7] Iran could respond in at least two ways.

Methodical Execution of an Attack

An initial strike would damage Iran's military capabilities, limiting its ability to respond. Iran could buy time to recover from the first strike with diplomatic appeals to the international community, citing its right to nuclear energy. By playing the good guy and calling for international condemnation of the preventive attack, Iran avoids the

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[5] Sarah Lyall, "Iranians, Alleging 'Agression,' Seize 15 Britons on Naval Patrol in the Waters off Iraq," The New York Times, March 23, 2007.

[6] Thomas Shanker and Brian Knowlton. "Iranian Boat Confronts U.S. in Persian Gulf," The New York Times, January 8, 2008.

[7] David E. Sanger, "U.S. Keeps Options Open on Iran; Washington Mixes Diplomacy with Shows of Potential Force," The International Herald Tribune, February 26, 2007.

appearance of weakness while planning its retaliation. The delayed response would be less extensive than a first strike, but more methodical that an immediate military response. Also, the international community might be less suspicious if Iran doesn't respond immediately, allowing some degree of maneuverability and planning for Tehran.

Rushed Execution of an Attack

Internal tensions of the Iranian regime and the desire for regional supremacy would likely be exacerbated by an attack on nuclear installations, making it more likely that Iran would act out of anger or desperation. If the regime is under duress, Tehran could use whatever is left after the initial strike to launch an immediate response. Iran could use non-military tools to overcome the military losses incurred during the initial strike. For example, Iran might launch a series of small boats suicide attacks in the days following the initial strike. These asymmetrical tactics could serve as a deterrent threat to a more extensive attack from the West.

In conclusion, Iran's ability to make trouble in the strait depends on how the conflict evolves. A carefully planned, methodical attack using the full arsenal of military capabilities will look very different from a rushed response to a U.S. or Israeli strike. The scale of the disruption would likely be smaller in the rushed and second-strike scenario than if Iran goes first with its full arsenal.

Chapter 4. Defining a Substantial Disruption to the Oil Market

When military disturbances occur in the Strait of Hormuz, analysts worry about the effects this might have on the world oil market. According to the Energy Information Administration (EIA), the Strait of Hormuz is one of the "world's most strategic chokepoints,"[1] which is responsible for nearly 20 percent of the world's oil supply. This agency describes any temporary disruption in the transport of energy through this chokepoint as a serious global problem that "can lead to substantial increases in energy costs."[2] Analysts and policy-makers believe that the effect from a military disruption in the Strait on the global oil supply could easily send prices soaring in the oil market. For example, according to The Lugar Energy Initiative, a disturbance "would affect our way of life—from the financial markets and international trade to airline travel and gas prices—for months."[3]

Serious implications are inherent in this kind of statement. Despite the Lugar Energy Initiative concerns that suspending oil traffic through the Strait is not only possible, but easily done, the data suggests otherwise. During the peak of the Tanker War in 1987 only a total of 154 merchant ships were attacked.[4] This represents a "small proportion of trade in the Gulf which averaged 580 large ship movements per month."[5] Closing the Strait would be an extremely difficult feat to accomplish even by a state military actor.

Because it is one of the main supply channels of the world's oil, a *sustained* disruption in the Strait of Hormuz would have a major impact on the global oil market. Yet, it is extremely improbable that a *minor* disruption, such as one on the scale of a terrorist attack or a state military actor, would be sufficient as to trigger an economic shock in the

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[1] Energy Infromation Administration (EIA), *World Oil Transit Chokepoints*. Online. Available: http://www.eia.doe.gov/cabs/World_Oil_Transit_Chokepoints/Background.html. Accessed: April 20, 2008.

[2] EIA. *World Oil Transit Chokepoints*.

[3] The Lugar Energy Intitiative, *World Oil Chokepoints*. Online. Available: http://lugar.senate.gov/energy/security/chokepoints.cfm#hormuz. Accessed April 26, 2008.

[4] Martin S. Navias and E.R. Hooton, *Tanker Wars: the assault on merchant shipping during the Iran-Iraq Conflict, 1980-1988* (New York: Tauris and Co Ltd, 1996), p. 163.

[5] Navias and Hooton, *Tanker Wars: the assault on merchant shipping during the Iran-Iraq conflict, 1980-1988,* p. 163.

global oil market. These small disruptions would not cause the kind of large-scale economic impact to the oil market that would be felt by taxpayers at the pumps.

In order to create a major shortage in the global oil market, a significant portion of the 17 million barrels leaving the Strait each day would need to be prevented from reaching its many destinations all over the world. A disruption would have to be sustained for a matter of weeks to overwhelm slack capacity in the market, and the publicly held and privately held strategic reserves.

Compensating for a Disruption

Most of the oil shipped out of the Persian Gulf is carried by very large crude carrier (VLCC's) tankers that can individually carry approximately two million barrels of oil. While this number may seem very substantial, two million barrels is a small fraction of the estimated 84.6 million barrels produced daily to meet world demand. Therefore, an attack on one oil tanker is highly unlikely to significantly impact the oil market. Multiple VLCC's would need to be stopped from transiting through the Strait to create a large disruption.

Sea routes are the primary outlets for oil from the Persian Gulf, but oil pipelines are also used to transport oil out of the region. Saudi Arabia's East-West Pipeline could potentially increase its capacity from 5.1 million barrels per day (mbpd) to 8.3 mbpd by increasing its pumping power with drag-reduction agent injectors.[6] The agent injectors allow for a higher volume of oil to be pumped out of this pipeline and into storage containers. In doing so, tankers could then travel and load oil at Yanbu. With the amount of oil output increased by 3 million barrels of oil, this additional production could maintain the level of oil coming out of the Gulf if 8 million barrels (about 4 VLCC's) were able to transport oil out through the Strait.

Unfortunately, loading at Yanbu instead of in the Strait of Hormuz does increase the transit time of traveling to Asia by five days.[7] This increase in production by approximately three mbd is also not a long-term solution. Increased production could only be sustained as long as the drag-reduction agent injectors would be able to pick up sludge in the line. In a temporary conflict, this adjustment in the pipeline production could easily compensate for a few million barrels prevented from passing through the

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[6] M. Webster Ewell, Jr., Dagobert Brito, and John Noer. *An Alternative Pipeline Strategy in the Persian Gulf.* Online. Available: http://www.bakerinstitute.org/publications/TrendsinMiddleEast_AlternativePipelineStrategy.pdf. Accessed: April 26, 2008. p. 9.

[7] M. Webster Ewell, Jr., *An Alternative Pipeline Strategy in the Persian Gulf.* Online, p. 9.

Strait. In the event of a short-term conflict in the Persian Gulf, this East-West Pipeline is an alternative to holding the supply level of oil at its current volume.

Besides this key pipeline, slack capacity in the form of reserves could also assuage an initial shock in the global oil market. The worldwide petroleum reserve is estimated to have over 4 billion barrels as of 2007. The United States and Japan collectively hold 55 percent of the world's publicly and privately-held stockpiles. When counting only the publicly held stockpiles, these two countries hold 2/3 of the global publicly held oil stockpiles.[8] Currently there are 698.6 million barrels of oil in the Strategic Petroleum Reserve (SPR), which could replace the daily consumption rate of oil for 57 days. President Bush recently authorized for the SPR to be increased to 1.5 billion barrels in order to meet future demand.[9]

Two key policy problems constrain usage of the SPR. First, there is no transparent policy instated that dictates exactly when and how the SPR is to be used. Currently, the SPR is under the jurisdiction of the president, and has been used in times of shortages such as after Hurricane Katrina. However, after the invasion of Kuwait by Iraq in 1991, five months passed before oil began flowing from the SPR to alleviate spiking oil prices caused by shortages. Given this slow reaction, it is questionable whether a disruption in the Strait would provoke an immediate response by the U.S. president. In order to combat the economic effects a disruption would have on the international energy market, U.S. policy-makers could develop and clearly stipulate a policy for using the SPR.

The second issue with using the SPR is that Government Accountability Office (GAO) estimates that a maximum of 4.4 mbpd could be drawn from the SPR.[10] If the demand for oil exceeded this amount, this might create an oil shortage in the market. This might not be a limiting factor given the difficulty of a sustained disruption in the Strait of Hormuz. If the Strait was only partially closed, preventing two or three oil tankers from transiting through each day, the U.S. could infuse an additional 4.4 mbpd for a total of 158 days (which would deplete the entire SPR and is also unlikely to occur, but possible). Also, the members of the International Energy Agency (IEA) could supply a surge of an additional 8.5 mbpd for approximately 90 days. Given the U.S. and IEA capability to supply the market with almost 13 mbpd for a minimum of two-three months, at least this much oil would have to be prevented from leaving through the Strait of Hormuz in order to cause a major economic impact to the world oil market.

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[8] Colin Murphy, *Current State of Slack Capacity in the Global Oil Market.* The University of Texas at Austin, December, 2007, p. 9.

[9] Ibid.

[10] Ibid, p. 11.

It is important to note that a disruption would necessarily affect importers *and* exporters of oil. A major disruption to the flow of oil would not only affect large importers of oil like the United States and China, but would crucially hurt oil-exporting countries in the Middle East, including Iran. According to the Central Intelligence Agency (CIA), 85 percent of the Iranian government's revenues are gained from its oil sector.[11] Any sustained disruption of oil would necessarily have a crippling impact on Iran's exporting capabilities, and therefore the country's revenue-generating capabilities.

Nevertheless, if an actor wanted to create a major economic crisis in the global oil market, a disruption in the Strait would need to be sustained until slack capacity in the market, publicly held reserves, and privately-held reserves were overwhelmed. A short-term disruption, such as stopping one or two VLCC's in a terrorist attack, may produce sensational reporting and cause panic, but would not create a major oil shortage in the global energy market.

While a sustained disruption in the Strait would affect the global oil market, it is challenging to define exactly how long it would have to be sustained to create a serious economic consequence. A one-day attack could not achieve a substantial disruption, and a year long campaign would certainly create an energy crisis. Given that notion it is important to understand how the oil market can adjust over time to fluctuations in oil production.

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[11] Central Intelligence Agency (CIA), *The World Factbook.* Online. Available: https://www.cia.gov/library/publications/the-world-factbook/geos/ir.html. Accessed: April 26, 2008.

Chapter 5. Oil Tankers

Due to the high volume and concentration of oil transiting the Strait of Hormuz each day, oil tankers can be seen as potential targets for someone intending to disrupt global oil markets. In 2005, 33,573 ships transited the Strait of Hormuz (16,953 inbound and 16,620 outbound).[1] Approximately 8,728 (26 percent) of these ships were crude oil tankers, meaning that an average of 23 tankers transited the Strait each day (12 inbound and 11 outbound).[2] Persian Gulf oil exports are transported through the Strait using *Suezmax* and very large crude carrier (VLCC) tankers, which can each hold up to one and two million barrels of oil respectively. In 2006, these tankers carried nearly 17 million barrels of oil per day (bbl/d) through the Strait, representing roughly two-fifths of global daily seaborne oil movements.[3]

Given the large quantities of oil carried by individual VLCC's, they make perfect strategic targets. However, the physical structure of modern oil tankers, and the number of available tankers for replacement make a sustained disruption of oil throughput in the Strait difficult. If one or more tankers were incapacitated, the size of the global oil tanker fleet and the dynamics of the tanker insurance market would ensure that replacement tankers were able and willing to fill the void.

Structure of Modern Oil Tankers

Nearly all modern oil tankers have double-hulls, inert gas systems, automatic fire-control systems, and sit very low in the water when filled with oil, making tankers difficult to successfully damage or sink. 1978 International Convention for the Prevention of Pollution From Ships (MARPOL) regulations require all oil tankers to contain segregated cargo tanks in order to minimize the likelihood of oil spillage due to grounding or collision.[4] In other words, if a tanker's hull were breached, it would only lose the oil from

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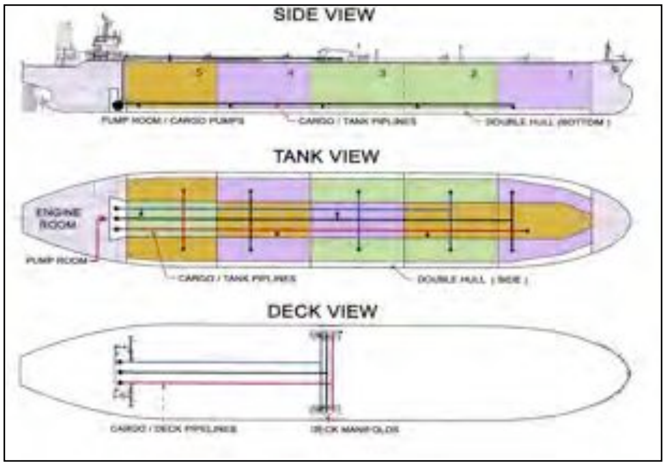
[1] Includes ships over 100 deadweight tons (dwt). Interview with Daryl Williamson and Wally Mandryk, Lloyd's Marine Intelligence Unit, London, United Kingdom, February 18, 2008.

[2] Interview with Daryl Williamson and Wally Mandryk, Lloyd's Marine Intelligence Unit, London, United Kingdom, February 18, 2008.

[3] "World Oil Transit Chokepoints," *Energy Information Administration*, January 2008, p. 3.

[4] "1978 Conference on Tanker Safety and Pollution Prevention," MARPOL 73/78. The Protocol expanded the requirements for segregated ballast tanks to all new crude oil tankers of 20,000 dwt and above and all new product carriers of 30,000 dwt and above. The Protocol also required segregated ballast tanks to be protectively located, in other words, placed in areas of the ship where they will minimize the possibility of and amount of oil outflow from cargo tanks after a collision or grounding.

the tank associated with that breach. The tanks are vertically segregated both from front to back (bow to stern) and from left to right (port to starboard), creating approximately 15 independent compartments (see figure 1).



Source: Pacific L.A. Marine Terminal LLC, 2008.

Figure 2. Double-Hull and Segregated Ballast Structure

Oil tankers' segmented cargo holds also help isolate fires, reducing fire damage and making the fire easier to contain.

Double-Hulls

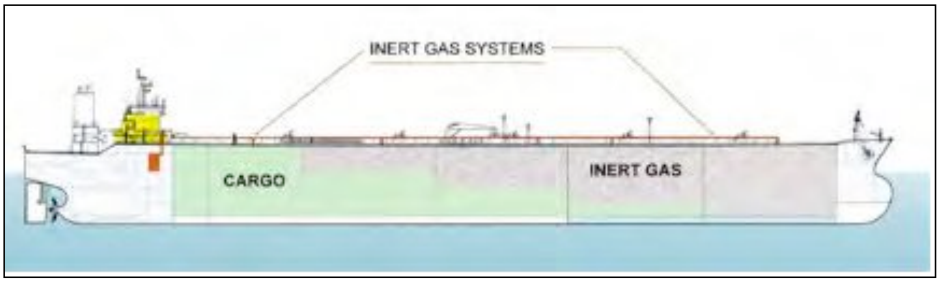
1992 MARPOL regulations stipulate that all oil tankers above 5,000 deadweight tons (dwt) are required to have double-hulls by 2010.[5] Largely the result of the 1989 *Exxon Valdez* (oil tanker) oil spill, the regulation was meant to minimize oil spillage after a collision or grounding. As a result, most modern oil tankers are double-hulled. In the event that either hull is breached—the inner hull due to metal fatigue or the outer hull due to metal fatigue or collision—the second hull serves to prevent cargo leakage and

[5] In 1992 MARPOL was amended to make it mandatory for tankers of 5,000 dwt and more ordered after 6 July 1993 to be fitted with double hulls, or an alternative design approved by IMO (Regulation 13F (regulation 19 in the revised Annex I which entered into force on 1 January 2007) in Annex I of MARPOL 73/78).

maintain the ship's ballast. Inadvertently, the regulation would also reduce subsequent oil spillage after a "collision" with a missile or mine.

Preventing Fire Damage to Cargo

Modern oil tankers also employ inert gas systems to prevent ignition of their cargo (oil) and automatic fire-control systems to minimize damages should a fire occur. Like gasoline, crude oil itself is not flammable. It is the oil's fumes, when mixed with oxygen in the atmosphere that are combustible. Because crude oil vapors will not generally burn in an atmosphere containing less than 11 percent oxygen by volume, inert gas, either from a dedicated inert gas generator or cleaned flue gas from the tanker's boiler, is pumped into any portion of a tanker's cargo holds not filled with oil to keep the oxygen levels below eight percent.[6] (see Figure 2).



Source: Pacific L.A. Marine Terminal LLC, 2008.

Figure 3. Inert Gas Systems

Because crude oil is flammable only when exposed to oxygen, mine attacks have often been ineffective against tankers. For example, when a Soviet-made M-08 contact mine hit the Bridgeton oil tanker as it was being escorted through the Strait of Hormuz by U.S. warships during the Iran-Iraq War, the mine created a large, thirty-by-fifteen foot hole in the tanker's bow, but failed to ignite its cargo or sink the ship.[7] Fire was prevented because the explosion occurred underwater and the tanker was able to stay afloat because only one of its cargo holds was breached. Because the majority of potential damage to oil

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[6] P. Galbraith, "Oil Tankers: Fire Safety by Design," *International Fire Engineers Journal* (January 1999). Online. Available: http://www.fire.org.uk/marine/papers/tankers.html. Accessed: April 10, 2008.

[7] Craig L. Symonds, *Decision at Sea: Five Naval Battles that Shaped American History* (Oxford: Oxford University Press, 2005), p. 285.

tankers happens after the initial attack, not from the initial explosion *per se*, modern inert gas systems represent one of the oil tankers' best defenses against extensive fire damage from an attack.

Most modern oil tankers also employ automatic fire-control systems. These systems include traditional water hydrants and foam-based systems, which help minimize subsequent fire damage if a tanker's oil cargo catches fire. Although the fire-control systems by themselves would be ineffective in a widespread tanker fire, a tanker's inert gas system and compartmentalized cargo holds would again likely isolate a fire, making fire-control systems more effective.

Burdened vs. Unburdened Tankers

Another important determinant of an oil tanker's resiliency against attack is whether it is full (burdened) or empty (unburdened). When an oil tanker is burdened, it sits very low in the water, as the oil it carries actually exceeds the weight of the ship.[8] This makes a fully loaded oil tanker difficult to identify both by the naked eye and by radar due to its smaller cross-section. Because such a large portion of the tanker lies below the sea's surface, a burdened oil tanker also has a much smaller vertical surface area for a missile to strike.

For example, Iran used empty oil tankers as decoys against Iraqi missile attacks during the Iran-Iraq War because the empty tankers were more likely to be identified and hit than the full tankers the decoys were protecting.[9] However, because replacement tankers would be available as substitutes, attacking an empty oil tanker would have only a negligible effect on oil throughput.

The Oil Tanker Industry

The oil tanker industry consists of four interrelated markets: 1) *Newbuilding* – trading of new vessels, 2) *Freight* – trading of sea transport services, 3) *Sale and Purchase* – trading of second-hand vessels, and 4) *Demolition* – trading of old and obsolete vessels.[10]

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[8] Thomas C. Gillmer and Bruce Johnson, *Introduction to Naval Architecture* (Annapolis: Naval Institute Press, 1982), p. 5.

[9] Martin S. Navias and E.R. Hooton, *Tanker Wars: The Assault on Merchant Shipping During the Iran-Iraq Crisis, 1980-1988* (New York: I.B. Taurus & Co Ltd, 1996), p. 87.

[10] "Oil Tanker Phase Out and the Ship Scrapping Industry," *European Commission Directorate-General Energy and Transport*, June 2004, p. 41.

The tanker market is highly fragmented, with over 80 percent of the world fleet owned by independent tanker companies. The ten largest independent tanker companies own 26 percent of the world fleet. Many private and state oil companies maintain their own fleets, which amounts to 11 percent of the world's tankers.

The size of the fleet is also an important factor in assessing how many spare tankers would be available if one or more tankers were incapacitated as a result of attacks in the Strait. A shortage of tankers might cause the cost of shipping to increase thereby increasing the cost of oil.

The cost of transporting oil via tankers is influenced by the amount of slack capacity, or unused tankers, in the tanker market. The shipping industry considers 90 percent utilization of the tanker fleet "full utilization" because tankers must dock routinely for maintenance. While the tankers are docked, they cannot transport oil. Therefore, if more than 90 percent of the tanker fleet is needed to transport oil, transportation costs would likely increase significantly.

In 2004, the world tanker fleet neared 100 percent utilization. As a result, tanker rates climbed to a record high. Currently, the utilization rate is dropping, increasing slack capacity, because many new ships were ordered in 2004 due to the high freight rates.

425 new oil tankers entered the market between 2001 and 2005, resulting in a worldwide fleet of 7,650 oil tankers.[11] Approximately 391 new oil tankers were also ordered in 2006 to be delivered in 2008 and 2009.[12] However, 151 single-hulled VLCC's are expected to leave the fleet by 2010 due to mandatory International Maritime Organization (IMO)/MARPOL 13-G phase-out schedules, leaving an estimated total fleet of 7,890 oil tankers by 2010, excluding any new orders after 2006.[13]

The age of the current oil tanker fleet helps determine the general characteristics (single vs. double hull, fire-control system, etc.) of the tankers comprising the fleet and how soon each tanker may be leaving the fleet.

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[11] "Tanker Fleet Development," *ISL Market Analysis*, 2005.

[12] A large number of VLCCs were ordered in March 2006 in anticipation of new Common Structural Rules (CSR), which took effect on April 1, 2006. Any tankers ordered prior to April 1, 2006 are exempt from the CSR, which would require higher construction costs. "2006 – A Record Year for Newbuilding Orders," *McQuilling Services, LLC*, June 6, 2007.

[13] Although single-hulled tankers can be converted to double-hulls, the age of the ships would require them to incur expensive, lengthy surveys and possible costly repairs. "Exits From the Fleet; By Choice or by Law?," *McQuilling Services, LLC*, May 23, 2007.

New tankers, "newbuilds", introduced in 2005 reduced the average age of the oil tanker fleet to 17.7 years.[14] Because oil tanker operating costs (survey, maintenance, possible repairs) increase as the ship gets older, a tanker's age is an important determinant in whether or not a ship will continue to sail or be scrapped. If a ship's expected future earning potential, less the expected cost of keeping the vessel in operation, is higher than the price it could obtain by selling it for scrap, the ship will not be scrapped.[15] The total number of tankers in operation, global oil demand, ship scrapping demand, and tanker freight rates (revenue received per voyage) all play a part in a tanker owner's decision whether to sail or scrap. However, the main cash inflow for oil tanker owners is still received from freight revenue.[16]

The Oil Tanker Insurance Market

Given that oil tankers are some of the largest and most expensive ships in the world—a typical VLCC is worth approximately $120 million—tankers are covered by several types of insurance: hull and machinery insurance, cargo insurance, liability coverage (protection and indemnity), and war risk insurance. Insurance rates are based on both tangible factors, such as deadweight tons and the value of the ship, and estimates of the likelihood of damage (risks).

Protection and Indemnity (P&I) Clubs

Because standard hull/machinery insurance and cargo insurance policies do not cover ship-owners' liabilities—considered a higher risk—most tanker owners cover these liabilities through Protection and Indemnity (P&I) Clubs. P&I insurance typically cover liabilities involving: death and personal injury of seamen, passengers, and third parties, liabilities regarding stowaways or persons saved at sea, collisions, groundings, damage to fixed and floating objects, pollution, wreck removal, towage operations, and cargo liability.[17]

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[14] "Tanker Fleet Development," *ISL Market Analysis*, 2005.

[15] "Oil Tanker Phase Out and the Ship Scrapping Industry," *European Commission Directorate-General Energy and Transport*, June 2004, p. 42.

[16] "Oil Tanker Phase Out and the Ship Scrapping Industry," *European Commission Directorate-General Energy and Transport*, June 2004, p. 42.

[17] Robert C. Steward, "The Role of Protection and Indemnity (P&I) Clubs," (paper presented at a seminar on "Protection and Indemnity" in Hong Kong, November 2002).

In operation since the mid nineteenth century, P&I Clubs are mutual insurance associations used to pool ship owners' liability risks. Approximately 95 percent of the world's ocean-going tonnage is insured by thirteen large P&I Clubs, which provide much higher levels of coverage than those normally available in the commercial insurance market.[18] These thirteen P&I Clubs cooperate with one another to share claims and purchase higher levels of reinsurance. P&I insurance thus operates in three tiers: claims up to $5 million are paid by an individual club, claims up to $25 million are shared by all P&I Clubs, and claims in excess of $30 million are covered by one collective reinsurance contract, said to be the biggest liability reinsurance contract in the world.[19]

War Risk Insurance

A 'War Risk Premium' is meant to cover any intentional damage to hull, cargo or persons caused by any third party. Generally, tanker companies and/or charters pay a yearly premium for war risk based on trading routes. Premiums are determined by numerous factors, including military risks, piracy concerns, as well as the time a tanker spends in port. A "basic" war premium may be very small, as low as 0.001 percent of market value of the vessel. Tankers that trade in low-risk areas like the Western Hemisphere might have to pay very little in war risk premium.

War risk premiums increase when ships enter designated conflict areas like the Persian Gulf. In any given year, perhaps 15-20 "additional premium" areas require tanker charter companies to pay additional fees above the basic annual war risk premium. Underwriters grant war risk premium coverage for a finite duration, usually between 48 hours and seven days, giving them the flexibility to adapt the premium to short-term threats near a particular destination. Additional premiums can sometimes rise to as much as ten percent of the value of the vessel, but lower rates are more typical.[20] During the Iran-Iraq War in the 1980s, war risk premiums sometimes reached 7.5 percent for short periods immediately following a successful attack (e.g., the attack on the *Yanbu Pride*). For most of the war, however, rates stayed closer to two percent.[21] And at no time during the war did insurance rates rise to the point where shippers chose not to purchase insurance.

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[18] Robert C. Steward, "The Role of Protection and Indemnity (P&I) Clubs," (paper presented at a seminar on "Protection and Indemnity" in Hong Kong, November 2002).

[19] Interview with John Culley, Thomas Miller War Risks Services Limited, February 20, 2008, London, UK.

[20] For example, tankers currently operating in Somali ports pay large war risk premiums due the combination of piracy concerns and the long time a tanker must spend loading in Somalia's older, less efficient oil export terminals (tankers are more vulnerable in port). Culley interview.

[21] Navias and Hooton, *Tanker Wars*, pp. 197-200.

Experts at Lloyd's Marine Intelligence Unit (MIU) do not recall any instances of shippers deciding against attempting transits due to high insurance rates.[22]

Considering that VLCC’s each carry around two million barrels of oil, amortizing the additional war risk premium across the vessel's cargo would produce a very small change in the overall cost of supplying oil to world markets. An incremental increase in the war risk premium of two percent would work out to roughly $1.20 per barrel, a small fraction of the current price of around $100 per barrel. One leading private insurer of VLCC’s described commercial shipping as an “economist’s dream,” as “there will always be people willing to transit the Strait for the right price.”[23]

Conclusion

Though a significant portion of the world’s oil supply transits the Strait of Hormuz on oil tankers each day, these tankers are not the easy targets they are often made out to be. The construction of modern oil tankers inadvertently makes them resilient to attack. The number of available tankers worldwide makes them easily replaceable. The attitude of tanker captains and economic benefits of delivering the oil outweigh any increases in insurance premiums. These factors ensure that the oil will always flow for the right

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[22] Interview with Daryl Williamson and Wally Mandryk, Lloyd's Marine Intelligence Unit, February 18, 2008, London, UK.

[23] Interview with John Culley, Thomas Miller War Risks Services Limited, February 20, 2008, London, UK.

price. As shown during the Iran-Iraq War, the global economy will find creative ways to ensure the delivery of its most prized commodity.

Chapter 6. Weapons that threaten tankers in the Strait of Hormuz

Besides Israel, Iran possesses the strongest military presence in the Middle East. Its military assets include an army, navy, air force and the Iranian Revolutionary Guard (IRGC). After analyzing the Iranian arsenal, we chose to focus on three weapons that would most likely be employed if Iran wanted to disrupt tanker traffic in the Strait of Hormuz. These weapons are small suicide boats, missiles, and naval mines. We selected them based on their historical use, explosive capabilities when facing a VLCC oil tanker, and the propensity of Iran to use those assets to achieve their goal. The following sections individually describe the characteristics of three weapons, how Iran might use them, and how they can damage a tanker.

Small Boats

Small boats have been used throughout the last century as a form of asymmetric warfare for attacking both military and civilian targets. During the Tanker War, small arms such as machine guns and grenades were fired from small boats to confront and interdict commercial traffic. These attempts were quite unsuccessful, however. Recent successful terrorist suicide attacks against the VLCC M/V Limburg and the destroyer USS Cole, along with the Tamil Tigers' operations to interrupt shipping, suggest that we should include small boat suicide attacks in our analysis of potential disruption to oil flows through the Strait of Hormuz.

The term "small boat" can refer to a number of potential watercraft. For example, a "small boat" can be anything from small freighters; large privately owned yachts and fishing trawlers to submarines, dinghies and jet skis.[1] For our purposes, based on a number of historical examples of these "small boat" attacks, the crafts in the analysis are less than 65 feet long, with a majority of boats less than 25 feet long.[2] Small boats have several distinguishing characteristics and can be used to meet a number of operational goals. Small boats are highly maneuverable, fast (some exceeding 52 kts), and extremely versatile. Relying heavily on the element of surprise, countries or terrorist groups have used one boat to attack or sometimes several small boats to swarm enemy vessels. To

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[1]James Carafano, "Small Boats, Big Worries: Thwarting Terrorist Attacks from the Sea," *Heritage Foundation – Backgrounder*, June 11, 2007. Available: http://www.heritage.org/Research/HomelandDefense/bg2041.cfm. Accessed October 5, 2007.

[2] Both the U.S. Navy and Coast Guard define "boats" as less than 65 feet long. GlobalSecurity.org also defines boats as less than 65 feet long: http://www.globalsecurity.org/military/systems/ship/boats.htm (Accessed October 12, 2007)

increase their element of surprise, the boats can strategically blend in with other small friendly vessels before an attack.[3] Due to their size and weight, operations relying on these vessels are subject to some uncertainty because of the condition of the seas and "fragility of weapons detonation and delivery."[4]

Logistics of Small Boat Suicide Attacks

Suicide attacks using small boats strive to inflict the most damage to the target through covert surprise attacks and careful planning. The amount of the explosive, the proximity of the small boat to the target, and the location of the impact all affect the success of the suicide attack.

In practice, the attackers pack explosives into the front end of the boat so that the impact of the explosive will be adjacent to the target. For example the Tamil Tigers, a militant organization fighting against the Sri Lankan government, loaded their boats with 10-14 claymore mines with an explosive power of one and a half pounds of C4 in each mine totaling 15-21 pounds of C4.[5] Their boats are small and made of fiberglass, similar to the GRP Launches possessed by Iran. The attacks on the USS Cole, a guided missile destroyer, and the M/V Limburg, a VLCC oil tanker, provide good examples of the capabilities of these small boat suicide missions. The RAND corporation estimates the yield of the explosion on the USS Cole at 600 pounds of C4, and the yield of the explosion on the M/V Limburg to be between 100 and 200 kilograms of TNT.[6] The resulting explosion of the USS Cole blew a 35 by 36 foot hole in the hull killing 17 US sailors and the two pilots of the craft wounding 39 others.[7] The suicide craft, an inflatable skill measuring less than 15 feet in length, was launched from a slip about 20 minutes away from where the Cole was moored.[8] As a comparison, the explosion of the M/V Limburg blew a 36 x 26 ft. hole through both hulls of the double-hulled tanker,

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[3] Chris Fowler, "**USS** O'Kane Conducts Counter Small Boat Attack Exercises," *Navy Newsstand (through globalsecurity.org)*, October 2, 2006. http://www.globalsecurity.org/military/library/news/2006/10/mil-061002-nns03.htm (Accessed October 2, 2007).

[4] Carafano, "Small Boats, Big Worries," p. 2.

[5] "M18 Claymore". http://www.globalsecurity.org/military/systems/munitions/m18-claymore.htm.

[6]Michael Greenberg, Peter Chalk, Henry Willis, Ivan Khilka, and David Ortiz. *Maritime Terrorism.* Santa Monica, CA: RAND Corporation, 2006. 20.

[7] John F. Burns, "Yemeni and U.S. Teams Focus On Boat Used to Attack Cole," *New York Times* 22 Oct. 2000: Section 1.

[8] Burns, "Yemeni and U.S. Teams Focus On Boat Used to Attack Cole."

resulting in an intense fire and the eventual loss of over 50,000 barrels of oil.[9] Three days after the attack, the Limburg was able to navigate under its own propulsion.[10] The tanker was eventually towed to the port of Dubai and salvaged. Very little of the suicide boat was recovered. The estimated amount of damage caused by these suicide attacks of the USS Cole and the M/V Limburg and projected explosives are most applicable to our analysis.

Detonating the explosive materials carried on the small boat on contact with the target is an important component in estimating the amount of damage to the tanker. Given the properties of the explosive, a lot of the energy from the explosion disperses into the air and the water. After the small boat intercepts the tanker, the impact of the force will then cause the small boat to float backwards away from its target. If the small boat does not get close enough to the target, the explosive power may actually propel the boat away from the target resulting in less damage inflicted on the target. Even when the boat strikes the target, some energy still dissipates outward from the intersection point. To lessen the effect of energy dispersion, the Tamil Tigers added steel rods to the front of their boat to penetrate their target. This way when the explosive detonates most of the energy generated from the explosion will pass on to the target and the small boat will not be thrown away from the target.

A suicide boat should strive to attack vulnerable and important parts of the target. Realistically it can be hard to navigate to those parts of the target or know where it is on different ships. For example, when attacking a VLCC oil tanker, strategically one would want to hit either the engine room or a full cell of oil. Hitting the engine room would inflict more electronic and functional damage that would take longer to fix then simply patching up a hole in the side of a double-hulled tanker. Navigating to the engine room may be very challenging for a small boat especially if the attacker is not familiar with the structure of the tanker. A burdened tanker would be an optimal target. As seen in the M/V Limburg attack, hitting a cell full of oil could produce a second explosion and an intense fire. This incurs more damage and a longer repair time. While it would be ideal for a suicide boat to hit a full cell, there is no way of knowing which cells are full. At the time of the Limburg attack, it was carrying a small amount of oil with only 3 of its 15 compartments in use.

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[9] Carafano, "Small Boats, Big Worries."

[10] International Union of Maritime Insurance Conference. "Limburg Terrorist Attack: The incident and the Insurance Settlement." IUMI, Singapore 15 September 2004. Available: http://adm-svv-shr-lnx.sc.previon.net/mediaserver/api/getMediadata.cfm?media_id=2569&mandator=fw40_mandator_0235. Accessed October 7, 2007, p. 15.

Iranian use of Small Boats in Suicide Attacks

Iranians used these small speedboats extensively throughout the 1980s Tanker War with Iraq, inflicting damage on vessels with RPG's and machine guns within the Gulf and the Strait.[11] During the war, the boats were primarily used in shallow coastal waters where the boats could be used to swiftly attack and hide among the "multitude of islands, islets and coral reefs" along the Strait's Iranian coastlines.[12] There is evidence of the existence of an estimated 700 Iranian "invisible piers" along the Strait in the Gulf.[13] These piers could pose a significant logistical (at least temporarily, until we find them) threat if any conflict were to arise in the Strait of Hormuz.

The Iranian naval arsenal is diverse when it comes to small boats. Iran possesses four classes of small boats that fall into the aforementioned classification and could be employed in a suicide mission: Navy Patrol Boats, Iranian Revolutionary Guard Corps (IRGC) Patrol Boats, Glass Reinforced Plastic (GRP) Launches, and improvised craft. These assets fit the characteristics of size and agility common to small boats. The Navy Patrol Boats consist of to about 15 U.S. Mk III and Enforcer class Patrol Boats sold to Iran during the 1970's. Given their relative scarcity and slow speed of 24-28 knots (kts) when compared to the other boats in Iran's arsenal, it is not very likely that Iran would use them in a suicide attack.

The best asset that the Iranians possess for completing suicide missions would be the IRGC Patrol Boats. They are the fastest (36-54 kts) and have a closed hull, which reduces the possibility of swamping when passing through waves. They have over 42 of this class. This asset is relatively scarce. It is possible that Iran would use the IRGC Patrol Boats for a few attacks. If Iran chose to engage in a long-term campaign, they might not waste these Patrol Boats. The GRP Launches have been used in the past to disrupt transit through the Strait and have speeds (40 kts) comparable to the IRGC Patrol Boats. Furthermore if this class of boats were used, the Iranian government could avoid taking blame for the attack. These boats are less than 20 feet in length and include an unknown number of fiberglass speedboats built domestically. The abundant number and historical use of these resources indicates that Iran would most likely use them in a suicide attack.

Improvised craft includes all smaller skiffs and slower dhows. Smaller craft such as these would be far more susceptible to rough seas, and their slower speeds would limit their usefulness in attacking moving targets. The USS Cole and M/V Limburg were attacked using small fiberglass boats and inflatable skiffs but they were both attacked while stationary, making them relatively easy to approach.

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[11] Francis Clines, "Attacks on ships in gulf continue; 9 reported hit," *New York Times*, September 2, 1987.

[12] Nadia El-Sayed El-Shazly, *The Gulf Tanker War* (New York, 1998), p. 320.

[13] Seymour Hersh, "Last Stand; Annals of National Security," *New Yorker*, July 10, 2006.

Missiles

Anti-ship cruise missiles (ASCM's) have been a component of naval warfare since World War II.[14] During the Tanker War, both countries used ASCM's to target merchant shipping – in nearly 60 percent of Iraqi and Iranian attacks on merchant shipping.[15] Since that time, there have been significant advances in ASCM technology. Modern ASCM's have greater accuracy, range, and speed than their predecessors.

Operational Characteristics

Anti-ship cruise Missiles have some advantages over traditional types of weaponry such as artillery, torpedoes, and mines. Missiles have bigger range capacity, higher hit accuracy, and capability for mass application. Missiles are mobile weapons which can be launched many miles away from the target from something as primitive as truck – this quality makes them very convenient for Iran to use in the Strait of Hormuz, given Iran's extensive coastline and control of nearly all of the strategically important islands in the Strait.

Various estimates suggest that Iran's arsenal of relatively modern ASCM's is comparably small: perhaps 100 C-201 Seersuckers, 125 CS-801 Sardines and 75 CS-802 Saccades.[16] There are also reports that Iran acquired the Russian SS-N-22 Moskit (a.k.a. Sunburn) missile from Russia.[17] While analysts dispute individual reports of Iranian missile acquisitions, for the purpose of not underestimating Iranian capabilities, our report

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[14] Known as *Ohkas* ("Exploding Cherry Blossoms"), Japanese pilots would actually fly with and guide these missiles until impact (similar to Japan's *kamikaze* planes). Eric. H. Arnett, *Sea-Launched Cruise Missiles and U.S. Security* (New York: Praeger, 1991), p. 4.

[15]Navias and Hooton..

[16] "C-201 / HY-2 / SY-1 CSS-N-2 / CSS-C-3 / SEERSUCKER" *FAS Military Analysis Network* available at: http://www.fas.org/man/dod-101/sys/missile/row/c-201.htm and E.R. Hooten, ed., Jane's Naval Weapon Systems. (Alexandria: Jane's Information Group Inc., 2004), 298-300, and "C-802 / YJ-2 / Ying Ji-802 / CSS-C-8 / SACCADEC-8xx / YJ-22 / YJ-82" *GlobalSecurity.org* available at: http://www.globalsecurity.org/military/world/china/c-802.htm

[17] Ariel Cohen, Ph.D., James Phillips, and Wouldiam L. T. Schiran "Countering Iran's Oil Weapon" Heritage Foundation, 2006

considers the reasonable possibility that Iran has the high-ranged ASCM's SSN-22 and CS-802.[18]

CS-802, once fired, boosts to 164 feet, cruises between 65 feet and 98 feet, and then descends to 16 to 23 feet before hitting its target. Unlike its predecessor (CS-801) that uses the solid-fueled booster, CS-802 uses a turbojet propulsion system. It has a range of 70-75 miles, and a warhead up to 363 pounds. This missile can be launched from land, air, or sea.[19] It also may be using a Global Positioning System (GPS), which allows this missile to detect its target with even higher accuracy.

SS-N-22 Sunburn is the Russian-made missile that has a maximum effective range of 155 miles. It employs a 660-pound, semi-armor piercing warhead containing 330 pounds of explosives. This missile has the fastest flying speed among its contemporary counterparts - it has three times the speed of American Harpoon. The SS-N-22 uses a dual rocket-jet engine and four solid boosters to reach a speed of M2.1 with a cruising trajectory between 23 and 33 feet above the water's surface.[20] It is fueled by a kerosene type fuel but has a solid propellant booster.

Iran's ability to launch missiles

Iran currently possesses sea, air, and land-based ASCM launch capability.[21] Given Iran's generally weak offensive airpower capabilities and the fact that the Iranian Air Force (IAF) remains largely deficient compared to Iran's other military branches, we disregard an air-launched ASCM attack in our analysis.

A land-based Iranian ASCM attack will constitute the highest probability of success due to the relative advantages of such attacks to Iran, including already existing, fixed launch sites, concealment, and ability to fire and get away ("scoot-and-shoot" capability). Given its extensive coastline and control of nearly all of the strategically important islands in the Strait of Hormuz, Iran is poised to take advantage of both fixed and mobile land-based ASCM launch systems.

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[18] "Iran" *INSS.org* available at: www.inss.org.il/upload/(FILE)1198577424.pdf

[19] E.R. Hooten, ed., Jane's Naval Weapon Systems. (Alexandria: Jane's Information Group Inc., 2004), pp. 298-300.

[20] Thomas G. Mahnken, "The Cruise Missile Challenge," Center for Strategic and Budgetary Assessments, March 2005.

[21] Michael Knights, *Troubled Waters: Future U.S. Security Assistance in the Persian Gulf* (Washington, DC: The Washington Institute for Near East Policy, 2006), p. 72.

A land-based ASCM attack could involve one or more autonomous firing units (with or without external communication) firing ASCM's from Iran's numerous coastal or island-based fixed-installations. However, susceptibility to counterattack would be higher using fixed-installation systems, due to the lack of shoot-and-scoot capability. This is especially true if Iran were to employ an island-based attack, as there would be less ground clutter for the shooter(s) to hide behind and fewer places to go once the missile were fired.

A sea-based ASCM attack is more technically difficult to implement and harder to evade counterattack. Iran currently has ten 68-ton Chinese-built Thondor (Hudong)-class fast attack craft (missile boats).[22] Each ship can carry up to four C-802 missiles and each maintains a crew of 28 men.[23] The Iranian Navy also has nine to 11 operational 275-ton French made Combattante II (Kaman-Class) fast attack boats; reportedly armed with two to four C-802 ASCM's.[24]

Sea-based "shoot-and-scoot" tactics are more difficult to execute, as they require hiding places and/or decoys that are more readily found/implemented on land. In other words, carrying out a sea-based ASCM attack would require more planning and coordination (to avoid a counterattack) than its land-based counterpart.

How Missiles Would Damage a Tanker

Because ASCM's are designed to attack warships, not oil tankers; ASCM attacks on the latter have been less successful, even though oil tankers have no dedicated defenses against an ASCM attack. For example, of the 239 oil tankers attacked during the Tanker War, only 23 percent (55 tankers) were significantly damaged or sunk.[25]

Examining the data from the Tanker War suggests that where a tanker is hit has a large effect on the ultimate outcome of the ASCM fire. The most devastating attacks in the Tanker War occurred when missiles were able to do damage to the tankers' engine room or electrical system. However, these are also the most rare occurrences of an attack. The most likely location of a hit is to the hull. "If a missile should blow a huge hole in a 1,000-foot tanker's hull, the effect … would be to flood one of up to 17 cargo compartments. This would merely lower the ship in the water without putting it in danger

[22] Cordesman, *Iran's Military Forces*, p. 123.

[23] Cordesman, *Iran's Military Forces*, p. 123.

[24] Importantly, Iran supplied Hezbollah the C-802s which were used successfully against one of Israel's Modern Sa'ar Class-5 missile ships in 2006. Cordesman, *Iran's Military Forces*, p. 116.

[25] Includes non-ASCM attacks. Navias and Hooten, *Tanker Wars*, p. 183.

of sinking."[26] In addition, modern, double-hulled tankers come equipped with advanced fire control systems, which minimize the probabilities for damage and leakage, as well as reducing crew size, and insurance costs.[27]

Although ASCM's were comparatively the most successful weapon against oil tankers during the Tanker War, Iran's limited number of missiles and the difficulty of severely damaging a tanker with a missile makes it unlikely that Iran will be able to disrupt oil throughput in the Strait for any prolonged period of time using ASCM's.

Mines

Mines have been used for a long time as one of the most cost-effective measures of naval warfare. Mines are small, easily concealed, cheap to acquire, require virtually no maintenance, have a long shelf life, and can be easily laid from almost any type of platform, including civilian ones. Mines can be used either strategically or tactically and also pose a significant psychological threat.[28]

Operational Characteristics

Modern naval mines are highly sophisticated, computerized weapons, capable of accurate target discrimination but the basic principles of mine design have changed little since their initial use. A mine consists of a fuse, detonator, explosive charge, and sensor. Mines wait at a single location until they sense a target.[29] They then detonate, and the underwater explosion threatens to damage the target by producing a shock wave and gas bubble that transmit destructive energy to the target.[30]

Mines can be deployed several ways. Drifting mines float freely on the surface of the water and follow prevailing currents and winds. Bottom mines sit on the bottom of the seafloor and detonate when a nearby target influences their sensors. Moored mines must maintain buoyancy to float in the water column usually below the surface; to maintain buoyancy, these mines can only carry limited explosive charges.[31] Moored and bottom

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[26] Malcolm W. Browne, "Tankers in the Gulf: Big Targets, But Hard to Sink." *The New York Times*, September 4, 1987.

[27] Rupert Herbert-Burns. Interview with John Losinger and Dr. Eugene Gholz. March 18, 2008.

[28] "Underwater Weapons – Mines", *Jane's Underwater Warfare Systems*, Mar 1, 2005.

[29] R.K. Tiwari, "Deadly Naval Mines," *SP's Military Yearbook*, 2006-2007.

[30] Robert Cole, *Underwater Explosions* (Princeton: Princeton University Press, 1948).

[31] John Rios, "Naval Mines in the 21st Century: Can NATO Navies Meet the Challenge?" Naval Postgraduate School, Monterey, CA, Jun 2005.

mines can each be designed to release a rocket propelled charge upon detection of an approaching target, allowing them to explode closer to the target, increasing the likelihood damage.[32]

Mines can recognize individual targets by their magnetic, pressure, and acoustic signatures and are capable of distinguishing between sizes and classes of ships.[33] Magnetic sensors respond to changes in the magnetic field surrounding the mine and can be designed to react to specific parts of a ship containing large amounts of metal, the machinery area or stern area.[34] Acoustic sensors for mines detect the noise signals of targets, including engine noise, propeller cavitations, or even imperfections in the regular sound pattern, when known, that might allow them to detect specific ships rather than just general types of ship.[35] Pressure sensors detect a reduction in pressure caused by the passage of a ship over or near a mine. [36]

Iranian Use of Mines

Mines threaten to damage ships, and mine-layers can channel ship traffic to certain areas by increasing the risk in other areas. Historically, fear of mines has dramatically affected ship captain's psychology. Physical damage from a mine is a product of the warhead size and the distance from the intended target; both horizontal and vertical displacements comprise distance. Although the effects of a detonating mine can be felt over a large distance, the effective radius of a mine is only the distance within which damage to a target occurs. The effective damage radius is the limiting constraint and significantly less than both the mine's sensing capabilities and total range.

Several readily available mines for Iran include the Italian Manta and MR-80 bottom mines and the Chinese EM-52 rising mine.

The Manta mine is a bottom mine, which utilizes both acoustics and magnetic influences for detonation of 330 pounds (lb) of high explosive. Similarly, the MR-80 is activated by magnetic, pressure, acoustic low frequency, and acoustic audio-frequency influences.

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[32] "Underwater Weapons – Mines", *Jane's Underwater Warfare Systems*, Mar 1st 2005

[33] Sheila Galatowitsch, "Undersea Mines Grow Smarter and Deadlier", *Defense Electronics*, vol. 23 n 3, Mar 1991.

[34] Sheila Galatowitsch, "Undersea Mines Grow Smarter and Deadlier."

[35] "Underwater Weapons – Mines", *Jane's Underwater Warfare Systems*, Mar 1, 2005.

[36] Sheila Galatowitsch, "Undersea Mines Grow Smarter and Deadlier."

The MR-80 contains explosive charges of 1058 lb, 1455 lb, or 2039 lb.[37] The depth of much of the Strait of Hormuz grossly exceeds the effective damage radius of even the largest bottom mines. As a result, the Manta is non-effective and MR-80 severely restricted.

The EM-52, which utilizes a 661 lb explosive and rises at rates up to 262 ft/sec, is a more ideal weapon for use in the deep waters of the Strait of Hormuz. The warhead does not have a guidance system as it rises, making it more suitable for large, slow moving targets as opposed to faster warships.[38]

How Mines Would Damage a Tanker

With the effective damage radius significantly less than the sensing capabilities on modern mines, mine explosive capabilities are the key limit on their effectiveness.

Explosions, including underwater explosions, cause two distinct events: 1) an initial pressure wave expanding outward from the detonation; and 2) a secondary gas expansion results from the chemical changes occurring during the detonation.[39]

A mine detonating in contact with, or in very close proximity to, the ship will tear a hole in the hull and rupture or deform bulkheads with direct exposure to the pressure wave. Although damage in the immediate attack area is devastating, it usually does not extend far into the ship or in the fore and aft directions. Flooding will likely be a primary concern for the ship. Underwater explosions further from the hull can sometimes threaten greater damage.[40]

The pressure wave moves faster than the gas bubble. An explosion creates enormous initial pressures that attenuate rapidly due to both dissipation and divergence. Dissipation is the loss of energy as it is transferred from one particle to another, such as in heat. Divergence results from the pressure wave encompassing an increasingly large area as it expands outward. The amount of energy per unit area decreases as the area increases.[41]

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[37] "Manta and MR-80", *Asian Defense Journal,* October 1983.

[38] Andrew Erickson et al, "China's Undersea Sentries," *Undersea Warfare.* Vol. 9 n. 2, Winter 2007.

[39] Paul Cooper, *Explosives Engineering*, (New York: Wiley-VCH, 1996).

[40] Alfred Keil, "The Response of Ships to Underwater Explosions," David Taylor Model Basin Structural Mechanics Laboratory, Department of the Navy, Nov 1961.

[41] Robert Cole, *Underwater Explosions*.

The second stage of the explosion process occurs, as the initial mass of explosives becomes a very hot mass of gas at tremendous pressure. As the gas bubble expands an additional pressure wave is emitted. This secondary pressure wave is considerably weaker than the initial pressure wave, but its time scale is significantly longer, meaning that it may transfer undesirable destructive energy to the target. Additionally, if a structure is within the path of the gas bubble as it rises to the surface, the gas bubble exerts an upward force on the structure, heaving it in an upward direction.[42]

As a pressure wave impacts a ship's hull, some of the energy is transferred to the ship while the remainder is reflected back away. If the energy transferred exceeds the ability of the ship to absorb the energy through plastic deformation, the hull ruptures. Energy transmitted throughout the ship dissipates through vibration and shock, which may also damage internal structures, break pipes, misalign the drive train, or otherwise disrupt normal ship operations.[43]

As the standoff distance of the mine from the hull increases, the effects of the explosion diminish. Even at large distances however, different portions of the ship will respond at different velocities, bending and flexing the ship.[44] This bending is further affected by the pressure distribution generated by the expanding and contracting gas bubble beneath. As the gas bubble vents at the surface to the atmosphere, it leaves behind a void that is quickly filled by water. This void has the opposite bending effect on a structure being lifted. Ultimately, this 'whipping' response may exceed the ship's girder strength and buckle and tear the ship's structure.[45]

Although Conclusion to mines – why they are/not effective and under what circumstances

Overall effectiveness of the weapons

While Iran possesses one of the strongest military presences in the Middle East, it is not very capable of inflicting any significant damage on a VLCC oil tanker.

Missile attacks can be the most effective if weapons are launched from mobile land-based platforms into the engine room of the tanker. Similarly, IRGC patrol boat suicide attacks

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[42] Robert Cole, *Underwater Explosions*.

[43] Alfred Keil, "The Response of Ships to Underwater Explosions."

[44] Warren Reid, "The Response of Surface Ships to Underwater Explosions", Ship Structures and Materials Division Aeronautical and Maritime Research Laboratory, Defense Science and Technology Organization, Melbourne, Vic, Aus. DSTO-GD-0109.

[45] Alfred Keil, "The Response of Ships to Underwater Explosions."

can inflict significant damage by hitting an engine room or an electrical system in the tanker. Data from Tanker War, however, showed that ability to damage these particular parts of VLCC is very low.

Bottom mines have also proved to be ineffective, due to the depth of the Strait exceeding the effective damage radius for them. With rising mines, even though damage in the immediate attack area is devastating, it usually does not extend far into the ship or in the fore and aft directions.

Even so, since the key to stopping a tanker's transit through the Strait of Hormuz is to significantly damage specific, sensitive parts of the ship, underwater attacks on tankers, notably from mines, offer a greater prospect of damaging a tanker's innards. As to the small boats and missiles, tankers that do not suffer especially "unlucky" hits to the engine room or fires that specifically burn electronics or control cables can be back in service almost immediately.[46]

Although Iran does not have a mine shortage in its arsenal, using mines to damage tankers will not enable this country to sustain a disruption of the flow of oil in the Strait of Hormuz. The psychological effect of a mine blowing up will have a more significant impact. Individual cases of mine explosions might cause tankers, in anticipation of more incidents, to change their behavior in the Strait.

[46] Interview at Arab Shipbuilding and Repair Yard, January 7, 2008, Manama, Bahrain.

Chapter 7. Analyses of Iran's Weapons as Disruption Mediums

After thoroughly reviewing characteristics of Iran's weapons arsenal, small boats, anti-ship cruise missiles, and mine warfare would be the most effective tools to attack and damage tankers. In this section, we determine the steps that would need to be taken in order for Iran to use successfully use these weapons to interdict tanker traffic in and out of the Strait. Each of the weapons systems also poses unique operational challenges. We look at the conditions in the Strait that would have an effect on the outcome of each weapons system such as weather conditions, bathymetric conditions, tanker resilience, and the volume of tanker and other commercial traffic in the Strait.

In analyzing the strengths and weaknesses each of these tools, it is important to note the amount of time that would be needed to plan and execute each of these attack methods. Using small boats would require the least amount of preparation time, needing only to place spotters in the Strait and load the suicide boat with explosives. Small boats suicide missions can also be aborted mid-course if necessary. ASCM's, however, would need more preparation time because of logistical and tactical challenges associated with using these missiles. The laying a minefield would require the longest period of preparation time needing anywhere from a few weeks, in a rushed scenario, to months, in a methodical scenario. These factors were taken into consideration in developing useful paradigms in which to think about and analyze Iran's true military capabilities in the Strait of Hormuz.

Analysis of Small Boat Suicide Attacks

To evaluate the potential threat of Iranian small boat suicide attacks to oil shipping, we looked at the assets available to the Iranian Navy and Revolutionary Guard Corps and assessed the probability of successful attacks against VLCC and smaller oil tankers. A typical suicide attack might operate as follows: when a potential target enters the Strait bound for the Persian Gulf (or bound for the Gulf of Oman) a suicide boat or its observer would need to identify the target. This identification would then be relayed to command for verification and permission to launch an attack. The suicide boat would then sortie from its staging area and attempt to intercept the target. Assuming that the craft was able to make a visual identification of the target it would need to get in position to attack the tanker, avoiding the bow wave and turbulence of the stern wake. If the craft were able to intercept its target it would detonate its explosives, yielding a range of possible damage to the target. Below is an ordered assessment of the probability of the success of such an attack.

Iranian Naval Assets

Our analysis divided Iranian small boats into several classes based on their speed, size, radar equipment, and hull construction. The speed of the boat and the design of the hull (specifically, whether it has an open or closed cockpit) help determine the probability of intercepting an oil tanker. Radar capabilities on the small boats would also play a major role in target identification. Our analysis focuses on glass reinforced plastic (GRP) launches as the most likely Iranian asset to be used in suicide attacks. These craft are generally capable of reaching speeds of 40 knots, have an open hull, a low freeboard, and were used in the past to disrupt transport through the Strait.[1] During the Tanker War, GRP launches would rapidly approach tankers and attack with small arm fire and rocket-propelled grenades. These tactics were largely unsuccessful at disrupting oil traffic.[2] This category of craft is the most likely to be used in a suicide attack, given its low cost and high number to Iran.

Although GRP launches constitute the most likely suicide attack asset, IRGC patrol boats have the greatest probability of success due to their design characteristics. This category is made up of ten or more MIG-G-1900 Class boats and 32 or more Boghammer Patrol Craft.[3] These boats are between 28 and 60 feet in length, and are capable of speeds of 36-54 knots. These boats were used extensively during the Tanker War to harass shipping traffic and their closed cockpit and speed make them ideal for suicide attacks. However, these craft are limited in number and are more likely to be used for other purposes by Iran, making them unlikely to be used as the mainstay of suicide attacks. Improvised craft, such as small skiffs and fishing dhows, are ill suited for suicide missions as well because of their slow-speed capabilities and open hulls. These characteristics would make approaching a 200,000 dwt ship very difficult.

Explanation of Variables

The variables in the analysis are directly correlated to the kill chain for a small boat attack. There are three major variables that would significantly affect the success of a

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[1] Eric Wertheim, *Naval Institute Guide to Combat Fleets of the World, 15th Edition: Their Ships, Aircraft, and Systems* (Annapolis: Naval Institute Press, 2007).

[2] Martin Navias and E.R. Hooton, *Tanker Wars: The assault on merchant shipping during the Iran-Iraq conflict, 1980-1988* (New York: I.B. Taurus and Co Ltd, 1996).

[3] Eric Wertheim, *Naval Institute Guide to Combat Fleets of the World, 15th Edition: Their Ships, Aircraft, and Systems* (Annapolis: Naval Institute Press, 2007).

suicide mission. The outcome of a small boat attack depends on target identification, target intercept, and explosive detonation; success in each of these three stages of the kill chain will yield a range of possible levels of damage to the target ship. The analysis calibrates these variables using analogous historical cases (modified to account for differences in the specific Iranian attack scenarios on moving oil tankers in the Strait of Hormuz) and then multiplies them to get the total probability of a successful attack (the joint success of each stage in the kill chain). The analysis also considers certain defensive measure that might help protect tankers threatened by small boat attacks.

Target Identification

This variable represents the probability that a tanker would be accurately identified while traversing the Strait. Because Iran has a limited supply of small boats suitable for suicide attacks, we assume that Iran would prefer to limit its attacks to the most valuable tanker targets, VLCC's. The probability of target identification takes into account weather conditions, technology on board the craft (specifically radar), and the interaction of spotters, suicide craft, and command-and-control. Attacks can only succeed following target identification and cooperation between the spotters and command-and-control.

Target Intercept

Small boats cannot necessarily reach and make contact with oil tanker targets because bow waves present a challenging obstacle. Small boats are more susceptible to capsizing and swamping in rough seas. Tankers produce considerable waves that move away from the bow at a 19-degree angle making an approach from the front or side difficult and unlikely.[4] Essentially, this step estimates the probability that the small boat will strike the target. The size, speed and hull design of the boat conducting the attack will determine the probability that it will intercept the tanker.

Detonation

This variable represents the chance that the explosives on board the small boat will detonate on contact with the tanker. Human error poses the largest threat to the success of detonation. This could be due to either mechanical error or timing error because of inexperience or nerves of the attacker. Failure of detonation would result in minimal or no damage to the target.

[4] Interview with Dr. Spyros Kinnas, Professor of Ocean Engineering, University of Texas at Austin, Austin, Texas, November 7, 2007.

Calibration of Variables: Baseline – No Defensive Measures

Probability of Target Identification

Table 1. Probability of Small Boats Identifying Targets in the Strait (no Defensive Measures)

Type of Boat Conducting the attack	Identity: Small tankers (approx. 75,000 DWT)	Identity: VLCC tankers (approx. 200,000 DWT)
IRGC Patrol Boats	.85	.90
GRP – Launches	.85	.90

Logistics for a small boat suicide attack on a tanker will encounter difficulties in correctly identifying a target. Smaller coastal tankers could be confused with larger cargo ships and bulk carriers. Distance and scale could also cause a problem where distant larger ships resemble smaller non-targets. Tankers that are burdened would also be more difficult to locate as opposed to unburdened tankers. However, it is important to remember that even if the tanker that is successfully attacked is unburdened, this attack could still potentially disrupt oil commerce leaving ship owners without a needed vessel to transport the commodity. Trying to attack a tanker in the Strait would involve several steps to properly identify the tanker. Although tankers are massive targets, they can still be confused with other ships or simply missed due to human error, weather conditions, or command-and-control issues.

Visibility

A tanker would need to be successfully identified by the spotter as well as the small boat carrying out the suicide mission. A spotter could be located on an oil platform, a fishing or recreational boat, or on one of the various islands in the Strait. The conditions for the lookout may not be ideal. The probability of correctly identifying a target is further hindered by the climate and sea conditions of the Strait. Visibility in the Persian Gulf and Strait of Hormuz can be particularly bad between June and November, the driest months, and during April, the beginning of the monsoon season. Visibility throughout the year can be poor, and winds, dust, and rain can significantly reduce line of sight.

Visibility is a function of elevation. Under normal conditions, horizontal visibility at sea level is limited to between three and five miles, a functional limit for spotters stationed on small craft in the Strait.[5] From the bridge of a tall ship visibility can reach 10-12 miles.

Given the climatic conditions of the Strait this 10-12 mile range is the maximum visibility on a normal day regardless of height (even though greater elevation should yield visibility distance gains).

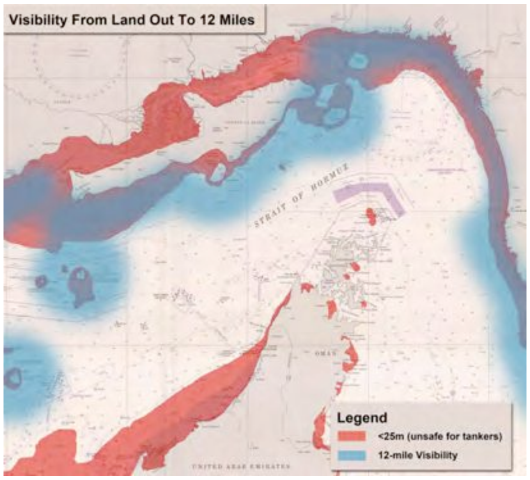

Figure 4. Visibility in the Strait of Hormuz

Observation Zone

Iran is likely to set up an observation zone or picket line of spotters to identify targets passing into the Persian Gulf (or out to the Gulf of Oman). The narrowest part of the Strait is the curve around the Musandam Peninsula. This area is the most logical location for attacks because it would require the least number of spotters. Iran's geo-strategic location gives it the ability to utilize oil platforms in the Strait, military bases, small ports and cities along Qeshm Island as staging areas for the suicide boats. The Iranian Revolutionary Guard Corps maintains numerous military bases in the Strait and controls all Iranian ASCM operations.[6] The IRGC have also developed a network of "mobile

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[5] Nadia El-Sayed El-Shazly, *The Gulf Tanker War* (New York: St. Martin's Press, 1998), 115.

[6] IRGC maintains military bases at Al-Farsiyah, Halul (an oil platform), Sirri, Abu Musa, Bandar-e Abbas, Khorramshahr, and Larak (island). Anthony H. Cordesman, "Iran's Revolutionary Guards, the Al Quds Force, and Other Intelligence and Paramilitary Forces," *Center for Strategic and International Studies*, August 16, 2007, p. 6, and James Devine and Julian Schofield, "Coercive Counter-Proliferation and Escalation: Assessing the Iran Military Operation," *Defense & Security Analysis*, Vol. 22 No. 2 (June

hilltop radars, coastal watchers, island and offshore platform observers, and so-called spy dhows (small fishing boats)" in and around the Strait to monitor maritime traffic.[7] Spotters would likely use binoculars, Global Positioning System (GPS) devices, and radar to ascertain the coordinates of a target as it enters the observation zone. A combination of these tools would help to provide more accurate target identifications. Radar provides perspective to a spotter by clarifying visual perspective and indicating distance to target. However, even with radar a visual identification is ideal in order to prevent mistakes and to help guide attack boats to their targets.

As the Strait arcs around the Musandam Peninsula, its distance across, through navigable waters, is roughly 30 miles. Assuming that Iran wants to maximize its ability to spot incoming tankers, an observation zone of 300 square miles in this area would aid identification. By creating a rectangle of spotters, 30 miles across and 10 miles in width, Iran would be able to maximize their odds of identification. Given an optimal visibility of five miles for small boats, one spotter would be able to cover approximately 79 square miles. Therefore, Iran would need only four spotters to cover the entire observation zone. If visibility were three miles Iran would need approximately 11 boats to cover the area. Iran could minimize the chances of a ship passing through undetected between the tangency of two spotters by overlapping the formation. Therefore, there is a high probability that utilizing an observation zone with 4-16 spotters would enable Iran to successfully identify tankers as they pass through the Strait. While not one hundred percent, the odds of identifying a tanker as it passes through the zone remain high, given the confined geographical area.

If a tanker was spotted near the leading eastern edge of the observation zone, and an attack was ordered, a small suicide boat would have up to 30 minutes to get in attack position before a tanker traveling at a speed of17 knots left the observation zone. Depending on where the observation zone is established, suicide craft could launch attacks from the port of Bandar e'Abbas, the smaller towns along Qeshm, Larak, and Hengam Island, oil platforms in the Strait or even as far as the Tumb Islands.

Command-and-Control

This step is crucial to the probability of identification. After a spotter identifies a target, he or she needs to describe the target and its location via radio to command. Therefore

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2006), p. 143.; and Daniel Byman, Shahram Chubin, Anoushiravan Ehteshami, and Jerrold D. Green, *Iran's Security Policy in the Post-Revolutionary Era* (Santa Monica: RAND, 2001), p. 41.

[7] Michael Knights, *Troubled Waters: Future U.S. Security Assistance in the Persian Gulf* (Washington, DC: The Washington Institute for Near East Policy, 2006), p. 72. However, this author assumes that Iran would indiscriminately attack shipping in the Strait and would not require "highly refined information for identifying targets or avoiding friendly fire.

reliable communication devices need to be available to spotters, command-and-control commanders, and lastly to the suicide attackers. Command would verify the target as not bound for Iranian ports and transmit the coordinates of the tanker to the awaiting attack boat. Because of the high volume of traffic in the Strait, misidentification could be an issue. However, all ships destined for Iranian ports must check in with Iranian Coast Guard prior to transiting the TSS.[8] This precaution would help prevent Iran from targeting tankers destined for Iranian ports. Targeting only non-Iranian bound traffic opens the possibility of false negatives, where command and control allow a target to pass, falsely believing it is bound for Iranian ports.

Probability of Intercept

Table 2. Probability of Small Boats Intercepting Targets in the Strait (w/o Defensive Measures)

Type of Boat Conducting the attack	Intercept: Small tankers (about 75,000 DWT)	Intercept: VLCC tankers (about 200,000 DWT)
IRGC Patrol Boats	.40	.40
GRP – launches	.30	.30

Piracy incidents provide a good stand-in variable for the probability of intercept calibration. The estimated probabilities of intercept above are based on data gathered about attempted and successful piracy attacks from the International Maritime Bureau.[9] We totaled the number of attempted attacks and successful attacks in the area around Saudi Arabia, including piracy attempts in the Red Sea, Gulf of Aden, Arabian Sea, Gulf of Oman, Strait of Hormuz, and Persian Gulf. We did not include cases of attacks on smaller craft, such as fishing boats, yachts, tugboats, and research vessels, craft that have substantially different characteristics from oil tankers. We also dropped piracy cases in which the targets were in port or stationary.

We included attacks that involved an attempt to board in our success category because it indicated a successful intercept of the target ship. The table below illustrates the final count of the attacks.

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[8] National Imagery and Mapping Agency, edited. *Publication 172 Sailing Directions (Enroute): Red Sea and The Persian Gulf, 9th edition* (US Government Printing Office: Bethesda, 2001), p. 184.

[9] International Chamber of Commerce International Maritime Bureau, *Piracy and Armed Robbery Against Ships Annual Report 2007* (London: ICC International Maritime Bureau, 2008).

Table 3. Small Boats Results in Baseline Scenario (w/o Defensive Measures)

2007 Data	
Successful Attacks*	7
Attempted Attacks*	26
Total Attacks	33
Success Rate	21%

* numbers adjusted for the location of the targeted craft and the type of craft

We adjusted the success rate to account for variation among the different kinds of Iranian attack boats and different sizes of tanker targets. The pirate attacks did not target VLCC tankers; therefore, the probability of successfully intercepting a VLCC is lower than the piracy average, given larger bow waves and stern wakes. On the other hand, one of the obstacles to a successful pirate attack is boarding a ship with a high freeboard (vertical height between the water level and the deck level of the ship), while suicide attacks do not need to board (they only need to crash into the hull). Therefore we adjusted the probabilities upward to account for the difference between successful boarding and successful intercept rates.

We use a probability of intercept of 0.40 as a conservative estimate for Iran's most capable small boat asset (IRGC Patrol Boats). This class has a closed hull and has the highest maximum speed. When calibrating the values for the other Iranian craft, we compared the attacking boat's dimensions, whether it had an open or closed hull, and its speed to the "best case" IRGC patrol boats, leading us to scale down the intercept percentages for other types of attackers. Although GRP launches and IRGC patrol boats are capable of similar high speeds, GRP launches have open cockpits and lower freeboards leading to an increased chance of swamping. We therefore scaled down the probability of intercept accordingly.

Probability of Detonation

If a small boat successfully identifies and intercepts a tanker, there is still a question of whether its explosives will detonate. Human error poses the largest threat to the success of detonation. When explosives are packed into a boat, a detonator must be installed within the bulk explosives. If the detonator is not wired correctly, the attack will fail. For example, in 2005 terrorists attacked London twice, the first time, all four bombs went off successfully, but the second time, none of the four bombs went off.[10] Even if the detonator is wired correctly, human error in completing the mission is still possible: small boat drivers may not time the explosion correctly. The attackers could possibly employ steel rods similar to the ones used by the Tamil Tigers to remain connected to the tanker after it has been intercepted. Because of nervousness or inexperience, though, the suicide attackers might explode the boat prematurely, resulting in less explosive force on the tanker, or wait too long, thereby sinking their boat without an explosion. Data gathered by Dr. Ami Pedahzur suggests problems with detonation timing in previous small boat attacks. Four out of the 17 documented small boat attack attempts over the past 25 years failed (approx. 23 percent) due to premature explosion caused either by defensive gunfire or bad timing by the suicide attacker; these cases resulted in no human casualties or injuries.[11] We used this number as a rough figure of the probability of detonation, and estimated that 20 percent of the time either mechanical or human error would result in no detonation.

Calibration of Variables – Scenario Including Defensive Measures

If defensive measures were taken in an effort to prevent attacks on tanker traffic, target identification and target intercept would be greatly affected. In our analysis, we have analyzed the following scenarios: 1) a convoy system, 2) offensive action against Iranian supply lines and staging areas, and 3) moving the shipping lanes.

Target Identification

Although meant to protect a tanker, a military escort would also improve a spotter's ability to locate the target. A convoy draws more attention by increasing the size of the target. The collection of smaller ships around a tanker will make it easier for the spotters to recognize a tanker. Assuming that Iran does not attack ships bound to Iranian ports, a convoy would signal to spotters and suicide attackers that a tanker in the convoy is a target. This would help decrease the number of false negative identification. However, a convoy may also contain dummy tanker ships, such as older scrap tankers, that would make identifying a viable target more difficult. These dummy tankers would also be more easily spotted by an attacker because unburdened vessels sit higher in the water, and are more easily identifiable by radar.

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[10] "In Depth: London Attacks" BBC News Channel, Available: http://news.bbc.co.uk/1/hi/in_depth/uk/2005/london_explosions/default.stm. Accessed: February 13, 2007.

[11] Ami Pedahzur, "Data Set: Suicide Attacks Worldwide". Available: http://dev.laits.utexas.edu/movabletype/blogs/tiger/Suicide_Attacks_world-wide.xls. Accessed: March 3, 2007.

Offensive attacks on staging areas (small ports, supply lines, and spotters) would reduce the likelihood of proper communication and would decrease accurate identification of targets. These offensive attacks would also try to jam radar emitters and radio communications to decrease Iran's ability to identify tankers and relay information from spotters to attackers.

Moving the shipping lanes away from Iranian coastlines and territory would increase the length of supply and communication lines for Iranian spotters and increase the distance that attacking boats would have to travel to reach their targets, therefore making identification more difficult. It is also possible that the U.S. and its allies could use these defensive measures congruently. The chart below shows how these defensive measures affect the probability of a successful attack on VLCC's.

Table 4. Probability of Small Boats Identifying Targets in the Strait (with Defensive Measures)

Type of Boat Conducting the attack	ID w/Convoy	ID w/ moving shipping lanes	ID w/ attacking staging areas and supply lines	ID w/ ALL Defensive Measures
IRGC Patrol Boats	.9	.81	.45	.3645
GRP – launches	.9	.81	.45	.3645

Target Intercept

Convoys will decrease the probability that a small boat will intercept its target. By escorting tanker traffic with warships and air assets it becomes increasingly difficult for small boats to complete their attack run. The defensive firepower provided by the escorting warships, and aircraft would significantly decrease the probability of a small boat successfully intercepting a tanker.

Moving the shipping lanes or engaging in offensive attacks on staging areas would not change the ability of a small boat to approach a moving ship. Once an attack is in motion the probability of intercept will not change. As mentioned before, those defensive measures will affect target identification.

Table 5. Probability of Small Boats Intercepting Targets in the Strait (with Defensive Measures)

Type of Boat Conducting the attack	Intercept w/Convoy	Intercept w/ moving shipping lanes	Intercept w/ attacking staging areas and supply lines	Intercept w/ ALL Defensive Measures
IRGC Patrol Boats	.20	.40	.40	.20
GRP – Launches	.15	.30	.30	.15

Probability of Detonation

None of these defensive measures affect the probability of detonation. The ability a small boat pilot to detonate his explosive will not be significantly affected by convoys, a shift in the shipping lanes, or attacks on staging areas and supply lines.

Combinations of Defensive Measures

These defensive measures can be combined to further deter suicide boat attacks. Once defensive measures are in place, especially in combination, the probability of a successful attack greatly decreases. Analyzing the three defensive measures simultaneously will provide an estimate of the worst-case scenario for Iranian attacks.

Calibration of Damage

Damage is estimated using accounts from the Tanker War and other significant incidents involving small boats, such as the attacks on the USS Cole, the M/V Limburg and the actions of the Liberation Tigers of Tamil Eelam. The predicted damage translates into a small boat's ability to cause delay to tanker traffic. Ideally, for the Iranians, a small boat attack would target a weak area on the tanker, such as a full oil cell, to inflict the most costly damage both monetarily and in repair time. Given that many tankers transiting the Strait are only partially full, it is unlikely that a small boat attack would always yield a rupture of a full cell. If a suicide attack punctures an oil cell there is a moderate possibility that the cell will be empty and the attack will result in minimal damage and no loss of oil. If the cell is empty, there is also less of a chance that a fire would ignite. The duration of the delay of the tanker (or, if the tanker were sunk, the permanent disruption to that transit) is the foundation for the damage scale. We have created a scale of possible outcomes ranging from no damage to the sinking of the tanker.

Type 1: No Damage, Minimal Delay

If an incident occurs, the tanker will be delayed for a short period even if the tanker is not significantly damaged. This minimal delay is not considered a disruption to tanker traffic.

Type 2: Limited Damage, Tanker Penetrated or Impaired

This type of damage might include dents, small holes, and minor impairments that require repairs before the tanker continues on its journey or that would reduce the efficiency of transport if the tanker continued without stopping for repair. This limited delay is not considered a disruption.

Type 3: Damage, Hull Rupture

A fire, propeller damage, or major hole in the tanker would cause a major delay. The tanker would be out of commission for several weeks for essential repairs. This category is calibrated based on the M/V Limburg case: three days of intense fire led to six months of repair work.

Type 4: Constructive Total Loss, (CTL)

A Constructive Total Loss occurs when the cost of fixing the damaged tanker exceeds the residual value of the ship. The amount of physical damage required to trigger a CTL depends on the value of the particular tanker, its size, and on market conditions (utilization rates of tankers, the number of new tankers under construction in shipyards, etc.).

Type 5: Tanker Sunk

The vast size of VLCC tankers, the strength of the material used to construct them, and the buoyant nature of oil make them very difficult targets to sink. Few tankers during the Tanker War were sunk outright.

These damages have a probability coefficient that will change with the tanker class. These probabilities are roughly distributed such that Type 3 Damage is the most likely scenario given historical precedence. Generally as the tanker size decreases the probability of no damage decreases and the probability of some type of damage increases.

Given that the Iranian aim is to significantly disrupt oil traffic only Damage Type 3-5 are considered successful attacks. Therefore, Damage Type 3-5 are multiplied by the probability of success (joint probability of Target ID, Intercept and Detonation) and then added to ascertain the probability of successfully disrupting oil traffic.

Conclusions from Analysis

GRP launches are the most likely asset to be used in small boat suicide attacks because of their low cost and high quantity. With no U.S. or allied defensive measures this asset has a 14 percent chance of causing moderate to severe damage to VLCC's that results in traffic disruption. With a likely combination of convoy, moving the shipping lanes, and offensive action against their supply and communication lines, the probability drops to 2.8 percent. IRGC patrol boats have the highest probability of success at 18.7 percent with no defensive measures and 3.8 percent with all defensive measures. However, given the scarcity of this resource and the ease of U.S. identification, they are unlikely to be utilized in this form of attack. An interesting case to note is the probability of significant damage with the minimal defensive effort of moving the shipping lanes. GRP launches drop to 12.6 percent and IRGC patrol boats drop to 16.8 percent simply by moving the shipping lanes. It is also important to keep in mind that these suicide missions would rely on Iran's ability to recruit a large number of people both willing to kill themselves for Iran's cause and with some training and the ability to pilot a in small boat.

Sensitivity Analysis

By assuming that Iran is more capable than our already generous estimates, it is possible to establish an upward limit of possible damage by raising the values of the key variables. If we raise the probability of target identification to 95 percent, double target intercept to 60 percent and raise the probability of detonation to 90 percent, the GRP launches would now have a 33 percent chance of inflicting significant damage. With defensive measures they would have a 7.1 percent chance of significant damage.

The probability of intercept is the major limiting variable on the success of small boat suicide attacks. It reflects the complexity of navigating a small boat to intercept a moving target and the difficulty in avoiding the bow wave and stern wake of a large ship. Small, open-hulled craft with low freeboards are more susceptible to swamping, which further decreases the probability of intercept against ships generating large waves. Command-and-control issues also limit the ability to target ships with small boat attacks, and command-and-control becomes particularly troublesome if the United States or its allies harass staging areas, supply, and communication lines.

Table 6. Probability of Damage on a VLCC without Defensive Measures

	IRGC Patrol Boats	GRP Most Likely	GRP Conservative
P(significant damage)	0.187	0.141	0.333
Total P(damage)	0.288	0.216	0.513

Table 7. Probability of Damage on a VLCC with Moved Shipping Lanes

	IRGC Patrol Boats	GRP Most Likely	GRP Conservative
P(significant damage)	0.168	0.126	0.3
Total P(damage)	0.259	0.194	0.462

Table 8. Probability of Damage on a VLCC with Defensive Measures

	IRGC Patrol Boats	GRP Most Likely	GRP Conservative
P(significant damage)	0.038	0.028	0.071

Small Boats Used as a Secondary Attack

The success rate of these suicide style attacks is quite low, and when defensive measures are factored in, damage inflicted on the target becomes minimal. The major limiting variable to this model is the low probability of intercept. Several pundits, such as Seymour Hersh, are correct in believing that small boats can present a threat, but it is not as drastic as they might think. According to our analysis, using conservative estimates, small boats have a moderately low probability of success when used as a first attack. However, given the historical use of small boats on stationary targets, it is possible that Iran might try to use small boats in a secondary attack on already hit and damaged tankers. In this scenario, the suicide boats would wait for a missile or a mine to strike a tanker. A successful hit would likely stop or at least slow the targeted tanker, dramatically raising the probability of intercept for a small boat. However, it is unclear if Iran would choose to expend multiple attacks on the same target given the constraints on its military assets, especially if the initial attack has already prevented the target from making its "normal" transit through the Strait.

Analysis of Attacks Using Anti-Ship Cruise Missiles

As previously noted, Iran has gone about building a substantial force of anti-ship cruise missiles, presumably with the goal of disrupting tanker traffic in the Strait of Hormuz.

Cruise missiles were used extensively by both Iran and Iraq during the Tanker War, and the information gleaned from that conflict informs our estimate for Iran's ability to disrupt tanker traffic using ASCM's in a hypothetical future encounter. The following section of this report will detail the data, assumptions, and methodology used to calculate the probable success of an Iranian attack using anti-ship cruise missiles in the Strait of Hormuz.

The Kill Chain

The outcome of an Iranian ASCM attack depends on Iran's ability to successfully perform a definable series of tasks in the course of firing a cruise missile. These steps are the ASCM's "kill chain" and probable success in each stage will determine the number of damaged oil tankers. First, the Iranians must be able to overcome climatic conditions to observe tankers traversing the Strait and correctly identify those tankers as targets, as they would need to do in the small boats analysis (Observation and Identification).[12] After a spotter observes and identifies a tanker, the tanker's location must then be effectively communicated to the missile-firing unit and an Islamic Revolutionary Guard Corps (IRGC) commander would decide whether or not to order the attack (Command-and-Control).[13] Once the shooters fire the missile, it must function properly by launching correctly, guiding itself toward the tanker, and detonating upon impact (Missile Function). Finally, the resulting explosion would cause a certain amount of probable damage the tanker. (Damage) The Iranian's ability to significantly damage an oil tanker depends on the integrity of this kill chain. Based on research and historical data, a probability of success will be assigned for each stage of the kill chain, allowing an estimation of Iran's overall probability of success in the mission.

The stages of the kill chain can be broken in two main categories: the ability to target and the ability to damage an oil tanker.

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[12] The tanker would need to be identified as non-Iranian, requiring the tanker's coordinates to be cross-referenced with the Iranian Coast Guard. 40% of Iran's oil exports are loaded on its own tankers and exported through the Strait. Based on 2007 Lloyd's Marine Intelligence Unit (MIU) data. "Iran Oil Exports at Risk in UK Ship Sanctions Plan," *Reuters*, June 26, 2007.

[13] All of Iran's missile artillery groups are officially under the command of the *IRGC*. James Devine and Julian Schofield, "Coercive Counter-Proliferation and Escalation: Assessing the Iran Military Operation," *Defense & Security Analysis*, Vol. 22 No. 2 (June 2006), p. 143.; and Daniel Byman, Shahram Chubin, Anoushiravan Ehteshami, and Jerrold D. Green, *Iran's Security Policy in the Post-Revolutionary Era* (Santa Monica: RAND, 2001), p. 41.

Targeting a Tanker

Observation and Identification

The targeting stage begins with the Iranian ability to observe a moving target in the Strait of Hormuz, and furthermore, to successfully identify that target as an oil tanker to be fire upon. Like in the small boats analysis, Iran's military presence along the Iranian coast will be a key advantage in identifying moving targets in the missiles analysis. To observe and identify tankers, the IRGC would likely position multiple spotters in small boats throughout the region, perhaps by placing observers on fishing boats that normally ply the Strait.

Once spotters are positioned in the Strait, climatic factors must allow them to visually observe and identify a target in the distance. The Abumoosa Meteorological Center, located on the Iranian Abu Musa Island, reports that 281 days of the year are clear (about 77 percent of the time). Haze caused by heat and sand inhibits spotters' ability to observe and identify targets even on normal days. Haze caused by dust is common during all seasons in the Strait, and sand storms are not uncommon, especially over Iran and the Persian Gulf.[14] At extremely high temperatures, heat can blur vision and reduce depth perception, which may cause a spotter to incorrectly verify coordinates of the position of a possible target.[15]

Even after a spotter sees a potential target, he must correctly identify it as a VLCC. Misidentification is possible because oil tankers are only one type of bulk carrier operating in the Strait. Smaller oil tankers are roughly the same size as some other bulk carriers, and can resemble them. It is possible for VLCC's to be mistaken for other classes of ships due to poor visual perspective and reduced depth perception; on the water, a large ship at a distance may appear much like a smaller ship that is relatively closer unless the spotter can use radar or another mechanism to measure distance; these techniques are likely to be available – unless an opposing force complicates the task with jamming.

These factors resulted in an average probability of 95 percent for successful observation and identification of an oil tanker. However, persistent climatic factors, such as dust or haze, would force this probability downward to 80 percent. This estimate does differ from the small boats model's probability of observation because the factor of command-and-control is included in the step for small boats. While the probability of identification for the small boats model and the ASCM model are very closely correlated, it is

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[14]Colbert C Held. *Middle East Patters: Places, Peoples, and Politics* (Boulder, Colorado: Westview Press, 2006), pp. 27, 44-45, and NASA Visible Earth, *OSS Dust, Sunglitter*. Online. Available: http://daac.gsfc.nasa.gov/oceancolor/shuttle_oceanography_web/oss_58.shtml. Accessed: 18 March 18, 2008.

[15] Interview with Commander Bancroft. 21 March 2008

important to remember that firing an anti-ship cruise missile would require a great deal of accuracy in communicating the coordinates. The step of command-and-control is extremely important in analyzing the Iran's capability of using ASCM's to attack oil tankers, and is therefore a separate step in the ASCM model.

Command and Control

Once a target has been identified, a series of order must be communicated to Iranian military personnel in order for a "fire" command to be executed. This process includes both the initial battle orders (command) and their subsequent implementation/coordination (control). In an ASCM attack in the Strait of Hormuz, command and control would involve communication between the military commander, the spotter, and the shooter, determining whether or not the correct coordinates were programmed, and whether the missile would actually be fired.

The IRGC have generally been given priority over Iran's regular armed forces, the Artesh, in leadership roles in Iran's military affairs. However, the IRGC often rely on the Artesh for expertise on military technology and professionalism (training and proficiency). Although the IRGC has tried to shed its image as an army of "professional martyrs," its command structures remain convoluted and training and overall military professionalism are still lacking.[16] It is also possible, depending on the circumstances of the attack that the Iranians would have to rely on less experienced, poorly trained recruits if preparation is lacking.

The large number of moving parts in the campaign would present many problems. First, there is the difficulty of coordinating the activities of a plethora of spotter boats: necessary because each boat would only be able to observe VLCC's passing within a relatively small area. These spotters must successfully communicate with land-based ASCM shooters. Shooters, in turn, must be prepared to move from a hide site to a shooting site, then they would fire, and "scoot" back into hiding for protection from expected counter-attack or suppression efforts. The likelihood of "fog of war"-induced errors would increase if the Iranians tried to selectively target only those oil tankers that serve non-Iranian ports, but that selective targeting might be important to help the Iranians achieve their political aims or to manage the economic cost that a campaign would inflict on Iran itself.

Climatic factors could also pose problems for the Iranians in this respect. Dust, ever-present in the Strait of Hormuz, could potentially cause equipment malfunctions or radio interferences that would disrupt communication.

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[16] Byman et. al., *Iran's Security Policy,* pp. 43-44.

Assuming a moderate level of military professionalism and familiarity with military technology, we estimate a 90 percent probability of successful execution of the command and control function. However, abnormal conditions in terms of troop readiness or climatic factors would cause this probability to drop to 85 percent.

Damaging the Tanker

Missile Function

Upon successful completion of the targeting stage, the Iranians will fire a missile at an oil tanker. The first factor affecting whether this fire will actually damage the target is the function of the ASCM. A missile must launch properly, guide accurately, acquire its target with its terminal seeker, and finally explode. If the missile fails to complete any one of these tasks, it will not significantly damage an oil tanker target.

First, the Iranian missile must be successfully launched from its platform on the Iranian coast. Most of Iran's missiles – whether propelled by solid-fuel rocket motors (Sunburns) or turbofan engines (Saccade) – start their flights with a solid rocket booster.[17] Atmospheric temperature can affect the burn rate of the propellant, and temperatures higher than 100° F can lead to unsatisfactory performance.[18] Given the potential for extremely high temperatures within the Strait of Hormuz, this fact threatens to reduce Iranian cruise missile reliability. Even the United States has had significant reliability problems with some of its missiles. In the Gulf War, a number of Tomahawk missiles failed to launch: Out of the 307 Tomahawk cruise missiles fired, 19 experienced pre launch problems, and six suffered boost failures causing the missile not to transition to the cruise phase.[19] When employing ASCM's, Iran could experience similar problems.

Post-launch, the Iranians must rely on the missile's guidance system to successfully direct the ASCM to the targeted tanker. A guidance system determines the flight path of

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[17] "Shaped trajectory cruise missile launch mode" Freepatents.com accessed at: http://www.freepatentsonline.com/H000159.html

[18] "SMS GUIDED MISSILES, AERODYNAMICS, AND FLIGHT PRINCIPLES" *GlobalSecurity* available: www.globalsecurity.org/military/library/policy/navy/nrtc/14110_ch9.pdf - a accessed at April 9, 2008

[19] "BGM-109 Tomahawk" *Global Security.org* available: http://www.globalsecurity.org/military/systems/munitions/bgm-109-var.htm accessed at: March 9th 2008. David J Nicholls " Cruise Missiles and Modern War," *Occasional Paper No. 13 Center for Strategy and Technology Air War College* May 2000 pg. 9

the missile by continuously tracking the position of the target and the missile and directing the missile towards the target.[20] Guidance radar sometimes picks up objects other than the target, and sea clutter (reflections from waves rather than ships) can reduce missile effectiveness, especially during the terminal guidance phase.[21] However, the sea state in the Persian Gulf is rarely high enough to cause substantial clutter problems. On average, the Persian Gulf experiences 5.8 days of thunderstorms. The average wind speed in the Strait of Hormuz is 6.8 knots although the months of March and April experience higher wind speeds - an average of eight knots.[22]

A more likely problem is failure of the target identification function. Under operational conditions in the Strait or the southern Persian Gulf, Iran's ASCM's are more likely to guide to the wrong target (another ship or an island) rather than to be confused by sea clutter. For example, when Hezbollah successfully attacked an Israeli frigate with an Iranian ASCM's in the summer of 2006, a stray missile hit a small cargo ship nearby. Similar "misses" for a campaign to disrupt oil traffic through the Strait of Hormuz are certainly possible, given the overall high traffic density there. This probability would increase if convoys of additional ships escorted tankers through the Strait.

Once a missile reaches its target, it must explode to cause significant damage. During the Iran-Iraq War, the Sea Killer missile failed to detonate twice out of 13 fires, and the Exocet missile failed to detonate 13 of 152 times.[23] The Argentines had similar problems with Exocets during the Falklands War, and similarly American air-to-air missiles often malfunctioned during the Vietnam War. The types of ASCM's in Iran's arsenal have not been used in combat, therefore empirical failure rate data is lacking. It is reasonable to assume, based on comparable ASCM's that the missiles will not work perfectly.

Given these factors and estimates regarding Iranian ASCM holdings, there is an 85 percent chance that the missile fired by the Iranians will function properly. However, if persistent climatic factors affect performance, or if Iran's missiles simply underperform relative to previous data, that probability would drop to 65 percent.

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[20] "SMS GUIDED MISSILES, AERODYNAMICS, AND FLIGHT PRINCIPLES" *GlobalSecurity* available: www.globalsecurity.org/military/library/policy/navy/nrtc/14110_ch9.pdf - a accessed at April 9, 2008

[21] Merrill I. Skolnik, *Radar Handbook (*McGraw-Hill Professionals 1990); Jing Hu ,Wen-wen Tung , and Jian-bo Gao "Modeling sea clutter as a nonstationary and nonextensive random process" *IEEE* Available: ieeexplore.ieee.org/iel5/10871/34214/01631833.pdf?tp=&isnumber=&arnumber=1631833. Accessed: March 10, 2008.

[22] Islamic Republic of Iran Meteorological Organization, Available: http://www.irimo.ir/english/statistics/synopH/ABOMOOSA.txt.

[23] Martin S. Navias and E.R. Hooton, *Tanker Wars: The Assault on Merchant Shipping During the Iran-Iraq Conflict, 1980-1988* (New York: I.B. Tauris and Co Ltd, 1996).

If all of the preceding stages are successfully executed, the ASCM will hit the tanker and detonate. As previously noted, tankers are difficult targets to destroy. The final variable in assessing an Iranian ASCM campaign in the Strait is damage. If a ship sinks, is declared a constructive total loss (CTL), or suffers significant damage that requires extensive repairs, Iran would succeed in causing an interruption in tanker traffic.

We developed a detailed dataset of the outcomes of missile attacks on oil tankers during the Iran-Iraq War, classified (as well as possible) by the size of the target, the amount and type of damage, and the number of missile hits on the target ship.[24] During the Tanker War, a number of ships were hit multiple times before sustaining significant damage. Only one ASCM attack on tankers over 100,000 dwt sunk the target ship (that being the Song Bong, hit by multiple missiles during a "major attack" on Iran's Kharg Island terminal). Approximately 19 percent of attacks that hit their target caused enough damage that tankers were declared a CTL. The most devastating attacks in the Iran-Iraq War occurred when missiles struck near the tanker’s engine room or electrical system, but hits on those locations were rare, given the huge surface area of the VLCC. 53 percent of attacks that hit the target during the Tanker War led to relatively slight damage and 28.1 percent did essentially no damage at all. Serious damage was largely the result of sustained air offensives from Iraq, mostly on stationary, docked tankers. Iran would not have this capability.

While attacks during the Iran-Iraq War frequently caused small fires or blasted holes in the hulls of tankers, the majority of this damage was quickly addressed without a significant disruption in transit. The vast majority of missile fires did not to cause any significant damage inside the ship. Due to the large surface area of the ship’s hull in relation to other parts of the ship, the most likely location of a hit is to the hull. In the case of double-hulled, compartmentalized modern tankers, this would have has little effect. When only one missile is fired at time, it is likely the tanker only incurs slight, easily reparable damage. During the Iran-Iraq War the financial and technical limitations of the Iranians prevented them from firing multiple salvos of the Silkworm missile. “Using a Silkworm against tankers turned out to be like shooting elephants with a .22 rifle. They could punch a hole in a tanker, but they seldom proved fatal or even particularly serious.”[25]

We adjusted these damage rates to account for the larger warheads of the missiles in Iran's current arsenal, the double hulls and new fire-suppression systems on modern tankers, and the likelihood that fewer missiles would be fired at each tanker. This scenario posits that Iran would fire its scarce ASCM’s from mobile land-based launchers

[24] Compiled from Navias and Hooton, Sreedhar Kapil Kaul, Anthony Cordesman and Abraham R. Wagner, and other sources.

[25] Craig L. Symonds, *Decision at Sea: Five Naval Battles that Shaped American History* (New York: Oxford University Press, 2005), pp. 288-289.

(in an effort to preserve the ability to fire again at another target).[26] However, it should be noted that given Iran's limited stockpile of ASCM's, multiple missile fires would be limited to salvos of two to a maximum of five. This scale of attack is nowhere near the large volley Iraq was able to fire from the air at stationary tankers during the Tanker War. As Dennis Blair and Ken Lieberthal note, "Even the most modern anti-ship missiles have relatively small warheads… [and] are not capable of sinking or disabling a large tanker… An attack would have to include a salvo of eight to ten missiles with conventional warheads."[27] Iranians could only fire this salvo number if it has a much larger stockpile than anticipated, or if it attempts only a short-term disruption that would quickly exhaust its resources.

The results of our analysis suggest a 4.5% percent chance of a single missile causing a disruption to an oil tanker. A disruption is defined as either a sunk ship, a constructive total loss, or severe damage resulting in sustained repairs. This probability would inevitably rise as more missiles were fired at each tanker.

Table 9. Anti-Ship Cruise Missiles Results

	Observe & Identify	Command & Control	Proper Missile Function	Probability of Sufficient Damage	Chance of Stopping a VLCC
Normal day, best estimate	95	90	85	12.9	8.6
Normal day, conservative	98	95	90	15.6	15.1
Abnormal day, best estimate	80	85	65	12.9	5.3

Calculations based on three missiles hitting each identified tanker.

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[26] Iraq was relatively free to fire multiple air-launched missiles at each identified target during the Tanker War because of its air superiority; attacks sometimes involved multiple Super Etenard aircraft, for example. Iran is constrained by the number of ground launchers. Some analysts have estimated that they only have around ten launchers ready for a campaign against shipping.

[27] Dennis Blair and Kenneth Lieberthal, "Smooth Sailing," *Foreign Affairs*, Vol. 86, Issue 3 (May/Jun2007). For similarly vivid quotes, see Craig L. Symonds, *Decision at Sea: Five Naval Battles that Shaped American History* (New York: Oxford University Press, 2005), pp. 288-289.

Methodology

The above data table documents the results of the analytical model of an Iranian attack in the Strait of Hormuz. The first step in the development of the analytical model was to define the various individual stages of the "kill chain" Iran would have to follow in order to successfully fire a missile. As noted above, these stages have been defined as: Observation and Identification, Command and Control, Missile Function, and Tanker Damage.

Once the probabilities had been assigned, a model was developed to calculate the estimated value of tanker interruptions (defined as either significant damage, constructive total loss, or a sink) based on the joint probability of a successful outcome of each stage. Our analysis is designed to provide an estimate of the percentage of tanker traffic that Iran could interrupt while passing through the Strait. Because about 22 tankers a day pass through the Strait (half entering and half exiting), the number of tankers is initially multiplied by the probability of success for Observation and Identification, as well as Command and Control. This provides an estimated value for tankers targeted that will be fired upon. Our model also provides estimations for tanker damage due to multiple missile fires. To begin this process, the model multiplies the estimated value of tanker targets by the number of missile salvos (from one to five). This provides an estimated value for missiles to be fired.

To examine the outcome of the actual attack, we developed an equation based on a binomial formula, which allowed for the calculation that 1,2,3,4 or 5 missiles actually hit the ship. This allowed for the possibility of a missile failing to strike a tanker due to either a malfunction of the missile, or the missile simply missing the target despite a successful launch. Based on the dataset from the Tanker War, we created probabilities of interruption for number of missiles (one-five) hitting a tanker (see below). An interruption was defined as a sunk vessel, a constructive total loss, or severe damage that resulted in sustained repairs. This calculation relies on the assumption that each missile fired exists as a statistically independent event. Using these damage estimates, the model finally calculates an estimated value and percentage for total tanker interruptions.

Outcomes and Sensitivity Analysis

In examining the outcomes of our calculations, it appears that the use of cruise missiles is a highly inefficient method of disrupting tanker traffic in the Gulf. In our initial calculations, we started with the our best estimates for an Iranian attack on a "normal" day in the Strait. In this case, we found the following percentages for tankers interrupted:

Table 10. Expected Number of Missile Hits & Tankers Interrupted (Best Estimate)

Number of Missile Hits	Percentage of Tankers Interrupted
1	2.96%
2	5.81%
3	8.57%
4	11.23%
5	13.81%

Although this scenario is not particularly optimistic for the Iranians, it is actually fairly generous. This scenario assumes no initial defensive measures on the part of tankers, nor any intervention on the part of the United States. Yet, the possibility that Iran would be allowed to fire at will at tankers lies only in fantasy. Moreover, when one considers just how favorable this scenario is to Iran, the degree of tanker resilience is impressive. Iran would have to fire at least three to four missiles at every ship in order to affect even a tenth of tanker traffic. Considering the limited number of missiles Iran has at their disposal and the historical willingness of tanker captains to continue traversing the Strait even in wartime, Iran has little ability to create a long-term disruption using anti-ship cruise missiles.

Table 11. Expected Number of Missile Hits & Tankers Interrupted (Conservative Estimate)

Number of Missile Fires	Percentage of Tankers Interrupted
1	5.31%
2	10.3%
3	15.05%
4	19.5%
5	23.7%

However, in the event that our data was somehow biased against Iran, we have prepared a conservative scenario that gives Iran the benefit of the doubt in every instance (see above chart). For this case, as noted above, every one of Iran's success probabilities has been increased beyond our logical conclusion.

This conservative estimate posits that Iran could potentially disrupt a quarter of tanker traffic firing five missiles at each tanker. However, this analysis presents an extreme case, with estimates far above what we would logically deduce. This estimate assumes no defensive measures and estimates that Iran can execute each stage of the kill chain with over 90 percent effectiveness – unlikely for even the most skilled military force. Yet, despite these advantages, Iran would still have to fire five missiles at every tanker passing through the Strait, exhausting their resources within a matter of weeks, at most. Simply put, anti-ship cruise missiles are not ideal weapons with which to target tankers, even in the best of circumstances. Our results provide little evidence that Iran would be able to overcome this deficiency and create a significant disruption in oil traffic using ASCM's.

Analysis of Mine Threat

Unlike the models of small boats and ASCM's who share many commonalities in their respective kill chains, the Iranian ability to use mine warfare to interdict tanker traffic is conceptualized in a very different way. Naval mines are one of Iran's most important tools of asymmetric warfare, and it is highly likely they will be used in any attempt to close the Strait of Hormuz to tanker traffic. It is therefore crucial that we determine Iran's mine-laying capabilities and the capability of mines to severely damage tankers within the Strait.

Iran's Mine-laying Capability

The method Iran uses to lay the mines will depend on the circumstances surrounding its decision to close the Strait of Hormuz. If the attack on the Strait is planned as a first strike, Iran would have months to lay the minefield covertly but would be constrained in its choice of deployment methods. In this scenario, Iran would use submarines to deploy mines surreptitiously. If closure of the Strait is a response to a U.S. attack, Iran would be forced to lay its minefield rapidly over a shorter period of time using all methods of deployment at its disposal, including small boats. If Iran tries to do this surreptitiously, we estimate a fourteen day timeframe before the U.S. Navy notices the increased level of activity and puts a stop to it. However, Iran might also choose to lay the minefield overtly, so we examine a scenario in which Iran deploys hundreds of small boats and assume that the U.S. Navy would stop the activity within one day. We have chosen to analyze the probability of damage to tankers in the context of these three scenarios.

- **Scenario One:** Iran lays minefield surreptitiously over a period of six months using Kilo subs
- **Scenario Two:** Iran lays minefield over fourteen days using IRGC small boats
- **Scenario Three:** Iran lays "hurry-up" minefield in one day using military and civilian boats

Iran has three Kilo-class submarines, which we believe will be used in Scenario One for laying mines surreptitiously. A Kilo sub can covertly lay 24 mines per sortie.[28] Although Iran gained experience laying simple contact mines during the Tanker War, its military is unlikely to have significant experience with the more sophisticated modern mines that will likely be used in these scenarios. Also, the more complicated the method of deployment, the greater the potential for human error or damage to result in improper deployment.[29] Deploying mines through a torpedo tube is a more complicated process than deployment from air or from a military ship. Thus, for this scenario, we estimate a 70 percent rate of proper deployment.

For the following calculations, we assume that the minefield would lie about 40 miles from Bandar e-Abbas, where the Kilos are stationed, so we estimate an average distance of 40 miles to the target for each sortie. The maximum speed of a Kilo submarine is approximately 17 knots submerged, but we assume a speed of about ten mph, with the expectation that Iran would not want to stress its submarines by running them at full speed. We estimate that it takes approximately 0.6 hours to lay a single mine and travel to the next deployment location.[30] We also estimate that the subs will spend four days at port in between each sortie for reloading, refueling, changing the crew, and maintenance.

Although we do not know the exact condition of Iran's ships and submarines, we expect a certain amount of damage due to wear-and-tear that could affect the readiness of the fleet. Likewise, Iran has never used its Kilo subs in military action before, which could result in slower response times. Thus, although Iran has three Kilo subs in its fleet, we anticipate that all three are available only 60 percent of the time.

Iran will likely invent a plausible cover story such as a series of training exercises to explain the increased level of submarine activity in the Strait. The submarines would then have to travel to other locations in the Persian Gulf or the Gulf of Oman for the story to be believable. In Scenario One, we expect these diversions to significantly increase the distance traveled on each sortie. Iran may also include "dummy sorties" (which would lay no mines) in its operation, which would have the same effect in the model of increasing total distance traveled by the Kilos.

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[28] Maj Dale R. Davis, "Iran's Strategic Philosophy and Growing Sea-Denial. Capabilities," *Marine Corps Gazette*, no. 79 (July 1995), p 22. and Michael Eisenstadt, "Déjà vu All Over Again? An Assessment of Iran's Military Buildup," Iran's Strategic Intentions and Capabilities," ed. Patrick Clawson (Washington, DC: Institute for National Strategic Studies, 1994), p. 120.

[29]Interview with John Huckabay, Director, Advanced Technology Laboratory, Applied Research Laboratories, The University of Texas at Austin. Conducted by Eugene Gholz, Piers Wendlant, Jacob Glowacki, Anne Womer, and Megan Montgomery, November 19, 2007.

[30] Michael A. Glosny (2004) "Strangulation from Sea? A PRC Submarine Blockade of Taiwan," *International Security* 28(4), 14.

For Scenario Two, we assume Iran will send out small boats in staggered groups of 10-20 in order to avoid suspicion, and that only 50 boats will be on the water at any given time. These small boats will consist primarily of the IRGC-owned fleet of small boats (<60 feet long, many <30 feet), of which they reportedly own hundreds.[31] However, we also expect a readiness rate of 95 percent since there is likely to be a large supply of replacement boats if one should become damaged. Because rolling a mine off the edge of a small boat is a fairly unorthodox deployment method, we estimate only a 30 percent rate of successful deployment. Due to the size and weight of the mines, we assume that each boat can lay one mine per sortie. The turnaround time will be significantly shorter for a small boat than for a more sophisticated deployment method; we estimate it will take about six hours. Likewise, we think it will take less time to drop a mine off the side of a boat—about 20 minutes. The "cushion distance" needed for a cover story will also be less, as the activities of small boats are likely to raise less suspicion than those of Kilo submarines.

For Scenario Three, Iran would send out as many boats as possible in a one-day mass mine-laying campaign. The boats would consist of both IRGC boats described in Scenario two, but also non-military boats like fishing trawlers or even dinghies. The campaign would require significant coordination and effort on the part of the Iranian military, both in managing their own boats and commandeering private assets from local fisherman along the Iranian coast. In addition to the private boats themselves, the Iranian military will also be forced to speedily recruit local fishermen or other citizens to take part in actually driving the boats and laying the mines. Conservatively, we estimate that Iran would be able to deploy a total of 600 small boats, military and civilian. We assume that each boat would only complete one sortie, thus laying only one mine each.[32] Because of the hurry-up nature of the campaign and the fact that some of the mines will be laid by fishermen, we assume a very low probability that the mines will be deployed correctly (15 percent).

Using this approach, we calculated the number of mines the Iranian military could lay in each scenario (see Appendix E for relevant formulas):

- **Scenario One:** 1067 mines
- **Scenario Two:** 814 mines
- **Scenario Three:** 120 mines

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[31] Matt Hilburn, "Asymmetric Strategy," *Seapower* (December 2006), p. 16.

[32] Because we assume only one sortie in only all-out day, we do not need to worry about average distance to the minefield, time to lay each mine and "cushion" distance because we are not trying to estimate how many sorties will be completed.

Probability of Damage to Ship

In the event that a ship hits a mine, the amount of damage caused will depend upon vertical separation (the vertical distance between the explosion and the keel of the ship), lateral separation (the horizontal distance between the explosion and the hull), and the size of the explosive charge. The shock factor is a scaled number used to estimate the amount of damage that will be caused by the shock wave of an exploding mine. It is calculated using the weight of the explosive charge and the standoff range (the distance between the mine and the ship).

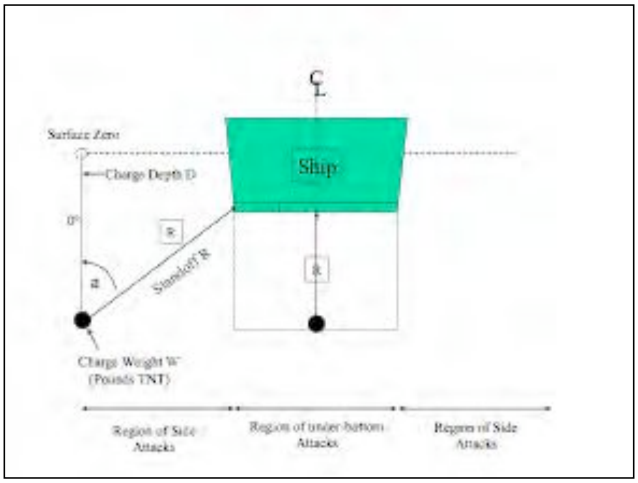

Figure 5. Visual Depiction of "Shock Factor"

Shock Factor = $\frac{W \cos \alpha}{R^2}$

- W = weight of explosive
- R = standoff range
- α = angle between standoff range line and vertical separation line (see Fig. 1)

We estimate that a shock factor of 0.2 will be required to disable a large, loaded oil tanker, and a shock factor of 0.1 will disable an empty tanker.[33] We calculated the shock

[33] Phone interview with George Pollitt, conducted by Piers Wendlant.

factor for mines with varying explosive charges, ranging from 100 lbs. to 2,000 lbs., and for varying lengths of lateral and vertical separation (see spreadsheet in Appendix D). We believe that none of the bottom mines that Iran could plausibly have in its arsenal, including Russian bottom mines with very large charges, can produce enough explosive energy to damage a VLCC enough to stop its transit through the Strait of Hormuz or the southern area of the Persian Gulf.

A number of reports suggest that the Iranian arsenal includes Chinese EM-52 rising mines.[34] When an EM-52's sensors detect a suitable target on the surface (using a combination of several types of sensors that would presumably allow the mine to selectively fire only at VLCC's), it fires a rocket that can propel a 300-kg warhead to the surface at rates up to 80 m/sec.[35] The explosion of a 300-kg warhead can produce a sufficient energy to immobilize even a laden tanker at lateral ranges as high as ten meters. Assuming the proximity fuse on the warhead is set to explode at the appropriate depth, a single EM-52 mine can cover an area 170 feet in diameter (the 100-foot beam of a typical VLCC plus 35 feet on either side of the ship). This is the effective diameter of the mine.

Probability of a Hit

Iran could lay mines in a wide array of patterns throughout the Strait of Hormuz. Presumably, they would use their familiarity with the normal shipping routes to guide their mine deployment operation. Analytically, though, we can consider the minefield as a series of North-South bands across the entire width of the Strait, each band sized so that a ship passing across it has the opportunity to encounter a single mine during that increment of its overall trip through the Strait (i.e. the width of the band is equal to the effective diameter of a single mine). The number of mines in each analytical band is simply the total number of mines in the minefield divided by the number of bands. We then calculated the percentage of the width of each band covered by the effective range of the mines within that band (that is, the probability of hitting a mine when trying to cross each band). Finally, we calculated the cumulative probability that a ship would traverse all of the bands without hitting a mine. The minelayers face an obvious trade-off between increasing the number of mines in each band (and therefore the probability that a tanker would hit a mine as it crossed each band) and increasing the number of bands (which would increase the number of opportunities to damage a tanker crossing every band in the field). (For relevant formulas in calculating probability of a hit, please see Appendix E.)

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[34] For example, Seth Carus, "Iran as a Military Threat," National Defense University *Strategic Forum*, No. 113, (May 1997).

[35] Andrew Erickson et al., "China's Undersea Sentries," *Undersea Warfare*, vol. 9 no. 2 (Winter 2007).

To estimate the sustained threat to tankers, we also calculate the expected number of mines that a ship will encounter as it crosses the minefield. When the Iranians first activate the minefield, tankers are likely to enter the field along several different paths. Each mine that explodes (and damages a tanker) leaves a hole in the minefield. We assume the Iranians will be unable to continuously re-seed the minefield, since Kilo-submarine movements are likely to be contested after the start of a conflict. If a series of tankers follow the same route through the minefield, they will eventually hit all of the mines in that path, yielding a cleared path known as a Q-channel. The total number of tankers likely to be damaged by the minefield is simply the sum of the number of initial hits (before the tankers concentrate their passage attempts on a single path) plus the expected number of hits along a single path. For a conservative estimate of the number of tankers stopped by the minefield, we count two standard deviations above the expected value of the number of hits in the path of the Q-channel.

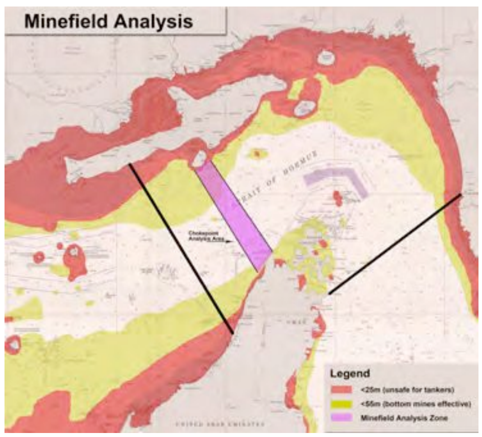

Figure 6. Minefield

Results

The deployment method in Scenario One (using Kilo subs over six months) results in a greatest number of mines in the field and thus a greater probability of a hit. The results below are based on a standard minefield length of 10,000 feet (approximately two miles) and 700 lbs of explosive, which is the average for EM-52 rising mines.

Table 12. Probability of Hitting a Tanker in the Three Mine Scenarios

Scenario	Number of mines in minefield	Cumulative probability of a hit
1	1,067	0.780
2	814	0.697
3	120	0.211

Because the length of the minefield in the above calculations is somewhat arbitrary, we attempted to find the minefield configuration that resulted in the maximum amount of expected hits for all three scenarios. Using the average 700 lb. EM-52 rising mine (with an effective diameter of 170 feet) we varied the length of the minefield from zero to 50,000 feet (about ten miles) to find the maximum number of expected hits. We chose an upper bound of ten miles, assuming that it would be too logistically difficult for the Iranians to lay a minefield larger than that. The expected hits calculation is the cumulative probability (in the table above) plus two standard deviations. For accuracy purposes, we used configurations where mines per band were very close to an integer value (+/- 0.05 of a mine). The results are as follows:

Table 13. Mine Analysis Results of Three Mine-Laying Scenarios

Scenario	# of Mines Deployed	Length of Minefield	Corresponding # of Bands	Corresponding Mines / Band	Exp # of Hits (+ 2 std dev)
1	1067	45,500	267	4	3.86
2	814	27,750	163	5	3.21
3	120	10,500	61	2	0.98

For all scenarios, a tanker is likely to encounter at most a handful of mines along a given path through the Strait. We assume that a few tankers will hit mines before others realize that the minefield exists and move to form a Q-channel. However, even given these initial hits, the Iranians can still only expect to disable six or seven tankers in total. Thus, it is clear that Iran will be unable to create a sustained disruption to oil traffic through the Strait using mine warfare.

Conclusion

There are key weaknesses in using each of these arsenals. The outcome of a successful Iranian attack against a VLCC depends on Iran's ability to perform a series of key steps. The working group pinpointed unique challenges associated with each of our three weapons models: small boats, missiles, and mines. Each model shows that Iran has a limited capability to disrupt oil transportation in the Strait, even in a short-term disturbance.

Chapter 8. Conclusion

Because of Iran's economic dependence on oil, the presence of the U.S. navy, and several other political factors, the Iranian government is not likely to take action to close the Strait of Hormuz. However, there are extreme political contexts in which Iran could find it strategically advantageous to disrupt the flow of oil through the Strait. For example, an aggressive adversary could push Iran to take a methodical or hurried action in response to economic sanctions or an adversary may take preventative military action against a perceived threat, Iranian nuclear facilities, prompting an Iranian response. Iran could employ each of the three of the highlighted weapons: small boats, missiles, and mines, in any of the postulated scenarios. Our analysis of the Iranian military suggests that out of their arsenal those three weapons would be the most effective to use to attack VLCC's.

In Iran's best-case scenario, small boat suicide attacks might be able to significantly damage 33 percent of the tanker traffic on a given day, about seven VLCC tankers. Most of the tankers could be repaired and returned to the tanker fleet after a period of time. This damage estimate compensates for any abnormalities in the data calibration and awards Iran the benefit of the doubt in every case including doubling the estimate for the limiting variable of the intercept. If they were to use missiles, they could expect to significantly damage about 25 percent of the tanker traffic on a given day, about five VLCC tankers. Again, this estimate favors Iran both in the number of missiles fired at the tankers and the estimates used for the steps of the kill chain. If Iran lays a minefield, only six or seven tankers would be affected during the entire time that the minefield is active, assuming tankers continue to complete their routes. These estimates change dramatically, cut almost in half in the case of small boats and missiles, using more realistic estimates based on the data.

The estimate of significant damage to tankers due to small boat suicide attacks may seem dramatic because it translates into 14 million barrels of oil prevented from going through the strait in one day. Again, it is important to remember that this estimate is skewed in favor of the Iranians. In a more reasonable estimate, six million barrels of oil would be taken out of the oil market on that day. This shortage could be compensated for through the SPR or increased production in other oil producing countries. Most likely the shortage will create some panic among the public and possibly increase oil prices for a limited time. These oil prices would drop when oil transport returns to normal shortly after the attack.

In order to increase the amount of damage, Iran might choose to use a combination of weapons. Given the historical use of small boats on more stationary targets, it is possible that Iran might try to use small boats in a secondary attack on already hit, damaged, stationary tankers. In this scenario, the suicide boats would wait for a missile or a mine to strike a tanker. A successful hit would likely stop or at least slow the targeted tanker, dramatically raising the probability of intercept for a small boat. However, it is unclear if Iran would choose to expend multiple attacks on the same target given the constraints on its military assets, especially if the initial attack has already prevented the target from making its "normal" transit through the Strait.

Depending on the severity of these attacks, defensive measures could range from tanker captains turning off their radar and varying their routes to a U.S. naval strike against Iran. In any case, the most significant damage will be done on the first day. It is highly unlikely that Iran would be allowed the opportunity to interfere with tanker traffic a second time. Additionally, without many defensive measures, oil tanker captains are still likely to complete their routes because of high economic benefits.

Iran possesses the initial capability to damage a VLCC in the Strait of Hormuz. Assuming that they successfully apply these capabilities (using a conservative estimate), the percent of significantly damaged tankers is noteworthy but should not elicit panic. Defensive measures could be employed almost instantaneously. Even given success on the first day, Iran could not maintain a sustained campaign and therefore could not create a disruption that would significantly impact the world oil market.

Appendix A. List of Acronyms

ARG	Amphibious Readiness Group
ASCM	Anti-Ship Cruise Missile
BBL/D	Barrels Per Day
CTL	Constructive Total Loss
DWT	Deadweight Tons
EIA	Energy Information Agency
ESG	Explanatory Strike Group
GAO	Government Accountability Office
GRP	Glass Reinforced Plastic
IEA	International Energy Agency
IAF	Iranian Air Force
IMO	International Maritime Organization
IRGC	Iranian Revolutionary Guard Corps
MARPOL	International Convention for the Prevention of Pollution From Ships (short for "marine pollution.")
MEU	Marine Expeditionary Unit
MIU	Marine Intelligence Unit (Lloyd's)
P&I	Protection and Indemnity (Clubs)
RPG	Rocket Propelled Grenade
SPR	Strategic Petroleum Reserve
TSS	Traffic Separation Scheme
VLCC	Very Large Crude Carrier

Appendix B. Small Boat Suicide Attack Calculations

No Defensive Measures

	P(ID) A	P(Intercept) B	P(Detonation) C	P (Dmg Type/Success) D	P(Damage) A*B*C*D
Navy - Patrol Boats					
Dmg Type 1	0.9	0.2	0.8	0.1	0.0144
Dmg Type 2	0.9	0.2	0.8	0.25	0.036
Dmg Type 3	0.9	0.2	0.8	0.5	0.072
Dmg Type 4	0.9	0.2	0.8	0.13	0.01872
Dmg Type 5	0.9	0.2	0.8	0.02	0.00288
				P(significant damage)	0.0936
				Total P(damage)	0.144
IRGC - Patrol Boats					
Dmg Type 1	0.9	0.4	0.8	0.1	0.0288
Dmg Type 2	0.9	0.4	0.8	0.25	0.072
Dmg Type 3	0.9	0.4	0.8	0.5	0.144
Dmg Type 4	0.9	0.4	0.8	0.13	0.03744
Dmg Type 5	0.9	0.4	0.8	0.02	0.00576
				P(significant damage)	0.1872
				Total P(damage)	0.288
GRP Most Likely					
Dmg Type 1	0.9	0.3	0.8	0.1	0.0216
Dmg Type 2	0.9	0.3	0.8	0.25	0.054
Dmg Type 3	0.9	0.3	0.8	0.5	0.108
Dmg Type 4	0.9	0.3	0.8	0.13	0.02808
Dmg Type 5	0.9	0.3	0.8	0.02	0.00432
				P(significant damage)	0.1404
				Total P(damage)	0.216
GRP - Conservative					
Dmg Type 1	0.95	0.6	0.9	0.1	0.0513
Dmg Type 2	0.95	0.6	0.9	0.25	0.12825
Dmg Type 3	0.95	0.6	0.9	0.5	0.2565
Dmg Type 4	0.95	0.6	0.9	0.13	0.06669
Dmg Type 5	0.95	0.6	0.9	0.02	0.01026
				P(significant damage)	0.33345
				Total P(damage)	0.513
Improvised Crafts					
Dmg Type 1	0.85	0.03	0.8	0.1	0.00204
Dmg Type 2	0.85	0.03	0.8	0.25	0.0051
Dmg Type 3	0.85	0.03	0.8	0.5	0.0102
Dmg Type 4	0.85	0.03	0.8	0.13	0.002652
Dmg Type 5	0.85	0.03	0.8	0.02	0.000408
				P(significant damage)	0.01326
				Total P(damage)	0.0204

All Defensive Measures: Attacking Staging Areas, Convoys, and Moving the Shipping Lanes

	P(ID) A	P(Intercept) B	P(Detonation) C	P (Dmg Type/Success) D	P(Damage) A*B*C*D
Navy - Patrol Boats					
Dmg Type 1	0.3645	0.1	0.8	0.1	0.002916
Dmg Type 2	0.3645	0.1	0.8	0.25	0.00729
Dmg Type 3	0.3645	0.1	0.8	0.5	0.01458
Dmg Type 4	0.3645	0.1	0.8	0.13	0.0037908
Dmg Type 5	0.3645	0.1	0.8	0.02	0.0005832
				P(significant damage)	0.018954
				Total P(damage)	0.02916
IRGC - Patrol Boats					
Dmg Type 1	0.3645	0.2	0.8	0.1	0.005832
Dmg Type 2	0.3645	0.2	0.8	0.25	0.01458
Dmg Type 3	0.3645	0.2	0.8	0.5	0.02916
Dmg Type 4	0.3645	0.2	0.8	0.13	0.0075816
Dmg Type 5	0.3645	0.2	0.8	0.02	0.0011664
				P(significant damage)	0.037908
				Total P(damage)	0.05832
GRP Most Likely					
Dmg Type 1	0.3645	0.15	0.8	0.1	0.004374
Dmg Type 2	0.3645	0.15	0.8	0.25	0.010935
Dmg Type 3	0.3645	0.15	0.8	0.5	0.02187
Dmg Type 4	0.3645	0.15	0.8	0.13	0.0056862
Dmg Type 5	0.3645	0.15	0.8	0.02	0.0008748
				P(significant damage)	0.028431
				Total P(damage)	0.04374
GRP - Conservative					
Dmg Type 1	0.406125	0.3	0.9	0.1	0.010965375
Dmg Type 2	0.406125	0.3	0.9	0.25	0.027413438
Dmg Type 3	0.406125	0.3	0.9	0.5	0.054826875
Dmg Type 4	0.406125	0.3	0.9	0.13	0.014254988
Dmg Type 5	0.406125	0.3	0.9	0.02	0.002193075
				P(significant damage)	0.071274938
				Total P(damage)	0.10965375
Improvised Crafts					
Dmg Type 1	0.325125	0.015	0.8	0.1	0.00039015
Dmg Type 2	0.325125	0.015	0.8	0.25	0.000975375
Dmg Type 3	0.325125	0.015	0.8	0.5	0.00195075
Dmg Type 4	0.325125	0.015	0.8	0.13	0.000507195
Dmg Type 5	0.325125	0.015	0.8	0.02	0.00007803
				P(significant damage)	0.002535975
				Total P(damage)	0.0039015

Appendix C. Missile Campaign Calculations

Normal Day- Best Estimate

Missile Fires
A
	Number of Tankers
	B
		P(Observation/ ID)
		C
			P(Com/ Con)
			D
				EV Shipping Targets
				E = B*C*D
					EV # Missiles
					F = E*A
						P(Function)
						G
							EV Missile Fire
							H=(F*G)

1	11	0.95	0.9	9.405	9.405	0.85	7.99425
2	11	0.95	0.9	9.405	18.81	0.85	15.9885
3	11	0.95	0.9	9.405	28.215	0.85	23.98275
4	11	0.95	0.9	9.405	37.62	0.85	31.977
5	11	0.95	0.9	9.405	47.025	0.85	39.97125

EV Missile Hits/Ships I = (H/E)*.90	**Probability of 0 Hits**	**Probability of 1 Hit** 1	**Probability of 2 Hits** 2	**Probability of 3 Hits** 3	**Probability of 4 Hits** 4	**Probability of 5 Hits** 5
0.765	0.235	0.765				
1.53	0.055225	0.35955	0.585225			
2.295	0.012977875	0.126741375	0.412583625	0.447697125		
3.06	0.003049801	0.039712298	0.193914304	0.420835298	0.342488301	
3.825	0.000716703	0.011665487	0.075949769	0.247240737	0.402423753	0.26200355

P(CTL/Sink) 1-5 Hits	**Probability of Interruption** 1 Hit	**Probability of Interruption** 2 Hit	**Probability of Interruption** 3 Hit	**Probability of Interruption** 4 Hit	**Probability of Interruption** 5 Hit
0.045	0.034425				
0.07	0.01617975	0.04096575			
0.12	0.005703362	0.028880854	0.053723655		
0.15	0.001787053	0.013574001	0.050500236	0.051373245	
0.185	0.000524947	0.005316484	0.029668888	0.060363563	0.048470657

Cum Disruption Probability	**EV (Ships Stopped)**	**% Affected**
0.034425	0.323767125	2.9433375
0.0571455	0.537453428	4.88594025
0.088307871	0.830535523	7.550322938
0.117234535	1.102590806	10.02355278
0.144344539	1.357560389	12.34145808

Normal Day- Conservative Estimate

Missile Fires
A
	Number of Tankers
	B
		P(Observation/ ID)
		C
			P(Com/ Con)
			D
				EV Shipping Targets
				E = B*C*D
					EV # Missiles
					F = E*A
						P(Function)
						G
							EV Missile Fire
							H=(F*G)

1	11	0.98	0.95	10.241	10.241	0.9	9.2169
2	11	0.98	0.95	10.241	20.482	0.9	18.4338
3	11	0.98	0.95	10.241	30.723	0.9	27.6507
4	11	0.98	0.95	10.241	40.964	0.9	36.8676
5	11	0.98	0.95	10.241	51.205	0.9	46.0845

EV Missile Hits/Ships I = (H/E)*.90	Probability of 0 Hits	Probability of 1 Hit 1	Probability of 2 Hits 2	Probability of 3 Hits 3	Probability of 4 Hits 4	Probability of 5 Hits 5
0.81	0.19	0.81				
1.62	0.0361	0.3078	0.6561			
2.43	0.006859	0.087723	0.373977	0.531441		
3.24	0.00130321	0.02222316	0.14211126	0.40389516	0.43046721	
4.05	0.00024761	0.005278	0.045001899	0.191850201	0.40894385	0.34867844

P(CTL/Sink)	Probability of Interruption 1 Hit	Probability of Interruption 2 Hit	Probability of Interruption 3 Hit	Probability of Interruption 4 Hit	Probability of Interruption 5 Hit
0.07	0.0567				
0.12	0.021546	0.078732			
0.18	0.00614061	0.04487724	0.09565938		
0.24	0.001555621	0.017053351	0.072701129	0.10331213	
0.32	0.00036946	0.005400228	0.034533036	0.098146524	0.111577101

P(At Least 1 CTL/Sink)	EV (Ships Stopped)	% Affected
0.0567	0.5806647	5.27877
0.100278	1.026946998	9.3358818
0.14667723	1.502121512	13.65565011
0.194622232	1.993126274	18.11932976
0.250026349	2.560519838	23.27745307

Atypical Day- Best Estimate

Missile Fires
A
	Number of Tankers
	B
		P(Observation/ ID)
		C
			P(Com/ Con)
			D
				EV Shipping Targets
				E = B*C*D
					EV # Missiles
					F = E*A
						P(Function)
						G
							EV Missile Fire
							H=(F*G)

1	11	0.8	0.85	7.48	7.48	0.65	4.862
2	11	0.8	0.85	7.48	14.96	0.65	9.724
3	11	0.8	0.85	7.48	22.44	0.65	14.586
4	11	0.8	0.85	7.48	29.92	0.65	19.448
5	11	0.8	0.85	7.48	37.4	0.65	24.31

EV Missile Hits/Ships I = (H/E)*.90	Probability of 0 Hits	Probability of 1 Hit 1	Probability of 2 Hits 2	Probability of 3 Hits 3	Probability of 4 Hits 4	Probability of 5 Hits 5
0.585	0.415	0.585				
1.17	0.172225	0.48555	0.342225			
1.755	0.071473375	0.302254875	0.426070125	0.200201625		
2.34	0.029661451	0.167247698	0.353638204	0.332334698	0.117117951	
2.925	0.012309502	0.086759743	0.244599758	0.344797249	0.243019748	0.068514001

P(CTL/Sink)	Probability of Interruption 1 Hit	Probability of Interruption 2 Hit	Probability of Interruption 3 Hit	Probability of Interruption 4 Hit	Probability of Interruption 5 Hit
0.045	0.026325				
0.07	0.02184975	0.02395575			
0.12	0.013601469	0.029824909	0.024024195		
0.15	0.007526146	0.024754674	0.039880164	0.017567693	
0.185	0.003904188	0.017121983	0.04137567	0.036452962	0.01267509

P(At Least 1 CTL/Sink)	EV (Ships Stopped)	% Affected
0.026325	0.196911	1.7901
0.0458055	0.34262514	3.114774
0.067450573	0.504530287	4.586638973
0.089728677	0.671170504	6.101550032
0.111529894	0.834243604	7.584032768

Appendix D. Mine Campaign Calculations

Maximum Explosive Capacity

Width of Field (N-S) in feet	100000	
Length of Field (E-W) in feet	10000	
Number of Mines	1067	
Tanker Empty/Full	Loaded	
Explosive Size (100-2000 lbs)	2000	
Reliability of each mine	0.8	
	Max Vertical Separation	**Max Lateral Separation**
Loaded	95.00	60
Empty	140.00	85
Effective Diameter (ft.)	220	
Number of Bands	45	
Number of mines per band (rounded up)	24	
Probability of crossing a mine in a band	0.0528	
Probability of hit in band	0.04224	
Cumulative probability	**0.85660**	
Expected number of hits	1.9008	
Standard deviation of hits	1.349262839	
Expected number of hits with 2 standard deviations	**4.599325677**	

Appendix E. Mine Campaign Equations

Mine Deployment

- Total sortie time $= \frac{2(d+c)}{v} + mt$

d = distance to target
v = speed of vehicle
m = mines per sortie
t = time to lay each mine
c = cushion distance

- Total number of sorties $= \frac{d}{(s+t)/24}$

d = number of days in scenario time frame
s = total sortie time
t = turnaround time

- Total mines laid = $mdtrf$

m = mines per sortie
d = deployment success rate
t = total sorties
r = fleet readiness
f = size of fleet

Probability of a Hit

For calculating the probability of a hit, relevant formulas are as follows:

- Number of bands

$$b = \frac{l}{d}$$

b = number of bands
l = length of minefield
d = effective diameter of mine

- Number of mines per band

$$n = \frac{m}{b}$$

n = number of mines per band
m = total number of mines in minefield
b = number of bands

- Probability of crossing a mine in a single band

$$p = \frac{nd}{l}$$

p = probability of crossing a mine in a single band
n = number of mines in band
d = effective diameter of mine
l = width of minefield (east-west)

- Probability of a hit in a single band

$$s = pr$$

s = probability of a hit in a single band
p = probability of crossing a mine
r = reliability of the mine

- Probability of a hit as ship crosses field

$$h = 1 - (1 - s)^b$$

h = probability of a hit as ship crosses field
s = probability of a hit in a single band
b = number of bands

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