A CROSS-DISCIPLINARY APPROACH TO THE MARITIME SECURITY RISK

OF PIRACY AND LESSONS LEARNED FROM AGENT-BASED MODELING

by

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ABSTRACT

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This dissertation takes a cross-disciplinary approach to understanding pirate activity. Maritime piracy presents a dynamic ever-evolving problem. In today's globalized world, contemporary maritime piracy presents a transnational threat. It is a complex socio-economic and political problem which the modern world considers to be criminal activity. Like all complex problems it must be deconstructed to fully comprehend it.

All criminal activity, maritime piracy included, has certain elements of supply and demand. For the activity to occur there must be a certain level, or supply, of targets. At the same time, we can posit that there must be a lack of other opportunities for the pirates, who calculate that the risk of engaging in piracy is worthwhile. This risk calculation is a function of the potential rewards minus the sum of the risks. An increase in pirate attacks creates a demand for better maritime security. An increase in maritime security causes an increase in risk to pirates. Improved pirate capabilities may decrease this risk. The result is a constantly evolving complex problem. This study proposes a parsimonious agent-based model, focused on the socio-economic and political variables that encourage piracy, with utility across many specific regional domains. By simplifying the details of certain aspects of the model, the focus is placed on the issues at the heart of the problem. This allows for new insights into the dynamic relationship between these factors.

For my Mother
who always encouraged me and never told me I couldn't.

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ACRONYMS

ABM	Agent-Based Model
ALARP	As Low As Reasonably Practicable
ASG	Abu Sayyaf Group
ATC	Agent Technology Center
BMP	Best Management Practices
CAST	Conflict Assessment System Tool
CMF	Combined Maritime Forces
CTF	Combined Task Force
DBN	Dynamic Bayesian Network
DES	Discrete Event Simulation
DP	Demographic Pressures (FSI indicator)
ECO	Poverty and Economic Decline (FSI indicator)
EU	European Union
FFP	Fund For Peace
FSA	Formal Ship Safety Assessment
FSI	Fragile State Index
GAO	Government Accountability Office
GIS	Geographic Information System
GISIS	Global Integrated Shipping Information System
HLH	Hong Kong-Luzon-Hainan
HMM	Hidden Markov Model

ICC	International Chamber of Commerce
IDP	Internally Displaced Person
IFC	Information Fusion Centre
IMB	International Maritime Bureau
IMO	International Maritime Organization
INTERPOL	International Criminal Police Organization
IRTC	International Recommended Transit Corridor
ISC	Information Sharing Centre
ISPS	International Shipboard Port Facilities Security (code)
ITOC	International Terrorism and Organized Crime Group
JHC	Joint Hull Committee
JWC	Joint War Committee
JWLA	Joint War Committee Listed Areas
K&R	Kidnap and Ransom (insurance)
MARISA	MAritime RISk Assessment
MSC-HOA	Maritime Security Centre – Horn of Africa
NATO	North Atlantic Treaty Organization
*NGA	National Geospatial-Intelligence Agency
*NGIS	National Geographic Information System
NRL	Naval Research Laboratory
NSMS	National Strategy for Maritime Security
OBP	Oceans Beyond Piracy
ODD	Overview, Design Concepts, and Details

ONI	Office of Naval Intelligence
OOS	Operation Ocean Shield
PAG	Pirate Action Groups
PARS	Pirate Attack Risk Surface
POM	Piracy Opportunity Model
PPS	Piracy Performance Surface
PPSN	Next Generation PPS
PRA	Probabilistic Risk Assessment
PRC	Piracy Reporting Centre
ReCAAP	Regional Cooperation Agreement on combating Piracy and Armed Robbery against Ships in Asia
RTM	Risk Terrain Model
SEC	Security Apparatus (FSI Indicator)
SL	State Legitimacy (FSI Indicator)
SLDS	Switching Linear Dynamic System
SOLAS	International Convention for Safety of Life at Sea
SRT	Skiff Run Time (POM variable)
SUA	Convention for the Suppression of Unlawful Acts Against the Safety of Maritime Navigation
UN	United Nations
UNCLOS	United Nations Convention on Law of the Sea
UNSCR	United Nations Security Council Resolution
VLCC	Very Large Crude Carrier
WFP	World Food Program

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CHAPTER 1

INTRODUCTION

For long as people have sailed the seas they have encountered risk. Everyday ships

are sailing on the waters of the world, carrying goods, enabling trade and making our

modern world work. Every day they take risks to do so. Maritime piracy is just one of

many maritime risks. No matter where or when they sail, there is a risk of maritime piracy.

Sometimes this risk is negligible and at other times it becomes quite significant. Therefore,

maritime piracy is always a consideration. Regulations and laws address the issue. Ships

engage in best practices to protect themselves from pirate attacks. When the risk is great

enough, maritime security forces conduct counter-piracy operations. All these efforts focus

on deterring or preventing a pirate attack without considering what motivates the activity

in the first place.

The risks of going to sea are great. How these risks are viewed depends on who is

looking at them. Mariners look at them in terms of what is the risk to their vessel. Social

scientists, policy makers, insurance actuaries, businessman and engineers all look at risk

from within their own paradigm. Social scientists and policy makers look at past events to

identify trends and indicators which may allow for predictions of future events. They often

use "soft science" approaches for these purposes, although some fields of study employ

empirical methods to analyze events and data. Engineers use "hard science" approaches to

analyze data and calculate performance.

Combining these methods allows for a more systematic evaluation of maritime

security risk. Systems engineers analyze complex systems and look for ways to reduce risk

and improve system performance. They take a holistic look at all the elements that compose the system. They then focus on areas of risk. As they increase their understanding of particular components and/or processes involved in that risk, that information is applied to the larger system.

This dissertation applies a cross-disciplinary approach to the problem of maritime piracy by using systems analysis to look at the issue as part of a broader system of related activity. This technique identifies critical components of the larger maritime system and the interactions between these components. In this work, the larger issue of maritime security is considered, but the focus is on maritime piracy. This project applies a systems engineering approach of risk analysis to the topic of maritime security, a subject which has predominantly been the domain of International and National Security studies. Because maritime security risks are primarily unlawful acts of terrorism and piracy, relevant criminology research is considered. Additionally, modeling and simulation techniques are used to gain insights into what motivates maritime piracy. By taking a systematic look at maritime security risks, it is possible to think about where maritime piracy fits within this broader topic. Then, by specifically focusing on the piracy threat, we improve our understanding of the issues associated with it. Lastly, the new knowledge gained can be applied back to the original system to provide us with a better understanding of the larger issues. This new information can then be used by policy makers, both government and corporate, to more effectively address the maritime piracy problem.

While this work is explicitly concerned with maritime security, there are broader implications for security studies in general. No matter the issue of concern, it can likely be thought of in terms of some sort of system. That system itself is part of a larger, more

complex system. When dealing with a particular issue, expanding the scope of

consideration can provide new insights. Narrowly focusing on just one aspect of an issue

may neglect important related information which is essential to gaining a comprehensive

understanding of the issue. Cross-disciplinary approaches are particularly well suited to

this since they offer varying approaches to the problem under consideration, highlighting

information which would have been overlooked by a narrower approach.

BACKGROUND

Mariners have encountered piracy throughout history. The maritime laws which

apply to the issue have evolved over time. In many parts of the globe, there are deep

cultural roots to this practice that may provide for localized acceptance and even support

for what is otherwise considered an illegal act. The very definition of what is and is not

piracy has changed with time. The frequency of pirate incidents varies across time, waxing

and waning, depending on many considerations. All of this makes piracy a multifaceted

issue for which the motivations must be considered.

The safety and security of international shipping has always been an important

issue. Shipping is the backbone of international trade and shippers and investors want

their cargos to arrive safely. Markets drive commerce and thus drive shipping. Maritime

risks are multi-faceted. There are two different types of events to be considered: maritime

safety accidents and maritime security incidents. Maritime safety accidents are

unintentional events which may occur because of natural causes, an action of the crew, or a

third party. These include events such as fire, equipment failure, and collisions. Safety

accidents may also be navigational in nature, caused by either weather or geography.

Maritime security incidents are intentional actions. These are comprised of unlawful acts, primarily maritime terrorism and piracy. When considering the risks from this category, the concern is how to enhance ship security without jeopardizing the ship's organizational efficiency and effectiveness. Additionally, while the two types of events are distinct in nature, a maritime safety issue may result in an increased vulnerability to maritime security risks. While thinking about the broader range of maritime risk, the focus here will be on maritime piracy. The key question is how great is the risk for such an event and what actions can be taken to reduce the risks. In order to answer this question, we must have a complete understanding of the issue, including what motivates piracy.

Risk, in its simplest definition, is the possibility that something bad may happen. The study of risk is an evolving field closely related to the subjects of probability and economics. Security, on the other hand, is the state of being protected or free from harm. The two concepts are inversely related. An increase of risk results in a decrease in security and vice versa. The three related processes of risk analysis, risk assessment, and risk management are used to better define and understand the implications of specific risks. When maritime risk management is discussed in terms of effective maritime security, what are people referring to? In a general sense, maritime risk management refers to the application of flexible and advanced risk modeling and decision-making approaches to the maritime industry. These techniques are applied to the design, production and operation of assets within the maritime domain. How the security risk in this domain is identified and managed is equally important to maritime safety.

RESEARCH DESIGN

The book *Advanced Risk Analysis in Engineering Enterprise Systems[1]* provides a look

at the emerging discipline of engineering enterprise systems. This provides a structured

approach for analyzing and managing risk in a complex system. A systems approach

requires a broad look at the bigger picture surrounding an issue. Just as we can think of a

system in terms of sub-systems, we can think about how a system fits into an even larger

system. These systems of systems are referred to as enterprise systems.

This concept of an enterprise system is used to think about maritime piracy and

informs the approach used for this dissertation. Maritime piracy is thought about in terms

of where it fits in the bigger issue of maritime safety and security. How the issue impacts

the maritime shipping industry is considered in terms of a system within a larger system.

When we seek to understand how a system works, we look at the components of the

system, consider what we know about those components, and how they interact. When we

want to have a better understanding of the system, we seek to increase our knowledge of

the various components. We then use that improved understanding to update the over-all

system.

As Pinto and Garvey say; "Engineers and managers must develop a holistic

understanding of the social, political, and economic environments within which an

enterprise system operates. Failure to fully consider these dimensions, as they influence

engineering and management decisions, can be disastrous."[2] This need for a holistic

understanding also applies to policy makers. They need to understand the system they are

concerned with. While they may not need to define the system with the same degree of

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[1] Pinto and Garvey.
[2] Pinto and Garvey, 2.

technical specifications, they do need to understand how the system of interest is related to other systems. They also need to develop that holistic understanding of the social, political, and economic environments within the larger enterprise system that their issue of concern exists.

Thus, this research expands our understanding of maritime piracy by thinking about it with a systems analysis approach. In the context of a system of systems, individual concepts are explored to provide a better understanding of the concept. How has the concept evolved and how is it thought about today? How do the concepts relate to each other? Background and history are provided to develop our holistic understanding of the issues. Surveys of the situation are made to understand the current status and identify the gaps in that understanding. Finally, a model is developed to allow for new insight into that gap in our knowledge.

OVERVIEW

I begin with background information on the maritime security problem of piracy. First, I discuss the historic origins of maritime piracy, to include the societal motivations and norms. Then the evolution of maritime law is considered, followed by a discussion of the current definition of piracy. The chapter concludes with a discussion of contemporary piracy.

Chapter 3 surveys existing models of maritime piracy. Since the goal is to expand our understanding of maritime piracy, it is important to understand what kind of modeling efforts have already been done. Chapter 3 provides an overview of existing piracy models. My work is then able to build on those efforts.

Because risk is a central concept of this work, Chapter 4 takes a detailed look at how the idea has developed. It looks at the current concept of risk, not only from the technical application of the concept for the purposes of analysis, but also how our modern society thinks about risk. Then it focuses specifically on maritime risk and how it relates to the topic of maritime safety and security.

Chapter 5 takes a survey of the data that is available to deepen our understanding of maritime piracy. Existing sources of piracy data are reviewed, followed by some basic analysis of the data. A spectrum of piracy is proposed that enables a clearer understanding of how piracy varies in both sophistication and motivation. The chapter concludes with a discussion of sociological data sources that are available to help understand the motivation for piracy.

Now, with a deeper appreciation for what maritime piracy is, as well as how it fits into the larger framework of maritime security, I present a Piracy Opportunity Model. The model takes an abstract approach to the relative opportunities that are provided on land compared to the opportunity of pirating. Chapter 6 focuses on the design and development of the model. Chapter 7 presents the model results and considers possible improvements and extensions of the model. Chapter 8 discusses model implications, and presents thoughts on future work. Lastly, Chapter 9 provides the conclusion of this research.

To summarize, the focus of this research project is to apply a cross-disciplinary approach to Maritime Risk Assessment, specifically maritime security, with an emphasis on maritime piracy. The project explores the application of a systems engineering approach to risk analysis by thinking about the issue as a component of a larger issue and exploring the connections between the issue and other variables. While it is beyond the scope of this

work to provide a complete system diagram, figure 1-1 provides a simple diagram of the

key portions of the system that this dissertation will consider.
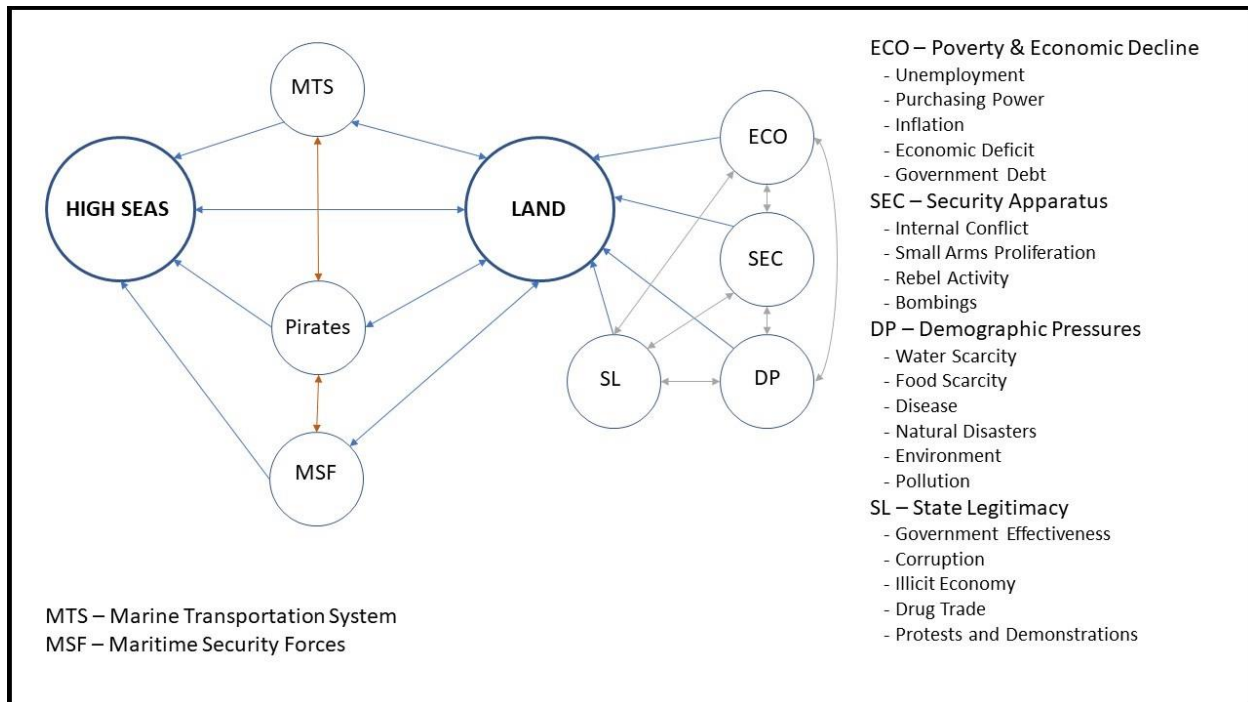
Figure 1-1. System diagram of high seas - land interface

CHAPTER 2

PIRACY

This chapter takes a deeper look at the issue of maritime piracy. A selective

discussion of the history of maritime piracy, using illustrative examples, provides an

understanding of how the issue has changed across time. It is not intended to be a

complete history. Additionally, the information which is available must also be considered

in context. As many have noted, the label "pirate" is an evolving concept and has been

applied to various people throughout history for political or economic reasons. Historical

records written by pirates themselves are scarce and therefore the accounts of piracy have

an inherent bias. Starting with the origins of the concept of piracy, the chapter explores the

cultural context. The segue between the past and present is a brief discussion on the

development of maritime law which leads to the current definitions for maritime piracy.

With this framework established, the chapter concludes with a discussion of contemporary

maritime piracy issues, including counter-piracy polices and operations.

MARITIME PIRACY

For as long as men have gone to sea, some of them have engaged in piracy. Maritime

piracy has deep cultural roots, which may provide for localized acceptance and even

support for what is otherwise considered an illegal act. This makes piracy a multifaceted

issue for which the motivations must be considered. Despite these considerations, an

understanding of the historical development of the issue clearly demonstrates that socio-

economic and socio-political variables are important.

While the Mediterranean and Southeast Asia are perhaps the best documented areas for early piracy, anywhere boats traveled along the coast, the potential for piracy existed. Thus, where there was maritime trade, there was likely maritime piracy; although perhaps the concept of piracy, the very idea that the activity was not acceptable, may not have yet existed. This activity can range from simple opportunist piracy motivated by dire circumstances all the way up to sophisticated and organized criminal activity. Individuals who find success at piracy will be encouraged to continue pirating, especially if there is a lack of other opportunities for them. The longer they pirate, the more sophisticated their activity may get.

States almost unanimously agree that piracy is illegal. In fact, piracy falls under the category of *jus cogens,* which are the highest level of international law. These laws are peremptory norms which an overwhelming majority of states, crossing ideological and political divides, have agreed to and to which no derogation is permitted.[1] The basis of these international laws comes from customs and treaties, and with respect to piracy, refers to piracy on the high seas where "any and every state may seize a pirate ship…arrest the persons and seize the property on board."[2] Each state also has the authority to exercise their jurisdiction over acts of piracy in their own courts. As Malcolm Shaw states, this makes the crime of piracy "quite exceptional in international law, where so much emphasis is placed upon the sovereignty and jurisdiction of each particular state with its own territory."[3]

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[1] Shaw, 126-127.
[2] Shaw, 615.
[3] Shaw, 616.

However, willingness to get involved in enforcing the international laws which prohibit piracy depends on complex considerations. Whenever you move cargo and goods by sea, from one location to another, there will be a chance (or risk) that someone will take your cargo. This risk can be lessened by gaining control of an area. But, maintaining control requires resources to be expended.

When pirate prey is international shipping and the risk of attack becomes too high, international attention demands counter-piracy actions be taken. In early times protection of merchant shipping was provided by a combination of great empire power and the power of mercantilism. The ability of the large mercantile companies to have what were essentially their own private navies disappeared as the mercantile companies either ceased to be commercial entities or were transformed into modern corporations.[4] This left enforcement of order on the seas to state powers with capable naval forces. For many years the British navy was unmatched upon the seas. More recently a combination of United States and Soviet naval power dominated the oceans. Today, the most effective control is with cooperative international efforts. These efforts alone are not enough to eliminate piracy. Ship owners and operators must take all reasonable actions to reduce their vulnerability. The better their knowledge of the risk for a pirate attack the better they can prepare.

HISTORICAL CONTEXT

Pirates must have a target ship and ships are found in port and along shipping lanes. As early as trade occurred by sea, piracy soon followed. Ships with limited navigational

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[4] Thomson, 102.

abilities would travel near shorelines and those who inhabited the shore would intercept the ship and take the cargo. Such raids were a normal part of survival and economic development during the early history of man.

Piracy has roots in the ancient world where taking from others was seen as a legitimate means of survival. The term pirate comes from the Latin *pirata* and from the Greek *peirates* meaning attacker. In describing archaic Eastern Mediterranean societies, Alfred P. Rubin claims "The word '*peirato'* and its derivatives seem to be applied to traditional Eastern Mediterranean societies operating in ways that had been accepted as legitimate for at least a millennium."[5] In ancient times, Greco-Roman laws, developed for and by the Greeks and Romans to instill order and further their economy, were either not recognized and/or understood by non-Greco-Roman societies. By means of Roman hegemony, Roman rules and laws were imposed on those they traded with or conquered. This *jus gentium* or law of the people is the basis for customary international law and forms the basis of Western culture. Rubin goes on to explain that the first recorded references were "not bound to 'piratical*'* acts on the 'high seas,' but to a conception of 'piratical' villages forming a society [*poleis*] on land that refused to accept Roman supremacy."[6] Thus the label pirate was as much about an older tradition which was originally viewed as legitimate being unacceptable to the new order.

Roman Roots

As trade through the Mediterranean increased so did incidences of piracy. Greek and Roman mariners who traveled the Mediterranean were victims of piracy. Early

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[5] Rubin, 6.
[6] Rubin, 8.

mariners navigated by remaining relatively close to the shorelines and thus were easy

targets for those who lay in wait behind headlands. These incidences of piracy were clearly

simple targets of opportunity. It is unclear that the concept of piracy even existed during

this time frame. In his book, *The Law of Piracy,* Rubin says:

> …the fundamental Greek and Roman conception of "piracy" distinguished between robbers, who were criminals at Roman law, and communities called "piratical" which were political societies of the Eastern Mediterranean, pursuing an economic and political course which accepted the legitimacy of seizing the goods and persons of strangers without the religious and formal ceremonies the Romans felt were legally and religiously necessary to begin a war.[7]

Rubin further explains that the Romans dealt with "pirates" as enemies who must be

met in war and defeated.[8] Thus when Roman authority was not accepted, it was imposed

by force. The Romans applied the term piracy to those "whose views of law and

intercommunity relations appear to have reflected millennium-long tradition that had

become an obstacle to Roman trade and inconsistent with Roman views of the world order

under Roman hegemony."[9] While Rubin is making this case about the communities of

Eastern Mediterranean people, the same argument can undoubtedly be made for other

communities of coastal people who took advantage of passing ships.[10] Life was rough and

survival was a priority. Nevertheless, as rule of law gradually replaced the chaos of nature,

the definition of acceptable behavior shifted.

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[7] Rubin, 12.
[8] Rubin, 12.
[9] Rubin, 12.
[10] In fact, Rubin speculates this may have been what Sir T.S. Raffles was thinking when he called some of the Malay sultanates "piratical" (Rubin, 12).

Asian Roots

In addition to the Mediterranean Sea, another geographic area where maritime piracy has a very long history is Southeast Asia. Martin N. Murphy describes Southeast Asia as the "ideal environment for piracy and one where pirate traditions go back virtually uninterrupted to the fifth century."[11] Just like the in Mediterranean Sea, where there is access to the water and passing ships, piracy will occur. If the Mediterranean is the crossroads of European trade, Southeast Asia is the crossroads for global trade. When European colonizers arrived in Asia in the 18th century, they found piracy to already be embedded in the culture as a way of life. However, as Martin states, piracy was likely a way of life in the archipelago long before there was a significant European presence in the region. "It is a region where pirates can hide in the creeks, small rivers and mangrove swamps that puncture the coast, and amongst the thousands of other small craft that ply their innocent trade between the islands."[12] Even a boat laden with a day's catch of fish could be a target for someone who would rather take someone else's catch than expend the effort to fish for themselves.

As Angus Konstam writes, the establishment of new trade routes brought European and American merchants into contact with what had been regional piracy. This pirate activity had likely been ongoing, but had not impacted many from other regions. Equally important, the merchant ships were seen "as lucrative prizes for many who would otherwise have been content to eke out a peaceable living from the sea."[13] Increased trade by European powers increased the targets for piracy. European presence brought western

[11] Murphy, 1983, 72.
[12] Murphy, 1983, 72.
[13] Konstam, 285.

culture. It also brought exposure to another way of life, with perhaps a higher standard of living. But it also brought western norms and laws. When these were not accepted they were imposed, often forcibly.

The Mediterranean

During the time of the early Roman Empire, piracy in the Mediterranean Sea peaked around the 3rd century BC.[14] The growing prosperity of the empire provided an increase in trading vessels transiting the sea. Many of the islands and coastal areas not controlled by the Romans provided bases for pirates. The Romans began a series of expeditions to clear these pirates out.   In some cases, the accusation of piracy was used as an excuse to invade and conquer an area. The last of these efforts was a massive military operation under the leadership of Pompey the Great in 67 BC, which resulted in the Romans having control of the Mediterranean, or the as they called it the *Mare Internum* (the inner sea).[15] The Romans would maintain this control for four centuries until their empire began to crumble.

Without sea control, piracy would return to the Mediterranean. First in the western Mediterranean, while the Byzantine Empire continued to control the eastern Mediterranean. But by the time of the Crusades, piracy had returned in force. The first Crusade was authorized in 1095 by Pope Urban II in an attempt to restore the Holy Lands to Catholic control.[16] Christian ships attacked Muslim ships and Muslim ships attacked Christian ships. Often these ships were powered by slaves – Muslim slaves on Christian

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[14] Konstam, 15.

[15] Konstam describes Pompey's campaign in more detail in *Piracy: The complete History* (Great Britain: Osprey Publishing, 2008), 20-22.

[16] The Crusades lasted for two centuries until the last Catholic outpost fell in 1291. During this time, there were six major Crusades and many smaller ones.

ships and Christian slaves on Muslim ships. Attacks that were made in the name of warfare were justified by the aggressor but often seen as piracy by the victims. The Greek Orthodox Byzantines were sometimes targets as well, since the Western Church viewed them as almost as much of a threat as the Muslims.

Since piracy was essentially a form of warfare, it was necessary to make a distinction between lawful piracy (in terms of the laws of war) and unlawful piracy. Lawful piracy became "privateering," whereby a privately operated vessel was authorized by a legal government to prey on enemy shipping. This authorization was communicated with a commission during times of war, or a letter of marque in peacetime, that provided instructions for the conduct of the privateer. The privateers were authorized to keep a portion of whatever they captured as their payment for the services provided. In essence, the use of privateers was an economical way to compensate for a lack of naval power. English privateering began in the 1200's when Henry III issued the first privateer commissions to vessels from certain English ports to attack the French. The commissions specified that half of what was captured was to be paid to the King.[17] But even before this, piracy was viewed by some as "a source of revenue rather than a hindrance to trade,"[18] and they were sometimes employed by one side against the other during the Crusades.

This wartime practice of commissioning private ships as privateers became common practice among western powers as an adjunct to naval power and was adopted by other cultures that interacted with European colonial expansion. It should be noted however, that while the European powers clearly recognized their own privateers, they often labeled the privateers of their opponents as pirates. Additionally, during peacetime, a

[17] Thompson, 22.
[18] Konstam, 31.

letter of marque might be issued to allow individuals "to seek redress for depredations they suffered at the hands of foreigners on the high seas."[19] The first letter of marque was issued in 1295 and directed against Portugal.[20] A letter of marque authorized the ship to seize something of equal value from a ship of the same nation as the ship which had caused their depredation. These two practices were easily confused and sometimes difficult to distinguish from piracy.

Janice E. Thompson claims that "Privateering commissions represent an effort by the state to both exploit and control individual violence in the international system."[21] Privateers operated at their own expense, which saved the state money on warships, as well as the crew to man them, and the state shared in the profit of their exploits. While the use of privateers was an accepted aspect of warfare and naval warfare was frequent, it was not a continuous state of affairs. During times of peace, some privateers just carried on as pirates. This activity was not sanctioned by the state, but as James Cable said, "the factors that had encouraged the employment of privateers in time of war aggravated the difficulty of suppressing them in time of peace."[22] This is one of the complexities of the issue; what is seen as a legitimate aspect of naval warfare, the taking of a competing nation's ship, becomes illegal during peacetime.

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[19] Thompson, 22.
[20] Thompson, 22.
[21] Thompson, 145.
[22] Cable, 96.

The Golden Age

David Cordingly claims that the "great age of piracy," in which western piracy

flourished, was from the 1650's until about 1725.[23] Others refer to the "Golden Age" of

piracy with definitions of it lasting from 1650 to 1730, although many shorter inclusive

time frames are also defined. These are the pirates who form the basis for the

romanticized popular image of maritime pirates. The era included different waves of

piracy, all of which operated from bases in the Caribbean and along the eastern seaboard of

North America. Marcus Rediker subdivides the Golden Age into three distinct periods.[24]

The first of these were the buccaneers; these were English, Dutch or French pirates and

privateers who targeted the Spanish colonies and shipping in the Caribbean and eastern

Pacific Ocean. The buccaneers were active from about 1650 to 1680. The second was the

Indian Ocean pirates who sailed the Pirate Round; a sailing route used primarily in the

1690's which took pirates traveling from the Atlantic around the Cape of Good Hope into

the Indian Ocean after Muslim ships and ships of the East India Company. The route also

saw a brief resurgence of piracy from 1719-1721. Last was the increase of piracy that

followed the end of the War of Spanish Succession. This wave lasted from 1716 to about

1726 and was comprised primarily of privateers employed during the war. At the end of

the war they were left without legitimate targets, but continued attack merchant vessels.

Narrower definitions of the Golden Age focus only on the period of time that

followed the end of the War of Spanish Succession. The Treaty of Utrecht was signed in

March and April of 1713. Some fighting continued until early 1715, by then additional

treaties had been signed and all hostilities ended.   Following the Peace of Utrecht, all

[23] Cordingly, xvi.
[24] Rediker, 8.

outstanding letters of marque were cancelled. Konstam describes the situation: "As many as 6,000 former privateersmen – all trained to prey on merchant shipping – found themselves unemployed and the major British and colonial ports were soon filled with former privateersmen, all looking for work."[25] Some took positions on the expanding merchant fleet. Others turned to piracy. At the height of their activity in 1720, there were roughly two thousand pirates operating in the Atlantic Ocean and jeopardizing legitimate trade.[26] When they sailed as privateers, many were considered national heroes. After the end of the war, their continued activity became a liability and they were hunted down. It took concerted naval effort to capture these pirates. The penalty was death by hanging.

While most historical accounts treat these individuals as criminals, a recent book by Colin Woodward takes a different approach. Woodward focuses on the timeframe of 1715 to 1725. He is concerned with a specific "clique of twenty to thirty pirate commodores and a few thousand crewmen."[27] He tells the story from the perspective of British tyranny and paints the pirate activity as a maritime revolt that "shook the foundations of the newly formed British Empire."[28]

In the summer of 1713, Benjamin Hornigold and a small band of pirates arrived in what was left of the port of Nassau on New Providence Island in the Caribbean. They encountered few residents, all living in dismal conditions. The island had been attacked and sacked four times during the war by the Spanish and French and conditions had never been restored. Using Nassau as a base of operations they began to amass their captured cargoes among the ruins. They established a market through Richard Thompson, the

[25] Konstam, 152.
[26] Cordingly, xvii.
[27] Woodward, 1.
[28] Woodward, 1.

largest and wealthiest land owner on Harbour Island, which is located approximately fifty

miles north of Nassau. Together with John Cockram, they became "the leading black-

market traders of the Golden Age of Piracy."[29]

The pirates continued to amass assets and treasure in Nassau and their numbers

expanded. By January 1716, Hornigold had over 100 men and a small fleet of ships. He was

unopposed in his authority. New Providence had become an outlaw state and every day its

population was increasing. "Most of the islands' pirates were mariners who long suffered

abuse and exploitation in the navy and merchant marine."[30] They rejected the traditional

system, electing their Captains, dividing the food, plunder and work equitably and making

most decisions democratically. By mid-1716, the pirates began to fortify Fort Nassau with

ships' cannons. As news of the pirate republic spread, disaffected people continued to

arrive; sailors, runaway slaves, free blacks and mulattos, indentured servants, poor

farmers, prostitutes and criminals – just about anyone who was dissatisfied with their lot in

life. "The presence of this rogue state was destabilizing the slave societies around it."[31]

As the pirate republic continued to strengthen, the activities of the pirate fleets

became more prominent. The pirates were interfering with trade routes and disrupting

transatlantic commerce. They defied the Royal Navy, blockaded colonial cities and put the

populations into "a state of terror."[32] Eventually, their actions reached the point where

King George I became determined to suppress the pirates. On September 5, 1717, he

signed *A Proclamation for Suppressing Pyrates.*[33] Phase one was to offer a pardon to any

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[29] Woodward, 90. John Cockram was one of the leaders among Hornigold's mariners. He married one of Thompson's daughters and settled on an adjacent island.

[30] Woodward, 132.

[31] Woodward, 159.

[32] Woodward, 307.

[33] Konstam, 157,

pirate who surrendered to a British Governor. Phase two was a counteroffensive against

the remaining pirates. British authorities took control of Fort Nassau at the end of July

1718. At the time, the population on New Providence was estimated at 500 to 700 pirates

with approximately another 200 non-pirates.[34] Many of the pirates surrendered, those

who did not were hunted down and executed. The island never again became a pirate

haven, although when Great Britain was again at war with Spain in 1719, privateering

commissions were given to many of the former pirates.

Whether the pirate republic fueled the "democratic sentiments that would later

drive the American revolution",[35] as Woodward claims in the prologue of his book, may be

debatable. However, the claim that it was "a zone of freedom in the midst of an

authoritarian age,"[36] is clearly true. The pirate republic did not last for long, but it offered

an alternative to the poor, disenfranchised men and women of all races. As an exhibit at

the Whydah Pirate Museum in South Yarmouth, Massachusetts said, "pirate ships were

islands of freedom in a world of few options."[37] Desperate people were willing to take

desperate actions – after all they did not have much to lose.

Although naval efforts were able to essentially eliminate western piracy, or piracy

committed by those they had sovereign control of, other acts of piracy continued. An

example of this was the Barbary pirates. These pirates had operated from the north coast

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[34] Woodward, 268.

[35] Woodward, 1.

[36] Woodward, 1.

[37] The Whydah Pirate Museum is the creation of underwater explorer Barry Clifford, who located the wreck of the Whydah in 1984 in the waters off Cape Cod. The Whydah, which sank in 1717, was the flagship of Sam Bellamy, one of the most notorious pirates of the Caribbean. The museum combines the artifacts recovered from the Whydah with other artifacts, maps and imagery of the 18th century to provide an accurate depiction of real pirates. Additionally, it provides education on the on-going underwater archaeological exploration of the Whydah wreckage. More information is available on the museum website: https://www.discoverpirates.com/.

of Africa, also referred to as the Barbary Coast, since the collapse of the Western Roman Empire. As European maritime trade expanded, the pirates were considered a serious threat.

Barbary Pirates

The Barbary pirates were also referred to as the Barbary corsairs. Corsair was originally the French term for privateers, but later it became associated with pirates in the Mediterranean. While western history commonly refers to the Barbary Corsairs as the "Barbary Pirates," they operated for the Ottoman Empire in much the same way as European privateers operated for their sovereign states. For example, Christian Corsairs, primarily operating out of Malta, were seen as privateers who paid a portion of their take to those who wrote their commissions.

Konstam points out that the term "pirate" was not in wide use until the 17th and 18th century. He makes the distinction that that they were Barbary corsairs when they were being strictly controlled by the Ottoman Sultan – up until Turkish rule collapsed in 1659. After that time, the beys were only nominally under the control of the Turks. They essentially operated like independent city-states. They answered to no one other than the corsairs who kept them in power. For these reasons, the maritime powers of Europe refused to recognize the authority of the Barbary rulers, who by then were elected from the ranks of the corsairs. So, Konstam refers to them as Barbary pirates from the mid-17th century on "to reflect their lack of international recognition."[38]

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[38] Konstam, 76.

As always, the line that divides a pirate from a privateer can be a very thin line, or perhaps a very wide gray line. Letters of marque were often interpreted with "considerable discretion."[39] Just as Barbary Corsairs sometimes attacked ships whose nations had negotiated immunity, Christian Corsairs occasionally attacked Christian shipping. To borrow an often-used phrase about terrorists and freedom fighters: One man's pirate is another man's privateer.

As the western powers brought piracy under control, the Barbary Pirates continued to operate under the authority of the Bey of Tunisia against those who refused to pay him the required tribute for freedom of navigation in the Mediterranean Sea. While richer nations paid the tribute fees, lesser nations suffered the consequences. An Islamic Barbary attack on the Island of San Pietro illustrates this.   At that time, The Kingdom of Sardinia refused to pay tribute, so the Bey commissioned a small group of privateers (Barbary pirates to the rest of the world) to attack the Island of San Pietro as "part of a centuries-old extortion scheme."[40] The ships arrived off the shore of the island on September 3, 1798 and sent their crews ashore before dawn when the islanders were asleep. When daylight arrived, a coordinated attack occurred. The sailors totally ransacked the island, looting anything of value, including the people. "An astounding 950 people, including 702 women and children," were captured and taken back to Tunis to become slaves or be ransomed.[41]

The motivations for counter-piracy operations were mixed. While the major western powers were eliminating the scourge of piracy from the Caribbean Sea and Atlantic Ocean, they were paying tribute to the Bey and allowing the situation in the

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[39] Cable, 97.
[40] Zacks, 3.
[41] Zacks, 4. For a more detailed description of the incident, and the events that followed leading to the eventual attack on Tripoli by U.S. Marines, see Zacks, 1-10.

Mediterranean Sea to continue. To some extent, this situation was in their commercial economic interest, since it caused more harm to the smaller nations. But by the end of the Napoleonic Wars, it was clear that the Barbary corsairs only served their own interests. Additionally, public opinion on slavery was swinging to the anti-slavery camp and this included the use of slaves to power galley ships. British naval forces bombarded Algiers in 1816 and forced the Bey to release 1,600 slaves. In 1830, the French occupied Algiers and the Barbary Corsair operations were effectively stopped.[42]   While, the corsairs have ceased to operate, their legacy remains as a reminder of how cruel and unpleasant piracy can be.

Colonization of Southeast Asia

On the other side of the world, the situation in Asia also illustrates how exploration and trade struggled to replace the traditional ways of maritime life which Western culture called piracy. As Europeans and Americans expanded their trade routes across the globe in the 18th century, they encountered "regional pirates whose influence had rarely been felt beyond their own shores."[43] By the early 19th century, the southern end of the straits of Malacca was renowned for piracy and the colonial powers continually struggled to control it. Some of this piracy can be attributed to American and European privateers and pirates who decided to sail the Pirate Round. This was dealt with in much the same way as piracy in the Caribbean.

The regional piracy was of a different nature. While the Europeans were motivated by commerce and its expansion, the Asian way of life was different. The Sultans saw the way Europeans conducted commerce as beneath them, but felt it was their birthright to

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[42] Cable, 96.
[43] Konstam, 285.

profit from the trade that passed through their waters. The region had served as a trading entrepôt long before the Europeans arrived. There is certainly a parallel between this attitude and the attitude of those who inhabited the coastal areas of the Mediterranean. Both believed passing ships to be fair game. For the Asians, when proper tribute was not being paid, they would take their portion. For this they were labeled as pirates by western powers.

To get a better understanding of the opposing positions on this issue, let us step back and review a bit of the regional history. The spice trade had long been established in southeast Asia beginning with the 7th century emergence of Srivijaya as a city-state, located on the Indonesian island of Sumatra. As Srivijaya expanded, it became a thalassocracy, or seaborne empire, with its focus along the coastline and in the ports. It covered both sides of the Malayan Peninsula, as well as Sumatra, controlling the straits of Malacca. Srivijaya essentially functioned as a "toll-keeper" for the trade between the Middle East, India and China.[44]

By the 11th and 12th centuries, Srivijaya was in decline. By the 14th century it had faded away. In the 15th century, it was replaced by the Sultanate of Malacca, an Islamic kingdom with influence that stretched as far north as the Philippine islands. The city-state of Malacca was the hub of an influential intra-island trading network and was considered one of the major world ports of its time.[45] Again, geographic position and maritime skills were leveraged to build prosperity.

This was the political organization that the Portuguese found during the explorations of Vasco da Gama in 1498. Shortly after da Gama's voyage, the Portuguese

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[44] Dean.
[45] Dean.

established trading posts throughout Asia. They defeated Malacca in 1511, with the

intention of establishing a monopoly over the spice trade. They spared the Hindu, Chinese

and Burmese inhabitants but slaughtered all the Muslims. The Sultan was able to flee from

the invading Portuguese and he established a new Sultanate of Johor. Without a complete

understanding of the spice trade, Portuguese rule merely forced many regional traders to

other ports and Malacca began a period of decline.

The Dutch arrived in the region, in the form of the Dutch East India Company, in the

early 17th century.[46]   They seized Ambon in the Maluku Islands in 1605 and Banda Island

in 1623. After repeated attempts, they ousted the Portuguese from Malacca in 1641. They

maintained their control of the spice trade with "divide and rule" tactics. This exploitation

allowed the Dutch to temporarily gain a monopoly of the Spice trade, but it had long term

negative consequences for the native peoples it impoverished. This included the both the

people working the land and the sea peoples who has traditionally made their living by

policing the waters and collecting port duties.   By dispossessing the sea peoples of their

traditional rights, the Dutch turned them into "pirates."[47]

Expanding from their base on the Indian continent, the British would arrive as the

English East India Company.[48] As early as 1685 they established a pepper trading post at

Bencoolen (Bengkulu) on the coast of Sumatra in Indonesia. They acquired control of

Penang, on the Malayan peninsula in 1786. In 1819, Stamford Raffles arrived in Singapore

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[46] The Dutch East India Company was established in 1602. It would come to be considered the largest and richest private company in the world with a fleet of more than 150 merchantmen and almost 50 warships. (Konstam, 250) The Netherlands granted the company the power "to make war, conclude treaties, acquire territories and build fortresses." (Thompson, 10).

[47] Trocki, 69.

[48] The English East India Company came into being 1600 when Queen Elizabeth I of England signed a charter which established the "Honourable East India Company" and gave it a monopoly on the trading rights in India. (Konstam, 250).

and negotiated the right to establish a trading post. By this time the thriving spice trade

had become a lucrative business for the European powers.

The rivalry between the Dutch and British for colonial power was not helpful to

improving the piracy situation in Southeast Asia. However, in 1824 these two European

powers signed the Anglo-Dutch Treaty which effectively divided the area into two separate

spheres of influence. Britain retained Malaya (current day Malaysia and Singapore) while

the Dutch were granted the area around Sumatra as the Dutch East Indies (current day

Indonesia). The British gave over Bencoolen to the Dutch, while the Dutch gave control of

Penang to the British. A further treaty between the British and the Sultan of Johor gave the

British possession of Singapore and established the Straits Settlements. This effectively

ended the Johor-Riau Empire.[49]

While provisions within the Anglo-Dutch Treaty called for cooperation to suppress

piracy, commercial competition prevented these efforts from being truly effective. On the

surface, it was easier to control the piracy that resulted from the end of the privateering

authorized during open hostilities. Less transparent, was the motivation behind some of

the "regional piracy." Gerrit Knapp provides an example of this when he credits Dutch

supremacy in Indonesia as manipulating Papuan pirates. As he says;

> ...robbery and barter were two complementary sides of one activity. For a long
> time, this activity was intrinsic to the political economy of the area. In such
> circumstances, violence was lingering never far beneath the surface. Those persons
> acting as pirates, the aggressors as it were, were certainly not part of a marginal
> criminal group on the fringes of society. On the contrary, the phenomenon was
> taken for granted and members of the elite were often heavily involved.[50]

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[49] Falconer, 193.
[50] Kleinen and Ossewijer, 11. Quote is credited to Garrit Knaap.

An Alternative Perspective

From examples such as this, it is clear that there is often more to the story than official dispatches might indicate. Additionally, colony powers, who recorded history, did so through the prism of their own paradigm. As Carl A. Trocki says in his book *Prince of Pirates,* there is a continuing need to "deconstruct and examine carefully the legacy of colonial history and its impact on our current understanding of the history of Southeast Asia and of Malaysia…" This region had a long and rich history before the Europeans arrived. To only think about history in terms of the colonialist paradigms slants our perceptions. Not only were the colonials biased by their values, they also sometimes labeled something for political efficiency. As Trocki says: "No country's history is so well documented yet so poorly understood as that of a former colony."[51]

Most histories of the region fail to consider the role of the entrepôt as the foundation of Malay power.[52] Malay *negeri* (or states) were not self-absorbed riverine enclosures as so many colonial histories describe them. They made themselves into the center of "expansive maritime networks with lines of communication reaching throughout the Southeast Asian seas and stretching from Africa to China and Japan, and from the Persian Gulf to northern Australia."[53]

Trocki writes about Temenggong[54] Abdul Rahman who was the sea lord of the Riau entrepôt. "Riau was part of the ancient Kingdom of Johor,[55] the maritime state which had

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[51] Trocki, 13.
[52] Trocki, 9.
[53] Trocki, 9.
[54] The Temmenggong was the police chief, port official and the minister in charge of defense and markets. He received all the import and export duties and had jurisdiction over all foreigners.
[55] At this time, Johor referred only to a vague geographical area, much of it composed of islands. It should not be confused with the current Malaysian state of Johor.

dominated the southern part of the Malay Peninsula and eastern Sumatra since 1512."[56]

His authority came from the Sultan and his governance was concerned with the *orang laut*

or sea peoples who lived on the various islands. The entrepôt was the last in a succession

of similar urban centers, dating back to Srivijaya. It maintained control of the international

maritime commerce that passed through the region. The people supported their way of life

with trade revenues. Any decline in trade could have a serious impact, as the revenues

were used to import the food supply. During these declines, "the sea peoples had to fend

for themselves by becoming pirates."[57]

When thinking about the 1819 treaty between the Sultanate and Britain it is easy for

us to understand the British desire to gain control of the region. For the Sultan, the treaty

was "an attempt to reorganize an empire based on the traditional pattern."[58] Allowing the

British to establish a trading post would encourage trade, of which the Sultanate hoped to

get a cut. This assumption failed to recognize that the British wished to establish a free-

trade zone. Conflicts ensued, which eventually lead to the 1824 treaty that was settled in

favor of the English East India Company. As a result of this second treaty, the Temenggong

lost all of his legal authority in Singapore and was forced to relocate to Teluk Belanga on

the west side of town, away from the Singapore river.

These arrangements failed to recognize the political and economic realities of the

situation and piracy became a stubborn problem. The *orang laut* traditionally patrolled the

many channels and straits of the region. Under the Temenggong, they assisted in collecting

the port duties from the vessels. The Temenggong also ran what amounted to an

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[56] Trocki, 15.
[57] Trocki, 17.
[58] Trocki, 18.

intelligence network concerning shipping traffic. Port people passed information about

who had or had not paid the proper duties. Those who had not paid would be attacked.[59]

All this was prohibited by the treaty. The allowance that the Sultan and Temenggong were

granted was insufficient to pay the sea peoples, so they continued with their former duties

on a free-lance basis – they became "pirates."[60] Trocki provides cultural context:

> As long as the Malay political system of the region was operative, the activities of the sea peoples had been violent but perfectly legitimate. The sea peoples possessed the seas and what floated on them by hereditary-feudal right from the Sultan of Johor. So long as their chiefs held a valid title from the Sultan, their "patrol" activities regarding trade were a legitimate naval operation.
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> Some groups of 'orang laut,' however, did not come under the recognized chiefs. These were 'perompak' – wanderers and renegades who included hereditary outlaw bands with no fixed abode.* There were also 'perompak' who were temporary bands of outlaws under down-on-their-luck rajas and foreign adventurers. At this time, certain groups were disorganized and in a turbulent state because of recent economic difficulties. They too had a traditional role in Malay politics, supplying much of the dynamic of political history in the region.** During the years 1787-95, when there was no legitimate ruler resident in the archipelago, everyone was a 'perompak.' But it should be understood that this was an exceptional period in Malay history.[61]

Under the 1824 treaty a power vacuum was created in the local political system and

so "piracy" reigned.[62] Throughout the decade that followed the topic of piracy and how

best to control it would occupy much of the Europeans' attention. The fact that all this

activity was considered piracy demonstrated how the Europeans failed to understand the

local culture.[63] They declared war on the pirates and set about eliminating them, but

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[59] Trocki, 70.

[60] Trocki, 68.

[61] Trocki, 68. *Buckley, *An Ancedotal History*, pp. 482-83. **Read, *Play and Politics*, p. 14.

[62] Trocki, 71.

[63] At this time, Horace St. John wrote the book *The Indian Archipelago* in which he equated all Malay political activity with piracy (Trocki, 76). Also see Nicolas Tarling, *Anglo-Dutch Rivalry in the Malay World 1780-1824*. (Cambrige: Cambridge University Press, 1962) for a deeper understanding of the Europeans' failure to recognize role of the traditional maritime empires and entrepots and the consequences. In addition to demonstrating a lack of appreciation for the local politics, this also paralleled the behavior of other colonizing

continued to struggle with the problem. By 1835, the British appointed Abdul Rahman's son Ibrahim, who had succeeded his father as Temenggong, the "colony's official pirate suppressor."[64] This arrangement can best be seen as a compromise by both the British and the Malay which allowed Singapore to move forward. In this role, Ibrahim had to tread a careful path while many of the Malays transitioned to agricultural pursuits.[65]

Singapore once again became a maritime empire; however, this time it was under the control of the British East India Company. Past maritime empires had existed by unifying the sea peoples. The British established their maritime empire by eliminating competition. The anti-piracy campaigns they waged in the name of peaceful commerce and free trade wiped out native commerce. They eliminated the sea peoples and replaced them with their own naval and merchant forces.[66]

A Different Path in Asia

Trocki writes specifically about the relationship between the Malay and the British, but the same is true with most colonial conquests. The relationship is unequal. The colonial powers hold the ultimate balance of power, so in confrontations, the native rulers have no choice but to submit.[67] However, some were harder to subdue than others. The Moro Pirates, also known as the Sulu Pirates, inhabited the small islands in the Sulu Island chain. They were Muslim outlaws of the southern Philippines who engaged in piracy primarily against the Spanish as early as the 16th century. Religious motivation was

people to include the Ancient Romans who labeled traditional activities as piracy and went about eliminating it.
[64] Trocki, 18.
[65] For more on this transition of the Malay polity see Trocki, Chapter 4, "The Temenggong and the Chinese 1844-1860," 98-123.
[66] Trocki, 207-208.
[67] Trocki, 18.

partially responsible for the wars that ensued in this region. While some of these pirates

functioned as privateers in these wars others were outright pirates. Across the four

centuries of the Spanish-Moro Conflict, the Spanish were never able to fully suppress

them.[68] Another group of pirates from the Philippines were the Ilanun pirates who savagely

attacked shipping and coastal villages until they were eliminated by a naval expedition in

1862.[69]

The geographic area of continental Asia is extremely large and the coastal regions

vast. There were plenty of places where boundaries were not definitive and when

contested, jurisdictions overlapped. In remote places, communities could easily exist

outside state-based norms and here those who would be labeled as pirates could exist

within a world of their own. Perhaps one of the best examples of this is Giang Binh (or

Jiangping as it was known in Chinese) a region where the Sino-Vietnamese border was

poorly defined during the latter part of the 18th century. Giang Binh is located in the Red

River Delta area at the mouth of a small unnavigable river. The land is agriculturally poor

and unsuited to farming. The area backs up to nearly impenetrable mountains. For these

reasons, the economic opportunities here are limited. Robert J. Antony describes it as the

most notorious clandestine port of this era. From 1780 until it was razed by royalist troops

fighting the Tay Son rebels in 1802, it was a lively border town that specialized as a black

market, handling stolen goods and provisioning pirates who utilized the port. Antony

describes it as an "integral node in the vibrant shadowy economy that crisscrossed the

South China Sea, linking and forming an extensive network of licit and illicit trade."[70] At its

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[68] For more on the history of the Sulu pirates see Eklöf.
[69] Cordingly, xvi.
[70] Antony, 106.

height, Giang Binh was the hub of an extensive network of black markets and ports friendly

to pirates which stretched southward along the Vietnamese coast and northward up the

Chinese coast.[71]

       The customs and traditions for the communities of Chinese that inhabited the

coastal areas of the South China Sea are very different from those of their western

counterparts. Along the rivers and in the ports of southern China there were floating

villages where the entire community lived and worked on boats. These boat people lacked

the long lineage of landed people due to their mobility and focus on the nuclear family.

They were socially remote and scorned by the onshore society. For the most part they

were beyond government control and created their own voluntary associations.[72] "Petty

piracy," as described by Dian H. Murray, was a survival tactic for those who had no other

means to survive within society and there are examples of it throughout history. In China,

where fishing is a seasonal pursuit, petty piracy was a means to supplement the meager

income of fishing. "During the summer when fishing was poor and dangerous, it was easy

for financially pressed fishermen to take advantage of the southerlies [southern winds] to

sail north to plunder and rob along the coast. Then, with the changing winds and the

approach of the fall, these part-time "pirates" would return home and resume their

fishing."[73] Clearly, piracy was employed when other opportunities were not available and

cases of this sort of piracy, engaged in as a survival tactic, are not the same as those that

occur for other motivations.

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[71] Antony, 106-107.
[72] Murray, 15-16.
[73] Murray, 17.

However, Chinese piracy developed into a much more sophisticated form than this simple opportunistic piracy. Prior to centralized authority, minor warlords controlled the areas along the coast. Their ships engaged in "trading, raiding or conducting piratical acts with equal ease."[74] During certain dynasties, the power of these warlords was reduced, and the problem of piracy lessened. Piracy would again flourish when control was relaxed. As a result, Chinese piracy became highly organized. The pirates formed large fleets and controlled long sections of the coastline. During the 15th century, the Chinese government adopted the practice of paying local rulers to suppress piracy. "While this policy certainly reduced regional involvement in piracy, it also meant that some of these dubious local rulers became little more than bandits who enjoyed the protection of the emperor."[75] All of this set up a pattern of socially accepted piracy.

By 1790 demographic pressures, including overpopulation, had caused an increase in the amount of survival piracy. "But it was still the petty piracy of individual enterprises undertaken on a short-term basis."[76] This rapidly changed. By 1795, the pirates had organized into gangs, many of which were based on family ties. Eventually the gangs became so large that they took on patron-client relationships to continue to expand. In many cases the pirate leaders adopted the young gang members as their sons. Murray credits the Tay Son Rebellion in Vietnam for enabling this rapid escalation. Many of the Chinese pirates served as privateers for Tay Son. During the reign of the Tay Son, the Emperor continued to use his "Navy" and the pirates used Vietnam as a "nest" from which

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[74] Konstam, 288.
[75] Konstam, 289.
[76] Murray, 30.

to operate. Receiving 20-40 percent of the profits from their booty, they reaped great profits under the Tay Son rule.[77]

By the time of the rebellion's ultimate failure in 1802, the character of piracy had totally changed. With the larger Vietnamese ships, armed with cannons, they were no longer simply concerned with survival. The gangs were substantially more complex and had become a formidable force. In 1805, a confederation of between 50,000 and 70,00 pirates controlled the coastal trade and fishing industry in Kwangtung province.[78] "The pirates reached the pinnacle of their power when they were able to extract protection payments from every type of vessel afloat. Merchants, boat owners, Pilots and fishermen alike were forces to buy protection before setting out on any voyage."[79]

The concept of a protection racket is not unique to Chinese piracy, but it does demonstrate that this form of piracy was endemically a part of these societies. The existence of Chinese piracy may be partially attributed to the internal focus of the Chinese empires. Traditionally, because of geopolitical considerations, the Chinese focused more on threats from the land than from the sea. China was domestically focused with little interest in the development of overseas trading arrangements.[80] While the Chinese authorities put a "tough, new sea-war policy" in effect in 1805 it was ultimately tensions from within the pirate confederation which led to its demise.[81] These tensions became apparent in 1809. The beginning of the end came on January 13, 1810 with the surrender of the first of the pirate fleets.

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[77] Murray 32-41.
[78] Murray, 1
[79] Murray, 87.
[80] An exception to this were the maritime expeditions of Chinese Admiral Zheng He (Romanized as Cheng Ho) during the Ming dynasty from 1405 to 1433. His voyages explored the Indian Ocean and the contiguous lands reaching as far as the African continent.
[81] Murray, 99, 137.

The Lessons of History

These are but a few examples of historical piracy. Clearly, the definitions of "pirate" and "piracy" are somewhat open to interpretation. Not only did European colonial powers introduce their western form of laws to a region which had previously functioned with their own societal rules and norms, but they also biased most of the written records of this activity. Adrian B. Lapian cautions that colonial records of piratical raids should not be taken as fact since the line between sea peoples and sea robbers is not clear.[82] Trocki's *Prince of Pirates* presents a totally different perspective: from the point of view of the indigenous population;[83] it is clear they did not consider themselves to be pirates. They were sea peoples who only resorted to piracy when forced by events outside their control. In fact, in the introduction to the second edition of the book, Trocki says the title "*Prince of Pirates*, was a calculated piece of irony…"[84] The Temenggongs were Sea Lords; however, British authorities called them "pirates."

In summary, there are important take-aways from this historical context. The behavior of taking goods from vessels passing near the coastline was a common practice of the ancient world. It happened independently across all coastal regions at various times. It was viewed as a legitimate means of survival. When this behavior became an impediment to the expansion of trade, the norms associated with it began to change. These new norms came primarily from the expansion of western culture. The terms pirate and piracy have been evolving and therefore do not always equally apply. The deep cultural roots of "piracy" may provide for localized acceptance and even support for what is otherwise

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[82] Kleinen and Ossewijer, 10. Quote is credited to Adrian B. Lapian.
[83] Trocki's research used the Johor Archives.
[84] Trocki, 6.

considered an illegal act. The murky distinction between pirates and privateers adds confusion to the issue. As Rubin writes in the preface to *The Law of Piracy*; "The use of the term 'piracy' as a justification for military action seemed to me inconsistent with its use in courts of law."[85] It is clear that the term has not been consistently used. While colonial powers might have labeled a particular activity piratical, in some cases as a justification for their actions; from the perspective of those who engaged in the activity, it was a defensive response to the infringement of western imperialism on their way of life. These considerations make piracy a multifaceted global issue.

Piracy in an evolving issue. The term has been used to characterize behaviors as unacceptable when they were previously seen as a normal means of survival. At times, piracy was engaged in when sea peoples were forced to adapt to the changing environment. While the activity is primarily concerned with the attacks on ships and the water domain, it cannot be separated from the land environment where the people live. To gain a fuller understanding of the issue, the motivations must be considered. And for this socio-economic and political variables are important.

DEVELOPMENT OF MARITIME LAW

Starting with the Romans, norms of behavior set by the *pater familias* were expanded into written Roman law.[86] Initially Roman law applied only to the Romans, but as the Roman Empire expanded the law was applied to all Roman citizens.[87] Laws define proper conduct within a society based on recognized values and rules. International laws

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[85] Rubin, xiii.
[86] Anderson, 192.
[87] Anderson, 192-195.

define behavior between states, including actions of the citizens of those states. These laws

are based on tradition and are codified by treaties and international agreements.

Roman maritime law grew primarily from Greek maritime tradition.[88] As the

Roman Empire spread, so too did what became known as maritime customary law. There

would be a lull in maritime activities during the Dark Ages, but by 1000 AD, Italian trading

city-states were developing. By 1400, Venice was the greatest maritime power of that time.

To administer maritime customary law, they established maritime tribunals in various

ports to allow "trading people the competency to iron out their own troubles."[89]

Although Hugo Grotius had formulated the concept of *mare liberum* or free seas in

1609, it was not generally accepted.[90] Throughout the centuries of global discovery by

European powers, claims had been placed on many regions of the globe, including portions

of the oceans. Many of these maritime claims were overlapping and conflicted.[91] In the

fifteenth and sixteenth centuries, the concept of *mare clausum* or closed seas was

proclaimed by Portugal and Spain and supported by the Papal Bulls of 1493 and 1506.[92]

Under this concept the oceans of the world were divided between these two maritime

powers. These claims were not accepted by other maritime nations and were contested

through piracy, privateering and outright naval warfare.

In parallel with these conflicting claims to the ocean, the concept of territorial seas

began to emerge. In 1598, the book *De Jure Belli Libri Tres* (Three Books on the Law of

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[88] Anderson, 195.
[89] Gilmore and Black, 5.
[90] Brittin, 122.
[91] Brittin, 122. At one-time, Great Britain claimed the Atlantic Ocean surrounding the British Isles and extending from Norway to Spain. England's Edward III proclaimed himself "King of the Seas." The Dutch claimed the seas between Greenland, Iceland and Norway. The Italian states claimed the Mediterranean Sea as their private lake. Spain and Portugal partitioned the Atlantic Ocean and divided all the other oceans between themselves.
[92] Shaw, 609.

War) was published by Alberico Gentili. In this text, Gentili put forth the idea that a sovereign could legitimately treat adjacent waters the same as their land territory. "The genesis of this concept appears to have been based on control over piracy and other acts that might threaten the security of a sovereign."[93] By the 17th century, this concept became clearly defined as three miles, which was the line of sight from the shoreline to the horizon at sea level. It was also the range of cannon at that time and therefore a distance which could reasonably be expected to be controlled from the shore. While the three mile limit was not uniformly adhered to, it was generally accepted. Over time, and as weapons technology advanced, arguments were made for longer limits. At the same time, not all nations had the capability of securing larger territorial seas. Extensive debates on this issue occurred, the latest during the UN negotiations for the 1982 United Nations Convention on the Law of the Sea (UNCLOS). UNCLOS defines territorial waters, or a territorial sea, as those waters establish by a state "up to a limit not exceeding 12 nautical miles, measured from baselines determined in accordance with this Convention."[94]

By 1815, nearly continuous naval warfare was over and British naval supremacy was established.[95] Great Britain slowly gave up its sovereignty claims over portions of the sea to open the way for British ships to sail freely over all of the seas.[96] Joined by the United States, Great Britain pronounced that the seas should be free and reinforced this concept with freedom of navigation activities. Gradually more and more nations agreed with this position.[97] The concept of freedom of the high seas, or freedom of navigation, has

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[93] Brittin, 65.
[94] UNCLOS, Part II Territorial Sea and Contiguous Zone, Section 2 Limits of the Territorial Sea.
[95] Cable, 97.
[96] Brittin, 123.
[97] Brittin, 123.

become a customary international law. Today, it is codified by UNCLOS in Article 87

"Freedom of the high seas."[98]

In the relative naval peace which followed the end of the Napoleonic Wars, focus

turned to the task of eliminating piracy. By 1856 international agreements began to outlaw

privateers in accordance with international maritime law.[99]   France, Britain, Russia,

Prussia, Austria, Sardinia (Italy) and the Ottoman Empire (Turkey) were all parties to the

Treaty of Paris, which formally ended the Crimean War. Attached to the treaty was the

Paris Declaration Respecting Maritime Law signed by the same signatories. This

declaration abolished the practice of employing privateers.   Not all states agreed with this

direction, significantly, the United States argued that privateering was a way for weak

navies to defend against more dominant navies.[100]   However, by the turn of the century,

states had banished privateers to the annals of history.[101] Section VII of The Hague

Convention of 1907 spelled out the requirements for merchant vessels to be employed as

warships. These requirements mandated the ship be placed under proper naval authority.

Thus, the ability to legally employ violence on the high seas was relegated solely to state

powers.

These changes to the maritime law reflect the how the concept of piracy evolved.

What began as customary law was progressively refined with the passage of time. Just as

western culture drove the concept of piracy, it shaped international maritime law. While

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[98] UNCLOS, Part VII, High Seas, Section 1 General Provisions, Article 87 Freedom of the high seas. The article reads: "1. The high seas are open to all States, whether coastal or land-locked. Freedom of the high seas is exercised under the conditions laid down by this convention and by other rules of international law. It comprises, *inter alia*, both for coastal and land-locked States: (a) freedom of navigation," (the other continues with other items to be included).
[99] Thomson, 70-71.
[100] Other nations that did not follow the Paris Declaration of Maritime Law were Spain, Mexico, Venezuela, Uruguay and Bolivia.
[101] Thomson, 76.

privateering served a legitimate purpose, it confused the issue of piracy. Eventually, it ceased to serve the greater good. What remained, and has never been totally eliminated, is piracy. The next section will look at how piracy has come to be defined.

DEFINITIONS OF PIRACY

The general definition of piracy is robbery or illegal violence at sea. Most of the time, piracy is a crime of opportunity. The issue of piracy is not simple and therefore a general definition is not adequate for today's global environment. Piracy in territorial waters and ports is the responsibility of the sovereign nation. As mentioned in the previous section, territorial seas can extend up to 12 nautical miles from shore. In these waters, it is often not considered to be piracy, but rather a form of armed robbery. Individual nations have specific laws which apply within their territory. National laws and rules regarding piracy/armed robbery vary, just as how capably these laws are enforced varies. The willingness of these powers to engage in anti-piracy efforts fluctuates greatly, depending on a multitude of factors. In some cases, the government might even be complicit with the pirates.

Eventually, although it is not clear exactly when, the concept of piracy, which began for political purposes as a means of justifying warlike naval activity, came to be associated with criminal activity on the high seas. The Geneva Convention on the High Seas of 1958 defined piracy as *jure gentium* in article 15.[102] It is considered to be a crime against international society, and as such it falls under universal jurisdiction.[103] Every nation has a responsibility to take action against this crime. The mostly widely accepted legal definition

[102] Shaw, 398.
[103] Shaw, 397.

of piracy is Article 101 of the 1982 United Nations Convention on the Law of the Sea

(UNCLOS):

> Piracy consists of any of the following acts:
> (a) any illegal acts of violence or detention, or any act of depredation, committed for private ends by the crew or the passengers of a private ship or a private aircraft, and directed:
>   (i) on the high seas, against another ship or aircraft, or against persons or property on board such ship or aircraft;
>   (ii) against a ship, aircraft, persons or property in a place outside the jurisdiction of any State;
> (b) any act of voluntary participation in the operation of a ship or of an aircraft with knowledge of facts making it a pirate ship or aircraft;
> (c) any act of inciting or of intentionally facilitating an act described in subparagraph (a) or (b). [104]

This legal definition is the result of much international debate and compromise, and

is therefore technically more discriminating than the general definition. Conversely, the

definition is not the most utilitarian as it imposes two constraints on the issue. First it

limits piracy to actions which are taken for private gain. Second it limits piracy to the high

seas. Both limitations deserve more discussion.

The first limitation attempts to draw a distinction between maritime piracy and

maritime terrorism.   However, as discussed in the last chapter, it is often difficult to

determine the motivation – whether it is politically motivated or for "private ends." As Eric

Ellen points out "very often, the identity of the attackers is in doubt and their motives

unclear."[105]

Limiting piracy to acts on the high seas respects the sovereignty of individual states,

but if those states do not have their own piracy laws this limitation puts the incidents

which occur in littoral waters or ports outside of a legal definition. The majority of

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[104] UNCLOS, Part VII – HIGH SEAS.
[105] Ellen, 237.

incidents occur either in port or within territorial waters.   While the limitation of the high

seas is politically sensitive of state jurisdictions it leaves vessels vulnerable in waters

where states are unable or unwilling to properly police these criminal actions.

English courts defined piracy as "any armed violence at sea which is not a lawful act

of war."[106] In an attempt to find a more pragmatic definition of piracy, the International

Maritime Bureau (IMB) defined piracy as "An act of boarding or attempting to board any

ship with the intent to commit theft or any other crime and with the intent or capability to

use force in the furtherance of that act."[107] The IMB used that definition until 2009 when

The International Maritime Organization (IMO)[108] defined armed robbery against ships as:

> .1 any illegal act of violence or detention or any act of depredation, or threat thereof,
> other than an act of piracy committed for private ends and directed against a ship or
> against persons of property on board such a ship, within a State's internal waters,
> archipelagic waters and territorial sea;
> .2 any act of inciting or of intentionally facilitating an act described above.[109]

The politically driven distinction of the act of piracy being committed for private

gain was useful for gaining consensus on international law.[110] The distinction divides these

actions on the high seas into maritime terrorism committed for political ends and maritime

piracy committed for private ends. This distinction is not always discernible since it

requires knowledge of perpetrator's motivations. Additionally, those actions committed

for private gain cover a very large group of actions from small time piracy committed by

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[106] Murphy, 1983, 8.
[107] Ellen, 237.
[108] The IMO is a specialized agency of the United Nations responsible for regulating shipping.
[109] IMO Resolution A.1025 (26) "Code of Practice for the Investigation of Crimes of Piracy and Armed Robbery against Ships" adopted on 2 December 2009 at the 26th Assembly Session of the International Maritime Organization (IMO). International Chamber of Commerce (ICC) International Criminal Services IMB Piracy Reporting Centre website, accessed December 15, 2014, https://www.icc-ccs.org/piracy-reporting-centre.
[110] Although the debate frustrated many as indicated by the following statement by Eric Ellen: "Much discourse during recent years has concentrated more on what the activity should be called rather than on the consequences – human or material – of the acts being considered." Eric Ellen, "Contemporary Piracy," *California Western International Law Journal* 21, no. 1 (1990): 1.

those driven by desperation to highly organized criminal activity. The motivation for this spectrum of maritime piracy varies greatly. The small-time piracy is more apt to appear when there is a lack of other economic opportunities, especially when the perpetrators consider themselves victims of social injustice. This form of piracy is more likely to be successfully addressed by offering alternative – and legal – economic opportunities. Conversely, highly organized criminal activity, such as what exists in the South China Sea, is a far more complex issue.

CONTEMPORARY MARITIME PIRACY

During the first half of the 20th Century, maritime piracy was virtually nonexistent, with only a few sporadic incidents reported around the globe.[111] This was likely in part due to the way pirates had been hunted down and hung for their crimes, with their bodies left to rot as a deterrent to other would-be pirates. As well, this was the time of great naval powers, who sailed and controlled the seas. Surely there were local regional incidents of piracy, but those were not the type of events to capture wider attention.

Following WWII, without open naval conflict, most nations decreased the size of their navies. Up until the end of the Cold War, the United States and the Soviet Union vied for control of the seas, but for the most part merchant ships were left to fend for themselves on the high seas. While private yachts were once the primary target for piracy, gradually the scope of the problem expanded such that now even the largest of merchant ships are vulnerable in certain waters. The high seas are a vast global commons beyond the sovereign jurisdiction of any one nation. Due to "vagaries of jurisdiction, sometimes

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[111] Konstam, 304.

confused and tumultuous international diplomatic relations, and divisive international political issues," pirates often find a permissive environment which essentially allows them to operate with impunity.[112] A topic which had nearly vanished from public concern is back. So now I shift to consider what modern maritime piracy looks like.

Obviously, there are some similarities in all maritime piracy incidents. One commonality necessary for piracy to take root in an area is a maritime tradition which provides the necessary skill set. Martin N. Murphy says that trading patterns are one of the factors that determine the acceptability of piracy. He posits that "piracy has deeper roots in Southeast Asia than in West Africa because important trading routes have bisected Southeast Asian archipelagos for centuries, making piracy there a way of life that has been established for generations, often on a clan or family basis."[113]

Piracy does not exist if there are no ships to plunder. Therefore, the shipping routes are just as significant. The Mediterranean is another area where the trading routes have a long history. At the same time, new shipping routes create new opportunities for piracy. The development of the petroleum industry and the shipment of oil is a major part of the global economy. Oil shipments now cross the globe. West Africa has a significant role in the shipment of oil, so while the trading routes from West Africa may not have the same continuous long history as other routes, they create an environment ready for contemporary piracy. Some aspects of contemporary piracy are different. The mercantile companies of old that essentially had their own navies are gone. As well, many of the national merchant fleets have been eroded; the majority of merchant shipping now sails under flags of convenience where the licensing costs are lower. Additionally, as maritime

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[112] Payne, 6.
[113] Murphy, 1983, 42.

technology advanced, the size of the ships increased while the size of the crews decreased. Today these large ships may have a crew of only a dozen or so merchant mariners, which reduces their ability to fend off a pirate attack. These factors make these ships particularly vulnerable to attack.

Meanwhile, modern-day pirates are also able to take advantage of technological advances.[114] Many have high performance boats with radios, radar, and satellite navigation. Weapons technology has also advanced and so modern-day pirates may be armed with automatic weapons. These factors also increase ship vulnerability and the risk of piracy.

These aspects are exasperated by the transnational threats which characterize the 21st century; competing demands for scarce security resources, global proliferation of arms, and areas of ineffective governance. Maritime piracy is a global phenomenon. It occurs as a means of subsistence all the way up to sophisticated organized crime.[115] No portion of the oceans is without the risk of piracy. However, incidences of piracy are not equally distributed across the globe. Both Asia, particularly the waters of Southeast Asia, and Africa have far more pirate attacks then other regions, and therefore deserve a detailed discussion.

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[114] A recent Seatrade Maritime News article by Vincent Wee reported "Pirates used AIS tracking app to identify ship to hijack." September 21, 2017. Accessed September 22, 2017, http://www.seatrade-maritime.com/news/asia/pirates-used-ais-tracking-app-to-identify-ship-to-hijack.html?utm_content=Pirates%20used%20AIS%20tracking%20app%20to%20identify%20ship%20to%20hijack&utm_source=Email&utm_medium=Seatrade%20Maritime%20News&utm_contact=23761008&utm_term=Newsletter_Seatrade%20Maritime%20Daily%20News&utm_campaign=97448.

[115] Chalk and Hansen, 498. They refer to the more sophisticated piracy as professional piracy.

Contemporary Piracy in Asia

Contemporary piracy in Asia continues to make Asian waters risky for Mariners. This activity reached a peak of 353 cases of piracy in the year 2000.[116] Most of the piracy occurring in Southeast Asia happens where there are concentrations of ships, especially in areas where the geography and congestion of ships require the vessels to slow their transit. There are plenty of coastlines which might harbor pirates. Stefan Eklöf describes the Southeast Asia coastline as the equivalent of several times the length of the equator.[117] Here the incidents are primarily opportunistic and are conducted by fisherman and other mariners looking to supplement their meager incomes.[118] Piracy in the Philippines is an exception to this. There the incidents are primarily in the waters off the island of Mindanao and are largely attributed to the inability of the Philippine government to maintain control in an area that is in conflict with Muslim separatists.[119]   Piracy in the South and East China Seas is more complex, involving multiple countries and various local criminal syndicates.[120]

The highest levels of reported Asian piracy incidents occur in Indonesia. If, as Murphy said; "Southeast Asia is the ideal environment for piracy," Indonesia is the most ideal given its geography as an archipelagic nation. Indonesia consists of over 17,500 islands (only about 6,000 of which are inhabited) and about 34,000 miles of coastline.[121] Although Indonesia is concerned about maritime security, their assets are limited and

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[116] ReCAAP *2006-2016,* 39.
[117] Eklöf, 3.
[118] Ellen, 239.
[119] Ellen, 240.
[120] Ellen, 239.
[121] CIA World Factbook "Indonesia." Accessed December 29, 2014, https://www.cia.gov/library/publications/the-world-actbook/geos/id.html. Murray cites other figures saying the coastline is about 50,000 miles and that even the Indonesian government is unsure of how many islands make up the archipelago (Murphy, 1983, 73).

piracy is not necessarily their primary maritime security concern.[122] In some areas their

control is tenuous at best. Added to these issues is the problem of government corruption,

"a common problem amongst agencies in the region charged with maritime law

enforcement…"[123] Most of the reported incidents which occur in Indonesian anchorages

and territorial waters are low-level opportunistic robberies. However, the increasing rate

of these incidents is reason for concern and the IMB has been working with the Indonesian

Marine Police to improve maritime security in these high-risk areas.[124] Since many

incidents occur to vessels at anchor, the Indonesian Marine Police have designated certain

anchorages where they will perform increased patrols; these are listed on the ICC

website.[125] Other anchorages may have a higher risk for piracy.

The geographies of the Philippines and Malaysia are similar to Indonesia although

neither of them is as vast in scope.[126] Murphy suggests that piracy in the Philippines is

likely as big or bigger of a problem but most of the incidents are unreported.[127]

Throughout the Philippine-Indonesia-Malaysia "tri-border" region, casual killing of

fishermen and local traders unfortunately seems to be a regular occurrence. Protection

fees are common. Piracy does not stop at the shorelines and coastal settlements have also

been raided and forced to pay protection fees. This form of piracy likely has connections

back to the historical regional piracy that typically does not garner international attention.

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[122] Murphy, 1983, 73. Murphy lists smuggling of people and goods and the degradation of the maritime environment through over fishing as higher concerns.
[123] Murphy, 1983, 74.
[124] ICC-IMB 2013, 24.
[125] ICC Website, "Piracy & Armed Robbery Prone Areas and Warnings." Accessed December 29, 2014, https://www.icc-ccs.org/piracy-reporting-centre/prone-areas-and-warnings.
[126] CIA World Factbook "Philippines." Accessed December 29, 2014, https://www.cia.gov/library/publications/the-world-factbook/geos/rp.html and "Malaysia." Accessed December 29, 2014, https://www.cia.gov/library/publications/the-world-factbook/geos/my.html.
[127] Murphy, 1983, 75. Murphy states that Eric Ellen and others have also cast doubt on the reliability of reported figures.

Adding complexity to this region is the Philippine Mindanao and Malaysian Sabah region which is effectively linked by the Sulu island chain. Eklöf believes this probably is "the most dangerous maritime area in the world."[128] Here the tradition of piracy was never suppressed by the Spanish, and what control the American occupation imposed, vanished with Philippine independence. Anthony Davis has suggested that there are six individual groups of armed pirates who operate in this region, some of them with links to the Abu Sayyaf Group (ASG).[129]

The piracy situation in the Straits of Malacca and Singapore is a very different issue. Here freedom of navigation and safe passage is of vital interest to many nations. John S. Burnett describes the five-hundred-mile passage of the Malacca Straits as "the commercial umbilical connecting Europe, the Middle East, and the Indian subcontinent to Asia and the Pacific."[130] Roughly a third of global commerce travels through these straits.[131] While piracy incidents in the straits are lower than their historic peak because of coordinated international efforts to control piracy, these passages are not risk free; incidents still occur and Burnett refers to them as "*Dangerous Waters*." The number of pirate attacks was so alarming in the early 2000's that the straits were declared a war zone in 2005 by the Joint War Committee.[132] This required ships making the passage to carry extra marine insurance. Through focused efforts, the situation improved and the straits were removed from the list in August 2006. The IMB has continued to provide a warning about these waters. Their 2016 annual report says; "The number of attacks continue to drop due to the

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[128] Eklöf, 43.
[129] Murphy, 1983, citing: Anthony Davis, "The Sulu Triangle." *Jane's IR,* vol. 16, no 6, June 2004, p. 40. Burnett also claims that ASG has attacked ships with self-propelled grenades, 104.
[130] Burnett, 11.
[131] Burnett, 11.
[132] ReCAAP *2006-2016,* 39.

patrols by the littoral states authorized since July 2005."[133] In both areas, Malacca and

Singapore Straits, ships are warned to maintain anti-piracy/robbery watches and be

vigilant.[134]

Reported incidents in the South China Sea have dropped significantly. Between

1993 and 1995 piracy in this region was second highest, only behind Indonesian

incidents.[135] The region of greatest concern is formed by a triangle from Hong Kong and

Macau to Luzon Island in the northern Philippines and to Hainan Island, the southernmost

province of China. This area is called the Hong Kong-Luzon-Hainan (HLH) triangle. Many

of the incidents here involved organized criminal activity and even more noteworthy,

official Chinese patrol craft were often involved.[136] One explanation for why this activity

significantly decreased in 1995 is that the Chinese government reigned in the local

administrations, because these piracy incidents were harming China's international

reputation and were a challenge to Chinese authority.[137] Yet in 2003, Burnett described the

South China Sea as "a lawless, disputed no-man's-land where ships are frequently hijacked

by pirates in the employ of organized crime syndicates for the precious cargoes they

carry."[138] Some of these waters still remain risky and the ICC website warns mariners to

remain vigilant "in the vicinity off Tioman / off Pulau Aur / off Anambas / Natuna /

Mangkai islands / Subi Besar / Merundung areas."[139]

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[133] ICC IMB 2016, 17.
[134] ICC IMB 2016, 17.
[135] Murphy, 1983, 94.
[136] Murphy. 1983, 94.
[137] Murphy, 1983, 95.
[138] Burnett, 12-13.
[139] ICC Website, "Piracy & Armed Robbery Prone Areas and Warnings," "South East Asia and Indian Sub-continent." Accessed August 8, 2017, https://www.icc-ccs.org/piracy-reporting-centre/prone-areas-and-warnings.

Certainly, one of the most important developments to come about because of piracy in Asia was the establishment of the ICC IMB Piracy Reporting Centre (PRC) in Kuala Lumpur, Malaysia. Alarmed by the increasing incidences of piracy, the IMB established the PRC in 1992 as a free service to mariners.[140] The Centre allows attacks to be reported and acted upon more quickly. While not specifically stated, another factor may have been the increasing probability that unchecked piracy operations could lead to an environmental disaster with far reaching consequences to those who depend on the sea for their livelihood. Murphy discusses two pirate events that could have resulted in a disaster. The first was in 1991 when, following a pirate attack, the *Eastern Power*, a fully loaded Very Large Crude Carrier (VLCC), steamed out of control in the Phillips Channel south of Singapore for 15-20 minutes.[141] The second incident occurred in 1992. A pirate attack left the *Valiant Carrier* on fire, steaming out of control, and close to the shore of Sumatra with a full load of furnace oil.[142] Aware of the incredible environment destruction caused by the *Exxon Valdez* oil spill in Prince William Sound, Alaska in 1989, it is hard to imagine that the IMB did not at least think about the potential for piracy to cause an environmental disaster when the PRC was created.

The Piracy Reporting Centre is a 24-hour operation. It functions as a non-governmental organization and is capable of being the first point of contact for mariner reports of pirate or armed robbery activity, not only in Asian waters, but globally. In October 1992, the IMB began to issue daily situation reports to improve situational

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[140] International Maritime Bureau website. Accessed December 30, 2014, https://www.icc-ccs.org/icc/imb.
[141] Murphy, 1983, 154.
[142] Murphy, 1983, 154.

awareness of ships at sea.[143] These reports allow mariners to make better informed decisions about their sailing routes. They have not eliminated the problem; in fact, it has generally continued to grow in magnitude. Perhaps more troubling is a parallel trend of "growing sophistication and increasing violence" in these pirate attacks.[144]

Between 1990 and 1994 there was an average of less than 100 incidents of piracy a year.[145] From 1994 to 1999, the annual average increased to 209.[146] In 1999 there were 285 piracy incidents; attacks on ships at sea, at anchor or in port.[147] There were 2,463 actual or attempted acts of piracy reported between 2000 and 2006, this increased the annual average to 352.[148] Analysis of the data for more recent years is provided in Chapter 5.

All of this clearly implies an increasing trend in the number of global piracy incidents, although some of it may also be attributed to better or more consistent incident reporting. When I spoke with Noel Chang, the Director of the PRC, in 2015 about how he measures the effectiveness of the Centre, his reply was the amount of cooperation between the ships and between governments.[149] The number of reported incidents is less important because there is no way to know what percentage of incidents are being reported. But increased communication, sharing of information, and cooperation leading to counter-piracy actions are critical to success.

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[143] Burnett, 70.
[144] USG, Int'l Crime Threat Assessment.
[145] USG, Int'l Crime Threat Assessment.
[146] Chalk, 2008, xi.
[147]USG, Int'l Crime Threat Assessment.
[148] Chalk, 2008, xi.
[149] Noel Chang, Director of the IMB ICC Piracy Reporting Center, interviewed by author, Kuala Lumpur, Malaysia, January 13, 2015.

Another cooperative international organization which has developed to deal with the threat of piracy in Asia is The Regional Cooperation Agreement on Combating Piracy and Armed Robbery against Ships in Asia (ReCAAP).[150] Unlike the ICC's IMB Piracy Reporting Centre, ReCAAP is the first regional government-to-government agreement to promote and enhance cooperation against piracy and armed robbery in Asia. The agreement to form ReCAAP was finalized on 11 November 2004, and the organization entered into force on 4 September 2006. There are currently 20 nations who are Contracting Parties.[151] ReCAAP's Information Sharing Centre (ISC) was established 29 November 2006 and has since been recognized as an International Organization. The ISC, located in Singapore, uses a secure web-based information network system to exchange information between the contracting parties. This network allows ReCAAP "Focal Points" (each contracting party designates a focal point) to be linked to the ISC and each other around the clock. They are able to exchange information about piracy incidents, support anti-piracy capacity building efforts and negotiate cooperative arrangements. However, it is worth noting that neither Malaysia nor Indonesia are member states (although they may become at some future date), and it is difficult for ReCAAP to operate efficiently without these two critical states' full participation.

In the event of a piracy incident, the ISC is able to facilitate appropriate responses: "The agency receiving the incident report will manage the incident in accordance to its

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[150] ReCAAP Information Sharing Centre. Accessed December 30, 2014, http://www.recaap.org/.

[151] The twenty Contracting Parties to ReCAAP are Australia, the People's Republic of Bangladesh, Brunei Darussalam, the Kingdom of Cambodia, the People's Republic of China, the Kingdom of Denmark, the Republic of India, Japan, the Republic of Korea, the Lao People's Democratic Republic, the Republic of the Union of Myanmar, the Kingdom of the Netherlands, the Kingdom of Norway, the Republic of the Philippines, the Republic of Singapore, the Democratic Socialist Republic of Sri Lanka, the Kingdom of Thailand, the United Kingdom, the United States of America and the Socialist Republic of Viet Nam. Accessed December 30, 2014, http://www.recaap.org/AboutReCAAPISC.aspx.

national policies and response procedures, and provide assistance to the victim ship where possible. The agency will in turn, inform their ReCAAP Focal Point which will submit an incident report to the ReCAAP ISC and its neighboring Focal Points."[152] The ISC attempts to validate and maintain accurate information on piracy incidents. They provide greater detail of the incident than the IMB and try to follow up on each incident to monitor law enforcement response.[153] The centre is also responsible for analyzing the statistics of piracy and armed robbery incidents to develop a better understanding of the situation in Asia. Lastly, they cooperate with other organizations and parties via information sharing, joint exercises, and other forms of cooperation, as appropriate, and agreed by the Contracting Parties.[154] This includes hosting workshops and participating in conferences to share lessons learned, including best management practices for anti-piracy efforts. They have formal cooperation agreements with the International Maritime Organization (IMO) and International Criminal Police Organization (INTERPOL) as well as other like-minded organizations.[155]   ReCAAP provides a strong example of why international cooperation is important on an issue as complex as piracy and provides a model for cooperation in other regions.

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[152] ReCAAP Information Sharing Centre website. Accessed December 30, 2014, http://www.recaap.org/AboutReCAAPISC.aspx.

[153] Murphy, 1983, 66.

[154] Murphy, 1983, 66.

[155] In addition to the IMO and INTERPOL, ReCAAP has formal agreements with the Republic of Singapore Navy's IFC, the Djibouti Code of Conduct Information Sharing Centres (DCoC ISCs), the Asian Shipowners' Forum (ASF), the Baltic and International Maritime Council (BIMCO), and the International Association of Independent Tanker Owners (INTERTANKO). ReCAAP, *Commemorating A Decade of Regional Cooperation 2006-2016: The Regional Cooperation Agreement on Combating Piracy and Armed Robbery against Ships in Asia*. Accessed August 28, 2017, http://www.recaap.org/DesktopModules/Bring2mind/DMX/Download.aspx?Command=Core_Download&EntryId=432&PortalId=0&TabId=78. However, they do not have an agreement with IMB and neither Malaysia or Indonesia are member states for various political reasons.

A third organization is the Information Fusion Centre (IFC) hosted by the Republic of Singapore Navy. The IFC is a regional Maritime Security information-sharing center which was opened in April 2009. As a military organization, the IFC is more operationally focused than the other organizations. The Centre hosts liaison officers from 15 partner nations and has linkages to another 20 countries and 65 agencies.[156] Staffed 24 hours a day, seven days a week, the goal of the IFC is to enhance the collective understanding of the maritime domain for collaborative strengthening of maritime security. In addition to providing real-time updates of actionable information, the IFC conducts capacity-building workshops and exercises.

The three organizations; the PRC, ReCAAP, and the IFC, demonstrate the wide variety of stakeholders with interest in the issue of maritime piracy. The PRC, while funded purely by donations, represents the commercial interests of the IMB. The Centre focuses on increasing awareness of piracy and protecting the lives of mariners. ReCAAP is an inter-governmental organization whose objective is to enhance cooperation and increase capacity to for counter-piracy efforts. The IFC is a military organization with the mission of sharing operational information. The need for all of these organizations speaks to the complex challenges to fighting piracy.

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[156] Information Fusion Centre (IFC) Fact Sheet dated 13 Feb 2015: Accessed August 8, 2017, https://www.mindef.gov.sg/imindef/press_room/official_releases/nr/2014/apr/04apr14_nr/04apr14_fs.html. The 35 countries involved with the IFC are Australia, Belgium, Brazil, Brunei, Cambodia, Canada, Chile, Denmark, France, Ghana, India, Indonesia, Italy, Japan, Malaysia, Myanmar, New Zealand, Norway, Pakistan, Peru, Philippines, Portugal, Russia, Senegal, Seychelles, Singapore, South Korea, Sri Lanka, Spain, Thailand, United Kingdom, United States, Vietnam and Yemen.

Contemporary Piracy in Africa

Forty years ago, West Africa had the highest rates of piracy anywhere in the world. In 1981, the IMO declared the Nigerian coastline to be the most dangerous worldwide.[157] By the 1990's attention shifted to Asia where there was concern that piracy rates in the Straits of Malacca would spin out of control.[158] As the new millennium arrived, the piracy rates in Somalia began to take center stage. By 2009, Somali piracy composed more than 50% of worldwide reported pirate incidents. In 2011, it peaked at nearly 54% of worldwide reported pirate activity. That year the IMB Piracy Reporting Centre received a total of 237 incident reports attributed to Somali pirates.[159] Over 700 hostages and 32 vessels were being held by Somali pirates, with huge ransoms demanded for their release.[160]

Up until 2013, Somali pirate incidents outnumbered the total incidents in all the rest of Africa. While it is difficult to determine the exact origin of these attacks, they began in the early 1990's following the political disorder that resulted from the ouster of Muhammad Siad Barre, the socialist dictator who was overthrown by clan-based warlords. Early on, Somali pirate attacks were a focus of concern because of the heavy weapons (e.g. mortars and grenades) which were used against ships transiting the coast as well as those in port.[161] These may have been supplied by the civil war which was ravaging the country, resulting in a near total breakdown of a functioning government. The pirates sometimes presented themselves as Somali Coast Guard officials. It is possible that they actually were

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[157] Ellen, 240.
[158] Ellen, 239.
[159] ICC IMB 2011, 20.
[160] Maritime Executive, November 28, 2016.
[161] Ellen, 240.

corrupt law enforcement officials.[162] Given the breakdown of Somali governance, past

government officials needed an alternate means of supporting themselves. The semi-

legitimate organizations such as the Somali Coastal Defense Force, the Somali Marines and

the National Volunteer Guard were all implicated in piracy operations, conducted under the

appearance of legitimacy.[163]

However, law enforcement officers were not the only ones who needed to find ways

to support themselves. Without a functioning government, conditions in Somalia were

bleak for many. Desperate fishermen turned to piracy. Initially, they targeted foreign

fishing boats. They would keep the catch and ransom the crews. When the fishing vessels

hired local warlords to provide protection, the pirates adapted and began to target

commercial vessels.[164]

Attacks by Somali pirates began in coastal waters and gradually increased in range

as the pirate tactics evolved. This is the warning in the IMB annual report for 2000:

> Somalian waters continue to be a risk prone area for hijackings. Ships should
> keep at least 50 nm and if possible 100 nm from the Somali coast. Ships not
> specifically calling at Somali ports should avoid approaching the Somali coast.
> Armed pirates in speedboats and gunboats open fire on ships / yachts and rob or
> hijack them. Some crew had been injured or killed in the past. Communications
> including the VHF in these waters should be kept to a minimum.[165]

In 2005, there was a significant increase in Somali pirate attacks. The IMB warnings

reported that Somali pirate attacks had been reported as far away from the shore as 400

nautical miles. The pirates were using larger vessels, which they had obtained or were

holding hostage, to function as "mother ships." This tactic significantly increased the range

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[162] Ellen, 240.
[163] Konstam, 309.
[164] Bahadur, 16.
[165] ICC IMB 2000, 11.

of the pirates. Ships not calling on any Somali ports were advised to maintain their track at

least 200 nautical miles from the Somali coast.[166] Murphy credits this increase of Somali

piracy to the inability to affect the economic factors which were driving it. As he says,

"Shadowy home-grown leaders with a clear understanding of supply and demand

transformed what was a small-scale nuisance before 2005 into a disciplined and effective

machine…"[167] Failure to address the initial problem allowed it to expand into a much

larger problem.

As a result of this surge in piracy incidents in the waters off Somalia, the European

Union Naval Force launched Operation Atalanta in December 2008 to "deter, prevent and

repress acts of piracy and armed robbery off the Somali coast."[168] Their specific tasks set

by the EU Council are:

1. Protect vessels of the World Food Programme (WFP) and other vulnerable

shipping;

 2. Deter and disrupt piracy and armed robbery at sea;

3. Monitor fishing activities off the coast of Somalia;

4. Support other EU mission and international organizations working to strengthen

maritime security and capacity in the region.[169]

As part of these efforts, The Maritime Security Centre – Horn of Africa (MSC-HOA)

was set up as a 24-hour manned watch center at the Northwood Headquarters in

Hertfordshire, England.   MSC-HOA monitors shipping traffic transiting the Gulf of Aden.

The Centre maintains an interactive website with the latest anti-piracy guidance. Shipping

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[166] ICC IMB 2005, 15.
[167] Murphy, 2012, 517.
[168] EU NAVFOR.
[169] EU NAVFOR.

companies and ship operators are "encouraged to register their movements with MSC-HOA to improve their security and reduce the risk of attacks or capture."[170]

By January 2009, Somali pirate activity increased enough to capture global attention. It was a maritime issue which had been festering within the shipping and maritime insurance communities. Now it became headline news and international action was demanded. The incidences of pirate attacks off the coast of Somalia and in the Gulf of Aden had reached unprecedented levels for modern times. Equally unprecedented was the global response. The UN Contact Group on Piracy off the Coast of Somalia was created and Combined Task Force (CTF) 151 was established with a "specific piracy mission-based mandate" under the authority of United Nations Security Council Resolutions (UNSCRs) 1816, 1838, 1846, 1851 and 1897.[171] In addition to the member nations who formally comprise the CTF, other nations have contributed naval assets to the anti-piracy mission to create a level of international naval cooperation never before seen. CTF 151 operated in conjunction with the EU Naval Force's Operation Atalanta.

On February 1, 2009, MSC-HOA established an Internationally Recommended Transit Corridor (IRTC) in the Gulf of Aden. This allowed for military assets, both ships and planes, to be strategically deployed along the route of the corridor and better protect transiting merchant ships. Ships could register the details of their intended transit. The

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[170] Maritime Security Centre Horn of Africa. "About MSCHOA and OP ATALANTA," (2016). Accessed September 21, 2017. http://www.mschoa.org/on-shore/about-us .

[171] Combined Maritime Forces website. CTF 151: Counter-piracy, (2017). Accessed September 22, 2017, https://combinedmaritimeforces.com/ctf-151-counter-piracy/. Combined Maritime Forces (CMF) is a multinational naval partnership which "exists to promote security, stability and prosperity across approximately 3.2 million square miles of international waters, which encompass some of the world's most important shipping lanes." In addition to CTF 151 it includes CTF-150 (Maritime Security Operations and Counter-Terrorism) and CTF-152 (Maritime Security Operations in the Arabian Gulf). Combined Maritime Forces website "About Combined Maritime Forces (CMF)," (2017). Accessed September 22, 2017, https://combinedmaritimeforces.com/about/.

ships were also encouraged to make the transit in groups based on their transit speed.[172]

In August 2009, the IMO officially endorsed the establishment of the IRTC and encouraged member governments to make ship owners, operators and crews aware of the guidance.[173]

Also in February, the first version of the Best Management Practices (BMP) to avoid and respond to a pirate attack were published. The BMP was developed by organizations who represented the interests of ship owner, mariners, and marine insurance companies. The New York Declaration was signed in May and September by ten countries committing them to promulgate the BMP to vessels on their ship registries and to ensure the ship's security plans required by the ISPS code included these practices.[174]

In August 2009, NATO's Operation Ocean Shield also began naval operations in support of the Combined Maritime Forces' anti-piracy efforts. NATO's ships focused on protecting the ships of Operation Allied Provider which were transporting relief supplies as part of the World Food Programme's mission in the region and capacity building of regional maritime security forces to assist in counter-piracy operations. Eventually, there would be multiple ongoing efforts operating in the Gulf of Aden; the three organized missions (EU, CTF 151, NATO) and a wide variety of independent ships from other navies, notably China, India, Russia, Japan, Malaysia, Indonesia, and Korea. Without a centralized command structure, they were voluntarily collaborating to secure the maritime region impacted by Somali piracy. As Donna Hopkins, the coordinator for counter-piracy and maritime

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[172] ICC IMB 2009, 21.
[173] IMO SN.1/Circ.281. The circular contains an Annex with the details of the IRTC.
[174] GAO Report #GAO-10-856, 13. The ten countries were Bahamas, Cyprus, Japan, Republic of Korea, Liberia, Marshall Islands, Panama, Singapore, United Kingdom, and United States. 73-75. The ISPS Code is the International Shipboard Port Facilities Security Code, it is discussed in further detail in Chapter 4.

security in the State Department's Bureau of Political-Military Affairs stated, that was a "remarkable phenomenon."[175]

Despite all these efforts, incidences of piracy attributed to the Somali pirates continued to increase. In 2010, the pirates continued to employ "mother ships" and their range of attacks were attributed to an "extended geographical area from the southern part of the Red Sea in the west to 72° East longitude and beyond in the east. Incidents have also been reported off the coast of Oman/Arabian Sea in the north extending southward to 22° South."[176] In 2011, the warning range was extended even further to 76° East longitude.[177] This year was the peak of activity with 237 incidents, making up more than half of the total 439 incidents reported for that year. The good news was that the number of successful ship hijackings decreased from 49 in 2010 to 28 in 2011.[178] The following year there was another significant decrease. Attacks in 2012 attributed to the Somali pirates accounted for less than 25 percent of world incidents; 75 of 297 reported attacks of which just 14 were hijackings.[179]

Finally, all of the efforts and resources which were being directed at the piracy problem were having an effect. The ships carrying the WFP relief supplies and humanitarian aid materiel were able to safely deliver their cargos with the escort of the EU and NATO ships. International maritime security forces' aggressive interdiction efforts reduced the number of successful pirate attacks. The implementation of the Best

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[175] Maritime TV panel discussion, "Donna Hopkins, U.S. State Department Coordinator Discussed Counter Piracy and Maritime Security," MarEX June 27, 2013. Accessed September 23, 2017, http://www.maritime-executive.com/article/Donna-Hopkins-a-US-State-Department-Coordinator-Discusses-Counter-Piracy-and-Maritime-Security-2013-06-27.
[176] ICC-IMB 2010, 19.
[177] ICC IMB 2011, 20.
[178] ICC IMB 2011, 24.
[179] ICC IMB 2012, 24.

Management Practices for Protection against Somalia Based Piracy[180] by the maritime

industry significantly decreased ship vulnerability – no ships with armed guards were

successfully hijacked.[181] And at least some progress was being made on the issue of how to

legally deal with detained pirates.[182] What remained to be seen was if this improved

situation was sustainable.

While acts of piracy were decreasing in the Gulf of Aden, they were on the increase

in the Gulf of Guinea. The ICC IMB annual report for 2012 reported the following trend: "As

for West Africa, piracy is rising in the Gulf of Guinea, with 58 incidents recorded in 2012,

including ten hijackings, and 207 crew members taken hostage. Pirates in this area are

particularly violent with guns reported in at least 37 of the attacks."[183] An article published

by the Africa Center for Strategic Studies attributed this increase to the region's rapid

economic growth, the limited maritime security presence, and the increasing use of the

area by traffickers of narcotics from South America.[184] As the Somali pirate attacks

continued to decline, this region became the area with the highest level of pirate attacks in

2013. The predominant perpetrators are Nigerian pirates, operating out of Lagos, although

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[180] *Best Management Practices against Somalia Based Piracy* (BMP) were developed by the International Maritime Bureau (IMB) in conjunction with a host of many other interested maritime organizations in 2010. The current version of these practices BMP4 (version 4) went into effect in August 2011 and is subtitled *Suggested Planning and Operational Practices for Ship Operators, and Masters of Ships Transiting the High Risk Area.* BMP4 is available for down load as a pdf file on the "Advice for Masters" tab of the International Chamber of Commerce (ICC) website. Accessed September 22, 2017, https://www.icc-ccs.org/piracy-reporting-centre/advice-to-masters.

[181] Christian Bueger, "Learning from piracy: future challenges of maritime security governance," Global Affairs, 1, no. 1 (January 2015): 33-42. Accessed 22 September 2017, http://dx.doi.org/10.1080/23340460.2015.960170.

[182] For a discussion on this issue see Peter Chalk, "Assessing the Utility of Current Counterpiracy Initiative Off the Horn of Africa," *Studies in Conflict & Terrorism*, 35, no. 7-8 (August 2012). Accessed September 22, 2017, http://dx.doi.org/10.1080/1057610X.2012.684653.

[183] ICC IMB 2012, 24.

[184] Osinowo, 1. Osinowo also believes that the reported incidents "represent only a fraction of the actual attacks in the region as ship owners and governments downplay incidents to avoid increased shipping costs or a reputation for insecurity." 2. For the issue of quantifying the amount of piracy, also see Steffen.

there have also been spikes of activity from Benin and Togo, and there are occasional

incidents in the waters of other Gulf of Guinea nations.[185]   The trends observed in the Gulf

of Guinea do not bode well; the percentage of the incidents occurring in international

waters has significantly increased, as has the severity of the attacks.[186] Both of these point

to an increased level of organization and sophistication of piracy in this region. Thus, I end

this discussion of contemporary African piracy where I began, off the coast of Nigeria,

emphasizing the cyclical character of maritime piracy.

Current Status

Contemporary piracy continues to be a very real and present danger for the

maritime industry. Much of the time piracy is a crime of opportunity. In other instances,

piracy is a highly organized criminal activity. Either way, maritime piracy continues to be a

very clear risk across the globe. Its prevalence varies based on complex considerations.   A

globally connected world depends on maritime shipping to transport vast amounts of

materials and goods. Increased shipping transits means increased opportunities for piracy.

The latest annual report from the ICC IMB reported the lowest worldwide total of

attacks since 1998. The total number of pirate attacks for 2016 was 191 incidents.

However, the number of mariners kidnapped was the highest in the last 10 years; 62 crew

were kidnapped from their vessels and another 151 were held hostage. The numbers

break down as follows: 150 vessels were boarded, 7 vessels were hijacked, 12 vessels were

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[185] ICC IMB 2013, 21.
[186] Osinowo, 3. Figure 3 provides a graphic of the data to support these trends. Steffen provides an analysis of the conflicting data in various data bases.

fired on and there were 22 attempted attacks.[187] There was a noticeable drop in

Indonesian incidents and incidents were also down in Vietnam and Bangladesh.

Conversely, there is an emerging threat of kidnapping in the Sulu Seas, which escalated in

quantity and scope during the last quarter of the year. The Gulf of Guinea remains a high-

risk area for kidnapping and there has been a noticeable increase in incidents off Nigeria,

some almost 100 nautical miles from shore. There were two attempted attacks off Somalia,

after there being none in 2015. Finally, there were 11 incidents recorded for Peru

compared to zero in 2015.[188]

　　Despite encouraging trends in some regions, the trends in other regions continue to

highlight the need for constant vigilance. And even in the Gulf of Aden, where the most

significant improvements have been made, that progress is very fragile. Although there

were no successful attacks on large merchant ships in 2015 or 2016[189] the pirate activity

off the coast of Somalia had "increasingly shifted to the hijacking for ransom of dhows and

foreign fishing vessels."[190] CTF 151 continues to operate; there are currently 32 nations

participating in the coalition.[191]   Additionally, the European Council has extended

Operation Atalanta until the end of 2018.[192] This decision was based on the fact that Somali

pirates still have the capacity and intent to engage in maritime piracy, as was demonstrated

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[187] ICC IMB 2016, 27.
[188] ICC IMB 2016, 5, 27.
[189] ICC IMB 2016, 5. There were two attempts in 2016.
[190] UNSC #S/206/843, 1.
[191] The 32 member-nations are: Australia, Bahrain, Belgium, Canada, Denmark, France, Germany, Greece, Iraq, Italy, Japan, Joran, Republic of Korea, Kuwait, Malaysia, The Netherlands, New Zealand, Norway, Pakistan, The Philippines, Portugal, Qatar, Saudi Arabia, Seychelles, Singapore, Spain, Thailand, Turkey, UAE, United Kingdom United States and Yemen. Combined Maritime Forces website. CTF 151: Counter-piracy, 2017. Accessed 22 September 2017, https://combinedmaritimeforces.com/ctf-151-counter-piracy/.
[192] Maritime Executive, November 28, 2016.

by six armed men 330 nautical miles off the coast of Somalia on October 22, 2016.[193]

Meanwhile, there are plenty of competing demands for maritime security assets. NATO

made the decision to end Operation Ocean Shield as of December 15, 2016.[194] This

decision was based on the changing political environment and the need to reallocate

resources to deal with the refugee crisis and human smuggling occurring in the

Mediterranean.[195]

     The significant gains made to improve the security of the maritime domain will be

fleeting if they are not matched by gains on the shore. The UN Secretary General's October

2016 Report called the progress on building a federal state in Somalia significant, but

fragile and reversible.[196] The root causes of piracy continue to be "a fragile economy, a lack

of alternative livelihood, insecurity and weak governance structures."[197] The report

further observed that "It is particularly important to direct collective international efforts

at tackling the root causes of piracy off the coast of Somalia, in particular in the coastal

areas."[198] Sadly, recent drought conditions in Western Africa have brought famine

conditions back to Somalia. A CNN World Report on March 8, 2017 summed up the critical

situation with the headline "Somalia: 'People are dying of hunger… there's no water.'"[199] It

was a mere two days later that pirates successfully hijacked the first commercial ship in

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[193] Maritime Executive, November 28, 2016. Details of the attack on CPO Korea are available in ICC IMB 2016 Annual Report, 57. This was one of the two attempted attacks for 2016.
[194] NATO Allied Maritime Command, NATO Shipping Centre, "NATO Operation Ocean Shield Closing," (December 15, 2016). Accessed September 22, 2017, http://www.shipping.nato.int/nsc/operations/news/2016/nato-operation-ocean-shield-closing.aspx.
[195] Christian Bueger, "'Ocean Shield' Achieved its Mission," The Maritime Executive Website, (January 2, 2017). Accessed September 22, 2017, http://www.maritime-executive.com/blog/ocean-shield-achieved-its-mission.
[196] UNSC #S/206/843, 2.
[197] UNSC #S/206/843, 6.
[198] UNSC #S/206/843, 14.
[199] David McKenzie and Brent Swails, "Somalia: 'People are dying of hunger… there's no water.'" CNN, March 8, 2017. Accessed September 23, 2017, http://www.cnn.com/2017/03/07/africa/somalia-famine-united-nations/index.html.

five years.[200] Following that event, there were two additional hijackings of dhows and five

commercial vessels have been fired upon. While it may be difficult to definitively prove a

direct cause and effect, the already poor conditions in Somalia appear to be worsening.

Before concluding this chapter, I want to take a short detour to an area which I have

not addressed. South and Central America and the Caribbean Waters make up another

region that the ICC IMB groups together. Typically, there are no significant events to

warrant attention. Between 2011 and 2015, the only place that earned a mention in the

section of the report for warning of areas prone to attacks, has been Guayaquil, Ecuador; in

2016, Callao Peru was added to the warnings. All the attacks listed for this region have

been robberies conducted on ships in the port or at anchorage. These are the type of low

level events which regularly occur without garnering wider attention. I want to mention a

place that has not been singled out since 2010.

Venezuela – an Illustrative Side Note

The economic situation in Venezuela has deteriorated to the point that most of the

population is in economic crisis. A July 2017 article in *The Economist* reported "An

astonishing 93% of them say they cannot afford the food they need, and three-quarters

have lost weight in the past year."[201] If the situation continues through the rest of this year,

inflation will have exceeded 1,000% and the economic collapse which started in 2012 will

have become the steepest in modern Latin American history. The average individual

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[200] The details of the hijacking are available on the ISS IMB's Live Piracy Map and Live Piracy Report. Accessed September 23, 2017, https://www.icc-ccs.org/index.php/piracy-reporting-centre/live-piracy-map, Attack ID: 030-17 dated March 14, 2017 pertains.
[201] *Economist.*

income has fallen to what it was in the 1950s. Price controls and government take-overs of private firms have led to shortages of critical supplies like food and medicine.

Weakened oil prices have certainly contributed to the situation; however, Venezuela has extensive oil resources which could still allow for the country to flourish. Instead, a corrupt government, the most corrupt in Latin America, has led the country backwards. Government officials have embezzled billions and the common people suffer. President Maduro "spends public money lavishly, especially on his supporters." When he cannot pay the bills, he prints more money."[202] There have been protests in the streets, but heavy-handed government tactics have led to over 100 deaths and hundreds more have been imprisoned for political reasons. Venezuelans are infuriated by the current situation which has become explosive.

This sort of environment, where social dissatisfaction is high and people are unable to improve their situation by normal means, provides incentives for illegal activity. In fact, the same article in *The Economist* reported that "Venezuela has become a favored route for drug-trafficking and is awash with arms."[203] Given that Venezuela has a long coastline, my hypothesis would be that this is also an environment where maritime piracy would be emerging. The data on piracy incidents, reported to the IMB, for the last 10 years is provided in table 3-1. The numbers show an increasing trend since 2013, but a higher number of incidents occurred in 2010. For the most part, these are non-violent low-level events that occur in territorial waters. At this point, there is nothing alarming about the data. The question to consider is: if the conditions in Venezuela continue to deteriorate will we see a higher number of attacks?

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[202] *Economist.*
[203] *Economist.*

Table 2-1. Actual and Attempted Piracy and Armed Robbery Attacks Against Ships[204]

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Venezuela	1	3	5	7	4	0	0	1	1	5

A December 2016 article on the website "Inside Crime" did in fact claim that the economic crisis in Venezuela is fueling piracy on the Caribbean coast.[205] The article focused on the coastal community of Sucre where there was once a thriving fishing industry. "People can't make a living fishing anymore, so they're using their boats for the options that remain: smuggling gas, running drugs and piracy."[206] Not all the fishermen are involved, but some are also victims of the crimes with their boats or boat motors being stolen, often with violence; dozens of fishermen have been killed during the robberies. The following analysis of the situation was provided:

> Acts of piracy against cargo vessels or private yachts off Venezuela's Caribbean coast have been reported for a number of years now, and Sucre's waters were already considered highly risky as far back as 2010, according to a report by a Venezuelan non-governmental organization working on maritime security. But the country's dire economic situation appears to be contributing to an increase in piracy targeting large and small commercial interests alike.[207]

In addition to the problem in Sucre, four anchored cargo ships were boarded in 2016 close to Puerto da la Cruz in Anzoátegui state (west of Sucre).[208] Additionally, an LPG tanker was boarded on 15 January 2017.[209] While it is difficult to draw a direct correlation between these incidents and the economic and political situation in Venezuela it is

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[204] Data compiled from the ICC IMB Annual Reports for 2007-2016. Looking back as far as 1991, the only times there were more events than 2010 were 2002 with 8 incidents and 2003 with 13 incidents.
[205] InSight Crime Website.
[206] InSight Crime Website.
[207] InSight Crime Website.
[208] InSight Crime Website. This data was credited to the ICC.
[209] IMB Live Piracy Map 2017 attack number 004-17. Accessed August 27, 2017, https://www.icc-ccs.org/index.php/piracy-reporting-centre/live-piracy-map/details/169/1348.

reasonable to assume some sort of relationship. This may be an interesting area to keep an

eye on.

Summarizing the Current Status

Maritime Piracy is here to stay. Despite increased international cooperation and

some very real progress with anti-piracy efforts, there is still plenty of piracy to go around.

Murphy has called it "a fluid crime of a fluid medium."[210] It is a fluid crime due to its

varying motivations and characteristics depending on where it occurs. Legal actions taken

to combat piracy must take the origin of the victims into account as well as the location of

the crime. It occurs in fluid medium, meaning that environment where it occurs, on the

high seas, causes the problem to be unbounded by the jurisdiction or control of a single

state and therefore it becomes "the subject of political interplay between states with

competing interests."[211] The earlier discussion of both the evolution of maritime law and

the definition of piracy reflect this as well. Furthermore, while piracy is executed at sea, it

is planned and supported on land. The complexity of the problem requires a multi-

approach solution.

Naval cooperation, whether it is an effort of neighboring littoral states, as in

Southeast Asia, or a truly international effort such as off the east coast of Africa, has a role

to play. Organizations such as the IMB's PRC and ReCAAP allow for the effective sharing of

information in a timely manner. Operational watch centers like MSC-HOA and Singapore's

IFC are critical to ensuring timely responses to vessels in distress. While the efforts of

these organizations are important, they are often reactive – after the incident. As Peter

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[210] Murphy, 2012, 507.
[211] Murphy, 2012, 507.

Chalk has said, "More attention needs to be devoted to ameliorating the underlying political and socio-economic drivers."[212] Oceans Beyond Piracy (OBP) is a relatively new organization. It is a project of the One Earth Future Foundation and describes itself as "developing a stake-holder driven approach to addressing maritime piracy."[213] The goals of the organization are to mobilize the stake-holders in the maritime industry, to form public-private partnerships which promote long term solutions, and to create sustainable deterrence based on the rule of law.[214] OBP and other non-governmental organizations have a vital role to play in improving the economic conditions and enhancing the security capability ashore.

As already discussed, piracy at sea is as much a result of the conditions on land as it is of the opportunities presented at sea. Piracy cannot flourish without land-based support. In addition to the need for safe harbors, there is a need for a labor pool which is willing to take the risks associated with pirating. An integrated approach which works to provide security at sea while minimizing the driving forces of piracy ashore is required for continued success. A better understanding of how the socio-economic and socio-political variables impact piracy is essential for make the right cost-effective decisions on how to employ limited resources.

The next chapter will provide an overview of the existing models of maritime piracy.

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[212] Chalk, 2010, 102.

[213] OBP website. Accessed September 23, 2017, http://oceansbeyondpiracy.org/.

[214] OBP website "About." Accessed September 23, 2017, http://oceansbeyondpiracy.org/about. OBP is a publicly funded, non-profit organization located in Colorado, USA.

CHAPTER 3

MODELS OF MARITIME PIRACY

This chapter explores the various piracy risk models that currently exist. These models vary from very sophisticated models funded by the U.S. Navy to more simplistic models. Most of the models focus on the piracy issue off the coast of Somalia and in the Gulf of Aden, which had a peak in pirate activity in 2010. This exceptional peak in piracy provided the motivation for many of these models. Yet because to the narrow focus on this specific region, most of the models have limited utility for the broader range of piracy. After a brief over-view of these models, the chapter concludes with a discussion of what is missing from these models and highlights for the need for a new model.

MARITIME PIRACY MODELS

Only recently have there been serious efforts to model pirate activity. This was primarily prompted by the huge surge in pirate activity off the coast of Somalia and in the Gulf of Aden. The anarchical status of Somalia resulted in a lawless region which encouraged piracy. The frequency of these pirate attacks grew at such a rate that an unprecedented international response was demanded by this activity. The European Union launched Operation Atalanta (Task Force 465) in December 2008 with a counter-piracy mission. A month later, the US-led Combined Maritime Forces, a multinational coalition of naval forces, formed Combined Task Force 151 (CTF 151) with a counter-piracy mandate

based on five United Nations Security Council Resolutions.[1] Maritime piracy was

frequently breaking news and counter-piracy operations were in the limelight. In this

environment, an interest in models of maritime piracy emerged. The result has been a

variety of different models, with various focus and goals. Each of these are briefly

discussed to provide an understand of how these models contributed to our understanding

of maritime piracy.

Naval Research Laboratory Models

Following the first pirate hijacking of an American flagged ship, MV *Maersk*

Alabama,[2] the US Naval Oceanographic Office developed a model that used forecasted

weather conditions and historical pirate incident data to predict the locations that would

be conducive to pirate activity in the Somali Basin Region and the Gulf of Aden. Using

multi-source intelligence and operational tactics employed by the pirates to inform the

Oceanographic Office's model, the result was a fairly sophisticated model that allowed

CTF 151 to better employ naval assets.

The resultant Piracy Performance Surface (PPS) model was developed within two

weeks of receiving the task by Dr. Jim Hansen, a physical scientist, at Naval Research

Laboratory (NRL) in Monterey, CA. The model used simulation to provide a forecast of the

probability of pirate activity in a specific location over time. The Monte Carlo method was

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[1] Combined Maritime Forces website "Combined Task Force 151" https://combinedmaritimeforces.com/ctf-151-counter-piracy/ accessed May 25, 2017. The UNSCRs are 1816, 1838, 1846, 1851 and 1897. Combined Maritime Forces had already been operating CTF-150 with a general security and counter-terrorism focus in the region since September 2001.

[2] United States MV *Maersk Alabama* was in route to Mombasa, Kenya from Djibouti on April 8, 2009 when pirates attacked, boarded the vessel and took Captain Richard Phillips hostage in a ship's lifeboat.
The ship was able to continue to Mombasa. Phillips was rescued by a coordinated effort of the US Navy on April 12, 2009.

used as the probabilistic forecasting tool. The inputs to the model were the environmental conditions or meteorological data, data about how the pirates operate and actual intelligence reports on pirate activity. These inputs were weighted such that suitable weather conditions comprised ninety percent of the forecast and historic pirate activity the remaining ten percent.

The PPS model was updated with user feedback and additional refinement to the pirate operating concepts. In March 2011, the Next Generation PPS (PPSN) model was released (it was later renamed Pirate Attack Risk Surface (PARS) model). The updated model factored in Pirate Action Groups (PAGs) which are groups of pirate dhows operating with the support of a "mother ship" off the coast. This operating concept significantly extends the range of pirate activity. The model output is the probability forecast of pirate presence as a function of latitude, longitude and time. Each forecast covers a 72-hour period in 0.2-hour time-steps and is generated by the model in 12-hour time steps. Recent pirate activity is weighed more strongly than historical attacks with a high risk in the vicinity of a recent attack for the next 48 hours and then dissipating over the next seven days.

Hansen describes the PARS approach as a "dynamic coupling of environmental and intelligence information."[3] The approach requires an extensive amount of meteorological data as well current intelligence on pirate activity. In a May 2013 power point presentation on the validation of PARS, Hansen says the next steps for PARS is to improve the probability code which would allow for the model to run faster and provide better algorithms for predicting future ship locations based on past behavior of ships with similar

[3] Hansen, et al., 110.

attributes.[4] Leslie A. Slootmaker completed research to refine the input variables of PARS to achieve maximum model performance.[5] In her Master's thesis she argues that the variables must be set to a realistic level to balance the model's efficiency and effectiveness.

Both PPS and PARS focus on just one region where piracy is an issue. Given adequate data and intelligence support, other regions could be modeled in a similar manner; however, a model at this level of detail would only be applicable for a specific region and not transferable to another region where the conditions and pirate tactics vary. Slootmaker's argument for a realistic balance between model efficiency and effectiveness would need to be considered in a model for any other region as well. Pirate operational patterns vary by region, thus the portion of the model's computer code for pirate behavior would need to be adjusted. With the decrease of pirate activity in the region, the modeling efforts of NRL have shifted to other topics. This reinforces the thought that this type of model had limited applicability. Not only were the models specific to a particular geographic region, but the level of detail in the modeling of the pirate operational tactics, as well as the need for current intelligence input, made them practical only when the rate of piracy incidents was very high.

Czech Technical University ATC Models

The Agent Technology Center (ATC) at the Czech Technical University in Prague, funded by a grant from the (US) Office of Naval Research, conducted research on agent-based modeling of maritime pirate activity.[6] The center's AgentC software "models sea

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[4] Hansen.
[5] Slootmaker.
[6] Smalley.

piracy and provides alternative routing for commercial vessels in waters off the Horn of Africa."[7] The ATC's website[8] describes three individual modeling efforts: "Maritime Simulation Platform," "Maritime Transit Simulation," and "Vessel Behavior Models." The Maritime Simulation Platform is a modular agent-base model of the platforms and forms the base for the Maritime Transit Simulation. The Vessel Behavior Models use real world data to provide a highly detailed agent-base model for each vessel class. The Maritime Transit Simulation combines the Maritime Simulation Platform with the Vessel Behavior Models to produce detailed simulation of maritime traffic. This simulation can provide an estimation of the piracy risk under various transit routes with various naval patrol strategies employed.

The Maritime Transit Simulation was demonstrated in the spring of 2011 at the 10th International Conference on Autonomous Agents and Multiagent Systems.[9] At the conference the following year, an update on the research was provided.[10] While the Maritime Transit Simulation can simulate maritime traffic on a global basis, the Agent Technology Center focused their suite of computational tools and techniques on the piracy issue in the Somali Basin and the Gulf of Aden. They were able to assess the efficiency of a "range of piracy counter-measures, including the recommended transit corridors, escorted convoys, group transit schemes, route randomization and navy patrol deployments."[11] They were also able to assess the best trade-off between cost and security by using decision-theoretic and game-theoretic optimization techniques.[12] When they published the

[7] Smalley.
[8] ATC website. Accessed September 30, 2014, http://agents.cz/projects/AgentC.
[9] Jakob et al., 2011.
[10] Jakob et al., 2012.
[11] Jakob et al., 2012, 37.
[12] Jakob et al., 2012, 37.

results of their research, the researchers at the Agent Technology Center believed "AgentC
is the only agent-based, micro-level simulation of global maritime traffic designed for non-
military purposes."[13]

The software used to develop AgentC is proprietary to the ATC and requires a
significant knowledge of JAVA and computer programming to use. While the marine transit
model considered global shipping traffic and transits routes, the more detailed model with
vessel traits was focused on the Somali Basin and Gulf of Aden. With the completion of the
grant funded project, the ATC has shifted their modeling efforts to other issues. The work
they have completed could form the basis for a model of other regions, but this would
require significant programming efforts.

The modeling efforts of both NRL and ATC resulted in highly detailed models
focused on the Somali Basin and the Gulf of Aden. Given that incidences of piracy in this
region have significantly decreased, and there are plenty of other regions where piracy
provides a significant risk, there is a need for a model that is less geographically dependent.

Risk Terrain Model

Criminology researchers at Rutgers University have taken a different approach to
modeling the risk of piracy using Geographic Information System spatial modeling tools.[14]
They use Risk Terrain Modeling (RTM), which is an approach to risk assessment used to
evaluate the occurrence of crime within a geographic area. RTM "standardizes risk factors
to common geographic units over a continuous surface,"[15] They argue that while favorable

[13] Jakob et al., 2011, 1.
[14] Caplan, Moreto and Kennedy, 98-115.
[15] Caplan, Moreto and Kennedy, 99.

geographic factors and the presence of a potential target vessel are necessary for piracy to

occur, these factors are not sufficient. They identify three risk factors for piracy: state

status (using the 2008 Failed States Index), shipping routes, and chokepoints. Using these

factors, they created risk map layers which they then overlay to identify the regions of

greatest risk. Once they compiled this global piracy RTM using 2008 data, they overlaid the

2009 reported incidents of piracy and found their RTM predicted the location of these

incidents with more than 60% accuracy. As they reported: "This is quite a feat considering

that pirate attacks were located in approximately 1.3 percent of all the cells, globally."[16]

While the factors considered for creating the piracy RTM could be revised or weighted

differently in the creation of the map layers, what was unique about this model is that it did

not use the occurrence of prior pirate attacks to predict future attacks. Since the

researchers used ArcGIS software to create the RTM of piracy, their effort could be

duplicated given the data they used or similar models could be created using different data.

Spatial Approach

A spatial model of where piracy risk exists has utility as input into a more

comprehensive model, but as a stand-alone model it does not provide any risk

differentiation for any of the other factors involved in pirate attacks. In fact, the zones for

increased piracy risk are identified by maritime insurance underwriters on an ongoing

basis without the benefit of a spatial model. Mariners are aware of areas where there is a

high risk for piracy. Mariners need a model that will allow them to better determine their

individual risk. This type of model should allow evaluation of risk mitigation options. The

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[16] Caplan, Moreto and Kennedy, 110.

model should also provide insight into how the other parts of the "system" may impact the vessel's voyage.

Two researchers from the Department of Security and Crime Science at the University College London, Elio Marchione and Shane Johnson, conducted research to examine patterns in the location and timing of maritime piracy incidents. They applied theories developed to explain spatial and space-time patterns in urban crime to maritime piracy. Their work drew on previously developed criminology theories such as crime pattern theory[17] and disease contagion models which look at time-space patterns for risk clusters.[18] They cited the RTM work of Caplan, Moreto, and Kennedy, discussed above, as a promising approach for identifying areas of risk for maritime piracy; however, limited security assets cannot constantly patrol all of these areas.[19] Thus Marchione and Johnson set out to identify "regularities concerned with when attacks might occur as well as where they are most likely."[20]

Marchione and Johnson examined spatial patterns to determine where pirate incidences tended to cluster and then looked at times-series data to determine how the patterns varied reflecting the local condition differences.[21] Their data consisted of 5,715 recorded events of piracy from the NGIS Anti-Shipping Activity Messages database. Once they created a kernel density map of these events, they used Moran's "I" statistic to determine the statistical significance of the spatial clustering.[22] They next evaluated their data in times-series with a Poisson model. This revealed some seasonal trends, but the

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[17] Marchione and Johnson, 506.
[18] Marchione and Johnson, 507.
[19] Marchione and Johnson, 509.
[20] Marchione and Johnson, 509.
[21] Marchione and Johnson, 510.
[22] See Marchione and Johnson, 510-512 for more details on how they evaluated the density map with Moran's I statistic.

trends varied by sub-regions.[23] Four geographic areas stood out as a result of their

analysis: near the coast of Sri Lanka, near the coast of Malaysia, near the coast of Somalia

and in the Gulf of Guinea. These four locations accounted for more than 70 percent of the

events in their data base.[24]

The final portion of their data analysis was to detect time-space clustering of the

incidents of piracy. They used both the Mantel test and the Knox test to determine this.

Separate analyses were completed for each sub-region to preserve local seasonal trends.[25]

The results of the analysis using the Mantel test revealed statistically significantly

worldwide clustering of piracy incidents from 1997 onward.[26] Since the Mantel test is only

suited for summarizing general patterns, they then applied the Knox test for more precise

information about the clustering. The results made it "clear that more events occur close to

each other in space and time than would be expected if the timing and location of attacks

were independent."[27] This work provided the basis for their development of a spatial

model of maritime piracy.

Marchione and Johnson, along with Alan Wilson, developed an Agent-Based Model

(ABM) to simulate the dynamic patterns of pirate, vessel and naval forces behaviors and

interactions. Their paper "Modeling Maritime Piracy: A Spatial Approach," provides a video

visualization of the NGIA dataset that Marchione and Johnson did their earlier analysis of.

They cite a noticeable burst of pirate activity around the Gulf of Aden in 2010 and focus

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[23] See Marchione and Johnson, 512-514 for more details on Poisson model time-series evaluation of their data.
[24] Marchione and Johnson, 510. 4,062 of 5,715 events were accounted by these four locations.
[25] See Marchione and Johnson, 514-518 for more details on how they applied the Mantel and Knox tests.
[26] Marchione and Johnson, 516.
[27] Marchione and Johnson, 517-518.

their modeling efforts on this geographic area.[28] Their subset of data included 56 incidents

of piracy that occurred in that area in 2010.[29] Data from the Suez Canal Traffic Statistics

was used to simulate the proper volume of shipping traffic passing through the canal as

well as the type and flag of the vessels.[30] This information was supplemented with

information obtained from Surface Synoptic Observation reports concerning the position of

vessels in the area of interest and the weather conditions at the time of their reports.[31]

Lastly, they based the number of naval units on the work of Peter Chalk who cited 14

international naval units operating in the Gulf during the time of the model's case study –

15 November to 31 December 2010.[32]

Their model consists of a grid representing the area of interest.[33] The model's agent

behavior condition action rules generate a dynamic maritime piracy risk map and allow the

testing of hypotheses about pirate activity.[34] The model outputs were tested using

separate data of pirate attacks in the Gulf of Aden from earlier in 2010.[35] They conclude,

that despite the simplicity of the model, it appears to "approximate the observed spatial

distribution of pirate attacks rather well."[36] Thus, they argue that their model provides the

basis for developing and testing "more accurate and realistic agent behavior, and the

simulated impact of specific types of policy intervention."[37]

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[28] Marchione, Elio and Johnson, paragraph 2.1.
[29] Marchione, Elio and Johnson, paragraph 2.2.
[30] Marchione, Elio and Johnson, paragraphs 2.4 and 2.6.
[31] Marchione, Elio and Johnson, paragraph 2.3.
[32] Marchione, Elio and Johnson, paragraph 2.4. Also see Chalk, 2010, 89-108.
[33] Marchione, Elio and Johnson, paragraph 3.1.
[34] Marchione, Elio and Johnson, paragraph 3.1. See Marchione, Elio and Johnson, paragraphs 3.2 -3.17 for detailed information on their model design.
[35] Marchione, Elio and Johnson, paragraph 5.1.
[36] Marchione, Elio and Johnson, paragraph 5.1.
[37] Marchione, Elio and Johnson, paragraph 5.6.

Marchione, Johnson and Wilson's spatial model is definitely a step in the right direction for portraying maritime piracy with an ABM since this allowed them to observe patterns of piracy which were not necessarily obvious before their efforts. Previously, most of the models had been developed to try and predict future occurrences of piracy or to evaluate the effectiveness of counter-piracy efforts. By choosing to use an ABM, they allowed for new insight concerning the relationship between the piracy events. However, just like most of the earlier efforts, they too focused on a subset of global maritime piracy because of the enormous scope of the issue and the differences in the characteristics of the problem between sub-regions. They centered their attention on the Gulf of Aden where a significant increase of piracy incidents in 2009 occurred as a result of socio-political and socio-economic variables. Their resulting model did not model the influences of these variables. As with other models of piracy in the Gulf of Aden, significant changes to the code portraying the pirates' concept of operations would need to be made for the model to be applied to another geographic sub-region.

Models Aimed at Improving Detection of Pirate Activity

There have also been efforts to allow earlier detection of potential pirate vessels by "focusing on the detection of anomalous shipping patterns."[38] Using data from the Automatic Identification System (AIS),[39] Richard O. Lane, David Nevell, Steve Hayward, and T. W. Beaney, used Bayesian network analysis to calculate the probability that a ship's

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[38] Khondaker, Rahman and Khan, 203.
[39] AIS is an automatic tracking system on ships used by vessel traffic services to provide each ship with a unique identification. It allows for the tracking of individual ship position, course and speed.

behavior is an anomaly from normal ship behavior.[40] The five behaviors they identified as

anomalous are: deviation from standard route;[41] unexpected AIS activity;[42] unexpected

port arrival;[43] close approach;[44] and zone entry.[45] Their work developed algorithms for

calculating the probability of one of these anomalies in simulated AIS data. The next step

would be to "determine the numerical connection between specific behaviors and threats"

and then apply the model to real data.[46] Maria Andersson and Ronnie Johansson write of a

similar effort for early detection of pirate activity using a fusion of information from AIS

and other sensors such as radar systems and optical sensors.[47] Sensor fusion can improve

the overall situational awareness by reducing uncertainty.[48] They used a Hidden Markov

Model (HMM) to develop an algorithm for abnormal behavior detection focused on piracy

operations.[49] For best results the parameters used in the HMM to develop the algorithm

need to be sea-area specific.[50] Because of the complexity of the anomaly detection in the

maritime environment, they conclude: "it is likely that a combination of several technical

and also organizational, measures will be required to improve situational awareness."[51]

These efforts, as well as other similar work,[52] to detect abnormal maritime behavior can

better inform piracy modeling efforts. However, as with the models described above, these

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[40] Lane et al.
[41] Lane et al., 1-3.
[42] Lane et al., 3-4.
[43] Lane et al., 4-5.
[44] Lane et al., 5.
[45] Lane et al., 5-6.
[46] Lane et al., 8.
[47] Andersson and Johansson.
[48] Andersson and Johansson, 2.
[49] Andersson and Johansson, 4-6.
[50] Andersson and Johansson, 6.
[51] Andersson and Johansson, 6.
[52] Andersson and Johansson devote section II of their paper to an overview of related work.

efforts are focused only on what is happening in the marine environment, not the root cause of the problem.

More Recent Modeling Efforts

There have been two newer modeling efforts. The first was a hybrid model developed by Turkish Naval Officers to evaluate maritime security operations with respect to counter-piracy operations.[53] The second was the work of South African scholars in which they proposed a generative model of maritime vessel behavior to develop and evaluate counter-piracy methods and algorithms.[54]

A. Emre Varol and Murat M. Gunal, developed a hybrid model utilizing an agent-based model with discrete event scheduling. The objective of this model was to provide a better understanding of the relationship between deployment of naval forces and piracy prevention.[55] Their model combined three separate systems. The backbone and data structures that support the model are contained in a computer-code class library they call Maritime Security Operations Library (MSOLib). They used the SharpSim Discrete Event Simulation (DES) engine to create the hybrid DES/ABM model. Finally, they used GMap.net Geographic Information Systems (GIS) package to interface their model with a map of the region of interest.[56]

The purpose of their model is to aid decision makers in understanding the relationship between pirate behavior and naval force planning. Therefore, the focus of the simulation efforts was on variations of maritime security patrols. Three separate maritime

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[53] Varol and Gunal.

[54] Dabrowski and de Villiers, 116-130.

[55] Varol and Gunal, 2038.

[56] Varol and Gunal, 2038.

security efforts in the Gulf of Aden are cited: Operation Atalanta,[57] Combined Maritime

Forces (CMF)[58] and Operation Ocean Shield (OOS)[59]. These security efforts were discussed

in greater detail in Chapter 2; however, it is important to note here, that unlike the efforts

of Marchione, Johnson and Wilson, Varol and Gunal include greater detail of the naval

security forces in their model. Specifically, they model three separate types of naval

security forces: Naval Patrol Ships an embarked Naval Patrol Helicopter;[60] Maritime Patrol

Reconnaissance Aircraft; and Naval Convoy Ships operating with a Naval Convoy

Helicopter. This increased fidelity of the maritime security forces allowed evaluation of

various operational employments of these assets. This is important to decision makers

who must make resource allocation decisions. For example, their model determined that

the Naval Patrol Ships did not require a helicopter if they were operating in cooperation

with the Naval Convoy Ship and its associated helicopter. The model confirmed a "strong

positive relationship" between the resource allocation and the success of the operation.[61]

The model also allows for decisions which could increase the efficiency of these operations.

The savings gained by eliminating the requirement for a Naval Patrol Ship to have a

dedicated helicopter could be applied elsewhere. While the level of detail provided in their

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[57] Operation Atalanta is the European Union's NAVFOR Somalia counter-piracy operation. Stood up in December 2008, the mission is on-going. Accessed August 10, 2017, http://eunavfor.eu/.

[58] Combined Maritime Forces (CMF) is a multinational naval partnership which operates Combined Task Force (CTF) 151, a counter-piracy task force authorized by United Nations Security Council Resolutions. CTF 151 has been operating in the Gulf of Aden since January 2009. Accessed August 10, 2017, https://combinedmaritimeforces.com/ctf-151-counter-piracy/.

[59] Operation Ocean Shield was NATO's contribution to counter-piracy operations. It began in August 2009 and concluded in December 2016. NATO Shipping Centre – Allied Maritime Command website. "NATO Operation Shield Closing," December 15, 2016. Accessed September 22, 2017, http://www.shipping.nato.int/nsc/operations/news/2016/nato-operation-ocean-shield-closing.aspx.

[60] See Varol and Gunal, 2041-2044 for a discussion of details on how these units were modeled. Space limitations of the journal article prevented similar details for the other units. An online supplement to the paper is available at http://www.simulationmodel.com/gunal/PirateSim/ where a link allows download of the complete model.

[61] Voral and Gunal, 2048.

model is adequate to support strategic decision making, additional details would be needed for operational use such as the inclusion of weather conditions.[62]

While Voral and Gunal's model significantly contributes to understanding how to improve the efficiency of naval force deployments aimed at preventing piracy, it does not focus on the root causes of the piracy nor does it provide enough fidelity of the merchant vessels for individual merchant ships to make risk analysis decisions.

Joel Janek Dabrowski and Johan Pieter de Villiers propose a multi-agent generative model of maritime piracy. They describe their model as "a novel variant of a dynamic Bayesian network (DBN) that extends the switching linear dynamic system (SLDS)."[63] The structure of the DBN is informed by prior knowledge of the maritime piracy and uses both discrete and continuous variables. They used the model to generate a synthetic dataset of pirate attack locations and then compared the dataset to real world data with encouraging results. The variables included in the model account for the class of vessel (private, commercial or fishing), the journey parameters, the external parameters (date, time, season, ocean and weather conditions), the state parameters (vessel activity or behavior) and an ocean current/weather variable which influences vessel motion simulation.[64] The purpose of their work was to provide an information system that can be used to test "maritime pirate behavior detection algorithms."[65] As with some of the other models already discussed, the more detailed the input to this model becomes, the more cumbersome it is to configure. And again, the focus of the model is on the maritime domain alone.

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[62] Voral and Gunal, 2048.
[63] Dabrowski and Villiers, 116.
[64] Dabrowski and Villiers, 118-120.
[65] Dabrowski and Villiers, 117.

With the decline in maritime piracy off the coast of Somalia, so too has there been a decline in the efforts to model the phenomena. As stated above, the efforts of the Naval Research Lab and the Czech Technical University have shifted to other issues. Security protocols, such as BMP-4, developed because of the significant scope of piracy off the Somali coast, continue to be employed by merchant vessels transiting the area. These protocols are being adapted for use in other portions of the globe. There continues to be a significant international naval presence providing maritime security along the International Recommended Transit Corridor (IRTC) although it has been somewhat reduced with the conclusion of NATO's Operation Ocean Shield in December 2016. While Somali piracy incidents had essentially been eliminated, 2017 has seen a renewal of piracy activity in the region. Within a week of news of the severity of the current famine in Somalia,[66] the first successful pirate attack since 2012 occurred on 14 March 2017.[67] While it is difficult to make a direct cause and effect case, especially considering the decreased maritime security forces, there continues to be a need to better understand the dynamics involved in maritime piracy with emphasis on the socio-economic motivations, not just the interaction of vessel traffic and maritime anti-piracy operations.

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[66] See the following as representative media coverage: Amanda Erickson, "In Somalia, a drought killed 110 people in just 48 hours," The Washington Post, March 4, 2017. Accessed May 26, 2017, https://www.washingtonpost.com/news/worldviews/wp/2017/03/04/in-somalia-a-drought-killed-110-people-in-just-48-hours/?utm_term=.1b653ead1f28. Hussein Mohamed and Sewell Chan, "U.N. Chief, Visiting Somalia, Pleads for Aid to Avert Famine," The New York Times, March 7, 2017. Accessed May 26, 2017, https://www.nytimes.com/2017/03/07/world/africa/united-nations-famine-somalia.html. David MeKenzie and Brent Swials, "Somalia: 'People are dying of hunger…there's no water'" CNN World Website, March 8,2017. Accessed May 26, 2017, http://www.cnn.com/2017/03/07/africa/somalia-famine-united-nations/index.html.

[67] Luke Graham, "Somali pirates hijack first commercial ship in 5 years," CNBS Crime website, 14 March 2017. Accessed May 26, 2017, http://www.cnbc.com/2017/03/14/somali-pirates-hijack-first-commercial-ship-in-5-years.html.

This concludes the discussion of some of the existing models of maritime piracy. It is possible that other models have been created or are currently being developed; however, this sampling of models illustrates that there is a need for a model with a different focus.

WHY A NEW MODEL IS NEEDED

Maritime piracy is a global issue. While we have data that indicates this, the data is relatively scarce and therefore inadequate for purposes of statistical modeling. Multiple other approaches have been taken to modeling maritime piracy. However, most of the models discussed above were designed for a particular geographic area, primarily the Gulf of Aden and the waters off the coast of Somalia. They focus only on the water side of the problem. Because of the differences in the tactics employed by pirates from one region to another, a significant amount of change would be needed to apply these models to another geographic region and none of them address the land-sea interface of the issue. The exception to this is the RTM model designed by Caplan, Moreto and Kennedy. Despite the RTM model, there is a need for a model that is less geographically dependent. The goal is not a macro level model of the world, but rather a more parsimonious model that has utility across multiple regions.

The ATC at the Czech Technical University initially developed a model of the world shipping routes. While this model was global in scope it did not specifically model piracy, rather it was informed by piracy reports as to where the main hubs of piracy are. This global model was used to inform their later development of a region-specific model for the Gulf of Aden. The Maritime Traffic Simulation model replicated "the key static and dynamic

features of maritime transit" for thousands of vessels consisting of several categories.[68] It

was based on real-world shipping information, shipping routes and recommended transit

corridors. While this global model was not limited to a specific geographic region, its global

scope makes it very large and complex. In the terminology used by Robert Axelrod, the

ATC's model was very heavy, requiring massive amounts of information.[69] A light model

which can allow us to concentrate on what is occurring in a limited amount of sea-space in

a more generic manner would be of value to various regions and therefore would provide

greater utility.

While the ATC models were designed for non-military purposes they were used to

evaluate the best route for the Internationally Recommended Transit Corridor and the

optimum patrol patterns of Naval Security Forces. Both of the other agent-based models

were designed to improve the operational tactics of naval security forces. What is needed

is a model which will allow mariners to better determine their individual risk depending on

the environment they are planning to operate in and support policy makers who need to

determine where to apply limited resources.

Maritime piracy is complex and it lends itself to the complicated models that have

already been developed. However, because of this complexity it is difficult to design a

model which applies to all piracy. A model can account for the specific characteristics of

piracy in a region by limiting its geographic scope. Heavy models with details of specific

piracy tactics or features unique to regional geography then become limited in their

application. Alternatively, it can ignore those details and simulate global piracy at a macro-

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[68] Michal Jakob et al., 2011, 1.
[69] Axelrod, 13-14.

level. There is a third option; the model can present a simplified representation of the phenomena of interest.

The objective of this work is to distill maritime piracy down to a form simple enough to portray generic phenomena regardless of geographic location, yet robust enough to provide insight into the associated issues, especially the sociological variables which have been lacking in the other models. An agent-based model is suited to this purpose because the emergent behavior of the agents can provide new understanding of how the variables interact. By simplifying the issue down to its essential elements, the model will not be tied to a specific geographic area. By focusing on the generic, the model will not attempt to portray reality but rather an abstraction of the issue and this will allow for a better understand the interaction of the variables. The intent of my modeling effort is to provide a tool which will provide new insights into the relationship between the socio-economic and political variables and piracy.

This model is the first step toward developing a more complex model which would provide a risk assessment based on the socio-economic variables in the vicinity of shipping lanes, the maritime security readiness of the merchant vessel, and the presence or lack of maritime security forces. Ideally, the model should also provide insight into how the other parts of the "system" may impact the vessel's voyage. Only by understanding the whole picture, to include what motivates the pirates, can policy makers make the best resource decisions. Additionally, with the right enhancements, this type of model would allow merchant vessels to assess their individual piracy risk. However, this foundational step has great value on its own. Moreover, it has potential for being the basis for modeling efforts in other applications where decisions are also made based on available opportunities.

To summarize; a new model is needed because there is inadequate data available to do statistical modeling. The complexity of piracy makes this scarcity of data even more problematic. Most of the models which have already been created are geographically specific. More specifically, they all focused on the water side of the problem without considering what the root causes might be and how the variables ashore impact the problem at sea. A model with broader application is needed. While there are a few global level models, these models provide a macro level view of the issue. Thus, the need exists for a light, parsimonious model which provides utility across regional domains but still allows focus on the core interaction of the socio-economic and political variables and piracy. Lastly, while the other models were primarily created to help predict where pirate attacks would occur or to evaluate the effectiveness of various counter-piracy efforts, the purpose for my model is to enrich our understanding of the core dynamics which drive the piracy problem.

In the next chapter, I take an in-depth look at the concept of risk and risk analysis, with particular emphasis on maritime risk. Then, Chapter 5 will provide a discussion of the data available to analyze the issue of modern piracy and provide some basic analysis of the most recent piracy data. With this additional information, all the components needed to begin building the model, developed in Chapter 6, will have been discussed.

CHAPTER 4

RISK AND MARITIME SECURITY

This chapter begins with the topic of risk. Most of the models discussed in Chapter 3 attempted to predict the risk of maritime piracy in one way or another. Risk is a term that we frequently encounter in our everyday lives, but that has not always been the case. To understand how the perception of risk has evolved, the concept of risk is explored from its historic origins to its current day applications in what is sometimes referred to as the "Risk Society." How the concept relates to the field of security studies is discussed. Next the systems approach to risk analysis is reviewed. The chapter then shifts to the more specific topic of maritime risk. The chapter concludes with some thoughts on the maritime environment.

LIFE IS RISKY

Risk in its simplest terms is the possibility that something bad will happen. In his book *Risk*, Jakob Arnoldi states "Risks are not *actual* but rather *potential* dangers."[1] Risk can be a consideration in our simplest day-to-day decisions. When we decide to do this or that, we weigh what the possible outcomes of our actions might be, taking potential dangers into consideration. We value positive outcomes and hope to avoid negative outcomes. If we perceive that there is a high probability of a negative outcome we may decide not to take the risk. Such simple informal risk calculations may occur many times in our daily life either consciously or subconsciously. More formal calculations of risk can be

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[1] Arnoldi, 8.

made using probability theory. To understand how the concept of risk evolved from informal calculations to a more structured discipline, a partial review of mankind's mathematical journey through history is needed.

In his book *Against the Gods: The Remarkable Story of Risk*, Peter L. Bernstein states that the development of the Hindu-Arabic numbering system was essential to the modern understanding of risk. This numbering system introduced the concept of zero and is the basis for current day mathematics, without which there would be no way to calculate odds and probabilities. Bernstein claims that "The revolutionary idea that defines the boundary between modern times and the past is the mastery of risk: the notion that the future is more than a whim of the gods and that men and women are not passive before nature."[2] Arnoldi agrees that there is a link between risk and modernity but cautions that the boundary is not as vivid as some might portray it.[3] Modernity is characterized by deliberate individual and collective actions "to shape the future to human will."[4] This necessitates a scientific understanding of risk in order to understand and engineer future outcomes. For this, mathematical probability theory, which of course has roots in the development of mathematics, is essential to the modern understanding of risk. However, "all cultures at all times have had (varying) conceptions of risk and various ways of managing and sharing risks."[5]

The ancient Greeks did not have a numbering system with which they could calculate. They used columns of pebbles to count quantities. From the Greek word *abax*, which means sand-tray and the Greek word *calculus* which means pebble we get the word

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[2] Bernstein, 1.
[3] Arnoldi, 22.
[4] Arnoldi, 23.
[5] Arnoldi, 23; (citing Bollig, 2006).

abacus. For centuries, the abacus would be the primary means for doing arithmetic – until a new numbering system was spread by the Arabs.

Under the urging of the Prophet Mohammed, an Arab empire was created to spread the Islamic religion. This empire stretched as far east as India. As a result of their invasion of India, the Arabs became familiar with the Hindu numbering system. This allowed them to "incorporate eastern intellectual advances into their own scholarship, scientific research and experimentation."[6] With the use of the Hindu numbering system into their culture, Arabs transformed mathematics and measurement and therefore commerce as well as astronomy and navigation.[7]

At the time the Arabs were expanding their empire, Christians were also exploring the globe and establishing colonies. While these two different cultures would share knowledge, they would also clash magnificently with the resultant Crusades. The first Crusade was authorized by Pope Urban in 1095. These religiously inspired battles would rage off and on for hundreds of years, and as discussed in Chapter 2, the Crusades would be justification for much of the piracy which occurred on the high seas.

Despite being exposed to Arab mathematical advancements, "Arabic numbers were not enough to induce Europeans to explore the radical concept of replacing randomness with systematic probability and its implicit suggestion that the future might be predictable and even controllable to some degree."[8] Religion played a significant role since Christianity and western culture strongly believed the future was determined by God. However, the power of the Catholic Church was weakened by the Protestant Reformation, allowing the

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[6] Bernstein, 19.
[7] Bernstein, 19.
[8] Bernstein, 20.

ideas of the Renaissance to have greater impact. This allowed western culture to reevaluate the relationship of God and man. If the future is not totally determined by God, then man must take responsibility for the consequences of his decisions. No single event can be credited with allowing the shift. Instead there was a gradual shift from the belief that the future is controlled by the gods, or God, to an understanding that individual agency and responsibility for one's actions can impact the future.[9]

As Bernstein writes: "With this opening up of choices and decisions, people gradually recognized that the future offered opportunity as well as danger, that it was open-ended and full of promise… The new sense of opportunity led to a dramatic acceleration in the growth of trade and commerce, which served as a powerful stimulus to change and exploration."[10] Trade involves both resources and markets and getting goods and materials from one market to another is risky business. The gradual shift from the belief that the future is determined by God, to a world where individuals are believed to play a significant role in their own fate, brought with it the desire to better understand the risks involved with individual decisions. This was the shift which was necessary for western cultures to really embrace mathematics and the numerous advances that followed.

The 1600's were a time of great mathematical advancements.[11] In 1637, René Descartes published his book which outlined his philosophical views; *A Discourse on the Method of rightly controlling the Reason and seeking Truth in the Sciences.* The last appendix of the book concerned the study of geometry. Here he developed a coordinate system which allowed for geometric shapes to be described using algebraic equations. At about

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[9] Arnoldi, 27.

[10] Bernstein, 21.

[11] Alfred Hooper's *Makers of Mathematics* offers a great history of mathematics and the individuals who made the advancements.

the same time that Descartes was developing his theories of analytic geometry, Pierre de

Fermat was also thinking about how the theory of numbers could be applied to lines and

curves. His work in this area anticipated Newton's development of calculus. But more

importantly, for the study of risk, is Fermat's work with Blaise Pascal which is credited

with laying the foundations of the theory of probability. As described in *Makers of*

Mathematics, it all began when the Chevalier de Méré sent Pascal a gambling problem.

Pascal worked out his solution and sent it to Fermat. Both agreed on the solution but gave

different proofs. The idea of *mathematical probability* emerged from their discussions of

the issue. Thus, from a gambling problem, came an important advancement in

mathematics which is essential to all branches of mathematical statistics, including

actuarial and insurance work. At last, not only had the Arab numbering system been fully

embraced, but significant advancements in mathematics were occurring which would allow

for other advancements. Bernstein claims that it was the growth of trade which

transformed the principles of gambling into the creation of wealth.   This ultimately lead to

capitalism which he calls the "the epitome of risk-taking."[12] Regardless, it was with the

shift from subjective probabilities to more calculated objective probabilities that the field

of statistics emerged and with it the study of risk.

MODERN CONCEPT OF RISK

While there was a time when the concept of risk was not formally recognized, today

we have been said to live in a "Risk Society." German sociologist Ulrich Beck proposed this

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[12] Bernstein, 21.

concept in his well-known book *Risk Society*.[13] In the book, he asserts that we have

transitioned from the industrial age to the risk society. The risk society is a result of the

technological advances of modern society which, while intended to solve problems, have

introduced a new set of unintended side-effects. In Beck's own words: "This concept

describes a phase of development of modern society in which the social, political, ecological

and individual risks created by the momentum of innovation increasingly elude the control

and protective institution of industrial society."[14] Beck draws a distinction between

dangers, which he defines as caused by nature, and risks, which he says are caused by

people. Statistical analysis allows for us to study risks.

Within the study of risk, there are three related processes: risk analysis, risk

assessment and risk management. "Risk analysis involves identifying the most probable

threats to an organization and analyzing the related vulnerabilities of the organization to

these threats."[15] This concept is at the core of security studies. "Risk assessment involves

evaluating existing security and controls and assessing their adequacy relative to the

potential threats to the organization."[16] Risk assessment goes beyond risk analysis. Once

the risks have been identified, risk assessment looks at what actions have been taken or are

planned in the event of an incident and assesses their adequacy for addressing the

individually identified risks.   Risk assessment is a concept that ship operators are very

familiar with. Portions of security studies also deal with risk assessment, although the

process is apt to be turned around and focused on the threat. The third process, risk

management, "is the systematic application of management policies, procedures and

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[13] Ulrich Beck, *Risikogesellschaft*. Frankfurt am Main: Sukrkamp, 1986.
[14] Beck, 1999, 72.
[15] Search Security.
[16] Search Security.

practices to the tasks of establishing the context, identifying, analyzing, evaluating, treating, monitoring and communicating risk."[17] Risk management is primarily a tool for project managers and engineers, yet there is great potential for security studies when security threats are assessed in a more systematic fashion. To apply risk management to a specific issue, it is necessary to gain a better understanding of the dynamics involved in the issue. For maritime piracy, this means that we must understand what is motivating the activity in addition to when and how it occurs at sea.   For these reasons, a model of maritime piracy that begins with the situation ashore is important. To date, the modeling efforts have focused on the water side of the issue, looking at ways to calculate the risk of a pirate attack or best ways to employ counter-piracy efforts. In all the models discussed in Chapter 3, the motivation for piracy is not considered. The existing models take a straight forward look at the risk of piracy at sea. We need a more holistic approach to understanding the piracy risk.

Let us return to the sociological study of risk. In his later book, *World Risk Society*, Beck expands his thoughts and says, "Risk society, fully thought through, means world risk society."[18] Dangers produced by modern civilizations "cannot be socially delimited in either space or time."[19] This thought certainly pertains to the transnational security challenges we face today.

Beck draws a distinction between the first modernity and what he calls the second modernity. The first modernity consisted of a world "based on nation-state societies, where social relations, networks and communities are essentially understood in a

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[17] Search Security.
[18] Beck, 1999, 19.
[19] Beck, 1999, 19.

territorial sense."[20] He characterizes this time as one with collective patterns of life, full

employment, progress and controllability, and the exploitation of nature. While the

industrial age produced plenty of risks, many of the risks produced by progress were

viewed as controllable. Additionally, modernity was thought to reduce many of the threats

of pre-modernity such as famine and epidemics; infant mortality was reduced while life

expectancy was increased; and technological advances improved quality of life and work

place safety.[21]

First Modernity

The term modernity refers to the modern era. It refers to the timeframe when

western civilization began to question and reject tradition. There is a link between the

development of risk and modernity. This was when the view of the future shifted from

being in the hands of God to the outcome of deliberate human activity aimed at shaping it.

During this era, western civilization moved from being primarily agrarian toward

urbanization and industrialization. The concept of capitalism was developed and the

market economy was expanded.

It was also during this time frame that the theory of probability developed into a

"serious instrument for forecasting."[22] In order for this to occur, the quality of the

information that forms the basis for probability estimates had to be known. How to

determine this was a central question of the eighteenth century. Jacob Bernoulli was the

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[20] Beck, 1999, 1-2.
[21] Beck, 1999, 48.
[22] Bernstein, 117.

first to ponder this issue seriously in the late seventeenth century.[23] After working on the subject for twenty years, he completed his work shortly before his death in 1705. His work, *Ars Conjectandi (The Art of Conjecture)*, was published, by his nephew Niklaus Bernoulli, in 1713.

Bernstein describe this as an effort to demonstrate where "the art of thinking – objective analysis – ends and the art of conjecture begins."[24] In *Ars Conjectandi*, Bernoulli purposed that it is possible to determine the likelihood of an event by calculating the exact number of possible cases and determining the relative likelihood of each case. Up until this time, the theory of probability was primarily use in games of chance, but Bernoulli envisioned wider applications. He drew "a crucial distinction between reality and abstraction in applying the laws of probability."[25] To apply the theory of probability to real life problems, relevant information is required. The difficulty is that we seldom have complete information. We can work with sample data and make assumptions about how well it represents all the possible data, but that is not the same as having complete data. To fill this gap, Bernoulli suggested that we assume "under similar conditions, the occurrence (or non-occurrence) of an event in the future will follow the same pattern as was observed in the past."[26] Bernoulli's theorem mathematically expresses how the size of a sample is related to the accuracy of assertions about the total population, as Arnoldi describes it, the "degree of truth value of statements regarding the causal laws of nature."[27]

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[23] Bernstein, 117.
[24] Bernstein, 118. Conjecture is the process of estimating the whole from its parts.
[25] Bernstein, 119.
[26] Bernoulli, Jacob, 1713, p. 1430. As cited by Bernstein, 121.
[27] Arnoldi, 29.

The next enabling mathematical advancement belongs to Abraham de Moivre. Based on the way randomly drawn samples disperse themselves around the average value, De Moivre determined that distribution formed a curve around the average. Today we call this a normal curve or a bell curve because of its shape. De Moivre used this normal distribution to calculate a statistical measure, which is now known as standard deviation. Given a normal distribution, approximately 68 percent of the sample will fall within one standard deviation and 95 percent within two standard deviations. This concept is "critically important in judging whether a set of observations comprises a sufficiently representative sample of the universe of which they are a part."[28] Put another way, this concept allows us to "evaluate the probability that a given number of observations will fall within some specified bound around a true ratio."[29]

The logical question that follows this is, how do we update our predictions as we acquire new information about the situation? For this we turn to the work of Thomas Bayes, a Presbyterian minister who was known as a philosopher and statistician. He formulated a theorem to deal with situations when we have "sound intuitive judgements about the probability of some event and want to understand how to alter those judgements as actual events unfold."[30] The theorem, which has become known as Bayes' theorem, was described in "An Essay toward solving a Problem in the Doctrine of Chances," and was presented to the Royal Society in 1763 by Richard Price after Bayes death.

Here is now Bernstein recounts Bayes' problem statement: *"Given* that the number of times in which an unknown event has happened and failed: *Required* the chance that the

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[28] Bernstein, 127-128.
[29] Bernstein, 128.
[30] Bernstein, 5.

probability of it happening in a single trial lies somewhere between any two degrees of probability that can be named."[31] The theorem allows us to revise inferences based on old information with new information, and this provides us with a means of dealing with uncertainty.

The ability to deal with uncertainty, or unknown probabilities, enabled many of the technical and social advances of the modern age. By quantifying risk, and then developing a way to deal with the risk, unintended consequences could be minimized and managed. At the heart of these efforts was the belief that, to a certain extent, risk can be controlled. Risk management improved safety and system performance. But the first step of this process is identifying the system. Today's systems are "more sophisticated and complex than ever before."[32] This leads us to a discussion of the second modernity.

Second Modernity and Complexity

In contrast to the first modernity, the second modernity is characterized by five interlinked processes that undermine the first modernity: globalization, individualization, gender revolution, underemployment and global risks such as climate change and the financial market crash.[33] These issues may all be considered as unintended consequences of the successes of the first modernity. While Beck describes the first modernity as "simple, linear, industrialization based on the nation state,"[34] he describes the second modernity as "radicalized modernization" with a "new kind of capitalism, a new kind of economy, a new

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[31] Bernstein, 131. Referencing Bayes 1763.
[32] Pinto and Garvey, 2.
[33] Beck, 1999, 2.
[34] Beck, 1999, 2.

kind of global order, a new kind of society and a new kind of personal life."[35] This second

modernity undermines the foundations of the first modernity resulting in the need for a

paradigm-shift for our social frame of reference.

The second modernity is defined in terms of globalization and transnational

interdependence. Changes are occurring with increasing speed, intensity and significance.

Risks can no longer be addressed individually, but rather need to be addressed

simultaneously. Modernity was typically defined by Western society, which also defined

other non-Western societies as *traditional* or *pre-modern*; not with their own terms, and

more importantly not even understanding those terms. The nature of the second

modernity requires us to understand the *pluralization of modernity* and that there are

"divergent trajectories of modernities in different parts of the world."[36]

Despite the complexity of the current world with its latent threats, it is important to

quantify these threats as best we can. The difficulty is that the complexity is not simply a

result of an expansion of what we consider when we think about risk. It is not merely an

added layer or even layers of additional consideration. Rather it is the interconnectedness

of all parts of the whole. Globalization is manifested in the interlinking of economic,

political and cultural processes. This process is fusing our world together into a more

unified entity.[37] At the same time that globalization is unifying, it also highlights the

differences between portions of our world. We continue to live in an industrial society that

is organized by nation-states, but those nation-states are increasingly impacted by the

effects of globalization in ways they cannot control. This is magnified by individualization,

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[35] Beck, 1999, 2.
[36] Beck, 1999, 3.
[37] Beck, 1999, 115.

where individuals, and even more dramatically, groups of them, are able to impact the

social agenda. Beck cites the theme of "an endangered world" as an example of this.[38] As

evidence of this, he points out: "the themes of the future… have not originated from the

farsightedness of the rulers or from the struggles in parliament – and certainly not from the

cathedrals of power in business, science and the state."[39] Beck's other three

characterizations of the second modernity: gender revolution, underemployment and

global threats, put added stress on a system that is already struggling to find a new balance.

The result of all this is that our world has become a place of increasingly rapid

change, characterized by new levels of uncertainty about the future. Gabe Mythen says,

"We are living in a 'runway world' stippled by ominous dangers, military conflicts and

environmental hazards."[40] Risk is omnipresent in the instability in which we exist. Far

from becoming more stable at the end of the Cold War, the world has been catapulted to a

new level of instability, which was accentuated by the events of September 11, 2001.

Mythen credits 9/11 as having been "a high voltage shock to the capitalist system," which

changed the way "we perceive the concepts of safety and danger."[41]

It is just as important today to define the system, to determine the risk. But many

systems are no longer stand-alone systems. We must look beyond the system to how it

interacts with other systems. As Beck says: "The calculus of risk connects the physical, the

engineering and the social sciences. It can be applied to completely disparate phenomena…

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[38] Beck, 1999, 68.
[39] Beck, 1999, 68-69.
[40] Mythen, 1.
[41] Mythen, 1.

it permits a type of *technological moralization* which no longer need employ moral and ethical imperatives directly."[42]

A good example of this, is the depletion of fisheries in Somali waters, caused by illegal fishing by non-Somali vessels. Modern technology allowed these vessels to fish further from their home waters and to preserve the fish, either by refrigerating or freezing, until they get it to market. This caused many Somalian fishermen to be unable to support their families in their traditional way. Some then turned to piracy, initially targeting those who were stealing their fish. This is perhaps a simplistic description of an issue which was discussed in more detail in Chapter 2, but it illustrates how an unintended consequence can result from technological advancements. Add to the issue, that some of the "pirates" were operating as Somali "Coast Guard," and the issue also illustrates that not all cultures view an issue through the same prism. The complexity of our modern world requires us to explore the historic and cultural aspects of an issue to fully understand it.

The next section will delve into how the field of security studies approaches the concept of risk.

SECURITY STUDIES APPROACH TO RISK

Security Studies is a subset of the field of International Relations. It is an evolving field which has expanded from its roots as Strategic Studies, focused primarily on the State as an actor, to include Human Security which is more concerned with individual security. Human Security includes issues of Human Rights and Human Development with emphasis on how these topics impact the individual, rather than just considering them from the

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[42] Beck, 1999, 51. Beck provides an example of this with mortality rates that consider certain conditions of air pollution.

broader policy aspect of traditional Strategic Studies. The expansion of Security Studies is

important because it recognizes that security is an issue that impacts all levels of society.

The decisions made by states determine how they relate and interact with other states, but

they also impact the people who make up the states.

While it is important to think about how the actions of the state may affect the

individuals of the state and elsewhere, it is even more important to consider how the

actions of the individuals may affect the state. Specific to this work, the policies of the

states set the conditions for the geo-political environment. Within a particular state, when

the conditions are not favorable for individual success, an individual may choose to act in

ways the state does not sanction – illegally. Such is the case for piracy, which is universally

considered to be illegal. An individual who is presented with limited, or no good, options

may see piracy as their best option.

The definition of security is somewhat subjective. What a state considers to be

security may vary from state to state and what an individual person values for security will

also vary depending on their individual values. Yet within the field of International

Relations, most scholars "work with a definition of security that involves the alleviation of

threats to cherished values."[43] Alternatively, in describing the shift in Strategic Studies to

Security Studies, John Baylis and James Wirtz say security is "defined in terms of *freedom*

from threats to core values."[44] In simpler and broader terms, *Security* is the condition of

being protected or free from harm. Security Studies typically focus on *threats* which are

essentially "things that can go wrong" and therefore by definition - risk. Yet the concept of

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[43] Williams, 1.
[44] Baylis, et al., 12.

risk is seldom directly addressed in traditional International Relations, so the connection

between the fields must be made.

The concepts of risk and security are inversely related. The greater the risks, the

less secure the situation is likely to be. The greater the security, the less risk exists.

Security Studies, with its focus on threats, aims at its core to understand and reduce risks.

While the concept of risk might not be directly addressed in traditional international

relations study, it is a topic which is frequently the focus of policy makers.

In February of 2005 The Heritage Foundation published *Making the Sea Safer: A*

National Agenda for Maritime Security and Counterterrorism. This report summarizes a one-

year project to examine the criticality of "protecting maritime commerce from attack or

exploitation by terrorists."[45] The Project specifically focused on the foreign policy,

economic and defense implications of this issue. The number one proposal for the

Administration was to create a Maritime Security Strategy.

In September 2005, the United States published the *National Strategy for Maritime*

Security (NSMS). This document was a joint effort between the Department of Defense and

the Department of Homeland Security. The goal of the NSMS is to integrate and blend the

public and private maritime security activities to address all maritime threats.[46] To achieve

this goal, the Departments developed eight supporting plans:

1. National Plan to Achieve Domain Awareness
2. Global Maritime Intelligence Integration Plan
3. Interim Maritime Operational Threat Response Plan
4. International Outreach and Coordination Strategy
5. Maritime Infrastructure Recovery Plan
6. Maritime Transportation System Security Plan
7. Maritime Commerce Security Plan

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[45] Carafano and Kochems, 1.
[46] *National Strategy for Maritime Security,* ii.

8. Domestic Outreach Plan

The introduction to the strategy concludes: "Together, the National Strategy for Maritime Security and its eight supporting plans present a comprehensive national effort to promote global economic stability and protect legitimate activities while preventing hostile or illegal acts within the maritime domain."[47] These efforts recognize both the importance of maritime activity to the wellbeing of the economy and the complexity of providing maritime security.

The directed strategies and plans are intended to be updated as required to reflect changes to the maritime environment and the threats to it. The plan and most of the supporting plans can be located on the Department of Homeland Security's website.[48] The Government Accountability Office (GAO) was tasked to assess the effectiveness of these efforts and this is an on-going effort. To provide guidance to the various agency decision makers, the GAO developed a risk management framework.[49] Figure 4-1 provides an illustration of this framework.

This risk assessment model is very goal/objective oriented as opposed to some models which start by identifying potential hazards. It begins with an objective to be achieved and then considers the possible constraints to achieving that goal. The risk assessment portion may be multi-faceted if there are multiple potential constraints (risks). However, for each risk the process is the same: evaluate alternatives, management selection of an action to eliminate or mitigate the risk, and then the actual implementation and monitoring phase which is then followed by repeating the entire cycle.

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[47] *National Strategy for Maritime Security,* ii.
[48] Homeland Security Digital Library. Access July 26, 2017, https://www.hsdl.org/?collection&id=4.
[49] Caldwell, 50.

Source: GAO.
Figure 4-1. GAO risk management framework

One of the areas where these concepts of risk and security are regularly applied is in contingency planning. Military contingency plans are the ones most closely related to Strategic Studies, but contingency planning may occur across all elements of government and in private industry, as well as for personal reasons. A contingency plan is made when there is a possibility that the planned outcome may not occur. It can be thought of as a "what if" plan; what if "this" happens instead of the "that" which we expected to happen? Or in other words, what if something goes wrong with our plans? An example of this is a ship's voyage plan to get from point A to point B and the considerations given to what

might go wrong during the voyage. The possibility of encountering pirates during the voyage is one of these considerations.

The likelihood of something going wrong is determined by a risk analysis. When the risk is significant enough to raise concern, a plan is developed to address the actions which should be taken in the event the risk is realized. These plans could be business continuity plans, disaster recovery plans or simply risk management plans. Returning to the example above, when the risk of piracy is great enough, a counter-piracy contingency plan is warranted.

The need for a plan may be triggered by a risk which is considered likely to occur or by an unlikely risk that would have catastrophic consequences should it occur. In this regard, it is useful to think of categories of risk. All risks can be subjectively evaluated to fall into one of four categories. They may be plotted onto a four-quadrant matrix which categorizes them in term of probability of occurrence and impact of occurrence. Figure 4-2 below depicts these categories.

In a world without resource constraints, it would be good to address and plan for each of these categories of risk. In reality, resources are always constrained. The risks that fall into the "high probability, high impact" quadrant obviously need to be planned for. These are risks which are likely to occur and when they do they will have a significant impact. It is equally important to plan for "low probability, high impact." While the likelihood of these events occurring may be very slight, their potential catastrophic impact requires these risks to be addressed. A pirate attack on a merchant ship is an example of a low probability event that could have a high impact associated with it. Although the media sometimes elevates awareness of these events, taken in the context of how many ship

transits occur, this is truly a low probability event. Lower probability and lower impact risks should be addressed as resources allow with the "low probability, low impact" category receiving the least priority.

Risk Quadrants
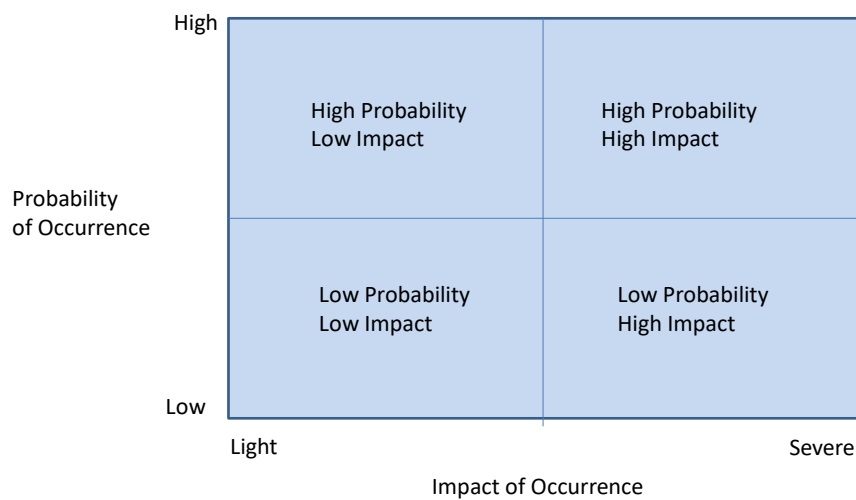
Figure 4-2. Risk quadrants

Early in the development of the study of risk, the occurrence of a particular risk was documented and the statistical consequences considered. This allowed for the refinement of insurance as the risk was then "personalized and shifted onto individuals."[50]   Having an insurance policy, is to a certain extent, a form of a contingency plan. If the event occurs, the policy will pay out and this allows future recovery actions. In this manner, an individual is better prepared for an event but likely has a very limited, if any, way to impact the

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[50] Beck, 1999, 51.

situation. When risks are considered as systemic events, they are "de-individualized."[51]

This shift in how we view risk allows us to better deal with the unforeseeable future. By

looking at an issue more holistically, we can focus more on prevention rather than reaction.

As a means of operationalizing this concept us let turn to the field of system engineering.

RISK ANALYSIS AND ENGINEERING RISK MANAGEMENT

As already stated: "Risk analysis involves identifying the most probable threats to an

organization and analyzing the related vulnerabilities of the organization to these

threats."[52] As just discussed, the risk quadrants can be a useful tool for categorizing risks.

Rather than thinking in terms of a plan, engineers think in terms of systems. Instead of

asking what could go wrong with my plan, an engineer will ask "What can go wrong with

my system or any of its parts?"[53] Despite the differences in terminology, it is easy to see the

parallels between these two processes.

There are many specific fields within the engineering domain and they each think in

terms of a system; mechanical engineers think in terms of the mechanical system; electrical

engineers are concerned with the electrical system, etcetera. However, systems engineers

specifically consider the interactions between the component systems.   It is the principal

discipline that addresses the "depth and breadth of sociotechnical challenges."[54] These

challenges include how the system affects society as well as how society affects the

system.[55] Even more comprehensive, enterprise engineering is concerned with very large

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[51] Beck, 1999, 51.
[52] Search Security.
[53] Pinto and Garvey.
[54] Pinto and Garvey, 19.
[55] Pinto and Garvey, 19.

complex "enterprise-wide" systems and is about shaping the environment of those systems. It "coordinates, harmonizes and integrates the efforts of organizations and individuals through processes informed or inspired by natural evolution and economic markets."[56]

International shipping can be thought of in terms of an unbounded system or a system of systems also knows as an enterprise system. A system is defined as "an interacting mix of elements forming an intended whole greater than the sum of its parts."[57] Enterprise systems cannot be centrally controlled and they require continual and evolutionary development.[58] They are a "mix of interdependency and unpredictability."[59]
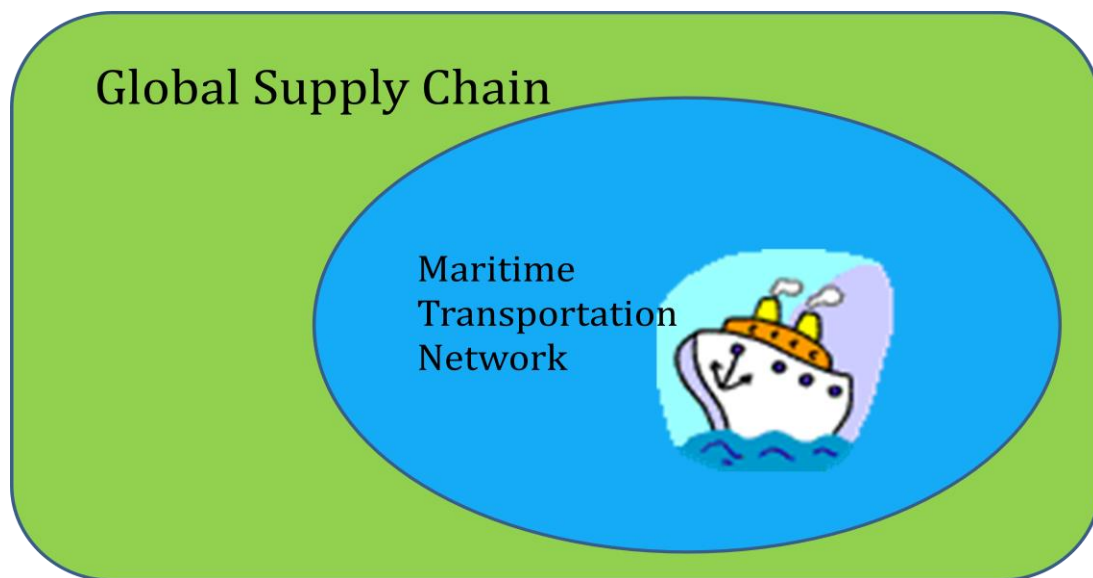
Figure 4-3. An enterprise system within another enterprise system

In a broader sense, international shipping can be viewed as a subsystem of the global supply chain and in this respect, as an enterprise system within another enterprise system.

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[56] Pinto and Garvey, 24.
[57] Pinto and Garvey, 15.
[58] Pinto and Garvey, 23.
[59] Pinto and Garvey, 22.

Figure 4–3 represents this concept of an enterprise system within another enterprise system.

Advanced Risk Analysis in Engineering Enterprise Systems provides a look at the emerging discipline of engineering enterprise systems. This discipline provides a structured approach for analyzing and managing risk in a complex system. It requires engineers and managers to develop a "holistic understanding of the social, political, and economic environments within which an enterprise system operates."[60] Since maritime piracy cannot be understood without considering it in the context of the larger complex system within which it exists, the engineering enterprise systems discipline provides a structured method for analyzing this problem.

Pinto and Garvey use Keating, Sousa-Poza and Kovacic's description of a complex system as "a bounded set of richly interrelated elements for which the system performance emerges over time and through interaction between the elements and the environment... and the appearance of new and unforeseen system properties which cannot be known before the system operates, regardless of how thoroughly they are designed."[61] They provide seven properties which characterize a complex system:

- Large number of richly interrelated elements
- Dynamically emerging behavior and structure that can dramatically change over time
- Uncertainty in outcomes
- Incomplete understanding of the system
- Multiple, and possibly divergent, system stakeholder perspectives
- Constrained resources and shifting requirements/expectations

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[60] Pinto and Garvey, 2.
[61] Pinto and Garvey, 347, citing Keating, C., Sousa-Poza, A., Kovacic, S., 2005. "Complex System Transformation: A System of Systems Engineering (Sose) *Perspective," Proceedings of the 26th ASEM National Conference*, 1.

- Urgency for immediate responses with dire, potentially catastrophic consequence for "getting it wrong"[62]

These characteristics of a complex system have obvious parallels to the description Beck provided for the second modernity. This reinforces the idea that it is useful to think about complex problems as a complex system.

Risk is often expressed in terms of probability; the probability that a potential event or action will occur. When factors involving the social, political and economic environment of the enterprise system are considered, objectively derived measures for the probability of certain event occurrences are not possible. Therefore, risk management in these situations must rely on probabilities that stem from expert judgment. These "subjective probabilities" are also called "measures of belief."[63] To determine these values, an expert must use all available evidence including experiences of similar events.

Since maritime piracy events fit into a category of data scarcity, an agent-base model is a good tool to assist the "expert" with plausible and consistent probabilities. I will return to this concept in the next chapter when we discuss contemporary maritime piracy in terms of the international shipping system and the environment it operates in.

While a systems engineering approach encourages us to look at our area of interest in a more holistic manner, it is still necessary for us to have an in-depth appreciation for our particular area of interest. Therefore, I will now turn to a discussion of maritime risk.

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[62] Pinto and Garvey, 347-348.
[63] Pinto and Garvey, 8.

MARITIME RISK

The risks involved in moving cargo by sea have always existed. The seaworthiness of the vessel is critical. The ship must be able to make the voyage. Even the most seaworthy vessel can become a casualty of extreme weather, and changes in the weather may come with little or no warning. But, more to the point, there has long been the risk that human intervention will prevent the cargo from reaching its destination. Interceptions and/or destruction of cargo ships have been a risk for as long as ships have sailed. When not viewed as a target of warfare, this risk was labeled as piracy by the ancient Romans. The risk of maritime piracy continues to be a big concern for mariners today and will be discussed in more detail in the next chapter.

Maritime risk assessment is a very broad topic that covers risks within the maritime domain, as well as threats from the shore to the maritime domain, and from the maritime domain to the shore. The topic includes the design, production and operation of maritime assets such as ships and off-shore platforms. In some cases, the port infrastructure is also considered in this topic.

A general literature review of maritime risk assessment determined the primary focus is safety at sea. This encompasses both the safety of the ship as well as the safety of the environment from the hazards of ship operation; primarily pollution. Much of the literature is concerned with applying the lessons learned from past maritime accidents and incidents to future ship design to improve the overall ship safety. The concepts employed in some of these efforts may have application to the operational aspects of shipping. Therefore, a selected number of them are discussed below.

For example, in a 2006 issue of *Quality & Reliability Engineering International*, W. Jin wrote an article to introduce a series of articles promoting research and development of maritime risk modeling and decision making. The article discussed how the maritime industry is moving from a largely prescriptive safety regime to a risk-based goal-setting regime. This shift recognizes that all safety issues cannot be cost effectively eliminated; however, they can be reduced to "as low as reasonably practicable" (ALARP).[64] The same can be said for maritime security risks. These risks cannot be totally eliminated; the cost to even attempt that goal would make marine transport prohibitively expensive. An ALARP standard also makes sense for maritime security threats.

Historically risk assessment has been used to improve ship design and operations to make shipping safer. J. Wang, et. al. discuss the use of risk assessment in ship design feasibility in "Use of Advances in Technology for Maritime Risk Assessment." The article begins with a brief review of the then current status of marine risk assessment. It describes both reliability analysis and safety analysis, allowing that there is considerable overlap between the two types of analysis.   Specifically, it defines reliability analysis as the study of system's characteristics "expressed by the probability that it will perform a required function under stated conditions for a stated period of time."[65]   A safety analysis extends beyond the reliability analysis "to include the study of the consequences of the failures of the item in terms of possible damage to property, injury/death of people, and/or the degradation of the environment."[66] The article then equates a safety analysis to a risk assessment.

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[64] Jin, 1-2.
[65] Wang, et al., 1041.
[66] Wang, et al., 1041.

A general process is described for risk assessment. The five steps of this process are:[67]

1. Hazard identification

2. Risk estimation

3. Risk-based design/operation strategy selection

4. Risk-based design/operation optimization

5. Risk-based operations/maintenance

The hazard identification step may either be a top-down or bottom up process. The top-down process is used if adequate failure data is available. When the data is not available or the reliability of the data is questionable a bottom-up process which looks at system as a series of subsystems and considers each component individually can be used. The hazards identified feed into the next step: risk estimation and so forth.
The article concludes by recommending a holistic framework that incorporates aspects from multiple techniques be employed for maritime risk assessment and "where appropriate risk modeling and decision-making tools [can] be selected for use at different stages of the design process and operations."[68]

Although the article is primarily focused on a method for safety engineers to incorporate lessons learned from prior accidents and incidents into future ship safety design, the techniques and process described may be applied to any large engineering system. Consequently, when the maritime shipping industry is thought of in term of an enterprise system the concepts and ideas of this article are useful. It is useful to note the parallel between the general process described above for risk assessment and the risk

[67] Wang, et al., 1045.
[68] Wang, et al., 1045.

management framework provided by the GAO in the reports discussed in the Security

Studies Approach section. While the two processes are very similar, the general process for

risk assessment begins by focusing on the hazards of whatever is being analyzed. The risk

management framework focuses first on the objective or goal and then evaluates the risk.

While this is a subtle difference, it is an important difference. The risk management

framework is focused on achieving a specific goal by managing risks. The risk assessment

process is focused on improving design and operation to make the system safer.

Identification of strategic goals, objectives and constraints is the problem identification

portion of the process and may be equated to the hazard identification step of the risk

assessment. The constraints to achieving a goal or an objective create a risk that the goal

will not be achieved. Risk assessment is equal to risk estimation except when there is a

lack of specific data to make the estimation. Then a more subjective assessment is

appropriate. The step to evaluate alternatives parallels the step where the risk based

design and operation strategy selection occurs. Management selection refers to

management desire to optimize outcomes and thus nicely equates to risk-based design

operation optimization. Finally, implementation and monitoring is the same as the last

step in the risk assessment where the risk based operations are conducted and maintained.

In 2006, Wang provided an update on the subject with his article "Maritime Risk

Assessment and its Current Status." He states that the maritime industry's interest in a

risk-based 'goal setting' regime dates back to the 1990s. Safety engineers have applied a

variety of risk-modeling and decision-making techniques to the process of Maritime Risk

Assessment. They have increasingly used Probabilistic Risk Assessment (PRA). These

methods are used for "verification purposes in design and operational processes of marine

and offshore engineering systems" and "for making decisions from the early stages."[69]

Safety improvement efforts for large engineering systems increasingly use risk analysis

methods both inside industry and from a regulatory standpoint. Both quantitative and

qualitative analysis methods are used depending on the information available. As

engineering systems become more complex and the public becomes more safety conscious

there is a need for the development and application of safety assessment procedures.

Wang's article briefly reviews four noteworthy offshore accidents, (offshore

accidents occur on platforms) followed by four maritime accidents (maritime accidents

occur on ships). These accident reviews are provided as a basis for the current status of

the safety assessment process. While Wang's article is particular to the UK system of

regulations and assessment techniques, general lessons can still be drawn from them.

Wang describes the reason for the IMO's role as a maritime regulatory organization: "The

international safety-related marine regulations have been driven by the serious marine

accidents. Lessons were first learnt from serious accidents. Then regulations and rules

were produced to prevent similar occurrences."[70]

Wang is primarily focused on design and operation of ships and platforms but he

does provide a discussion on Port Safety as well. He provides a list of potential benefits of

formal safety assessments and goes on to discuss the "Formal Ship Safety Assessment"

(FSA):

> FSA is a new approach to marine safety that involves using the techniques of
> risk and cost–benefit assessment to assist in the decision-making process. It
> should be noted that there is a significant difference between the safety case
> approach and FSA. A safety case approach is applied to a particular ship,
> whereas FSA is mainly designed to evaluate existing and new safety

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[69] Wang, 3.

[70] Wang, 8.

regulation although it may also be applied to safety issues common to a ship type (such as high-speed passenger vessel) or to a particular hazard (such as fire). It is noted that the purpose of FSA is not to take account of any specific systems or their arrangements, operations, etc., nor is the process design to look at the risks facing a particular stakeholder associated with a ship. ...whilst features specific to a particular ship cannot be taken into account in a generic application, the commonalities and common factors that influence risk and its reduction can be identified and reflected in the generic approach for all ships of that type.[71]

The article provides a discussion of each of the FSA steps (note the similarities to the risk assessment steps discussed in Wang's earlier article):[72]

1. Identification of Hazard

2. Assessment of Risk

3. Risk control options

4. Cost-Benefit Assessment

5. Decision Making

Earliest possible risk estimation is important, however early risk estimates likely involve more uncertainty so risks should be ranked relatively rather than with absolute values. As a design proceeds the risk assessment must continue. At a certain point a "mathematical model consisting of safety, cost and other objectives can be formulated and thereafter formal decision-making techniques can be used to process the model in order to optimize the design."[73]

Similar to the earlier article, this article is primarily focused on safety engineering. However, this article proposes that these methods have value for regulators and the development of more effective regulations. It is also conceivable that the recommended

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[71] Wang, 11.
[72] Wang, 13-15.
[73] Wang, 15.

processes, FSA in particular, have application for the broader enterprise system of international shipping beyond just the regulatory aspect.

The article concludes with a list of recent research activities in maritime risk modeling and decision making and the following list of "novel risk-assessment tools being developed:[74]

1. Expert judgement and approximate reasoning approach for dealing with problems associated with a high level of uncertainty. This includes subjective safety-based decision-making method, evidential reasoning technique, fuzzy set modelling method and Dempster–Shafer method for risk modelling and decision making.

2. Safety-based design/operation optimization approach.

3. Application of methods developed in other disciplines, such as artificial neural network approach and Bayesian networks for risk estimation and decision making.

4. Methods for modelling of human and organizational factors in the design of offshore structures.

Some of the most interesting work occurring in the field of maritime risk assessment deals with the use of fuzzy logic to define an individual ship risk factor. Two articles describe the development of the MAritime RISk Assessment (MARISA) tool. Both articles were written by Jean-Francois Balmatt, Frederic Lafont, Robert Maifret and Nathalie Pessel and were published in *Ocean Engineering.* "MAritime RISk Assessment (MARISA), fuzzy approach to define an individual ship risk factor," presents what was then

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[74] Wang, 16.

(2009) a new approach to maritime risk assessment.[75] The article presents the MARISA

system as a tool to determine individual ship risk factors based on multiple inputs using

fuzzy logic to create a single factor. The risk factor is comprised of both static and dynamic

factors. The static factor provides for the ship's characteristics and is comprised of the

ship's age, flag, gross tonnage, number of companies, duration of detention and type. The

dynamic factor is comprised of input on the sea state, wind speed and visibility. The

primary focus for MARISA is safety at sea with emphasis on environmental concerns and

pollution.

The article provides the background for the fuzzy logic approach, followed by an

assessment of works using fuzzy logic in the maritime domain. The data for MARISA is

discussed as well as the MARISA system architecture. Lastly, the results of simulations

using MARISA are provided.

The 2011 article "A decision-making system to maritime risk assessment," is an

extension of the work.[76] In this article, MARISA has been updated to incorporate the ship's

speed and its position relative to maritime shipping lanes. The MARISA architecture is

hierarchical and modular; therefore, the additional factors simply build upon the earlier

model. The next step would be to expand MARISA even further by incorporating

information about maritime traffic density and/or maritime risk zones. While the intended

focus of MARISA is environmental safety at sea, it is easy to think about a similar

architecture focused on maritime security.

Psarros, Skjong, and Eide have done some interesting work specific to maritime

security risk. In their 2009 article "The acceptability of maritime security risk," they look at

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[75] Balmat, et al., 2009, 1278–1286.
[76] Balmat, et al., 2011, 171–176.

the general issue of how to define acceptable risk.[77] Since resources are limited, industry is

interested in maximizing the benefits of investments in maritime security. They propose

that maritime security use the same criterion used for maritime safety which is based on

averting fatalities. Their article proposes the decision criterion be the value of $6 million.

In another article, they look at the incidents of maritime piracy. The article "On the success

rates of maritime piracy attacks," analyzes available statistical data from the IMO's monthly

piracy reports from 2000 to 2009.[78] Using trend analysis, they determine the attack rates

on specific vessel voyage segments for each geographic area of pirate activity and find that

each trend is unique by region. They use this information to estimate the probability of a

pirate attack using logistical regression. The conclusion from their modeling is that the

pirate attack success rates decrease with vessel size, but increase with pirate capability.

The results of this sort of data analysis could be utilized in an expanded version of MARISA,

specifically to help identify maritime risk zones and to identify the extent of the risk.

Marine insurance is another method shippers and mariners use to deal with risk.

Maritime insurance can be traced back to Greek Antiquity when "sea voyages would be

'insured' by high-interest maritime loans that were repayable only if the ship and cargo

made it safely to their destination."[79] A lender making these high interest loans was able to

off-set the losses from unsuccessful voyages with their large gains on the successful

voyages. They were even able to develop a certain level of sophistication for this primitive

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[77] Psarros, Skjong and Eide, 149-163.

[78] Psarros, et al., 309-335.

[79] Arnoldi, 25. This is also another example where the concept of risk was understood during pre-modernity without advanced mathematical probability concepts.

insurance by varying the 'interest rates' depending on the season; "according to the

probability of storms and rough weather."[80]

As maritime commerce prospered and the trade routes lengthened, maritime

insurance became more institutionalized.   In the early years, the insurance was provided

by individual underwriters. These underwriters might be acting alone or in organized

groups. One of the first insurance markets to provide maritime insurance as a specialist

insurance business was Lloyd's of London.[81]

Today, huge amounts of capital are invested in ships and their cargoes. Marine

insurance continues to play a role in safeguarding these major investments. Hundreds of

insurance companies around the world provide marine insurance and it is a complex

process consisting of individual policies to cover the hull of the ship, the cargo, and the

owners' and operators' liability, as well as other specialized policies packaged together as

needed. Specialized polices might include items such as "Kidnap and Ransom" or "War

Risks."

There is no specific policy to directly protect against the risks of maritime piracy

and terrorism; rather these risks are incorporated into the various policies as appropriate.

Just as improvements in ship construction allow for the rates on hull insurance to be lower,

security enhancements which reduce the ships vulnerability to pirate attacks can reduce

some insurance costs.

As in all forms of insurance, there are clauses which clarify the coverage, as well as

when it applies and does not apply. There are also different classes of insurance which

cover the various aspects being insured – hull insurance for the actual ship; cargo

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[80] Arnoldi, 25; (citing Franklin, 2001: 259).
[81] Mutenga and Parsons, 453.

insurance for what the ship is carrying; liability insurance to protect the owners; and specialized policies for more specific risks. The risk of piracy is not specifically addressed, as it crosses into many of these types of insurance that a ship will have. Yet, when the risk of pirate attacks increases, the cost for insurance also increases.

Some regions of the oceans require higher risk insurance. Specifically, a normal insurance contract can be voided if the ship transits a designated war zone. The Joint War Committee (JWC), which is comprised of underwriting representatives from Lloyd's and the International Underwriters Association, determines and publishes a list of the areas which are considered war zones. The transit of these areas requires a special "war risks" policy. In 2005, the JWC in conjunction with the Joint Hull Committee (JHC) produced wording which allowed underwriters to put the piracy peril into the war policy. Areas with significant pirate activity are now listed on the Joint War Listed Areas (JWLA). The current areas of "perceived enhanced risk" are listed in JWLA022.[82] Additionally, ships that sail these waters may carry kidnap and ransom insurance (K&R). K&R insurance protects individuals in high-risk areas around the globe from kidnapping, extortion, wrongful detention and hijacking. It is often purchased for situations on land, but it can also apply at sea. Paradoxically, K&R insurance could make mariners better targets for the illegal activity of holding them for ransom payments.

Maritime insurance is one way to deal with certain maritime risks; however, the institution of insurance has also likely played a role in the escalation of piracy in certain regions. Ships that have insurance are more likely to sail through risky waters. Ships that have insurance make profitable targets. As Terry McKnight said in his book *Pirate Alley*

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[82] Lloyd's Market Association website: Accessed July 26, 2017, http://www.lmalloyds.com/lma/jointwar. The list was published 10 December 2015. It was reviewed with no changes made in June 2017.

when describing the escalation of Somali piracy, specially referring to the increase in ransom demands by the pirates: "...while piracy is making millions for the pirates, it's actually making a lot more for several legitimate international businesses."[83] In the time frame that pirates collected an average of $160 million in ransom payments, maritime insurance companies collected five time that amount in increased premiums and service fees.[84] In situations like that, where is the incentive for change? It must come from those who are being targeted, the mariners and the nations who support them. Therefore, let us dive a little deeper into the issues of maritime safety and security.

MARITIME SAFETY AND SECURITY

The safety and security of international shipping has historically been an important issue. Shipping enables international trade, and shippers and investors want their cargos to arrive safely. It is a topic which begins with the design and construction of each and every vessel. It continues with how the ship is manned and operated, as well as how it interacts with other vessels at sea. Since man first put to sea, constant improvements have been made to make going to sea safer.

Today, those practices have evolved into the more structured practice of maritime risk assessment. Maritime risks are multi-faceted. They can be divided into two major categories of events; maritime safety accidents and maritime security incidents. Maritime safety accidents are unintentional events which may occur because of natural causes, an action of the crew or a third party. These include events such as fire, explosions or collisions. Safety accidents may also be navigational in nature, caused by either weather or

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[83] McKnight, 210.
[84] McKnight, 210-211.

geography. However, maritime security incidents are intentional actions. These are

comprised of unlawful acts of piracy and terrorism. When reducing the risks from this

category, the concern is how to enhance ship security without jeopardizing the ship's

organizational efficiency and effectiveness. Although this work is primarily concerned with

Maritime Security issues, there are valuable lessons to be learned from looking at how the

maritime community has dealt with safety issues. Additionally, while the two types of

events are distinct in nature, a maritime safety issue may result in an increased

vulnerability to maritime security risks. Or as in the case of the June 2017 collision

between the USS *Fitzgerald* (DDG-62) and the Philippine flagged container vessel, ACX

Crystal, what appears to have been a navigational incident, could perhaps have been an

intentional act and consequently a maritime security incident rather than a maritime safety

accident.[85] The line between these two categories is not always clear.   For these reasons, a

brief discussion of maritime safety is provided before shifting to the issue of maritime

security.

Maritime Safety

The international maritime community has long been concerned with improving

safety at sea. Following the sinking of RMS *Titanic*, the first version of the International

Convention for the Safety of Life at Sea (SOLAS) was negotiated and agreed upon in 1914.

This treaty has been revised and updated to continually improve safety at sea issues. The

fifth and current version of SOLAS was adopted in 1974 and entered into force in 1980.

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[85] ACX *Crystal* plowed into the starboard side of the USS *Fitzgerald* around 0220 on Saturday, 17 June 2017, approximately 56 miles south of Yokosuka, Japan. The resulting damage to the *Fitzgerald* was significant enough that the ship would have sunk without the heroic damage control actions of the ship's crew. There is an on-going investigation of this incident, at this time there has been no indication of terrorism.

The current version has been updated and amended as needed and is referred to as "SOLAS, 1974, as amended." The Convention specifies "minimum standards for the construction, equipment and operation of ships, compatible with their safety."[86] Flag States are responsible for the ships that sail under their flag and must ensure they comply with current SOLAS requirements. Port States are authorized to inspect the ships entering their ports to verify that they comply with all requirements.

The first SOLAS convention prescribed the number of required lifeboats and other emergency equipment, including radio communications equipment, and safety procedures. These types of equipment directly impact life safety in the event of an emergency. Newer versions of the convention were adopted in 1929 and 1948. With the establishment of the International Maritime Organization in 1948,[87] the SOLAS convention came under the IMO's purview. The 1960 SOLAS convention, the first update that the IMO was responsible for, represented a major advance in updating shipping regulations to reflect new technology and maritime procedures. Many of the SOLAS requirements deal with ship construction standards which are intended to make the ship more survivable in the event of extreme weather or collision. Modern day environmental concerns are included in the current convention, such that, in addition to the original aims of ensuring safety by preventing injury or loss of life, avoidance of damage to the environment is now addressed.[88]

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[86] SOLAS, 1974.

[87] Following the establishment of the United Nations, an international conference in Geneva "adopted a convention formally establishing IMO (the original name was the Inter-Governmental Maritime Consultative Organization, or IMCO, but the name was changed in 1982 to IMO)" International Maritime Organization Website "Brief History of the IMO." Accessed August 15, 2016, http://www.imo.org/en/About/HistoryOfIMO/Pages/Default.aspx.

[88] Talley, 2008, 12. "Guidelines on Management for Safe Operation of Ships and for Pollution Prevention" were adopted in 1989 following the sinking of the *Herald of Free Enterprise*.

The 1974 version of the convention included a clause which allowed for amendments to the convention to be made by tactic agreement, whereby the amendments enter into force on a stated date unless objections to the amendment are received by a specified number of convention parties.[89] Since then the SOLAS convention has been amended numerous times and in addition to safety issues, maritime security issues are also addressed.[90] Specifically, in 2002, Chapter XI-2 "Special measures to enhance maritime security," was adopted and entered into force on 1 July 2004.[91] This chapter was added to clarify the requirements of authorized organizations to carry out inspections and surveys, including the operational responsibilities of the port State.[92] The chapter is organized into two sections; the first section provides a general introduction to the new requirements while the second section provides the details of the new regulations. Most significantly, this chapter introduces the International Shipboard Port Facilities Security Code (ISPS Code). Part A of the code is mandatory and Part B provides guidance on how to best comply with the mandatory code.[93] The safer we can make ships and the ports they sail to and from, the less vulnerable the ships will be. This provides a good transition to the topic of maritime security. More details of these developments as well as maritime security policy will be discussed in the next section.

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[89] SOLAS, 1974.
[90] SOLAS, 1974: Brief History. The website provides a list of amendments by year.
[91] SOLAS, 1974: Brief History.
[92] SOLAS, 1974.
[93] SOLAS, 1974.

Maritime Security

Unlike safety accidents, maritime security incidents are intentional actions caused by someone or some group of actors. The major distinction which makes these issues different from maritime safety issues is the unlawfulness of the acts. The incidents can be divided into two major groups; terrorism and piracy. Acts of terrorism at sea are a relatively recent consideration, while piracy is as old as seafaring. Maritime piracy was discussed in Chapter 2. Here we will take a brief look at maritime terrorism.

Martin N. Murphy credits the distinction between maritime piracy and maritime terrorism as a result of the hijacking of the *Santa Maria* in 1961. Because this act of piracy was politically motivated, "Modern legal thinking was reluctant to label the act one of piracy and therefore, retrospectively, it was labeled terrorism."[94] Murphy contends that many commentators do not agree with this categorization of these acts. Specifically, he states; "In the view of James Cable, the noted diplomat and naval historian, the difference between piracy and terrorism is artificial, one that is not recognizable in practice."[95] Despite this somewhat artificial distinction between maritime piracy and maritime terrorism, the risks for mariners are very real and can be extremely costly.

The hijacking of the MS *Achille Lauro* in October 1985 brought renewed attention to the issue of maritime terrorism. The following month, the IMO assembly developed "Measures to prevent unlawful acts which threaten the safety of ships and the security of their passengers and crew."[96] The next year, the Maritime Safety Committee issued a Circular entitled "Measures to prevent unlawful acts against passengers and crews onboard

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[94] Murphy, 1983, 1.
[95] Cable, 1.
[96] IMO resolution A.584(14).

ships."[97] These efforts lead to the "Convention for the Suppression of Unlawful Acts Against

the Safety of Maritime Navigation," commonly referred to as the SUA convention, which

was adopted by member nations on March 10, 1988 and entered into force on March 1,

1992.[98]

Article 3 of the convention states that "Any person commits an offence if that person

unlawfully and intentionally:

> 1. seizes or exercises control over a ship by force or threat thereof or any other form of intimidation; or
> 2. performs an act of violence against a person on board a ship if that act is likely to endanger the safe navigation of that ship; or
> 3. destroys a ship or causes damage to a ship or to its cargo which is likely to endanger the safe navigation of that ship; or
> 4. places or causes to be placed on a ship, by any means whatsoever, a device or substance which is likely to destroy that ship, or cause damage to that ship or its cargo which endangers or is likely to endanger the safe navigation of that ship; or
> 5. destroys or seriously damages maritime navigational facilities or seriously interferes with their operation, if any such act is likely to endanger the safe navigation of a ship; or
> 6. communicates information which he knows to be false, thereby endangering the safe navigation of a ship; or
> 7. injures or kills any person, in connection with the commission or the attempted commission of any of the offences set forth in subparagraphs (a) to (f)."[99] [of the SUA Convention]

The suicide bombing of the USS *Cole* (DDG-67) in 2000 and the 9/11 terrorist

attacks in 2001 brought even greater focus to the issue of maritime security. The

International Ship and Port Facility Security Code (ISPS Code) was established in December

2002 as an amendment to SOLAS. The measures in the Code entered into force in July

2004. The Code, which has two parts, one mandatory and one recommendatory, is a

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[97] IMO MSC/Circ 443.
[98] 1988 SUA Treaty.
[99] 1988 SUA Treaty, Article 3.

comprehensive set of measures to enhance the security of ships and port facilities.[100]

Essentially, the Code equates to doing a risk assessment and implementing risk

management practices.

The IMO website summarizes:

> In essence, the Code takes the approach that ensuring the security of ships
> and port facilities is a risk management activity and that, to determine what
> security measures are appropriate, an assessment of the risks must be made
> in each particular case. The purpose of the Code is to provide a standardised,
> consistent framework for evaluating risk, enabling Governments to offset
> changes in threat with changes in vulnerability for ships and port facilities
> through determination of appropriate security levels and corresponding
> security measures.[101]

Also following the 9/11 terrorist attacks, the SUA Convention was amended by the

Protocol of 2005. This protocol acknowledged "terrorist acts threaten international peace

and security" and requested new measures "in order to prevent and suppress terrorism

against ships and to improve security aboard and ashore, and thereby to reduce the risk to

passengers, crews and port personnel on board ships and in port areas and to vessels and

their cargoes."[102] Specifically, the protocol spells out in detail the threat of nuclear,

chemical and biological weapons and goes into detail on state responsibility for bringing

perpetrators to justice.

In 2006, the RAND Center for Terrorism Risk Management Policy published a study

of the risk and liability associated with maritime terrorism. Even though only two percent

of all international terrorism incidents over the last 30 years involved seaborne strikes,

policy makers had become increasingly concerned by the possibilities of maritime

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[100] The ISPS Code is implemented through Chapter XI-2 Special measures to enhance maritime security in the International Convention for the Safety of Life at Sea (SOLAS), 1974.
[101] ISPS Code.
[102] IMO Protocol of 2005 SUA Convention.

terrorism. Maritime terrorism, like maritime piracy is a low probability, high impact event.

However, it is likely a lower probability, but possibly higher impact event than piracy. A

maritime terrorist attack has the potential to cause mass casualties, severe property

damage and perhaps significant disruptions to commerce.[103] Add, the fact that many

maritime assets are particularly vulnerable and the issue simply cannot be ignored.

The RAND study only looked at a limited number of attack scenarios involving

passenger and container shipping.[104] However, their findings are germane to the topic in

general. They looked at the issue in terms of vulnerability, capability and intent. For the

most part, terrorist groups have not been geographically located in coastal areas or have

not had the necessary skill set needed to operate in the marine environment. Similar to

pirates, to operate at sea terrorists must have "mariner skills, access to appropriate assault

and transport vehicles, the ability to mount and sustain operations from a non-land-based

environment, and familiarity with certain specialist capabilities."[105] Despite this, the study

lists several groups that have clearly integrated waterborne capabilities into their skill

set.[106] While maritime targets are often out of sight and therefore "relatively speaking also

out of mind,"[107] modern media abilities could allow for them to be more visible, particularly

in the case of cruise ships.

The study found that on-board explosive attacks were most probable for cruise

ships and ferries. Such an attack could cause high casualty rates, particularly on a ferry

where passengers are concentrated and the vessels are especially vulnerable. While an

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[103] Greenberg et al., xviii.
[104] Greenberg et al., 9.
[105] Greenberg et al., 10.
[106] Greenberg et al., 19. See the study for an actual list of the organizations.
[107] Greenberg et al., 11.

attack on a cargo ship is less likely to cause high profile casualties, these vessels are susceptible to being used as a concealed-weapon platform. The greatest risk in this category would be radiological or nuclear detonation, but even a conventional explosion could cause significant economic impact on a port facility.[108] These sorts of findings are very useful for prioritizing limited resources that are required for detection, prevention and interdiction efforts.[109]

Maritime Security Environment

The oceans are large, and while shipping lanes and ports determine where the majority of merchant ships will travel, the areas to be protected remain vast. The high seas cover more than 130 million square miles of the earth's surface.[110] These waters are by definition beyond the sole jurisdiction of any one state.

In early times, protection of merchant shipping was provided by a combination of great empire power and the power of mercantilism. The ability of the large mercantile companies to have what were essentially their own private navies disappeared as the mercantile companies either ceased to be commercial entities or were transformed into modern corporations.[111] For a while, state sponsored privateers were employed as an adjunct to more proper naval power, however by 1856 international agreements began to outlaw privateers under international maritime law.[112] By the turn of the century, states

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[108] Greenberg et al., 139.
[109] Greenberg et al., 134.
[110] Greenberg et al., 1.
[111] Thomson, 102.
[112] Thomson, 70-71.

had banished privateers to the annals of history.[113] Thus, the ability to legally employ violence on the high seas was relegated solely to state powers.

Safe transit of maritime vessels continues to be a primary motivation for naval power in modern times. During the era of Pax Britannica, the British Empire functioned as a global hegemonic power and essentially provided a global police force. The British controlled most of the key maritime routes and the British navy was for the most part unchallenged upon the seas. The First World War put an end to that world order and by the end of the Second World War a new world order was emerging. The bi-polar security arrangement which emerged divided the world between American and Soviet spheres of influence. During the Cold War, the American and Soviet Navies vied for control of the seas. Between them they patrolled and controlled much of the seas while maintaining relative order on the high seas. Both nations significantly reduced their presence in the relative peace that followed the end of the Cold War. However, with the end of the bi-polar global security environment, the world has, in some ways, become a far more complex place. Increasing rates of piracy at sea, as well as the 9/11 terrorist attacks on the United States, have brought a renewed focus to maritime security issues and a need to fill the void left by the decrease in US-USSR naval activity.

Currently the security of the seas is provided for in a variety of ways. The efforts vary by region, depending on the needs for security. Within territorial waters, security is the responsibility of the state and may be provided for by marine police and coast guard forces. Alternatively, when the state does not have the resources to defend its waters, other states may be invited to assist. In international waters, security is the responsibility

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[113] Thomson, 76.

of all nations. These efforts are primarily provided by multi-national cooperative efforts. How willing these forces are to get involved in piracy depends on a multitude of factors. Even though states nearly unanimously agree that piracy is illegal, willingness to get involved in enforcing the international laws which prohibit piracy depends on complex considerations to include what to do with pirates who are apprehended. However, when pirate activity increases enough to capture global attention, international action is called for. Such was the situation in January 2009 when incidences of pirate attacks off the coast of Somalia and in the Gulf Aden reached extraordinary levels for modern times. The response was an unprecedented international maritime cooperative effort to combat piracy in that region.

As maritime trade continues to expand, and the availability of naval assets shrinks, providing security on the seas becomes increasing challenging. Since maritime security forces cannot be everywhere at all times, mariners debate how much self-protection they should sail with. Key among the factors considered is the risk level of piracy. As John S. Burnett so well, states: "Indeed, there is not a shipping lane, a navigable strait, an important canal, that is safe from those determined to take over a ship." [114] The question is, how great is the risk for such an event? An even more important question is, whether we can have a greater impact on this risk by concentrating on the motivators ashore, than on our interdiction and counter-piracy efforts at sea?

Despite continual efforts to increase security at sea, it is important to take a more holistic view of the issue, to include what motivates piracy in the first place. If we have a better understanding of what motivates piracy, we should be able to put policies in place

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[114] Burnett, 11.

that help prevent piracy by eliminating or minimizing the conditions which encourage it. This kind of prevention may be more effective than the reactive efforts to interdict piracy operations at sea or taking actions after a pirate attack.

THOUGHTS ABOUT THE OTHER PIRATE RISK

When we think about pirate risk, we are normally thinking about the risk to a ship or yacht in the event of a pirate attack. Indeed, the previous section of this chapter described the marine environment and the efforts to make it safe from piracy. When we think about maritime piracy in terms of a system, we understand the pirates are an essential part of the problem. Without pirates, there is no piracy. To understand the risk of a pirate attack, we must understand the pirates and their motivations – this includes the pirate's risk. What risks are pirates considering when they decide to engage in piracy?

First there are the normal risks associated with going to sea on a boat. These risks vary depending on the seaworthiness of the boat, including the dependability of the engine; the seamanship skills of the pirate operating the boat; and the weather and sea conditions or operating environment. At the top of this list, is the risk of drowning since there is no guarantee that a boat that goes to sea will return to land. We can assume that able mariners would take all these risks in stride just as they would if they went to sea to fish or trade. There are days when the risks are high enough that they do not go to sea. This could be problem with the boat, perhaps the engine is not operating properly. Stormy weather could also prevent someone from going out in a boat. This is reflected in the seasonal cycles of piracy in certain areas. The PPS and PARS models developed by the Naval Research Laboratory used meteorological data to account for this. Richard Phillips

discussed this in his book, *A Captain's Duty*. He says, "Piracy has seasons, just like the weather."[115] During the monsoon season, the ocean is dangerous for small boats, so piracy ebbs. For example, piracy season in the Indian Ocean runs from October to May. This trend is also reflected in the IMB piracy reports, when the number of attacks by region are analyzed by what time of year they occurred.

The maritime security environment presents another set of obvious risks. These are the risks associated specifically with the act of piracy. Some of these risks are related to the target ships. What kind of ship is it? How much freeboard is there – meaning how difficult will it be to board. What kind of counter-piracy measures has the ship employed? Some ships have fire hoses rigged to repel boarders. Others may have barbed wire obstacles. Many ships have taken to sailing with armed guards when they transit dangerous waters. These are just a few of the best management practices merchant mariners employ to discourage pirates.   All these efforts factor into how risky a particular target is for pirates. Then there is the security environment itself. Are there maritime security units operating in the area; naval vessels or coast guard, etc.? What is the risk of being interdicted by these security forces and what is the punishment?

During the early days of CTF 151, the unwritten policy for the U.S. Navy was to "catch and release" the pirates.[116] This was because the legal ramification of taking them into custody was far too complicated. The point here, is that if the pirate knows there is no penalty for being caught in the act of piracy, he will view the risk of engaging in piracy totally different from when the risk is incarceration or possible death. Thus, even the reputation of the state's legal system can factor into the pirate's calculation of risk. The

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[115] Phillips, 64.
[116] For more about this policy, see McKnight, 26-28, 97-99, and 104-105.

total risk of engaging in piracy is the sum of all the individual risks. All of these risks are

likely subjectively calculated based on the pirate's experience.

For the pirate, the risks are half of the calculation. What is the potential reward? If

the reward is high enough, the pirate will be willing to take bigger risks. Many of the

contemporary incidents of piracy involve hijacking the vessel and holding the crew for

ransom. In 2012, the average ransom was $4 million per incident and as much as $12

million. The total ransom paid out in 2011 was $135 million.[117] Some people would be

willing to take quite a bit of risk for this kind of payment. It should be noted that the

pirates who are demanding these high ransoms are not the disorganized ad-hoc type of

simple opportunistic piracy we often think about. These incidents are the piracy engaged

in by a "highly developed transnational criminal enterprise."[118]

For a more accurate calculation for the risk to reward ratio, the risk calculation

should include a factor for the probability of success. This is where effective counter-piracy

efforts of the vessels and counter-piracy operations by maritime security forces can have a

big impact. But these are costly efforts to employ, so we return to the question asked

earlier; is it possible to have a bigger impact on reducing the risk of maritime piracy by

concentrating on reducing the motivators ashore?

The next chapter returns to the issue of contemporary maritime piracy. It will

provide some initial analysis as well as a discussion of the available data.

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[117] McKnight, 107.
[118] McKnight, 107.

CHAPTER 5

PIRACY DATA AND ANALYSIS

This chapter begins with a discussion of the data available on maritime piracy. It provides some basic analysis of the data to establish what the risk of a pirate attack is for merchant shipping as well as how successful pirate attacks tend to be. A spectrum of piracy operations is proposed which illuminates the need to consider the motivation for piracy. Finally, the chapter concludes with a discussion of data on socio-economic and socio-political factors.

MARITIME PIRACY DATA

Data on current pirate attacks is only as good as the reports of these attacks allow. There are a few comprehensive sources of this data. The International Chamber of Commerce (ICC) maintains a "Live Piracy Map" of incidents of piracy at sea for the current year.[1] A Map of the previous year is also available. The data is gathered by the International Maritime Bureau (IMB) Piracy Reporting Centre (PRC) in Kuala Lumpur, Malaysia. They get the information directly from the ships or owners of the ships who make reports to the Centre. The ICC also produces quarterly and annual reports of "Piracy and Armed Robbery Against Ships," and these reports are available from the Centre.

The IMO maintains statistical data on reported incidences of piracy and armed robbery dating back to 1982.[2] The data comes from the Global Integrated Shipping

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[1] ICC, Live Piracy Map.
[2] IMO, Knowledge Centre.

Information System (GISIS). The UK Defence Intelligence Staff, International Terrorism and

Organized Crime Group (ITOC), Maritime Branch issues a "Worldwide Threats to Shipping

Report" monthly. Both the IMO and ITOC draw most of their data from IMB PRC.

The US Office of Naval Intelligence (ONI) provides piracy analysis and weekly

warnings of the world-wide threat to shipping. Two separate documents are produced by

ONI; "Piracy Analysis and Warning Weekly" and "World Wide Threat to Shipping." ONI

draws on multiple sources to include the data from the IMB, IMO and ReCAAP to make this

information available.

The Regional Cooperation Agreement on Combating Piracy and Armed Robbery

against Ships in Asia (ReCAAP) is a regional government-to-government agreement. The

ReCAAP Information Sharing Centre (ISC) is located in Singapore.[3] The Centre is focused

on piracy in Asia. It provides a network for the sharing of timely and accurate information

about incidents of piracy, issues warning and alerts to the shipping industry, and produces

periodical reports of maritime piracy.[4] The agreement entered into force on September 4,

2006, so they also recently published a 10th anniversary report *Commemorating a Decade*

of Regional Cooperation 2006-2016.[5]

Lastly, Oceans Beyond Piracy (OBP) is a program that was launched in 2010 by the

One Earth Future Foundation, a privately funded, independent, non-profit organization.

Their goal is to develop public-private partnerships which promote long-term solutions

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[3] ReCAAP "Home."

[4] ReCAAP "About ReCAAP ISC."

[5] ReCAAP, *2006-2016,*

both ashore and at sea to combat the issue of maritime piracy. They produce an annual

report on the State of Maritime Piracy. The 2016 report is their seventh annual report.[6]

Efforts to collect reports of piracy and disseminate warnings have steadily

improved. Greater details, when available, of the incidents allow for better analysis of past

events. This analysis provides feedback so that reporting requirements may be adjusted.

Conversely, we do not know what we do not know. The estimates for what percentages of

incidents are reported widely vary. More optimistic estimates believe that up to fifty

percent of incidents are reported, while others predict as little as ten percent.[7] No matter

the precise percentage, many incidents are not reported and therefore are not captured in

any of the data bases.

The best incentive to report incidences of piracy is to provide better warnings for

other mariners. In fact, the IMB annual report clearly emphasizes this. In the section about

the IMB Maritime Security Hotline, the report says "All information received will be treated

in strict confidence and will passed on to relevant Authorities for further action. Maritime

crime and security concerns us all and with your help, we can try to minimize the risk and

help save lives and property."[8] The section ends with "**REMEMBER:** Your information may

save lives. All information will be treated in strict confidence."[9]

Unfortunately, there are many disincentives for reporting. Peter Chalk reports that

most ship owners are reluctant to alert authorities about attacks on their vessels, primarily

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[6] The report is available at http://oceansbeyondpiracy.org/publications/state-maritime-piracy-2016
Accessed August 28, 2017.
[7] Murphy, 1983, 67-68.
[8] ICC IMB 2016 report, 19.
[9] ICC IMB 2016 report, 19.

because of the resultant delays and costs associated with the investigations.[10] Ships might

also be reluctant to report out of concern for how the incident could impact their

reputation.[11] Operational costs would be increased if crew members demanded additional

pay to sail through "pirate-prone areas."[12] There is also a concern that reporting incidents

will lead to higher insurance rates.[13]

      The worst reason that some incidents do not get reported is that, as they say; "dead

men tell no tales," and therefore some victims of piracy are unable to make reports. Finally,

pirates seldom, if ever, self-report. This is especially important as we lack data on precisely

what motivates piracy. Since the data is gathered by incident, we do not know much about

the population of pirates. Is there a large population of which each is only involved in a few

attacks, or a smaller number involved in more attacks? This might not matter to the

victims; however, it can make a significant difference in terms of pirate tactics and

capability – pirates learn.

      With any kind of data, the details matter. The annual reports produced by the ICC

IMB compile a year's worth of data on "Piracy and Armed Robbery Against Ships." As

discussed in Chapter 2, the distinction between a pirate attack and an armed robbery is

where the incidence occurs. When the incidence occurs on the internal waters of a state or

within the territorial waters of a state it is considered to be armed robbery, whereas those

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[10] Chalk, 2008, 7. Chalk credits IMB officials in Kuala Lumpur with this information and cites: "According to analysts in Malaysia, the losses incurred by delays to onward journeys (known as demurrage costs) hurt ship owners the most. These losses, which can reach $20,000-30,000 per day, are especially severe in countries where police authorities lack efficiency or professionalism, both of which can result in investigations that take weeks, or even months to complete." (Author interview with maritime analysts and IMB official, Kuala Lumpur, August 26, 2006).
[11] Murphy, 1983, 68. The ship might be blamed for taking insufficient precautions to prevent the attack.
[12] Murphy, 1983, 68.
[13] Chalk, 2008, 7.

that occur on the high seas are acts of piracy.[14] The report also lists actual attacks and attempted attacks; therefore when looking at the summary of all attacks in the first table of the report the number of events include the combined totals of pirate attacks and attempted attacks as well as the same for armed robbery events. In 2016, there were a total of 191 events across the globe reported by 49 specific regional areas.[15] This total continued the general downward trend of the last few years following record highs of 445 events in 2010 and 439 in 2011 (see figure 5-1).[16]

Each annual report provides five years' worth of data for comparison. The overall summary of actual and attempted attacks includes all incidences of reported piracy and armed robbery. The actual attacks consist of vessel boardings (events when pirates enter the vessel and then depart), and hijackings (events when pirates enter the vessel and take control of it). Attempted attacks are divided into two categories as well; simple attempts and attempts in which the vessel was fired upon. Each of these categories is later broken down into more detail. In addition to where the events occurred, the data also provides greater details as to what kind of ship was attacked, what kind of weapons were used, what sort of violence occurred, and what the status of the ship was at the time of the attack; berthed (pier side in a port), anchored or steaming.

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[14] The IMO uses the 1982 United Nations Convention on the Law of the Seas (UNCLOS) definition of piracy and the IMO definition of armed robbery.

[15] ICC IMB 2014 report, 5.

[16] ICC IMB 2016 report, 5. There were 297 events in 2012, 264 in 2013, 245 in 2014 and 246 in 2015.
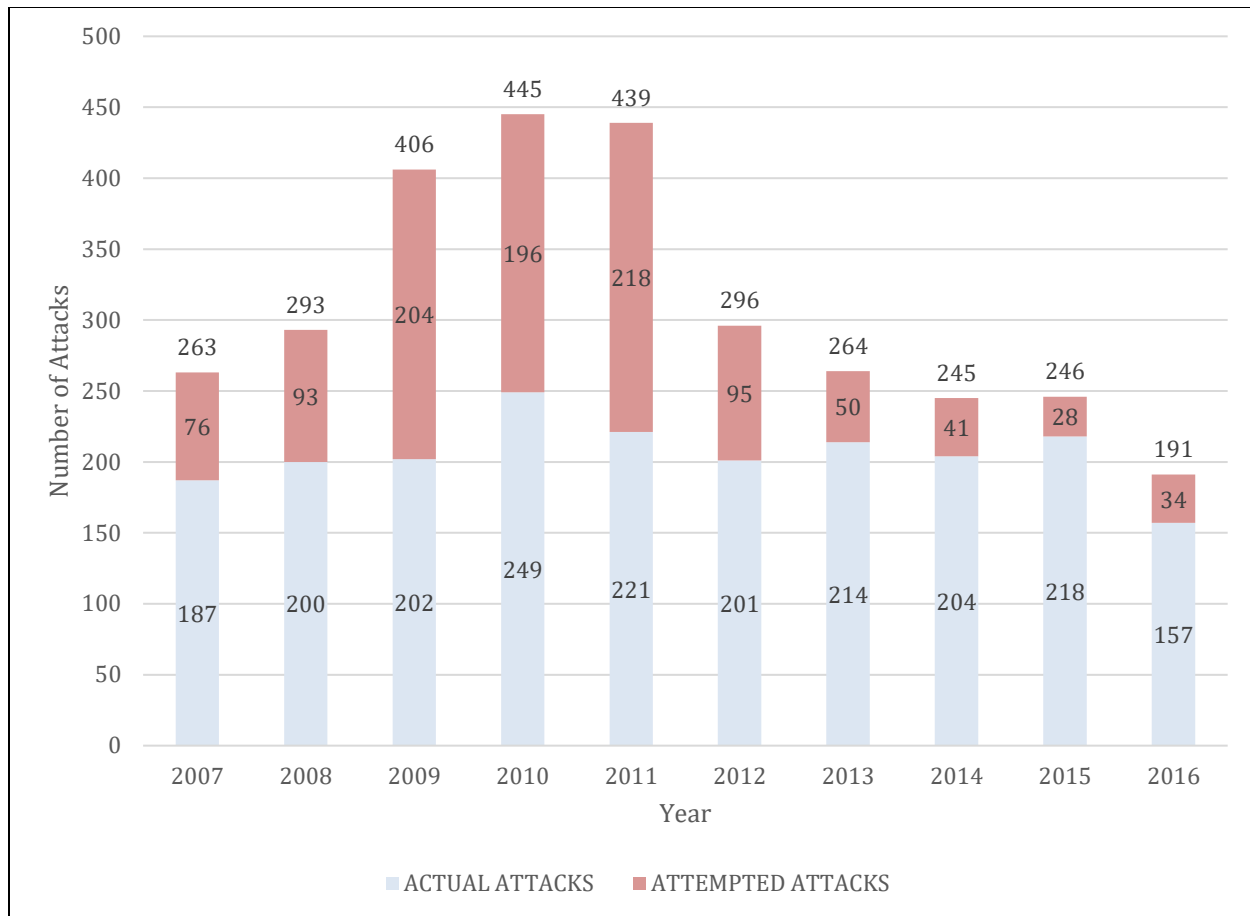
Figure 5-1. Actual and Attempted Attacks 2007-2016[17]

Each category of ship status at the time of incident has different security implications that depend, to some extent, on the level of onboard readiness to deal with any incident, no matter where it occurs. However, they also are each unique because the security environment in each situation is dependent on different variables. In a port, jurisdiction belongs to the state in which the port is located and may fall to local security forces. Anchorages are located within the territorial waters of specific nations who then have a sovereign responsibility to provide security. Some anchorages are known to be

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[17] ICC IMB Annual Reports 2007 through 2016.

more prone to incidents of "armed robbery"[18] and ICC offers warnings about these areas.[19]

The level of security provided in a port or around an anchorage falls to the host nation and

varies directly with that nation's capabilities and willingness to provide security.

When a ship is operating in a steaming condition it may be in territorial waters or

on the high seas. In territorial waters, security continues to remain the responsibility of the

host nation. These events, as well as the ones that occur in the port or at anchorage, would

technically be classified as armed robbery and be under the auspicies of local authorities.

However, on the high seas the responsibility for ship security rests solely with the vessel

and others operating in the vicinity. There is no permanent international maritime security

force. However, as demonstrated off the coast of Somalia, a coalition or coordinated effort

by multiple navies can play a significant role in reducing the threat of piracy.

The majority of the reported incidents occur when the ship is berthed or at

anchorage, and for many locations listed in the report, there are no incidents for ships in a

steaming status. This means that very few of the events occur on the high seas. These

factors lead to the conclusion that the data on pirate attacks on the high seas is relatively

scarce. This makes it difficult to create a model based on existing data. Instead a model can

be created making certain assumptions and then be used to help us understand the

dynamics which are in play.

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[18] By definition, pirate attacks that occur at an anchorage are incidents of armed robbery because they occur in territorial waters.

[19] See ICC IMB 2014 report, page 20 for warnings about anchorages in Bangladesh and Indonesia. Additionally, Table 3 of the report lists the ports and anchorages which had three or more incidents in 2014.

SOME SELECTED PIRACY DATA

Globally there are plenty of relatively small incidents which occur as opportunities present themselves. The data on these events is probably highly under-reported. Payne cites the estimated 3000 annual attacks on yacht and small boats as an example of this.[20] These are the sort of piracy and armed robbery events that require relatively no equipment, can happen quickly and then the transgressors can be on their way again. Few of them make it into the IMB PRC's data base.[21] Larger attacks may still be relatively simple. The common thread is often a lack of proper governance, as on open waters, in places like Somalia, or when complaisant authorities either look the other way or are themselves involved.

To the individual merchant ship, a pirate attack would likely be considered a low probability, high impact event. Although when conditions are right, such as off the coast of Somalia from 2008-2010, the occurrence of piracy incidents can significantly increase. Even with such an increase, it would be difficult to classify the risk as anything other than low probability. Let us look at some of the specific numbers for some of the busiest shipping lanes from available data. Two separate regions will be considered, East Africa and Southeast Asia.

In generic terms, we know that about 90 percent of the global trade is transported by the international shipping industry. This industry consists of over 50,000 merchant ships sailing under the flags of over 150 nations.[22] The world merchant fleet consists of

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[20] Payne, 191.

[21] Payne, 191.

[22] International Chamber of Shipping website "Shipping and World Trade," (2017). Accessed August 27, 2017, http://www.ics-shipping.org/shipping-facts/shipping-and-world-trade.

many different types of vessels, figure 5-2 shows the composition of the merchant fleet by type of vessel.
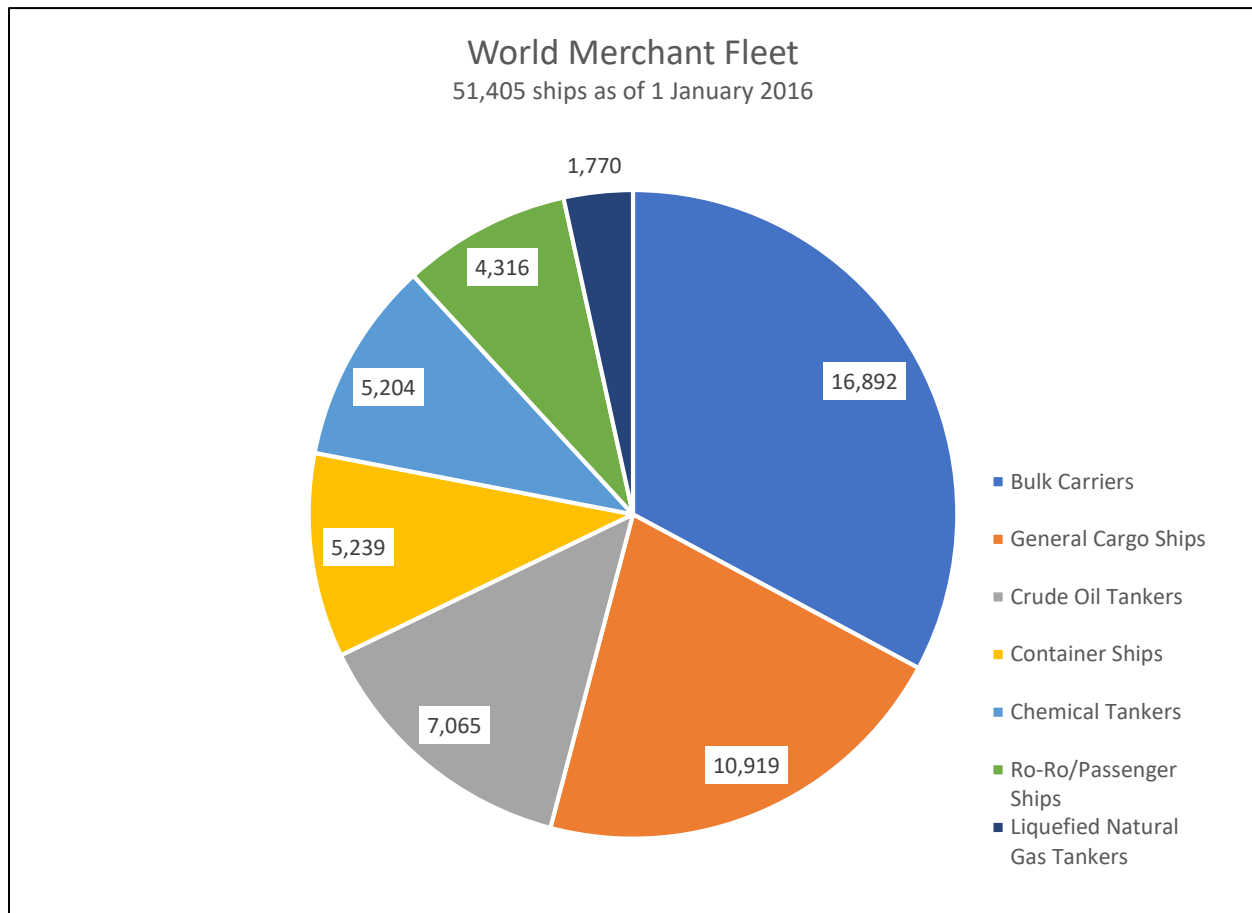
Figure 5-2. World Merchant Fleet as of 1 January 2016[23]

Using data from table 5-1 of the total attacks worldwide for the years 2009-2016 we would get an annual average of just under 320 actual and attempted attacks. Since we know that the higher than normal rate of piracy off the coast of Somalia skews the data, we can consider just five years from 2012 to 2016. This would lower the annual average to

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[23] Compiled from data on the Statista website, "Number of ships in the world merchant fleet as of January 1, 2016, by type." Accessed September 2, 2017, https://www.statista.com/statistics/264024/number-of-merchant-ships-worldwide-by-type/.

just under 250 attacks. While 250 still sounds like a lot of attacks, taken in perspective of

how many ships there are, the risk of an attack is very small. If we want to consider the

piracy that occurred on the high seas we can just look at incidents that occurred for ships

listed as steaming. For 2016, a little more than 25 percent (52 of the 191 total) of the

pirate attacks/ attempted attacks occurred on ships in a steaming status. These events

occurred in just 11 of the 49 regional areas defined in the annual report. However, even

this percentage is likely high because some of the ships were likely steaming in territorial

waters.[24] To get to this level of detail, the geographic location of each incident would need

to be compared with a map delineating territorial waters. Even without making that

distinction, it's reasonable to consider the attacks on the high seas to be rare events,

especially in comparison to the size of the merchant fleet, the number of fishing boats

which are likely to be operating as well as the number of yachts that make up the potential

target pool.

Looking specifically at the Somali piracy issue during the timeframes 2009 to 2011

and 2012-2016 allows for analysis of two very different amounts of piracy. Using an annual

shipping rate of 17,885[25] for 2009 to 2011 we find a piracy a rate of 1.24 percent.[26]

Specifically, for the year 2011, when the rate peaked, the piracy rate was 1.32 percent.[27]

We get a very different result when we consider the last three years. From 2014 to 2016

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[24] To determine where the ship was specifically steaming (in territorial waters or on the high seas), the location data of each individual incident would need to be analyzed. Since there is a scarcity of piracy data to start with this was not done for this work.

[25] This is based on the max capacity of the Suez Canal being 49 ships per day for an annual total of 17,855 (49 x 365).

[26] (222/17,885) x 100 = 1.24.

[27] (236/17,885) x 100 = 1.32.

the annual average number of attacks due to Somali pirates dropped to 4.3, which would

indicate a piracy rate of 0.024 percent.[28]

Table 5-1. Actual and Attempted Attacks for Horn of Africa and Southeast Asia[29]

Region	Location	2009	2010	2011	2012	2013	2014	2015	2016
Horn of Africa									
	Gulf of Aden	117	53	37	13	6	4	0	1
	Red Sea	15	25	39	13	2	4	0	0
	Somalia	80	139	160	49	7	3	0	1
	Sub-total	*212*	*217*	*236*	*75*	*15*	*11*	*0*	*2*
SE Asia									
	Indonesia	15	40	46	81	106	100	108	49
	Malacca Straits	2	2	1	2	1	1	5	0
	Malaysia	16	18	16	12	9	24	13	7
	Singapore Straits	9	3	11	6	9	8	9	2
	Sub-total	*42*	*63*	*74*	*101*	*125*	*133*	*135*	*58*
Rest of the Globe		156	165	129	121	124	101	111	131
TOTAL		**410**	**445**	**439**	**297**	**264**	**245**	**246**	**191**

For this specific geographic area, we see that amount of piracy occurring, which was

attributed to the Somali pirates during the first timeframe, was more than ten times the

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[28] (4.3/17,885) x 100 = 0.024.
[29] This data was compiled from the IMB Annual reports for 2013 and 2016.

rate of the next riskiest area of the globe. During the second timeframe, the rate decreased by a factor of about 50.

In the case of Southeast Asian piracy, looking at the data in terms of two separate timeframes allows for an increased amount of shipping to be accounted for. The amount of shipping passing through the Straits of Malacca was estimated to be 70,000 ships per year in 2010.[30] Following a trend of increasing shipping volume, an all-time high of 79,344 ships was reported in 2014.[31] Using these two pieces of information we can make some estimates for piracy risk in this region. Using the annual piracy data from 2009 to 2011 we find there to have been an average of 60 attacks per year. Combining that with the shipping rate of 70,000 ships per year we estimate a piracy attack risk of less than 0.1 percent.[32] Assuming that the increasing trend in shipping volume continued, it is reasonable to use 80,000 ships per year for the years 2014 to 2016. During this timeframe, there was an average of 109 pirate attacks each year. Those assumption lead to an increased piracy risk of 0.136 percent.[33] It is clear that along with the increase in shipping volume the number of pirate attacks was also increasing.

Given that the reported shipping rate for the Malacca Straits increased by 10,000 transits from the earlier timeframe to the later one, the rate of piracy increased at an even higher rate. Therefore, there was an increase in the percentage of reported piracy

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[30]Rachmat, Budiman, Republic of Indonesia, Ministry of Foreign Affairs, "Security the Straits of Malacca and Singapore: Lessons Learned," Brief at the Asia-Europe Meeting Seminar on Piracy at Sea, Brussels, 4-5 May 2010. Accessed September 26, 2017, http://www.asem8.be/sites/1226.fedimbo.belgium.be/files/presentation_budiman.pdf.

[31] Marcus Hand, "Malacca Strait traffic hits an all time high in 2104, VLCCs and dry bulk lead growth," Seatrade Maritime News (London: Seatrade UBM (UK) Ltd., 27 February 2015). Accessed July 24, 2017, http://www.seatrade-maritime.com/news/asia/malacca-strait-traffic-hits-an-all-time-high-in-2014-vlccs-and-dry-bulk-lead-growth.html.

[32] (60/70,000) x 100 = 0.0857 or 0.1.

[33] (109/80,000) x 100 = 0.136.

incidents. However, if these two rates are rounded, they could both be considered to be approximately 0.1 percent. Looking at just the peak year of 2015 we find a slightly higher a piracy risk of 0.169.[34]

As I said at the beginning of this section, the risk of a pirate attack would be considered a low probability, high impact event for a merchant ship. Since there are some parts of the oceans where the risk of a pirate attack is nearly zero, we can globally bind this risk as zero up to a high of 1.32 percent at the peak of the Somali pirate crisis. In the next chapter, this range of risk will be considered during the development of the model.

The numbers used to do this rough analysis of the probability of a piracy event occurring does not consider if the incident was an actual attack or just an attempt. The data provided by the IMB breaks the numbers down into "actual attacks," which consider the number of boardings and hijackings, and "attempted attacks," further divided to indicate which vessels were fired upon versus a non-violent attempt. Using just the broader categories which indicate if an attack was successful or not from table 5-2 we can calculate the percentage of times an attack is successful. During that ten-year time span the percentage varied from a low of 50 percent in 2011 (this was at the peak of the Somali pirate crisis when the incentive to report any pirate activity was likely increased) to a high of 89 percent in 2015. If we consider all of the annual percentages we get an average 70 percent success rate.

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[34] (135/80,000) x 100 = 0.169.

Table 5-2. Actual and Attempted Pirate Attacks 2007-2016[35]

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
ACTUAL ATTACKS	187	200	202	249	221	201	214	204	218	157
ATTEMPTED ATTACKS	76	93	204	196	218	95	50	41	28	34
TOTAL ATTACKS	263	293	406	445	439	296	264	245	246	191
Percent successful	71	68	50	56	50	68	81	83	89	82

A SPECTRUM OF PIRACY

Not all piracy is created equal. There are different levels of piracy in both

sophistication and motivation. Phillip Gosse claims; "In all the seas of the world and in all

times piracy has passed through certain well-defined cycles."[36] He describes the cycle as

beginning with only a few individuals of poor coastal areas banding together to attack the

weakest merchant ships. As the pirate activity becomes more organized, bigger pirate

gangs emerge. The smaller groups either join up or get driven out of business. The

greatest of pirate organizations pose a threat to all shipping, and no ship is safe from pirate

attack.

While each incidence of piracy may not fit neatly into a category, it is useful to at

least consider what I propose as a spectrum of piracy operations. This is an expansion of

the piracy cycle that Grosse describes. On one end of the spectrum is simple piracy. This is

low-level activity, that occurs independently when an opportunity presents itself. It can be

thought of as "come as you are" piracy since it utilizes the boat available with the tools on

hand. This is perhaps what Dian Murray refers to as "petty piracy" as referenced in

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[35] This data was compiled from the IMB Annual Reports from 2007-2016.
[36] Gosse, 1.

Chapter 2. It might be seasonal, engaged in when fishing is not productive. As we move along the spectrum, piracy becomes more sophisticated, either in the planning/coordination of the activity or the platform and tools/weapons employed. Cooperative piracy would involve more than one pirate boat working together. This could be a small group or a large network, sharing information and targets. It would still be relatively low-level piracy, occurring from the shore – so with a limited range of operations. Advanced cooperative piracy would involve more sophisticated tactics, perhaps the employment of mother-ships to extend the range of operations; more sophisticated coordination, such that larger targets are lucrative because the network includes a means for dealing with the complexity presented by these targets, including connections to illicit markets for trading the captured cargo.

Simple Piracy	Cooperative Piracy	Advanced Cooperative Piracy	State Sanctioned Piracy (privateers)	Organized Crime Piracy	State Sponsored Piracy (Privateers)

Figure 5-3. Spectrum of Piracy Operations

On the other end of the spectrum are the far more complex forms of piracy. State sanctioned piracy would be piracy that occurs with the knowledge of the state, or at least some corrupt state officials. Here I put "privateers," but with a lower case "p" as historically this would have been the privateers that operated with a wide range of freedom. The political goals of this form of piracy are less well defined. Today these pirates are obviously not called privateers and the international community considers this to be

piracy. The primary aim is to make a profit. Organized crime piracy is the most complex in terms of a network. It can consist of a large multinational organization with a sophisticated ability to leverage illicit markets. These organizations are involved with the cartels that smuggle drugs, weapons and people. Last on my spectrum is state sponsored piracy. Here I label "Privateers" with a capital "P" as historically these would have been the privateers who engaged in naval warfare. This piracy was engaged in for political purposes – although that is not to say that there was no monetary motivation. Today, this piracy is at the nexus of terrorism.

Certainly, this spectrum greatly simplifies a complicated issue. It is not perfect, and in fact the first criticisms come from myself as I struggled, especially with the right side of the spectrum. Did I place organized crime in the right position or should that perhaps be on the far-right side, since its multinational character and extended range of operations makes it the most sophisticated? But I decided to put state sponsored piracy on the far right because it is the nexus with terrorism. As discussed in Chapter 4, the division between piracy and terrorism is not always clear, particularly because it is the motivation for the action which makes the distinction between the two and often insight into the that motivation is lacking. However, I did try to add a bit more nuance into the issue with the division between what I call state sanctioned and state sponsored piracy.

To my way of thinking, state sanctioned piracy includes the piracy engaged in by naval personal. Here the very people who are tasked to police the piracy are themselves implicit in the activity. The state does not, in fact may not be able, to provide these mariners a living wage and so they supplement their income with piracy. This sort of

activity has been most notable in places like Indonesia, China, Iran and Nigeria.[37] The

activity could also involve port security and customs officials, although then the activity is

more likely to occur in the port and be more broadly defined as corruption.

As already mentioned, some piracy does not fit neatly into a specific category.

Where do we place the Somali piracy which was occurring in the dysfunctional

environment left by civil war? Some of this piracy perhaps began on the lower end of the

spectrum and then advanced to the right as it grew in scope and sophistication. At its

height, when it was highly organized and controlled by warlords, perhaps we would place

it between the state sanctioned (although the presence of a functional state was lacking)

and organized crime piracy. As well there were those who expressed concern that perhaps

this piracy was actually on the other side between organized crime and state sponsored

piracy; that perhaps some of the money was being funneled to terrorist groups. So, while

the proposed spectrum is not without fault, it does provide a tool for discussing the range

of activity which we label as piracy.

It is also important to remember that there are connections between the different

levels of piracy. Murphy says there are links between the lowest level of piracy, what he

calls "common piracy," and the highest level, what he calls "organized piracy;" and links

between "attacks on local fishermen and local boats and attacks on international traffic."[38]

Despite not knowing what motivates these linkages and how they are maintained, it is

important to recognize their existence. Left unchecked, even common piracy can grow in

scope. Murphy quotes Samuel Menefee: "attacks on fishing boats, if not checked, lead in

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[37] Murphy, 1983, 125.
[38] Murphy, 1983, 127.

time to attacks on supertankers."[39] Developing a model of piracy that takes various

sociological variables into consideration has the potential to help us understand these

connections. To do that, sociological data must be considered.

SOCIOLOGICAL DATA

It would be wonderful if an elementary data analysis could be conducted to

determine potential relationships between incidents of piracy and various socio-economic

and socio-political variables. However, because the piracy data is so limited this traditional

method for determining correlation between variables is not possible. Statistical analysis

will not tell us the reasons for maritime piracy.

Murphy states the reason for piracy is that "Piracy is a low-risk, criminal activity

that pays well."[40] He continues by saying "It occurs for one over-riding reason:

opportunity."[41] Yet that over-riding reason requires a maritime environment and therefore

the problem is geographically specific. Maritime piracy is not equally common in all

maritime environments so there must be more to the issue. John Burnett says that poverty

is the primary motivator for piracy.[42] Murphy finds this explanation too simplistic, but he

does agree that economic dislocation contributes to the issue.[43]

Opportunity also requires a permissive legal environment with a lack of sufficient

security. When a society is formed there are norms for acceptable behavior. As the society

becomes more developed, these behavioral norms become codified into rules and laws.

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[39] Murphy, 1983, 128. Citing Samual Pyeatt Menefee, "Under-reporting of the Problems of Maritime Piracy
and Terrorism," 157.
[40] Murphy, 1983, 25.
[41] Murphy, 1983, 25.
[42] Burnett, 117.
[43] Murphy, 1983, 25-26.

Each society develops its own means for ensuring that these rules are followed. It may be that justice is in the hands of tribal elders, or in more sophisticated society departments of justice are created to enforce the laws and provide punishment for those who break the laws. Thus, there are a few scenarios that allow for piracy. The first is a permissive legal environment that turns a blind eye on the issue for cultural or other reasons. The other is a state with an inadequate security infrastructure which cannot enforce the laws. It is also possible for there to be a combination of these situations.

As mentioned in Chapter 3, the Risk Terrain Model that Caplan, Moreto and Kennedy created used the Failed State Index to create one of the risk layers of their model. A better understanding of this index is needed to appreciate what that layer in their model represented. The Failed State Index was an annual report published in the United States by the think tank Fund for Peace and Foreign Policy magazine. This index has been published since 2005. In 2014, the name of index was changed to the Fragile State Index (FSI).

It is reasonable to think that fragile coastal states provide a more favorable environment for maritime piracy to flourish. Fragile states are less able to provide for the wellbeing of their citizens and are not able to impose the rule of law upon those who engage in illegal activities. Both factors; lack of opportunity and lack of repercussion for bad actors, encourage illegal activity. Given the right environment and the skills necessary to go to sea, a pull toward piracy will develop. So, let's look at what the Fragile State index is specifically comprised of.

The FSI ranks 178 sovereign states who are members of the United Nations "based on their levels of stability and the pressures they face."[44] Each state is ranked from 0 to 120 with 0 indicating those which are most stable and 120 indicating the least stable. When the scores are compared from year to year a lower score for an individual state indicates improvement, while a higher score indicates worsening conditions. The scores are assigned using the Conflict Assessment System Tool (CAST) which is a proprietary analytical platform based on "comprehensive social science methodology,"[45] Each year millions of documents are analyzed and data from three primary sources is triangulated to determine the state scores, which are based on twelve key social, economic and political indicators as well as greater than 100 sub-indicators. Before assigning the final scores, the ratings are subjected to critical reviews. As the Fund for Peace states: "No framework, methodology, or Index is perfect;"[46] however, the index offers a standardized approach which allows for comparison of annual results.

C.S.C. Sekhar writes that "A state is defined as "failed" or "fragile" when it is unable to perform its core functions and displays vulnerability in the social, political and economic domains."[47] The Fund for Peace defines a fragile state as having certain attributes which manifest themselves in various ways. The most common state fragility attributes may include:

Loss of physical control of its territory/monopoly on the legitimate use of force;

Erosion of legitimate authority to make collective decisions;

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[44] Messner, 3. This issue comprises data collected between January 1, 2015 and December 31, 2015. This is the eleventh edition of the annual Index.
[45] Messner, 3.
[46] FSI website, "Reviews and Studies of the CAST Methodology and Fragile State Index." Accessed September 22, 2016, http://fsi.fundforpeace.org/reviews.
[47] Sekhar, 263.

Inability to provide reasonable public services;

Inability to interact with other states as a full member of the international community.[48]

Each of the twelve indicators has a value from 0-10. These values are then added to get the fragile state index. States are then placed into four categories based on this score. Those with a composite score equal to or greater than 90 are given a red status and placed in the "Alert" category; the orange/"Warning" category is composed of states with scores between 60-89; the yellow/"Moderate" category is for states with scores between 30-59; and states with scores less than 30 are green/"Sustainable." While the raw data that these scores are based on are not available for review,[49] the index does provide the individual values for each of the twelve indicators.

Caplan, Moreto and Kennedy's Risk Terrain Model demonstrated that there may be a connection between coastal states with high Failed State Index values and rates of piracy. However, the overall Fragile State Index score is too broad, covering too many categories, to draw out specific causal relationships. Yet, the overall index scores are compiled by adding up the individual indicator scores. This allows for the overall score to be deconstructed and individual indicators to be looked at in more detail.

The twelve indicators are organized into three categories of indicators; social, economic, and political. The Fragile State Index website provides details for each of the

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[48] "Fund of Peace Fragile State Index Frequently Asked Questions." Accessed September 22, 2016, http://fsi.fundforpeace.org/faq-06-state-fragility.

[49] "The content analysis component of the Fragile States Index draws upon raw data from over 40 million news articles and reports every year. As this content is the property of the copyright holders and is not the Fund for Peace's to share. Further, as a practical matter, the content analysis is not replicable without the methodology and the software (including the algorithm and Boolean search terms) which is a proprietary framework that we do not make publicly available." Cited from: "Fund of Peace Fragile State Index Frequently Asked Questions." Accessed September 22, 2016, http://fsi.fundforpeace.org/faq-10-public-access.

indicators. In brief, the four social indicators are: Demographic Pressures, Refugees and IDPs, Group Grievance and Human Flight and Brain Drain. There are just two economic indicators: Uneven Economic Development and Poverty and Economic Decline. Lastly, there are six political indicators: State Legitimacy, Public Services, Human Rights and Rule of Law, Security Apparatus, Factionalized Elites and External Intervention.

If available opportunities are truly critical to the decision to pirate or not pirate, the indicator that would be most useful for understanding this issue would be Poverty and Economic Decline (ECO). This is described as straining "the ability of the state to provide for its citizens if they cannot provide for themselves."[50] When this type of situation exists it "can create friction between the *haves* and the *have-nots*."[51] The indicator consists of measures of multiple items including unemployment and youth employment. These are items that are directly applicable to individuals being able to provide for themselves and their families.

Along with the ECO indicator, the Demographic Pressure Indicator (DP) would provide greater insight to the environmental conditions on the land. This indicator takes into account issues that make it hard for the government to protect its citizens or which indicate a lack or capacity to take care of the citizens. The Issues considered by this indicator are listed as: natural disasters, disease, environment, pollution, food scarcity, malnutrition, water scarcity, population growth, youth bulge and mortality.[52] Many of these items could contribute to a situation where an individual is put into a desperate situation, such as a loss of livelihood, and might encourage them to take the risk of piracy.

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[50] FSI Indicators website.
[51] FSI Indicators website.
[52] FSI Indicators website.

In addition to looking at the economic opportunities and the environmental conditions, it is important to consider the capabilities of the government. The two political indicators which are most useful for this are State Legitimacy (SL) and Security Apparatus (SEC). State Legitimacy is concerned with corruption and the lack of representation in the government. Among the many issues this indicator considers are government effectiveness, corruption, and illicit economy. All of these could contribute to enabling a piracy problem. The Security Apparatus indicator considers to what effect the state has a monopoly on the use of legitimate force. Included in the issues measured by this indicator are items like internal conflict, small arms proliferation, rebel activity and militancy. These sorts of conditions might contribute to some of the more violent forms of piracy.

While specific sociological data correlated to incidences of piracy would be ideal, this is not feasible due to the lack of adequate piracy data, especially when only the incidences occurring at sea are considered. Because the data available is insufficient for statistical modelling, an ABM can be developed to provide us further insight of the issue. By incorporating the indicators discussed above into an ABM, the relationship between these issues and the problem of piracy can be explored. An ABM is particularly suited to this purpose, as the emergent behavior of the agents can provide new insight to the dynamic relationships between the variables.

By using the data from the Fragile State Index, a somewhat consistent mode of consideration can be made for these factors across geographic regions. This brings us full circle to the discussion of piracy models in Chapter 3, and more specifically to what is lacking in all the models. Each of the modeling efforts discussed focused on the water side of the problem without considering what the

root causes might be and how the variables ashore impact the problem at sea. So,

let us return to the system diagram proposed in Chapter 1, figure 1-1, with four of

the FSI indicators acting on the land. Figure 5-4 show the same relationship of

system components without the verbiage.
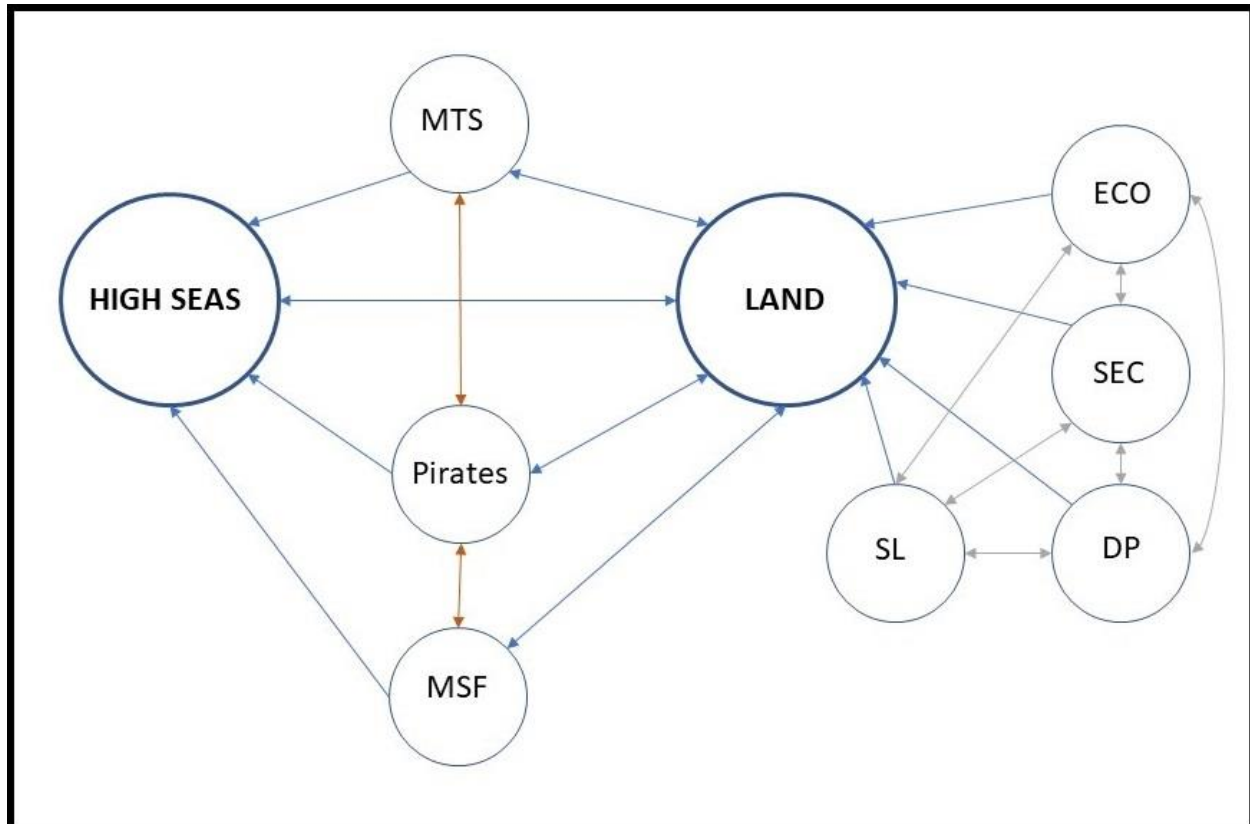
Figure 5-4. System Diagram of High Seas Land interface

Despite being a simplified depiction of the high seas land interface, the

complexity of the issue is clear. There are multiple variables that not only act on the

land and through the land to the other nodes, but they also impact each other.

Before we can begin to model this issue, we need to simplify the system further until

we are left with only the elements essential to beginning our exploration of the

issue. Figure 5-5 provides a simplified system diagram. Here the diagram has been

changed to only include the core elements necessary to create a model of the issue

that we want to understand better. The model will focus on the interface between

the land and water, represented by the high seas. The elements required for this are

the pirates and the ships they target, as well as the opportunity that drives their

decision to pirate or not. The ECO variable was chosen to represent the variables

that impact the land and therefore piracy.
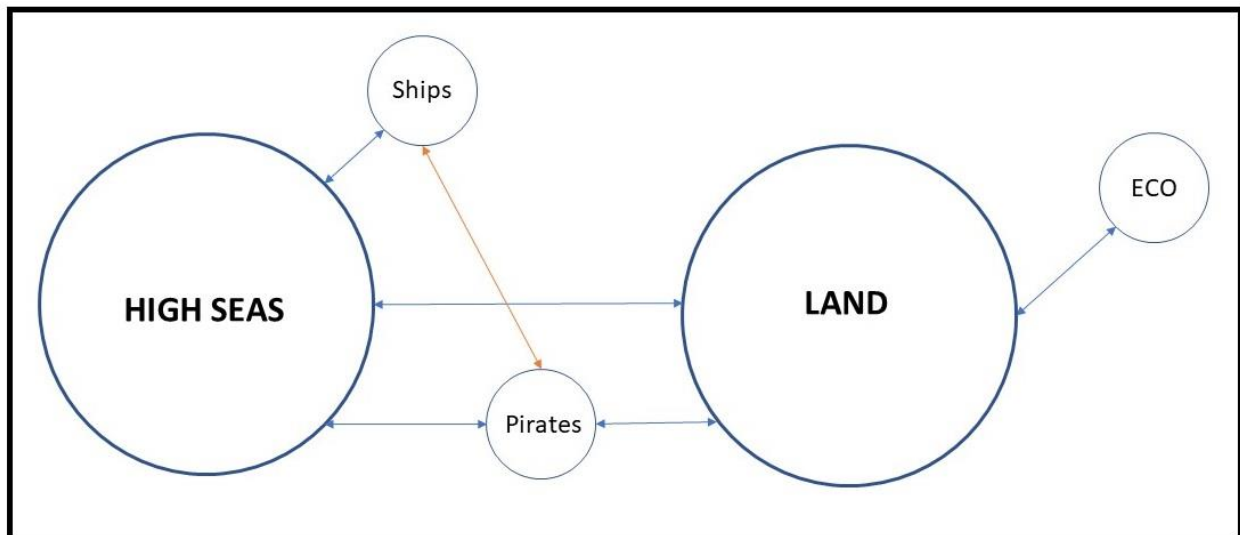
Figure 5-5. Simple System Diagram of High Seas Land interface

The next chapter will discuss the development of an ABM for the interface of

the land variables with the waterborne piracy activity.

CHAPTER 6

PIRACY OPPORTUNITY MODEL

This chapter focuses on the design, development, validation and to the extent possible, the verification of the Piracy Opportunity Model. This model explores how conditions on land impact maritime piracy. It incorporates a socio-economic variable into a basic piracy risk model. After a brief introductory section, the ODD protocol[1] is applied to the model. The actual code for the latest version of the model is provided in Appendix A, while Appendix B provides a commented version of the code that details its evolution from earlier versions of the model. The chapter concludes with a brief discussion of model verification.

A BRIEF REVIEW OF WHY A NEW MODEL IS NEEDED

The biggest reason for a model of piracy which includes sociological variables is that the data available on the issue is simply insufficient to for us to really understand the issue. For this reason, an ABM is best suited to the problem. Agent-based models consider the actions and interactions of autonomous agents who follow simple rules of behavior. The models often result in emergent behaviors that develop as a result of the "agents" interacting with each other and their environment. In this manner, an ABM can help us find order in the apparent disorder of a complex system, or at least provide us new insights into understanding that system.

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[1] The ODD protocol is a standardized protocol for describing agent-based models. ODD stands for Overview, Design Concepts, and Details. The protocol was proposed by Volker Grimm et al in "A standard protocol for describing individual-based and agent-based models," *Ecological Modeling* 198 (2006) 115-126.

We often model to be able to make predictions; however sometimes we model even when the model might not provide useful predictions as a way to better understand an issue. In his article "Why Model?" Joshua M. Epstein discusses many reasons to model other than for prediction.[2] Here I will discuss just a few of them. The first reason is to explain. A model which explains how or why a phenomenon is happening can help us to better understand an issue. Such a model can also guide future data collection. Since we do not have adequate data to fully understand the dynamics occurring in maritime piracy this is important for future work.

While maritime piracy is a global issue, there are regional differences in both the operational tactics of the pirates and those who respond to piracy. Most of the models discussed in Chapter 3 were designed for a particular geographic area, primarily the Gulf of Aden and the waters off the coast of Somalia. For the most part, these models used an inductive approach to create a high-fidelity model, relying on lots of data about the maritime environment and using the available data on past piracy events. With this level of detail, they model specific geographic regions. Thus, there is a need for a model that is not geographically limited. Additionally, most of the previously discussed models are very heavy,[3] requiring massive amounts of information. A light model, which allows us to concentrate on what is occurring in a limited amount of land/sea-space, in a more generic manner, would provide greater utility. The objective of this work is to distill maritime piracy down to a form simple enough to portray generic phenomena regardless of geographic location yet robust enough to provide insight into the associated issues, especially the sociological variables which have been lacking in the other models. For this,

[2] Epstein, 2008, 1.9.
[3] See Axelrod.

a more deductive approach is necessary. A highly abstract model allows generalization of the variables outside the focus of the model. Additionally, as Epstein says, simple models can be "illuminating abstractions," which can be "invaluable without being 'right'."[4]

Such a model could also provide a foundation for a more fully developed model, which would allow mariners to better determine their individual risk depending on the environment they are planning to operate in. Therefore, this work begins with a simplified prototype. Ultimately, the model could evolve to the extent that it will provide a risk assessment based on the socio-economic and socio-political variables in the vicinity of the merchant ship's operating area, the maritime security readiness of the vessel, and the presence or lack of maritime security forces. Ideally, the model would also provide insight into how the other parts of the "system" may impact the vessel's voyage. Only by understanding the whole picture, to include what motivates the pirates, can piracy risk truly be assessed. This information would be valuable to yacht owners, ships, shipping companies, insurance companies, and maritime security providers as well as policy makers.

This work takes the first steps toward exploring the value of such a model. As already stated, to increase the utility of a model, it must be as simple as possible. Models which are heavy with details become limited to the application of situations for which the details pertain. The challenge is to build a parsimonious[5] and simple model that nevertheless captures the essence of piracy. For this reason, the initial NetLogo[6] model

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[4] Epstein, 2008, 1.12.

[5] A parsimonious model is a model that accomplishes a desired level of explanation or prediction with as few predictor variables as possible.

[6] NetLogo is a multi-agent programmable modeling environment for simulating natural and social phenomena. It is open source code which was authored by Uri Wilensky and has been in continuous development since 1999 at the Center for Connected Learning and Computer-Based Modeling (CCL). NetLogo

developed here can be thought of as a prototype. In this model, the issue is looked at in a

very parsimonious manner with focus on an overarching sociological variable that

represents opportunity and its effect on piracy. The ECO indicator from the FSI is used to

portray this variable. The range of the economic opportunity is defined by the ECO rating

of the state. Since everyone has a different experience of economic opportunity, assigning

random values to the land within that range, can represent the different experience of

every individual. The ECO rating for a particular state can be found in the FSI. This

information is available for the current report year as well as past years. While we do not

have data for specific individuals, conceptually we can still simulate the variation in

opportunity between individuals. By allowing the ECO value to be set on the model

interface across the full range of values found in the FSI, the model can also represent the

median economic opportunity available to a society or within a state.

Also in keeping with the need to start somewhere, this model focuses on the level of

piracy that is occurring on the left side of the piracy spectrum that I proposed in Chapter 5.

This is individual piracy which does not require coordination between multiple pirate

boats. Future work could provide extensions of the model which would represent other

forms of piracy on the spectrum.

Although this model is simple, it can provide insight into the type of interactive

dynamics that exists between the economic variation of the environment and the decision

to pirate. It can further illuminate the relationship of this changing environment to

changes in the value of pirating. The question is: Can the model reproduce patterns of

maritime piracy related to the socio-economic conditions on land which we observe with

Accessed January 8, 2016, https://ccl.northwestern.edu/netlogo/. The Piracy Opportunity Model is written
in NetLogo version 5.3.1.

the limited real-world data that is available? From this we can ask if it is more effective to increase humanitarian efforts on land (improving the economic conditions) or to expend the limited resources on added maritime security.

The focus of the model is a generic small area with adjustable variables to simulate regional differences.   The land and sea portions of the model interact in a dynamic manner, providing for a constantly changing push and pull from one side to the other. When economic opportunities on land are poor, there is a push toward piracy. However, the potential risk and pay-off for pirating activity is constantly assessed; it continually changes with pirating competition and the pirates' successes and failures. When the risk is low and the pay-off is high, there is a pull toward pirating. Conversely, when the risk increases and/or the pay-off decreases the pull is reduced. The assumptions made to reach this basic level of simplicity are described below.

MODEL OVERVIEW (THE "O" IN ODD)

Purpose

The purpose of this model is to provide insights into how the economic opportunity on the land affects an individual's decision to pirate or not. In particular, the model examines the relationship between economic opportunities on land with changing reward rates for maritime piracy. This model also serves as a prototype for a more complex model which would include additional sociological variables.

State Variables and Scales

The model comprises two interacting environments; the land and the sea. There are three breeds of agents that exist within the model: People (or potential pirates), Pirates (represented as pirate skiffs), and Ships (merchant ships).[7]   The agents' world consists of a generic coastal area that is 200 patches wide and 100 patches from top to bottom. The top area, representing water, is further defined by shipping lanes and shallower coastal zones. The bottom section represents land, including a single port area. There are no specific dimensions to the area being modeled. Time is represented by model ticks and distance is relative and only relevant on the water where agent speed is adjustable. Finally, the model is not necessarily intended to represent a realistic amount of pirate attacks since those are relatively rare events.[8]

Process Overview and Scheduling

The model proceeds in time steps (ticks) which have no specific equivalency but rather allow for relative interactions. Within each time-step people assess their opportunities and decide to pirate or not; ships transit the shipping lanes; and if present, skiffs engage in piracy operations.

More specifically, people identify themselves as pirate or not-pirate. If they are not a pirate, they roam on land by randomly moving and evaluating their economic

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[7] The initial concept for the model included a fourth breed called Units which represented security units. To simplify the model these were deleted based on the assumption that the presence of security units would increase pirate risk and decrease successful pirate attacks and the lack of them would decrease pirate risk and increase their success but the basic decision process to pirate or not to pirate would remain the same.
[8] As the purpose for the model is to explore the relationship between the variables in a generic setting comparison to real-world quantities of piracy is problematic. Future evolutions of the model could move in that direction by scaling the model parameters to represent specific distances. For a specific example of model calibration see section 4 of Marchione, Johnson and Wilson.

opportunity. They compare the utility of pirating to their economic opportunity and decide to pirate or not. If they are a pirate, they move in the direction of the port, but continue to evaluate their economic opportunities. If their economic opportunity exceeds the utility of pirating they will change their mind and return to roaming. Once they reach the port, pirates no longer assess their opportunities. Instead, they move about the port until an adequate number of pirates are available to man a skiff. Once assigned to a skiff they pirate until they return from an unsuccessful pirating run, at which time they return to roaming on land as a not-pirate.

Ships transit the shipping lane at half of their maximum speed. They constantly check for skiffs in their vicinity. If there is a skiff, they increase their speed to the max allowed. If captured, they change their heading and speed to follow their captor. When a ship reaches the edge of the model, or the port, they are replaced by another ship. Pirate skiffs operate in one of seven operational modes; transit from the port to a patrol area, transit back to port in a low fuel status, loiter in the patrol area, chase, return to port with captured ship, return to port after an unsuccessful attack, and wait in the port to re-sail.

MODEL DESIGN CONCEPTS (THE FIRST "D" IN ODD)

Emergence

The pull and push of piracy emerges as the model simulation runs. A relatively high expected reward will pull people toward piracy because the utility of pirating will more often be greater than their economic opportunity on land. Since the number of target ships is limited, when a lot of people decide to pirate there will be far more pirates than targets. The probability of success will decrease and the expected reward will trend downward.

This will push people back to roaming. The point during a model-run at which this phenomenon tends to occur is dependent on the initial reward level and the economic environment.

Adaptation

People adapt to poor economic opportunity by pirating. When unsuccessful at pirating, they adapt by returning to roaming.

Fitness

Fitness seeking is modeled explicitly. People calculate their fitness for economic opportunity by comparing what they have experienced on land with what they may find by pirating.

Prediction

People predict their future economic opportunity by averaging the value of the most recent ten moves. They predict the value of pirating by using a utility equation.

Sensing

People know what the expected reward of pirating is.

Interactions

People continuously interact with their environment to assess their economic opportunity. The utility function that they use is updated based on the successes and

failures of other people. However, the people do not directly interact with each other. For people to actually pirate, they must join up with other pirates and man a skiff; at this point the pirates on a skiff act as one entity, there is no interaction between pirates. Skiffs and ships interact. Ships will speed up when a skiff in detected. When a skiff detects an available target ship, it will chase the ship and attack.

Stochasticity

At initialization, economic opportunity values are randomly distributed across the land based on the setting of the ECO range. The ship reward value of individual ships is randomly assigned using a normal distribution around the model reward setting. Each ship is randomly assigned to an east or west passage of the shipping lane. Each skiff is randomly assigned a heading that will allow them to transit to the shipping lanes. When people roam on land, their movement is random. Finally, the success of each skiff attack on a ship is randomly determined based on a thirty percent chance that the ship will deter/repel the attack. This value is based on the average 70 percent success rate of pirate attacks as discussed in Chapter 5 (table 5-2).

Collectives

People are grouped into two categories, pirates or not-pirates.

Observations

For experimentation, we record people who decide to pirate, successful ship transits, skiff sorties, captured ships, pirating utility, pirating success, total reward,

expected reward, the average skiff run time and the probability of successful piracy. Time
plots of expected-reward, probability of capture (p-capture), p-capture times expected-
reward, number of people pirating, and pirating utility are created while the model
simulation runs, as well as a histogram of pirate success rates.

MODEL DETAILS (THE SECOND "D" IN ODD)

Model Pseudo Code

Initialization:

    Create 100 People and distribute on land

        Endow each with a decision list

        Seed list with 10 random opportunity values

    Create 3 Ships and place them in the shipping lanes

        Endow each with random reward value

        Coin flip determines east or west heading

Execution:

    Loop forever:

        Each person

            Randomly roams on land

            Adds eco-op value to start of decision list

            Drops oldest eco-op value from list

            Assesses opportunity value

            Compares opportunity to pirating utility

            Decides to pirate or not

        Each pirate:

            Heads toward port

            If opportunity exceeds pirating utility, returns to roaming

            At the port - mills about until manning a skiff

            Hides when assigned to a skiff

Figure 6-1. Pseudo Code for the Piracy Opportunity Model

Input (environmental conditions)

Prior to model initialization the ECO value (1-10) and the amount of reward (0-1,000,000) may be selected with a slider on the model interface. A visual display of the economic opportunity values of land can be turned on or off.

Initialization

During model initialization, the global values are set, the land and water patches are established, the people and ships are set-up and the ticks are reset to zero. Table 6-1 lists the global variables and their initial values.

Table 6-1. Piracy Opportunity Model Global Variables

Variable	Initial Value	Comments
Sorties	0	
Victory-party	50	Time/ticks in-port for skiffs following a capture
Successful-transits	0	
Captured-ships	[ ]	Empty list
Total-rewards	Reward*1000	Artificial reward history
Expected-reward	Reward	Seed value - set by user on model interface
Minimum-manning	3	Required skiff crew size
Number-of-pirates	[ ]	Empty list
P-capture	0.1	Piracy-Probability
Total-p-capture	0.1	Sum of p-capture values for each tick
Current-p-capture	0.1	Total-p-capture divided by ticks
Total-SRT	170000	Artificial total (SRT seed value*1000)
Average-SRT	170	Seed value determined by earlier model runs

The model world is 200x100 parches with the origin in the center. Patch size is 6. Wrapping is turned off. The world is divided in half horizontally with water on top and land below. Water is further delineated as shallow coastal, territorial and international

shipping lanes. This is represented by graduated shades of blue. Land patches are set on

the bottom half of the model. A subset of the land is designated as the port around the

origin of the model. Each patch of the land environment is randomly assigned an economic

opportunity value during the set-up of the model. These values are determined by a slider

on the model interface where the user can adjust the ECO level. Possible ECO levels range

from one to ten and correspond to the Poverty and Economic Decline (ECO) economic

indicator of the FSI, thus the lower the ECO level the better the economic opportunity. The

ECO level set on the interface translates to individual values of opportunity on each of the

patches of land. This is done randomly during the model set-up using an "eco-op" variable

which is set with the following equation: eco-op = (100 – (ECO * random 10)). Thus, when

ECO is set to one, which would represent the best economic indicator from the FSI, the

economic opportunity values randomly assigned to the land patches will vary from 91 to

100. Conversely, when ECO is set to 10, the worst possible economic indicator, the

economic opportunity values randomly assigned to the land patches will vary from 10 to

100. These values may be visualized by turning on the "Economic-Opportunity" switch on

the model interface; this changes the color of the land patches from brown to variations of

brown depending on the eco-op value. Every time the model is set-up, these patch values

are randomly assigned. Lastly, the economic opportunity value for the port patches are all

reset to 100. People only use port economic opportunity values when they return from an

unsuccessful pirate run. This ensures the first few values added to their opportunity list

equal 100. It encourages them to continue to roam and prevents them from immediately

deciding to pirate again, simulating the relative optimism an individual might have about

the opportunity on land after not succeeding at piracy.

One hundred people are created. This population level was arbitrarily chosen. Each has a Boolean variable that determines if they are a pirate or not. It is initially set to false. They have another Boolean variable that indicates if they are assigned to a pirate skiff, this is only used when they are a pirate and is initially set to false. Their "pirate-success" variable is a list initially set to zero. Finally, their decision list, which tracks the ten most recent economic opportunities they encounter when roaming is artificially seeded with ten values using the same equation that assigns the economic opportunity values to the land patches.

Merchant shipping traffic is simply represented by a constant presence of ships (pirate targets). Three ships are created during model initialization. (This quantity of ships was arbitrarily determined and remains constant throughout the simulation and represents shipping lanes with constant ship traffic.) Their maximum speed is set to 2 while their transit speed is set to half of maximum speed. They have two Boolean variables. The first determines if they have completed a successful transit, this is set to false. The other indicates if they have been captured by a pirate skiff, this is also set to false. The variable "captor" is set to *nobody*. Their payoff variable is randomly assigned using a normal distribution of the "Reward" set on the model interface.[9] Each ship is placed somewhat randomly in the shipping lanes with either an east or west heading.

The simulation begins with zero pirating. P-capture is set to 0.1, which is equivalent to a 10 percent probability.[10] This is the piracy probability, or the probability that a pirate

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[9] [payoff = random-normal Reward 30000] This assigns a random value using the normal distribution with a mean of "Reward" (as selected on the model interface) and a standard deviation of 30000.

[10] Lacking real world data to determine this value, it was derived during the model development. See Chapter 7, The Issue of Model Initiation.

skiff will be successful. Once a ship is captured this value becomes dynamic and adjusts

depending on the future success and failure of the skiffs.

Three ships are randomly placed in the shipping lane and 100 people are randomly

placed on the land. There are no pirate skiffs. Each ship has a reward value that reflects a

normal distribution of the reward value set on the model interface. The reward value on

the model interface is also used to provide a seed value to the variable "total-rewards."

This is done by initially setting total-rewards to 1000 times the Reward value set. Each

time a person decides on the utility of pirating they use the value "expected reward" to

determine the current average value of a target ship. Initially, the expected-reward is equal

to the total-reward divided by 1000, or the value set on the interface. By creating an

artificial history of 1000 rewards, the calculation of expected rewards is less sensitive to

the addition of captured ship rewards. (Once a ship is actually captured the total reward is

increased by the actual reward value of the captured ship and expected-reward is

determined by dividing total-reward by the number of captured ships plus 1000. Expected

reward is continuously updated throughout the simulation, which makes the pirating

utility value dynamic after the first successful ship capture.)

SUBMODELS

To a certain extent, the model is two models in one. The lower half of the model

considers the opportunity available to people on land.   This half of the model uses a

deductive approach that models the economic opportunity in a highly abstract manner.

The upper half represents water and models piracy operations in a shipping lane.   This half

of the model uses a more inductive approach by using the work already done in some of the

other piracy models, but in a simplified manner. Figure 6-2 shows a typical initial setup for

this two-part model.

Using a "two models in one" approach further distinguishes this model from other

existing piracy models. The decision to do this was arrived at because the water side of the

issue has already received a considerable amount of attention. As discussed in Chapter 3,

multiple water models of piracy have been developed. The piece that is lacking is the

dynamics occurring on land that either encourage or discourage maritime piracy.

Therefore, the land side offers a greater heuristic value by remaining as simple and

transparent as possible, yet is able to leverage the more developed models of maritime

piracy with a heavier model of what occurs on the water. The focus of this model is shifted

from the details of piracy at sea, to what motivates an individual to become a pirate.
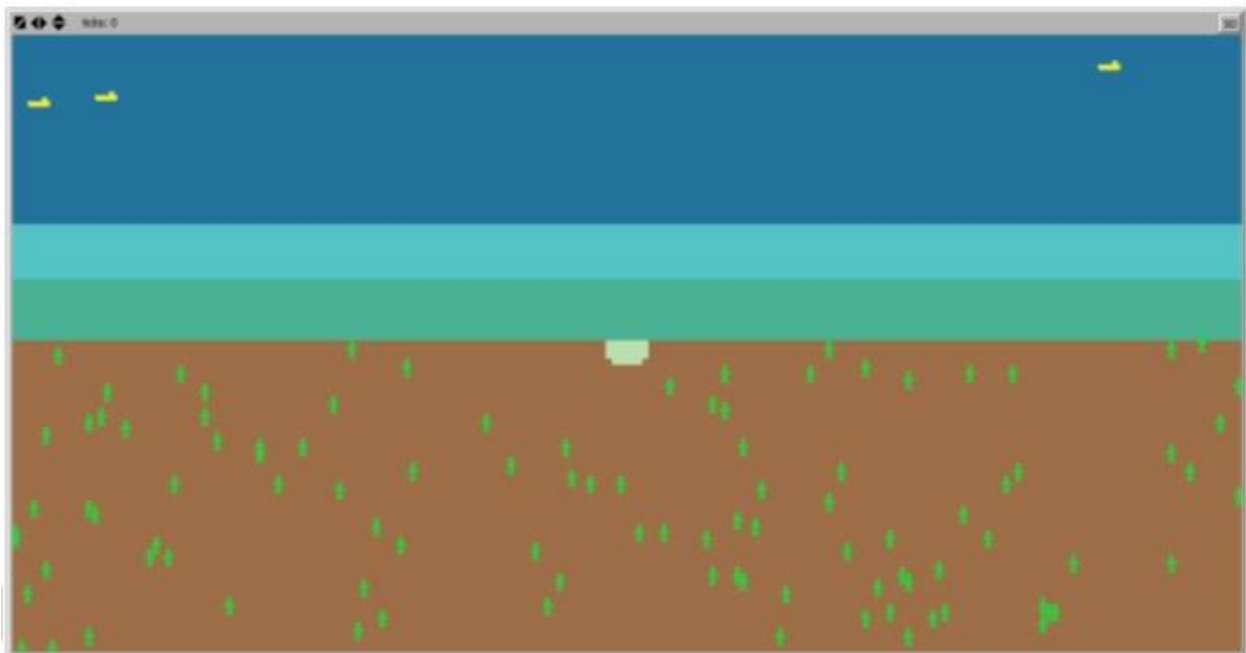

Figure 6-2. Typical initial setup of the Piracy Opportunity Model

The main loop of the model consists of five steps. First the people move. Next the ships move. After that, the skiffs move. With all the movements completed, the piracy probability is updated (p-capture related values). Finally, a time step or *tick* is taken. Movement of people occurs in the land portion of the model while movement of ships and skiffs primarily occur in the water portion. The calculation of intercept probability and advancement of time apply to the entire model.

Land Model

The land portion of the model is similar to other agent-based models such as Uri Wilensky's Rebellion model[11] or D. Scott Bennett's Insurgency model.[12] In these models, agents randomly move around being exposed to their environment and make decisions based on their interaction with that environment and the other agents in the environment. This portion of the model is simple with light-agent[13] formation. In this half of the model, people assess their opportunities on land and compare them to the risk and potential pay-off of pirating. To do this, the people randomly wander from patch to patch.

Each of the people is assigned a variable called opportunity. This assumes that everyone has a different experience with economic opportunity. This variable consists of a decision list with ten values. The decision-list is initially seeded with values using the same equation that assigned eco-op values to the land patches. As a person randomly wanders, the eco-op value from the patch they are on is added to the decision list and the oldest value drops off. The average of these values is what the person uses when making the

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[11] Wilensky, 2004.
[12] Bennett.
[13] A light agent has relatively few traits and makes simple binary decisions.

decision to pirate or not to pirate. This abstraction of how an individual might evaluate

their economic opportunity was conceptualized by thinking about how an individual

without steady employment might look for work. On some days, they find a really good

opportunity and on other days they do not. Here in the United States one might find a

group of migrant workers looking for employment outside of large home stores. These

workers may or not be approached with an offer to work and the specific opportunities will

vary. The odds of the opportunity being good are impacted by the overall economic

opportunity of their environment. As described above, the lower the ECO setting on the

model interface, the better the economic environment and therefore their odds of landing

on a patch with a higher economic opportunity value. Figures 6-3 and 6-4 show how the

environment looks with the Economic Opportunity display turned on. The lighter the color

of the land patch, the better the economic opportunity.

Figure 6-3. Typical initial setup with ECO = 1 and the Economic Opportunity display on; ECO values vary between 91 and 100
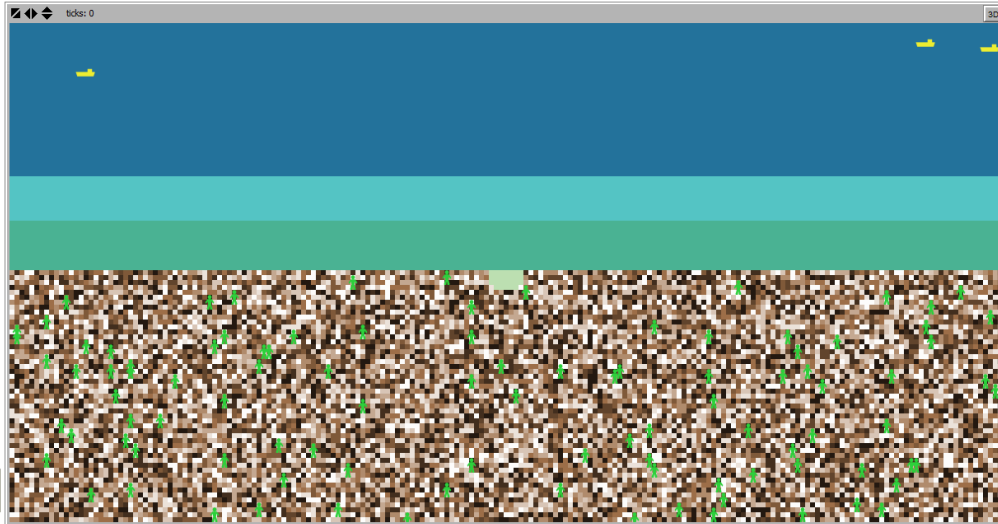
Figure 6-4. Typical initial setup with ECO = 10 and the Economic Opportunity display on; ECO values vary between 10 and 100

Comparison of figure 6-3 and figure 6-4 shows that in addition to the median ECO value increasing as the ECO setting approaches 1, the range of possible values the people can encounter becomes narrower. In a strong economy, everyone is able to have good economy opportunities. The weaker the economy the chance of this lessens. Some people will still encounter the high values (91-100) but there are far fewer of these values and many more lower values to encounter. Following each random move, a person assesses their opportunity and decides to pirate or not. The people are assumed to be rational actors and make this decision based on a utility function. The value of pirating is called pirating-utility and is continually updated as the model simulation runs. Pirating-utility is a function of the expected reward for pirating *times* the probability of a successful pirating run, *minus* the lost opportunity cost which is equal to the individual's opportunity *times* the average amount of time a person would be engaged in pirating.

Let us assume that the utility of pirating is U_p, the expected reward for pirating is R, the current-p-capture value is p; the person's opportunity value is O; t is the average-SRT, and m is the minimum manning value for a skiff.

$$U_p = \frac{R*p}{m} - (O * t)$$

Minimum-manning refers to the number of pirates required to man a skiff, who would be splitting the reward; average-SRT refers to the average Skiff Run Time or the number of "ticks" that a skiff is operational for a pirate run. Minimum manning is set at three for this model but it could be made into a slider on the model interface if other skiff manning levels were desired. While all skiffs in this model have the same manning level a certain amount of variation could easily be introduced. Average-SRT is initially seeded with historic data from earlier model-runs and is dynamically updated as the simulation runs.

Once the decision is made to pirate, the agent begins to make its way to the port area. As long as their relative situation does not improve during this transit they will arrive at the port. (If their opportunity exceeds the pirating-utility, they will change their mind and return to roaming.) Once at the port, the pirate is added to the list of port pirates. When an adequate number of people wanting to pirate congregate (minimum-manning), a skiff is created and the agents transition to the water half of the model in a skiff; this is discussed in the water model portion.

At this point the people hide. They will remain hidden and associated with a specific skiff so long as the skiff is successful at pirating. When a skiff returns from an unsuccessful pirate run, the people are disassociated from the skiff, their Boolean for pirate is reset to false, and they return to roaming on land.

People are green when they are first created. If they decide to pirate they turn red as they head to the port. When they reach the port as a pirate, they turn black. If they change their mind about pirating before they reach the port, they turn yellow and return to roaming. When they return to roaming after pirating they are purple. These color codes help the user recognize behavior changes during model-runs.

Water Model

The water half of the model is less abstract but still represents pirating activity in a simplistic form. Certain assumptions were made about the generic water area modeled. First assumption: the area is part of an established shipping lane, which means merchant ships are apt to transit the area. Second assumption: the area is near the littorals, but outside territorial waters, and therefore considered to be international waters or on the high seas. This assumption is important since most pirates operate from land. Territorial waters extend up to 12 nautical miles from the coastline and within this area the state has jurisdiction. The orientation for such an area of water would vary depending upon the coastline. For simplification purposes, the model area is depicted with the landward area to the south (bottom) and the shipping lane oriented horizontally. The patches are colored to indicate shallower water to the south, outside the shipping lane.

Before ships move, three checks are done. First a location check is done. For each ship at the edge of the model, the count of successful transits is up-dated and another ship is created using the *orient-ship* subroutine. Next, ships check for skiffs in their area of perception (7 patch radius). If there is a skiff, they set their speed to max speed.[14] If they

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[14] The max speed for a ship is 2 while the max speed for a skiff is 3.

perceive no skiffs, they set their speed to half of max speed. Finally, ships check to see if

they are captured; if so they set their heading and speed to match their captor. With these

checks completed, each ship moves forward by the amount of their speed. The color of the

ship is a basic indication of its status. Yellow ships are transiting at half their max speed.

Red ships are moving at max speed. Black ships have been captured and are following their

captor to port.

In the *orient-ship* subroutine a new ship is created to replace a ship which been

removed from the simulation. In addition to this happening after a successful transit, it

also occurs when a captured ship reaches the port with its captor. A new ship is created

similar to the way they were created at model initiation; however, now they are placed at

either end of the shipping lanes. This ensures a constant movement of ships in the shipping

lanes.

There are no skiffs when the model is initialized. The skiffs are created based on the

number of pirates in the port using a subroutine *orient-skiff*. Skiffs have seven operational

modes identified with a variable called *opmode*. The "sail" of the skiff is an indication of its

opmode. Table 6-2 provides a summary of the opmodes.

Table 6-2. Summary of Skiff Operational Modes

Opmode	Description	Sail Color
1	Transiting from the port to patrol area	Black*
2	Loitering on patrol	
3	Chasing a target ship	Gray
4	Captured target; returning to port with prize	Red
5	Failed attack	Blue
6	Low fuel status, returning to port	Yellow
7	In-port	
note:	*First sortie Black, then Brown	

A newly created skiff is randomly placed along the water edge of the port. The opmode variable is set to opmode 1 and the prey variable is set to nobody. The skiff is assigned a random course between 310 and 050 which will send it out to the shipping lanes. This ensures that multiple skiffs are somewhat spread out in the shipping lanes before they start patrolling. (Their patrol range is set to 39; this is the distance they must be from the port before they will shift from transit mode to patrol mode.) Maximum speed is set at 3 and the skiff's speed is set to one third of max speed. Maximum fuel is set to 100 and the skiff's fuel status is set to max-fuel. Skiff attack range (the distance a skiff can "see") is set to 6. Their crew is set to the agent numbers of the first three pirates in the list of port pirates and the list is updated to remove those pirates. At this point, the model counter for sorties is updated (sorties are counted at the time they commence) and the at-sea-tick-counter of the skiff is reset to zero.

Skiffs move depending on their opmode. For every time-step of the model their Skiff-Runtime is increased and their fuel is decreased. In opmode 1 they transit from the port to the area of the shipping lanes. They do this with the initial course they were assigned and at one third of their maximum speed. If they detect a target ship during their transit, they will shift to opmode 3 (chase mode) and pursue the target. If they have not detected a ship before they reach the patrol zone (39 patches from the port), they will shift to opmode 2 (loiter mode). In this mode, they operate at very low speed (one twentieth of their maximum speed) and randomly shift their heading while searching for ships. Again, when a ship is detected they shift to opmode 3.

In opmode 3, a skiff will head toward the ship at maximum speed and then adjust their speed to attack the ship when it is within attack range. Attack success is determined

by a simple probability: roughly 70 percent of the attacks succeed and 30 percent fail.[15]

When the attack is successful they will return to port with the prize ship (opmode 4),

otherwise they will return in opmode 5. If, at any time, the skiff's fuel status gets low they

will shift to opmode 6 and return to port.

When a skiff returns to port, all the dynamic variables are updated; average skiff

runtime, expected reward, and the probability of capturing a prize. For those that came

back due to low fuel or a failed attack, they are considered unsuccessful; their pirate crew

returns to roaming and the skiff is destroyed (the agent "dies").   When a successful skiff

returns with their prize ship, it shifts to opmode 7. In this mode, the skiff waits the

designated amount of time before it may re-sail in opmode 1. Figure 6-5 provides a flow

chart of how a skiff transitions between the various opmodes.

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[15] This value is based on the basic data analysis provided in Chapter 5 of the actual and attempted pirate attacks from 2007 to 2016, as reported in the IMB Annual Reports. See Table 5-2.
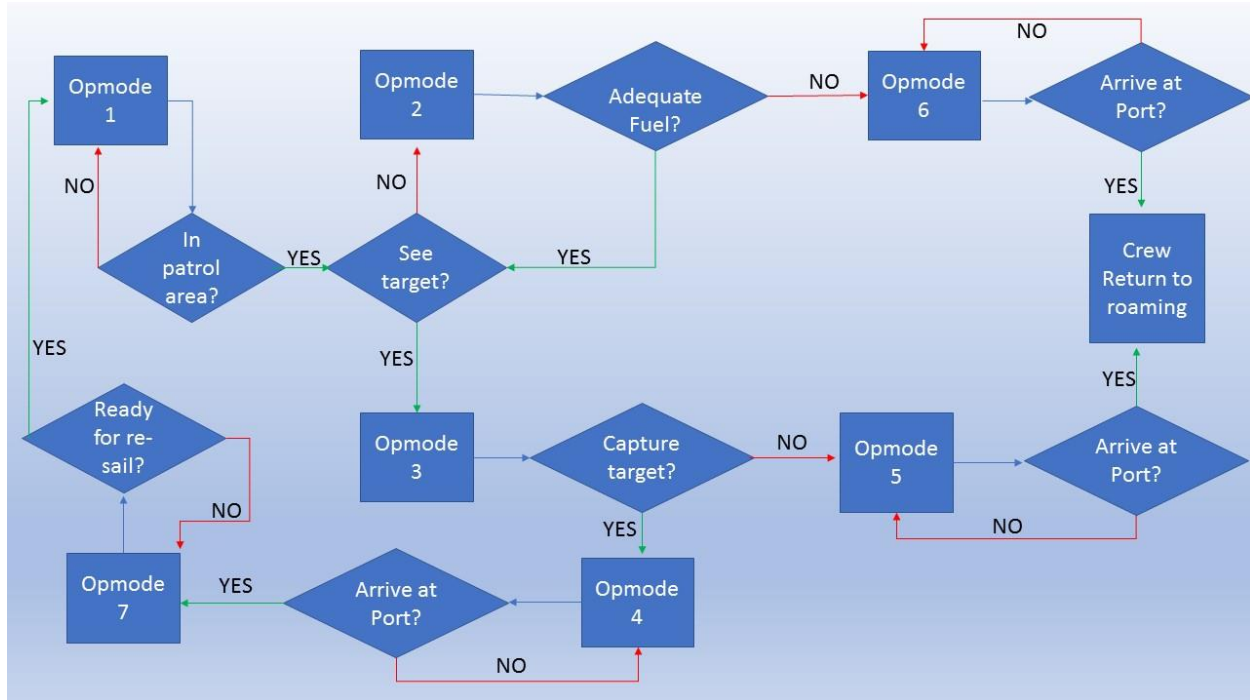
Figure 6-5. Flow chart of the skiff decision process

MODEL VERIFICATION

As the model was being developed, adjustments were made to the model code to correct run-time errors or to clean up obvious issues. Many of these are documented in the comments at the beginning of the model code, in a comment box labeled "Working Prototype," which discusses the differences between the various model versions. These comments may be reviewed in Appendix B.

Early changes were made to get a basic functioning model where people roamed on land (and not in the water) and skiffs and ships stayed on the water. Each new version of the model added or took away something significant. Very early versions of the model were focused on simply getting the "world" set up properly.

After the model appeared to be operating properly, basic runs were performed in an attempt to determine which variables – and some hard-coded numbers – had the most

obvious impacts on piracy. Settings such as attack range, fuel, p-capture, ECO and Reward were varied, including the presence of maritime security forces in the early versions of the model. While all of these variables produced interesting results, it was decided to concentrate on the primary socio-economic ECO factor.

When a flaw in the logic of the model code was identified, corrections were made. This is what occurred when I realized that new ships were being placed randomly into the shipping lane just as for model set-up. While it makes sense to randomly place the initial three ships so that they are somewhat separated, new ships should enter from one side or the other (not pop into the middle). At other times, the problem may have been caused by my initial failure to understand the specifics of how certain NetLogo primitives function.[16]

Sometimes a new version incorporated a new variable to capture more data. The "pirate-success" variable is an example of this. This variable was added so that the data could be gathered on the success rate of each pirate.

Other changes were made as more information became available. For instance, some very basic runs of the model were done to track how long the pirate skiffs were operational. A BehaviorSpace[17] experiment was designed to capture this information. Based on this data, the average Skiff Run Time (SRT) was calculated. This value got incorporated into a newer version of the model to provide a seed value for model initiation. Once skiffs are created and operating in the model this average SRT becomes dynamic, updating with each completed skiff run. This was an important step in the model design

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[16] A primitive is procedure or command that is built into NetLogo to tell agents what to do. Primitives simplify the model coding process, but care must be taken to understand what the primitive will actually do.
[17] BehaviorSpace is a software tool which is integrated with NetLogo. It allows users to perform experiments with models. The model's settings can be systematically varied and the number of repetition for each set of variables can be specified. The results of each model run are recorded.

since people continually assess their opportunity value and compare that to the utility of pirating. To make a proper comparison, they must consider the total opportunity on land that they would be giving up to pirate; their average opportunity times the amount of time they would be at sea. To estimate this, the model uses the average SRT value for the time at sea.

As the model was being developed it became obvious that some portions of the model needed to be simplified. An example of this is that security units were eliminated because it is reasonable to assume they would decrease the success of the pirates by some factor. While we do not know what that factor is, we can assume that the basic relationship between the economic opportunity and pirate reward is the same.

Eventually, around version 16 of the model, it was functioning without any run-time errors and it was time to start experimenting. These experiments also led to newer versions of the model. The next chapter discusses these experiments and their results.

CHAPTER 7

MODEL RESULTS

The previous chapter described the design and development of the Piracy

Opportunity Model. It discussed how the original design was simplified to the essential

variables needed to focus on the relationship between the socio-economic variable of

economic opportunity and frequency of piracy. This chapter discusses the experimentation

results from this parsimonious model. The basic experiment runs and their results are

examined. The implications of repeated runs are discussed. To allow repeated models

runs to begin with the same starting point, exported worlds are explored. Finally, a model

version with an improved conceptualization of economic opportunity is created and

compared to the earlier model. The chapter concludes with a discussion of possible model

improvements.

The model path is dependent, so the initial world drives the results. Given the

amount of stochasticity designed into the model, it is no surprise that there is a good

amount of variation between individual model runs. Yet it is this very variation, measured

as variance in the data sets, that allows for different results to emerge as the models runs.

The success or failure of the first few pirate skiffs significantly influences the ability of the

model to sustain pirate operations. Despite a fixed pool of potential pirates (100 people)

and a fixed quantity of targets (3 merchant ships), boom and bust trends of piracy occur.

These trends create an oscillating pattern similar to that of a predator-prey system. Unlike

a true predator-prey system, because the prey population is held constant, a dual

oscillating pattern does not develop. Nevertheless, it is helpful to think about the on-going

piracy dynamics of the model in terms of a predator-prey system. What conditions allow

for a stable system which sustains piracy populations and which conditions drive the

system to pirate extinction?

BASIC RUNS

With the model developed enough for it to function well, BehaviorSpace was used to

experiment with the model. As various experiments were run on the model, the model

code was updated to adjust for any issues the experiments identified. In some cases, a new

version of the model merely cleaned up or simplified model code. These changes to the

model are documented with comments at the beginning of the model code and are

available for review in Appendix B. With repeated experiments, some trends emerged in

how the model performed.[1]

The model parameter space consists of the full range of values that the model can be

initialized with. In my model the two variables that can be varied are the ECO value and

Reward level. The parameter space is therefore composed of the points that represent all

the possible combinations of the ECO and Reward values. This parameter space can be

explored by running experiments involving a subset of all the possible values. This allows

us to see relationships form between different model settings and the behavior of the

system. BehaviorSpace is a NetLogo tool that runs the model many times, systematically

varying the model's settings depending on those selected for the experiment. The inputs

for each experiment are the variables and the interval to be tested as well as how many

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[1] Except for the additional experiment performed to test the hypothesis about ECO levels 1-3, all experiments were run using the range 4-10 for ECO. This allowed the experiments run more efficiently, since most of the data for ECO levels 1-3 had zero piracy – exception as note in Figure 7-2. This also allowed for comparison between data sets.

iterations to run for each combination of settings. BehaviorSpace records the results for each of the model runs. By running various experiments, we can explore the model's parameter space and determine where the behaviors of interest occur.

Having made the decision to concentrate on the primary socio-economic ECO factor first, BehaviorSpace experiments were setup to explore the relationship between ECO and Reward. The Reward variable is essential to the pirating utility function, so a reward level which was expected to allow a fair amount of pirate activity was selected. For the first experiment, the reward level was set at 300,000. The ECO value was varied from 4 to 10. By running 100 iterations of the model, for each of the ECO levels, for the specified reward level, data was gathered concerning how the ECO variable impacts the decision process to pirate or not-pirate. Since the model is designed to run indefinitely, each of the model runs was limited to 2000 time-steps. This run time was an adequate length of time for any sort of piracy pattern to emerge. For each of the runs, the number of people who decide to pirate was tracked at each time step.

This partial exploration of the ECO parameter was selected with the assumption pirating would not occur when there was plenty of economic opportunity.[2] The change in the ECO value can be thought of in terms of a step function. The ECO value remains constant with the 100 iterations of the experiment and then changes to the next ECO value for the next 100 iterations. No one pirated at ECO 4 and everyone always pirated at ECO levels 9 and 10. At ECO level 5, if the first few people who pirate were not successful, no one else would pirate; that was the scenario for most of the runs. If they were successful,

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[2] This decision was influenced by the size of the experiment and the time needed to run it. Testing one Reward value for seven ECO values resulted in 700 iterations of the model rather than 1000 for the full ECO range.

everyone else pirated. This shows up as the outlying point at 100 on the box plot in

figure 7-1.
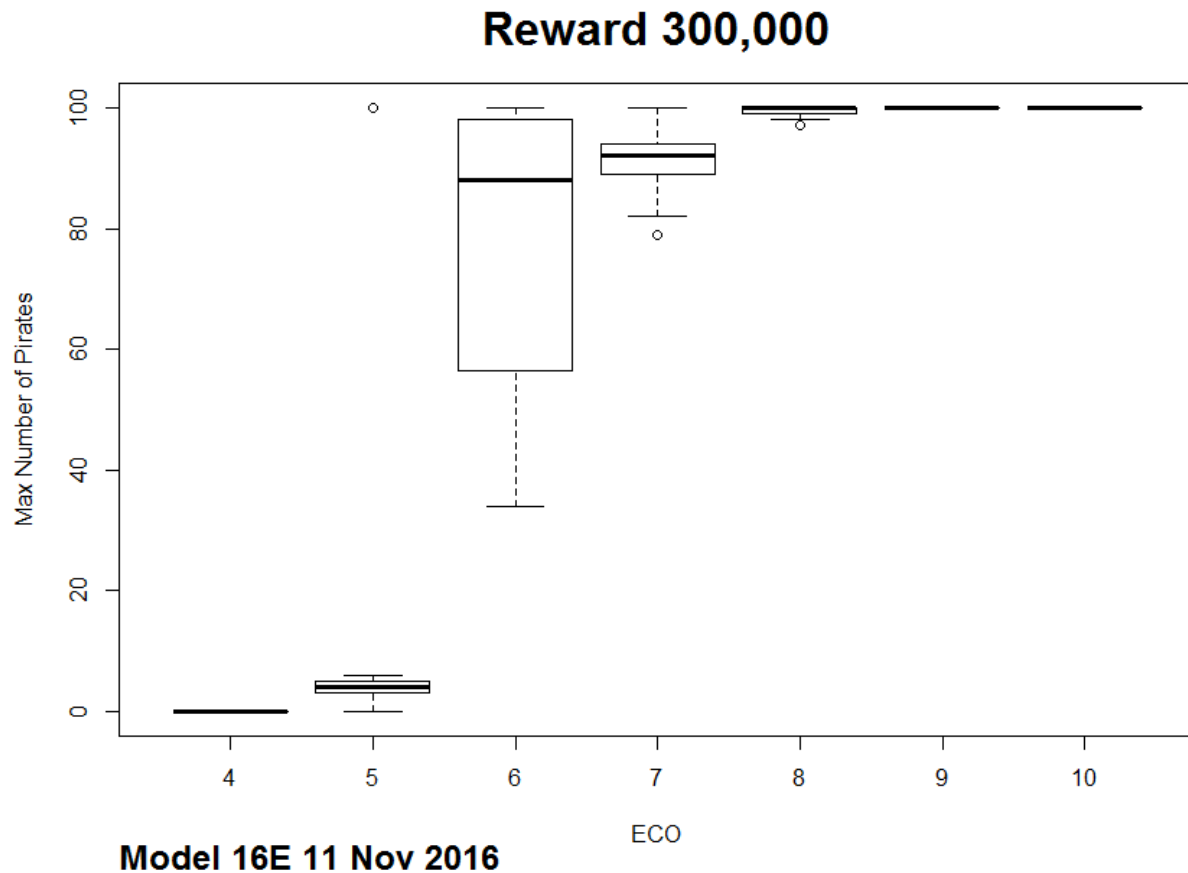
Figure 7-1. BehaviorSpace generated data from Model 16E for Reward = 300,000

This is no doubt a result of the expected reward either dropping below the level which

would encourage piracy or remaining high enough to make piracy attractive. The greatest

range of max number of pirates is at ECO 6. Since the number of pirates differs throughout

the simulation, looking at the maximum number to of people who made the decision to

pirate is of limited use.

A look at the box plots for the median number of pirates (figure 7-2) provides us some better insight into what was occurring in the model runs at each ECO value.

Reward 300,000

Model 16E 11 Nov 2016
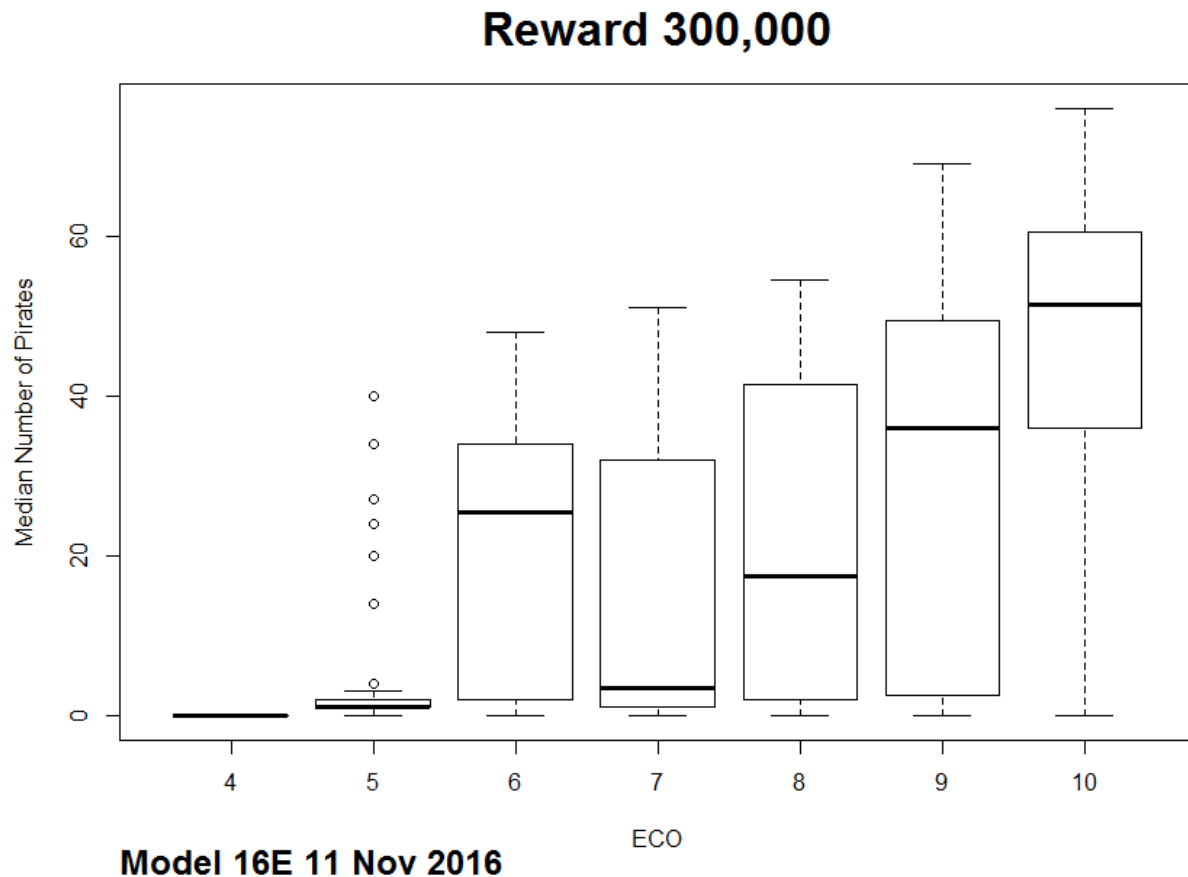
Figure 7-2. BehaviorSpace generated data from Model 16E for Reward = 300,000

Looking at the results for ECO 5, we again see that in most of the model runs there were very few people who decided to pirate. But it is also here that we get the largest number of outliers. These represent the model runs where the first few pirates are successful. This increases the value of p-capture and more people decide to pirate. The success rate of those pirates determines how long people will continue to decide to pirate.

The results from ECO 6 are the most interesting. Why is the mean value of the median number of pirates so much higher than the it is for ECO 7? It is even higher than the value for ECO 8. What is going on here? If individual model runs are watched for ECO 6, we observe people gradually making the decision to pirate at the beginning of the simulation. The pirates make their way to the port and man up skiffs. This happens a few people at a time and so just a few pirate skiffs are operating at any one time.   Just as for ECO 5, the success or failure of the pirate skiffs matters. However, with the poorer economic conditions, the pull toward piracy will continue at lower p-capture values, so more people pirate, and it takes longer for any failures to have an impact on people's decision.

By contrast, when we watch the simulation for ECO 7, the pull toward piracy is strong enough that nearly everyone decides to pirate – as soon as the simulation begins. This results in a swarm of pirates heading to the port where skiffs are rapidly manned. Then a swarm of skiffs sets off on pirate runs. Since there are only three ships transiting the shipping channel, most of these skiffs will return in a low fuel status without ever having attempted to attack a ship. The value of p-capture drops and most people stop deciding to pirate. We will even see many of the pirates who were heading to the port, change their minds (they shift from black to yellow) and return to roaming at this point. Just as for ECO 5, the future of these simulations is very dependent on the success or failure of the few skiffs that actually have an opportunity to attack as ship. If they succeed, the drop in the value of p-capture is slowed and others will decide to pirate. If they fail, p-capture is decreased that much more. At some point, no one else will pirate. We can think about this swarming effect as a crowd-out event. So many skiffs are operating at the same

time, with a limited number of ships, that they crowd out the competition. This pattern is

repeated for ECO 8, but to a lesser extent. In the simulations for ECO 9 and 10, the

economic opportunities are so poor, relative to the reward, that the pull toward piracy will

typically continue to be strong long enough for the system to correct after this initial

massive swarming event.

At every ECO value, there was a significant amount of variation between the

individual model runs. This is indicated by the mean values of the standard deviation and

variance for the number of pirates, across the 100 runs for each of the ECO values. Both the

randomness of the initial model setup and the random decisions of the agents contribute to

the variations between model runs.

Table 7-1. Data summary of 11 November 2016 BehaviorSpace experiment for Reward 300,000 (Model 16E)

Mean Values for 100 Iterations (Number of Pirates)				
ECO	max	mean	median	*std*	*var*
4	0.00	0.00	0.00	0.00	0.00
5	20.92	4.59	2.71	5.29	115.34
6	79.18	23.69	20.22	15.63	262.92
7	91.54	14.09	16.01	21.57	477.10
8	99.56	29.19	24.16	25.41	659.40
9	100.00	38.52	31.66	24.53	625.70
10	100.00	49.66	45.72	22.33	531.00

This simple experiment verified that the model code was performing as intended

and validated that the model portrays how changing ECO levels influence an individual's

decision process. When the person has adequate economic opportunity, they are content

to continue with their way of life. As their opportunities decline, they are more disposed to

take alternative actions – in this case to turn to piracy.

Since the decision to pirate also depends on the expected reward, the next set of BehaviorSpace experiments included variation of the initial reward value. Beginning with reward set to 200,000 it was varied in increments of 50,000 up to 400,000. The ECO value was again varied from 4 to 10 and 100 iterations were run for each ECO value. [3] For each reward level, a similar trend of increasing rates of piracy occurred with increases in the ECO value. However, at lower reward levels the ECO value had a more dramatic effect on the trend; while at higher reward levels the ECO value effect was more gradual. With initial reward value set to 200,000 pirate activities did not begin until ECO level 7. With each increase in the reward value, the ECO level necessary for piracy decreased, such that by 350,000, piracy activity occurred at all ECO levels (4-10) that were being evaluated. Since even more pirate activity occurred at all levels for an initial reward of 400,000 it is logical to assume that piracy could be enticing even at ECO values lower than 4.

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[3] Testing these two variables in pairs increased the number of model runs to 3500 iterations – 100 iterations for each for the 35 possible variable combinations.
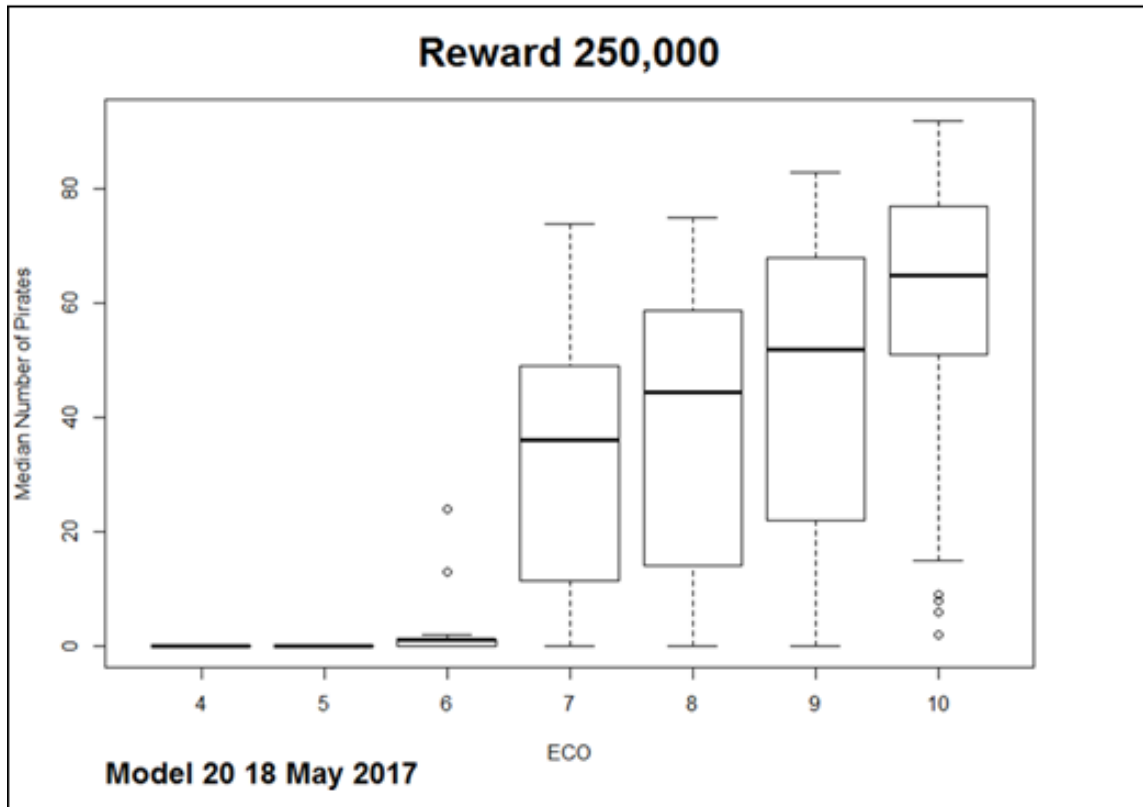
Figure 7-3. BehaviorSpace generated data from Model 20 for Reward = 250,000

The data displayed in figure 7-3 is an example of how ECO value has a greater impact at relatively low reward levels. The data displayed is for 100 runs at each of the various ECO values. Once the ECO value is high enough for pirating to occur, there is a lot of variance between individual model runs as indicated by these box and whisker plots. This variance represents the different piracy patterns which emerge as the model simulation runs, depending on the random decisions made during model set-up and operation.

Figure 7-4 shows that at higher levels of reward the impact of the ECO value is more gradual, but there is still a lot of variation between the individual model runs for each ECO value.
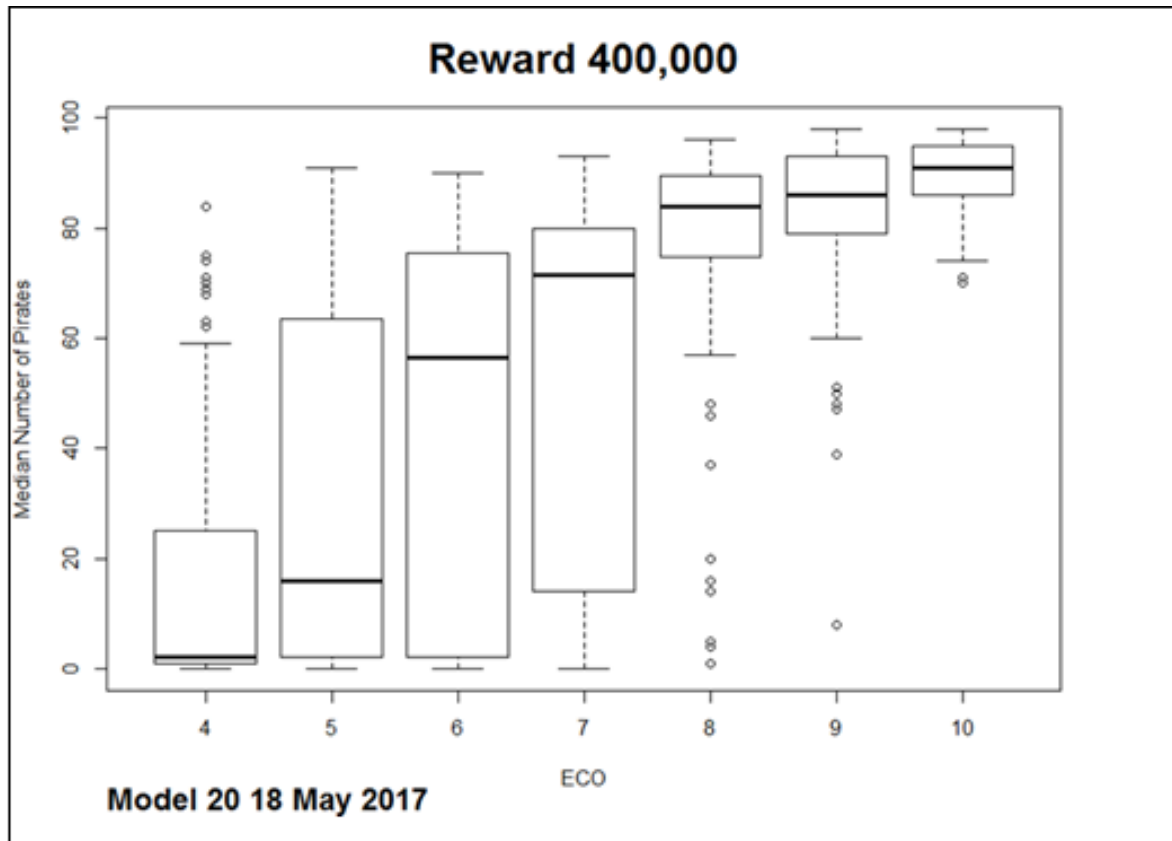
Figure 7-4. BehaviorSpace generated data from Model 20 for Reward = 400,000

An additional experiment was run to test this theory that people would decide to

pirate with good economic opportunity if the reward is high enough. With Reward set to

400,000, the ECO level was varied from 1 to 10. And in fact, even at ECO level 3, some

people made the decision to pirate at reward level 400,000. Similar to what happened with

Reward 300,000 and ECO 4, more piracy occurred at ECO 3 for Reward 400,000 than did at

ECO 4. This indicates that even with strong economic opportunity, people might decide to

pirate if the expected rewards are very high. Since only a few people will make this

decision at a time, a low level of piracy might be sustainable in these relatively strong

economic conditions because there is little or no competition between the pirates. This

pattern is similar to the results produced in the earlier experiment. There is a relatively low

ECO value (for Reward 300,00 it was ECO 6) that allows for a sustained pattern of piracy, and then the system reaches an ECO value tipping point which causing swarming and pirate competition to occur. Figure 7-5 provides box plots for each ECO value at reward level 400,000.
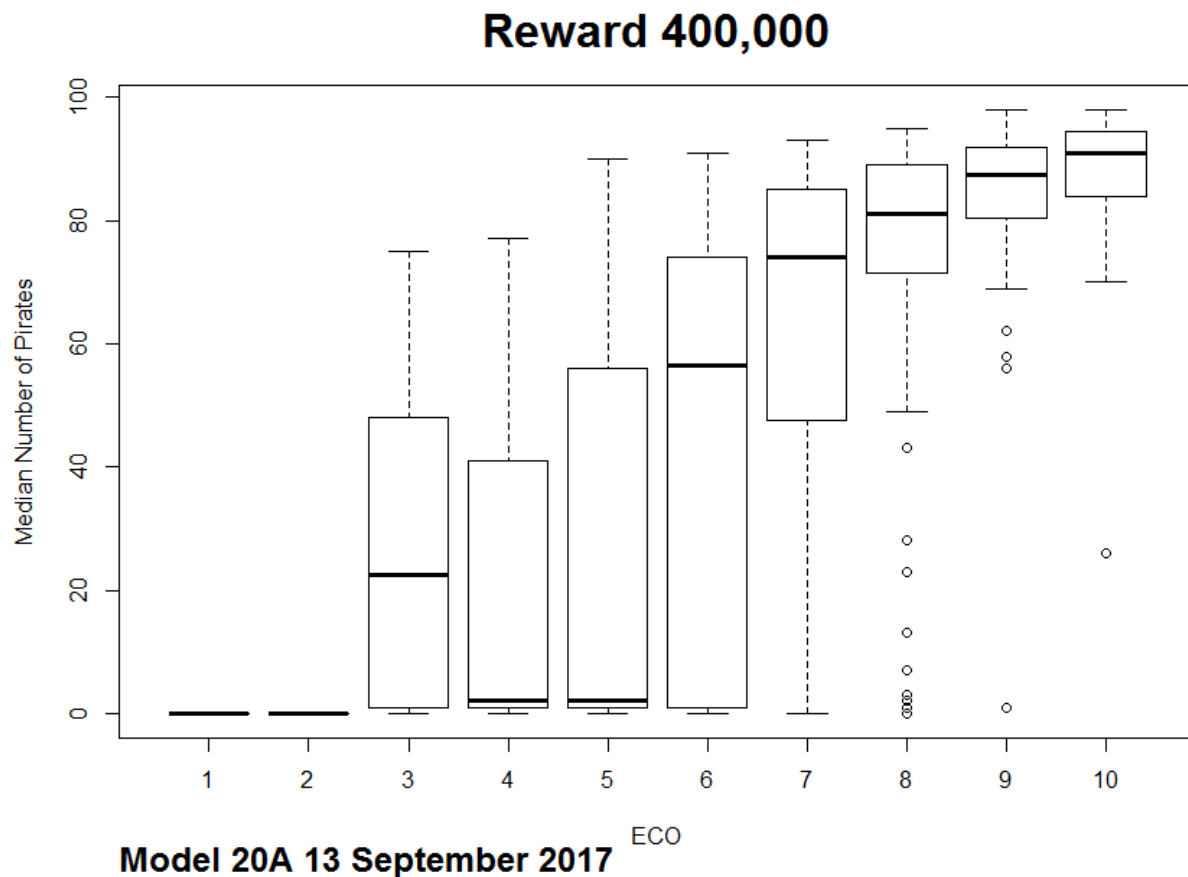

Figure 7-5. BehaviorSpace generated data from Model 20A for Reward = 400,000

RESULTS OF REPEATED SIMULATIONS

Observation of repeated simulations demonstrates some general patterns of the system dynamics of the model. When the economic opportunity is relatively high and/or the reward for pirating is relatively low there is no incentive to pirate, since the average

economic opportunity is always higher than the expected utility of pirating. As economic opportunity weakens and/or the reward for pirating increases there is a threshold at which point the situation will shift and some people will decide to pirate. At this threshold, the first few skiff sorties are very significant. If too many of these early attempts at piracy are unsuccessful, the expected reward for pirating is lowered enough that the system crosses back to the condition of no one pirating. If, however, these first few pirate runs are successful, the expected reward and the piracy probability of success is increased and more people, even those with slightly better average opportunity, decide to pirate.

On the other end of the spectrum, when the economic opportunity is relatively low and/or the reward for pirating is relatively high, there is strong motivation to pirate, as the average economic opportunity is always lower than the expected utility of pirating. In this situation, all or at least most of the people will initially decide to pirate. This sends a swarm of pirate skiffs out into a region where the potential targets (merchant ships) are limited (for the model purposes there is a constant shipping population of just three ships transiting). Obviously most of these skiffs will not be successful, so they will drive the expected reward of pirating down. As this occurs, eventually a point is reached when it is no longer desirable to pirate. When this happens, no one else will make the decision to pirate.

In between these alternatives there is a range of ECO and expected reward values which will allow for the system to sustain a certain level of constant piracy. This situation appears to be as much concerned with the frequency of the pirate runs as with the success of those runs. If the frequency shifts to the swarming situation, the expected rewards will be driven down and the frequency of pirate runs will be decreased as the pirating utility is

decreased. There must be some successful piracy attacks to maintain an adequate level of

expected rewards, along with an adequate probability of success to continue to encourage

the pirating behavior. As already discussed this occurred at ECO 6 for Reward 300,000 and

at ECO 3 for Reward 400,000. However, at very high ECO values, beyond the tipping point

for swarming, the pull for piracy is strong enough for the system to recover and sustain a

pattern for piracy despite the initial crowd-out effect.

      These system dynamics parallel those of a predator-prey ecosystem.[4] A stable

predator-prey ecosystem is self-sustaining, or in balance. It will continue to maintain itself

despite fluctuations in the population sizes. In contrast, an unstable predator-prey system

will result in extinction of one or more of the species in the system. These types of systems

are grouped together because no matter the kind of species involved, if there is a predator-

prey relationship, they display similar system dynamics. "Notably, when the sizes of the

predator and prey populations are compared over many generations, we tend to find

regular oscillations in these sizes that are out of phase; where one increases, the other

tends to decline, and vice-versa."[5] For this reason it may be useful to think of the maritime

piracy issue in terms of a predator-prey system.

      In a true predator-prey system, the populations of both the predator and prey

oscillate. These oscillations are out of phase such that as one group is increasing, the other

is decreasing and vice versa. With this model, the amount of shipping transiting the area is

held constant. This is an artificiality that was built into the model design for simplicity. In

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[4] For a classic example of a NetLogo model of a predator-prey ecosystem see the Wolf Sheep Predation model: Wilensky, U. (1999). NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

[5] Wilensky and Reisman, 178.

reality, the amount of shipping transiting an area varies and can be impacted by maritime security threats. The IMB monitors pirate activity and sends out notices and warnings. When an area is designated as having a higher likelihood of piracy, insurance rates are increased and ships may choose to avoid that area if possible. This results in less ship traffic. When the threat has been abated, the shipping traffic will increase again.

Future versions of the model could allow for a dynamic flow of shipping traffic. This would allow for the predator-prey relationship between the pirates and ships to be further explored. Such a model would have to account for more of the economic variables that impact a ship's decision concerning what route to sail.

A CLOSER LOOK AT SOME INDIVIDUAL REPRESENTATIVE MODEL RUNS

Given the amount of stochasticity in the model, nearly every model run produces different results. With specific populations of agents, there is a limit to the possible variety of results. But given the number of variables that determine these results, even in this parsimonious model, in conjunction with the decisions the agents in the model make at each time step, the number of different result is enormous and expands with each time step the model is run. The chance of the model simulation running the same way twice, particularly when the initial set-up is random, is extremely slight. It is however possible to compare the trends that occur in repeated model runs.

Here I present fifteen specific examples, each from a different run of the model to illustrate some of the patterns that emerge in the pirate population as the model runs. This allows a discussion of what was occurring during the simulation to cause these patterns. I use the graphs of "People with pirate" that the model generates while running to illustrate

these examples. For each scenario presented, a full screen capture of the model interface at the end of the model run is available in Appendix D.

The model is very sensitive to initial pirating activity. Failure of the first few skiffs to capture a ship drives the system toward extinction. When pirating activity occurs slowly, meaning there is time between the individual skiffs departing the port, the model is better able to absorb failure and has the opportunity to rebound when new skiffs head out. Another way to think about this is that a lower rate of piracy (measured by the quantity of skiffs pirating at a particular time), equates to a slower drop in p-capture caused by unsuccessful skiff runs. However, when the model conditions are such that the people swarm to the port, a high level of failure will result. A swarm of skiffs ensures a low level of success and a rapid drop in the p-capture value.

Combinations of the Reward and ECO variables which produced a lot of variation between the individual model runs were chosen for twelve of the fifteen examples since these produce a wide variety of results to select from. Six of the examples are from model runs in an environment where the reward is relatively low and the economic opportunity is very poor. In this environment, the Reward level is 250,000 with an ECO value of 9. Six more examples come from model runs in an environment with better economic opportunity, but with a relatively high reward level for piracy. This environment has a Reward level of 400,000 and an ECO value of 7. The last three examples use Reward level 300,000 with an ECO value of 6. This combination of variables was discussed earlier in this chapter. This combination of Reward and ECO produces a wide range of median number of pirates. It provides scenarios without initial swarming.

These fifteen examples, although only illustrative, clearly demonstrate the differences that can occur with the same variables as well as a comparison between the different variable settings. A graph of the number of pirates versus time supplements the discussion of each scenario. More details of each scenario are provided in Appendix C.

First a look at the examples from Reward level 250,000 and ECO 9. In each model run there is an initial swarm of piracy. Everyone, or nearly everyone, decides to pirate in the early portion of the simulation, so there is a quick ramp-up to a boom of piracy. It is not possible to sustain this level of piracy, since there is a very limited quantity of target ships. Therefore, this initial boom of piracy is shortly followed by a bust in the amount of piracy as failures drive the incentive to pirate down. In scenario 1, the initial boom is followed by a bust which eventually leads to the extinction of piracy before the end of the 2000 step model run. Since only one ship was captured extinction happens quickly.
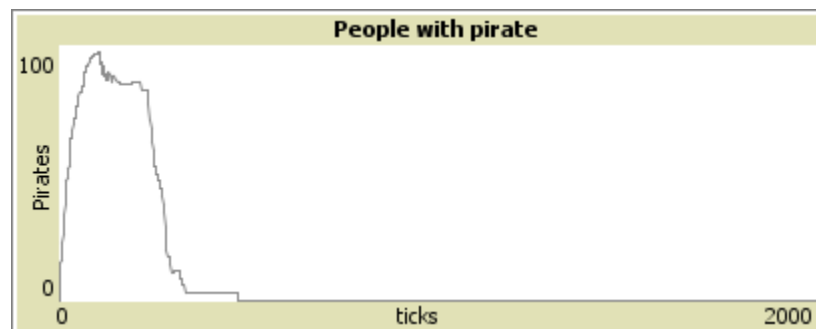
Figure 7-6. Scenario 1: Model 20, Reward = 250,000, ECO = 9

The next scenario presents a similar start pattern; however, in this run, extinction has not yet occurred. By the end of the 2000 steps, there are still three pirates; enough for one skiff to be operating. If that skiff fails to capture a ship, piracy extinction is highly probable.

Alternatively, it that skiff is successful, other people may decide to pirate and the system may rebound if those pirates are also successful.
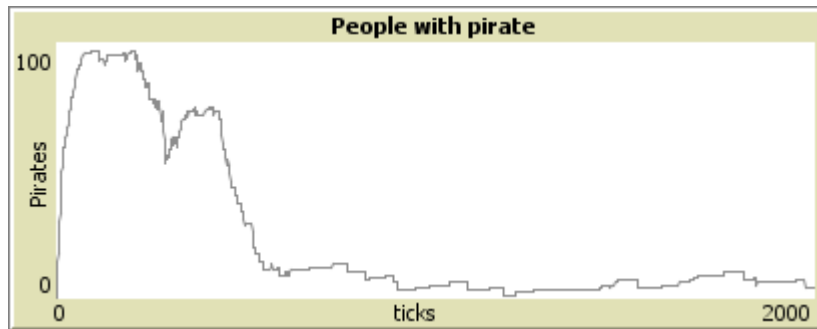
Figure 7-7. Scenario 2: Model 20, Reward = 250,000, ECO = 9

In the third scenario, the piracy bust is followed a very low level of sustained piracy. Gradually the system recovers and another piracy boom occurs but without the degree of swarming that occurred in the initial boom.
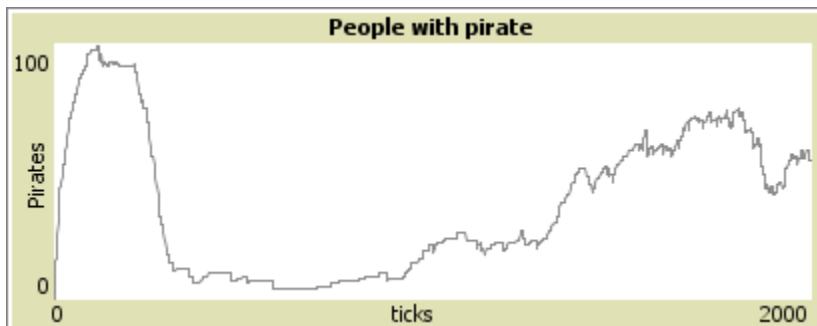
Figure 7-8. Scenario 3: Model 20, Reward = 250,000, ECO = 9

The fourth scenario presents a different initial pattern. Following the nearly immediate boom of piracy, a bust occurs, but the level of piracy never drops very far. The result is a fairly stable high level of piracy. This is a less likely scenario as a high rate of pirate success is needed to sustain this system.

Figure 7-9. Scenario 4: Model 20, Reward = 250,000, ECO = 9

A similar pattern is evident in Scenario 5. In this case, the system levels out to a low level of

piracy. In both this scenario and the previous one, the relatively long run of fairly stable

piracy illustrates the oscillating pattern typical of a predator-prey system.
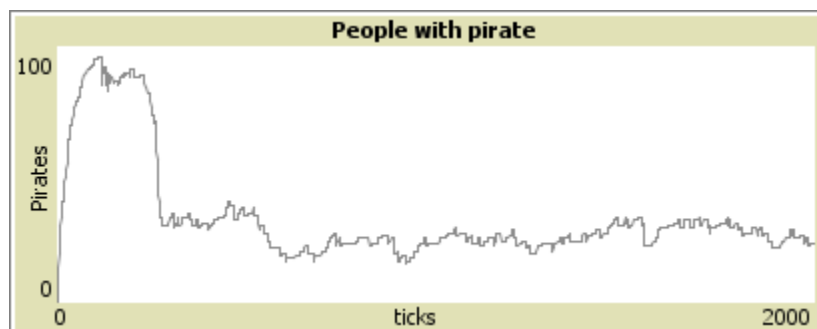
Figure 7-10. Scenario 5: Model 20, Reward = 250,000, ECO = 9

The last scenario provides an example of the initial bust being followed by a gradual

recovery and then a pattern of mini booms and busts. Again, these are just a few of the

many possible patterns that are seen with repeated runs of the model. As long as piracy

extinction has not occurred, the model stochasticity will continue to produce an ever-

changing pattern.
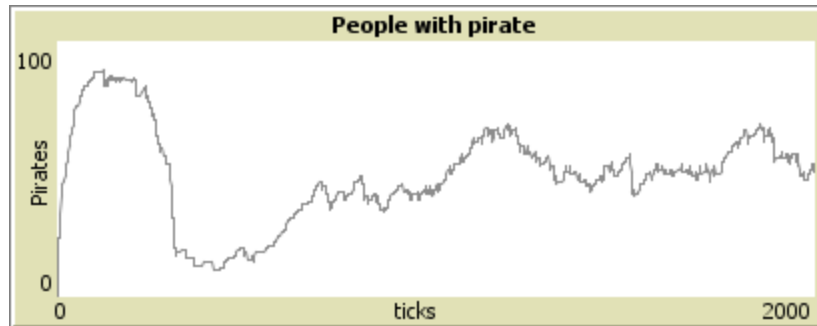
Figure 7-11. Scenario 6: Model 20, Reward = 250,000, ECO = 9

Now, I turn to the other environment to provide the last six scenarios, with Reward

set at 400,000 and ECO set at 7. As in the first environment, the combination of economic

opportunity and reward in this environment provide a strong initial pull toward piracy. In

fact, here the pull is even stronger than in the first environment. Everyone is immediately

pulled to pirate and they swarm toward the port. Once at the port, they man the skiffs and

swarms of skiffs venture out. This is evidenced in the graphs for each of the remaining

scenarios with a vertical rise to 100 pirates[6]. Scenario 7, similar to scenario 1, shows the

bust that shortly follows the initial boom. The results are even more dramatic than in

scenario 1. Only two of the 33 skiffs that initially head out successfully capture a ship.

Then, neither of them are successful when they re-sail, and piracy extinction occurs

relatively rapidly.

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[6] The 100th pirate waits in the port until two unsuccessful pirates who have returned to roaming, again decide to pirate and make their way to the port.
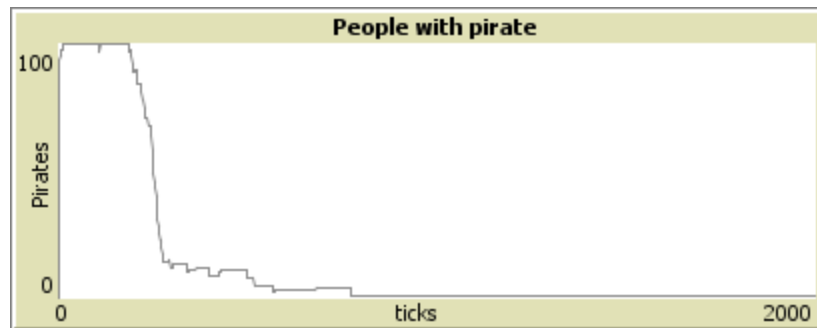
Figure 7-12. Scenario 7: Model 20, Reward = 400,000, ECO = 7

This a good representation of the crowd-out effect that was discussed earlier.

Because the pull toward piracy is so strong at a high level of reward, everyone decides to

pirate at the beginning of the simulation. The resulting swarm of skiffs overwhelm the

target population. At best, only three will find ships to attack. In this particular scenario

only two were successful and the value of p-capture drops enough that people no longer

decide to pirate. Just one more successful ship capture can delay the point at which piracy

extinction occurs, as illustrated by scenario 8. In scenario 8, three captures occur from the

initial swarm which allows piracy to continue. In this scenario, there were six successful

captures, but then no more.
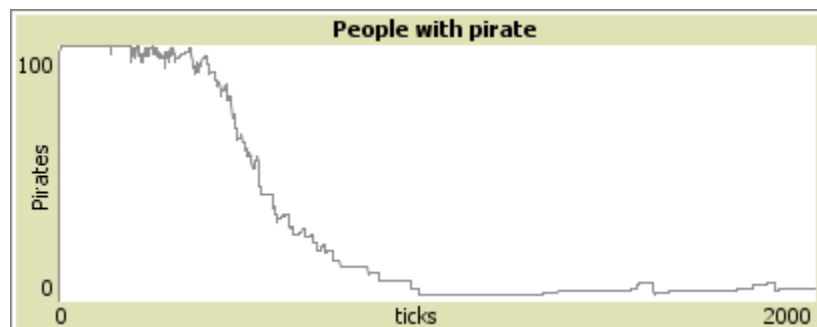
Figure 7-13. Scenario 8: Model 20, Reward = 400,000, ECO = 7

The graph for scenario 8 does not indicate piracy extinction because there is still one skiff operating. That one skiff is returning to port unsuccessful (see scenario 8 in Appendix D). When the skiff reaches the port, extinction will occur and no one else will pirate. Alternatively, if that skiff had been successful there would have been a chance for a recovery.

In scenarios 9, there is never a bust. Despite an initial swarm of pirates enough of them are successful to sustain a high level of piracy. This scenario does illustrate a very gradual downward trend resulting from the high amount of failures that slowly drive down the expected reward.

Figure 7-14. Scenario 9: Model 20, Reward = 400,000, ECO = 7

The bust that follows the initial boom is not complete in scenario 10, and its followed by a recovery rapid enough that everyone again decides to pirate. This allows the system to settle into a fairly stable pattern of on-going piracy.

Figure 7-15. Scenario 10: Model 20, Reward = 400,000, ECO = 7

In scenario 11, after the bust there were no successful captures until the last skiff that set out. This drove the p-capture variable down, so that despite the high reward, no one was willing to pirate until that last skiff succeeded. After that, the system makes a gradual recovery. Eventually, it returns to a high level of piracy that is somewhat stable.
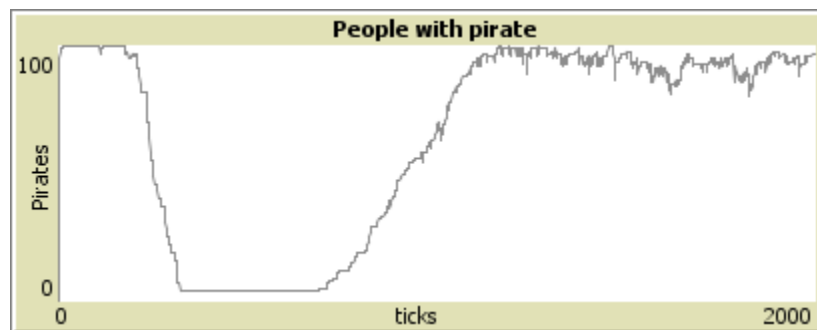
Figure 7-16. Scenario 11: Model 20, Reward = 400,000, ECO = 7

Scenario 12 illustrates how just enough pirate success can cause the p-capture value to cross back and forth across the point where it results in a swarm of pirates. Each time the system is in decline, a successful skiff run allows the system to recover. The result is a very jagged saw-tooth pattern of small booms and busts. Initially they trend downward, but enough successive captures reverse the trend.
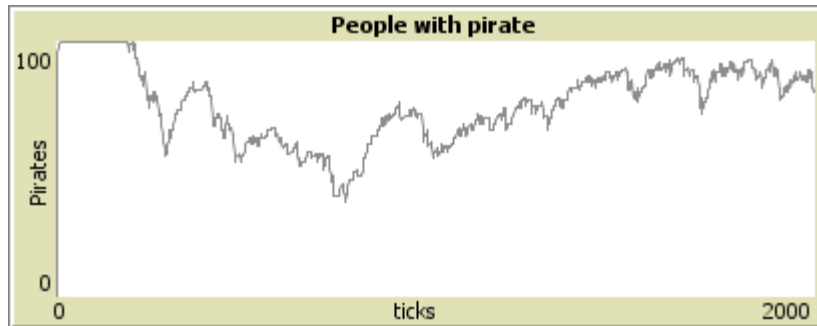
Figure 7-17. Scenario 12: Model 20, Reward = 400,000, ECO = 7

The last three scenarios are just a few illustrative examples of the wide variety of possible patterns that emerge when piracy starts more gradually. All three of these scenarios begin in a similar way; people decide to pirate at a much slower pace. It takes time for there to be enough of them to man a skiff. Meanwhile more of them are making the decision to pirate and they also head toward the port. Skiffs gradually begin to operate. When skiffs return without being successful, those pirates return to roaming and the number of pirates begins to decline. After this point the future is again determined by the success or failure of the skiffs. In scenario 13, only two of the skiffs were successful and the system eventually reached extinction. This shows that even when the pirating starts gradually, the model is still very sensitive to the success of failure of the first few skiffs.
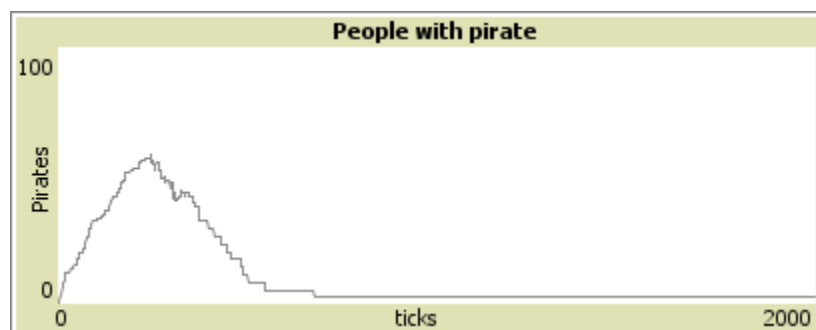
Figure 7-18. Scenario 13: Model 20, Reward = 300,000, ECO = 6

The model run for scenario 14 had eight ships captured. This was enough for the system to ramp-up with a good number of active pirates. Failures decreased the pirate population but not enough to drive it to extinction. Additional captures encouraged new pirates. The model run ended with just ten active pirates; nine of them manning three skiffs and one more waiting in the port. That could be enough to sustain piracy if some of the skiffs are successful (although one skiff is already returning to port in a low fuel status). Alternatively, failure by all three of the skiffs would result in piracy extinction. (The pirate waiting at the port for two more crew members is unlikely to get them, since one pirate has already decided to return to roaming rather than pirate as indicated by his yellow color.)
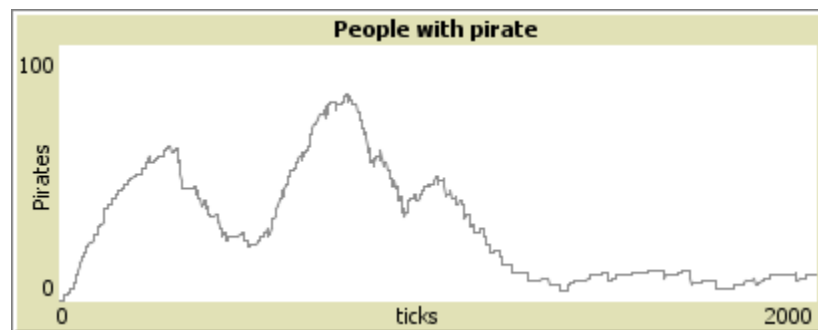
Figure 7-19. Scenario 14: Model 20, Reward = 300,000, ECO = 6

The last scenario shows a model run which has a good amount of ongoing piracy. There have been 23 captured ships and the model has settled into a relatively stable pattern of piracy. When the model run ended there were 48 pirates. Most of them are out in skiffs, a few more of them are making their way to the port. This indicates people are still deciding to pirate. One of the people, who had decided to pirate, has returned to roaming. That indicates there will be fewer deciding to pirate unless some of the current skiffs are successful.
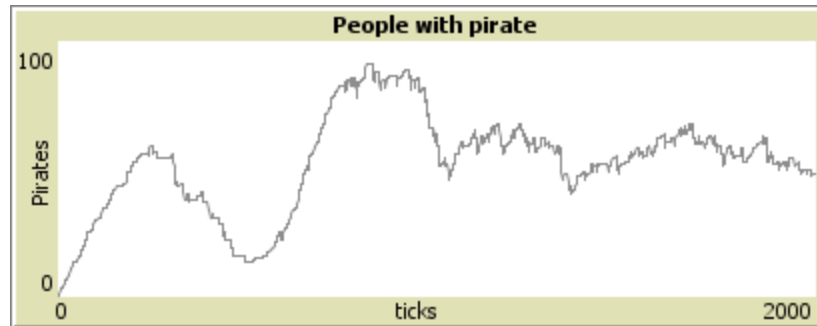
Figure 7-20. Scenario 15: Model 20, Reward = 300,000, ECO = 6

While these scenarios are only representative of the possible combinations of ECO level and Reward value, they show the wide variety of patterns of pirate population changes that the model can produce. This indicates that the model is very sensitive to the level of stochasticity. Because the difference between one more successful skiff run or another failure can be the difference between extinction or recovery, it would appear there are threshold effects that matter in each ECO level depending on the Reward value. This sensitivity is particularly critical as the beginning of a model run.   For that reason, I now shift to a discussion of model initiation.

THE ISSUE OF MODEL INITIATION

When the model is set up and begins to run there is no piracy. This is somewhat reasonable as there are areas without piracy or times when the conditions do not favor piracy. However, in this case we are setting the economic opportunity and an expected reward as initial conditions of the model. Those conditions will result in piracy or not. In the situations when the combination of opportunity and reward result in no piracy the system is in equilibrium. People will roam contentedly on land and none of the dynamic variables will kick in. Alternatively, when that combination lures people to piracy there is a

start-up time frame for the model to make the shifts from seed values to dynamic values for the average time of a skiff run, the expected reward, and piracy probability. Each of these variable transitions are dealt with differently.

The skiff run time (SRT) is seeded with a value which was determined by running the model multiple times and gathering all the individual skiff run times and then averaging them. This value was then set into the model code. An artificial history is created by multiplying this value by 1000 and dividing the average by the same. As skiffs operate, they track the time they spend at sea and when they return that time is added to the total, which is then divided by an incremented denominator. As the model simulation runs the average SRT varies but not by much. It is important to note that SRT is primarily influenced by the skiff's maximum fuel, since fuel limits the amount of time a skiff can remain at sea. If the initial fuel setting is altered a different seed value would be needed for the model.

The initial expected reward value is determined by the Reward level selected by the user on the model interface. Using this value, a similar artificial average is created by multiplying the reward by a factor of 1000 and then dividing the average by that number. Thus, the initial expected reward is an average which is equal to the reward setting. As ships are captured, their reward is added to the total and the denominator is increased. For each unsuccessful sortie, the total remains the same (zero reward for that sortie) but the denominator is still incremented. As the model simulation runs, expected rewards tend to trend down since there are far more unsuccessful skiff runs than successful ones. [7]

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[7] This tendency of expected reward needs further exploration. It may be that the distribution of rewards among the ships is not ideal. Alternatively, this could be a problem with how the expected reward is

Setting an initial piracy probability is a more difficult challenge. This is the probability that a pirate skiff will be successful and is used in the utility function. The lower the probability the less enticing the reward of pirating is. This can be thought of in terms of risk as well. A low probability of success is the same as a high risk of failure. If the probability of success is too low no one will pirate; alternatively, if it is too high everyone will pirate. The range for these all-or-nothing values is relative to the reward level setting.

As discussed in Chapter 5, the real-world probability of a ship being subject to pirate attack varies depending on the waters the ship plans to sail in. Through some rough analysis, qualified by the data that is available, it was determined that piracy probability risk experienced by shipping can be globally bounded as less than 0.005 percent up to a high of 1.32 percent at the height of the Somali pirate crisis. Unfortunately, we cannot estimate the probability of the pirate's success since we do not know how many pirates there are. As we do not have good data for the quantity of pirates, it is impossible to set this value based on real-world data.

In the model, piracy probability, represented by the p-capture variable, is the overall probability that a pirate skiff will make a capture. This is different from the probability of an attack being successful since this also accounts for all the times a skiff returns from a sortie without even encountering a ship to attack. Early versions of the model had a selector switch to set the piracy probability. The value could be varied between 0 and 10, in increments of 1. Obviously, if the probability of success is 0, no one will pirate. At 0.1 the model ran reasonably well. Increasing the probability to 0.2 caused everyone to pirate all the time. There was no need to experiment with higher values. Instead, the scale on the

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calculated. In the real-world we clearly see trends of increasing rewards for pirating under certain conditions. In the model runs, there are small bumps in the expected reward but not an upward trend.

selector switch was adjusted to allow for smaller increments to be tested. The increments were changed from 0.1 to 0.01. Following this adjustment, the sensitivity of an initial p-capture was tested for the range 0.08 to 0.12 with the ECO and Reward values held constant in a range which had previously produced plenty of piracy. Given the amount of stochasticity in the model it was difficult to determine if this level of discrimination in the initial p-capture value was significant, it certainly did not appear to be. Since, the ability to select the initial value of the piracy probability did not appear useful, the selector switch was eliminated to simplify the model. P-capture was given an initial seed value of 0.1 in the model code.[8]

For a person to make the decision to pirate, the combination of reward and risk must outweigh the opportunity on land (this opportunity is multiplied by the average SRT since a person gives up multiple opportunities when they make a pirate run). In the utility function, the expected reward is multiplied by the piracy probability (p-capture) and then divided by three (the minimum manning level for the skiff). The result of this calculation is then compared to the individual's opportunities (their average opportunity times the average SRT).

Once a ship has been captured, this value becomes dynamic and is a ratio of total sorties to those that were successful. Shifting directly to the dynamic value would cause an unrealistic shift in this probability since it all depends on when that ship is captured compared to how many skiffs have gone out to pirate. The following possible scenarios bound the issue:

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[8] While each data set from a BehaviorSpace experiment varied, when the total number of captured ships and sorties was record by an experiment on 31 May 2017, the probability of pirate success was 56,010/536,216 or 0.104454. This experiment involved 3,500 runs of the model. This verified that 0.1 was a reasonable seed value.

Scenario one: The first skiff is successful and no other skiffs have gone out. The dynamic value, the number of captured ships divided by the number of skiff runs, would max out at 1. This of course is an unlikely but not an impossible situation and represents the upper limit for the probability.

Scenario two: There are ten skiffs out when a skiff is successful, this would cause the value to be 0.1 and no change would occur.

Scenario three: 33 skiffs are out (everyone - except the last guy who needs two more partners to man a skiff) when a skiff is successful - this would cause the value to be 0.0303....

Scenario three is close to the lower limit for the probability since they go back to roaming if they are not successful; however, they could soon decide to pirate again which would drive the value even lower. At some point, if no pirates capture a ship, it will be too low for anyone to desire to pirate. This is the point which was described above as piracy extinction.

These scenarios present three of many possible situations which will occur when the probability of capture becomes dynamic. Except for scenario two, all the possible situations will cause a jump or dive in the probability of capture. To mitigate these potential swings, the element of time passage is added to the calculation of the current value of the probability. As the model simulation runs, a total is created by adding the probability value at each time step and then dividing that total by the number of time steps. This essentially averages the value. During the model start-up phase, while the value is static, the average is the same as the seed value. Once the value becomes dynamic that

value is what gets added to the total. The utility function uses the average value (referred to as current p-capture).

On model initiation, all these variables function with their seed values until a ship is captured. After that, they shift to dynamic values. SRT is updated each time a skiff returns and tends to stay close to the seed value. Total-rewards is updated each time a captured ship is brought to the port.   Expected-rewards is updated every time a skiff returns to port. The probability of capturing a ship is updated each time increment and changes when a skiff sorties or a ship is captured.

EXPORTED WORLDS

Every time the model is initiated, it randomly sets up the starting conditions of the model. Therefore, each model run begins differently dependent upon these initial conditions; the distribution of economic opportunity on the land and in the experience list of the people, the location of the people on land, the rewards allocated to the ships and their location in the shipping lane. These differences between the starting conditions account for some of the variation that is seen in the results. It is possible to eliminate this portion of the variation by having each model run begin with the same starting conditions. This can be accomplished by setting up the model and then exporting the world. The model is then reset for each model run by importing that world. Although the repeated simulations use identical starting conditions, each simulation will still be unique because NetLogo uses a random seed for each model run.[9]

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[9] NetLogo uses a pseudo-random number generator to determine the pattern for random number choices. This means that while the numbers appear random, they are generated by deterministic process.   For each model run, unless otherwise specified, the number generator is seeded with a random number based on the

Another consideration for model start-up is that it begins with the seeded variable settings and runs with those until enough activity has occurred to allow those variables to become dynamic. Because this transition of the model from initial seed values to dynamic values causes swings, it is useful to look at scenarios that start with ongoing piracy. To do this, the model is run for a determined amount of time and then stopped. This freezes the world as it was at that time. The frozen world is then exported and used as the imported world for further testing of the model. To find scenarios where all the variables have shifted to their dynamic mode, the model [Model-20A] was run at relatively low levels of rewards (200,000 – 250,000) at the ECO values where these reward levels saw a shift from no, or nearly none, piracy to somewhat sustained piracy. For a reward of 200,000 this is an ECO value of 8 and for a reward of 250,000 it is an ECO value of 7. After running for 500 time-steps, the model was frozen, saved, and then used as a repeated starting point for additional testing.[10] By using the same world as a starting point, the initial conditions of each model run are the same. Given the amount of stochasticity built into the model, the results of these runs still had a good amount of variety when repeated runs were made. But this variety can now be attributed primarily to the functioning of the model rather than the shift from seed values to dynamic values.

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current date and time. For more information on NetLogo random numbers see "Random numbers" in the NetLogo Programing Guide. Accessed September 19, 2017, http://ccl.northwestern.edu/netlogo/docs/programming.html#random.

[10] Some initial testing was done with 1000 time-step model runs. The exported worlds that were then tested did not appear to produce good results. I thought this might have to do how high some of the values had gotten, (this was before I made the adjustment to the p-capture variable by creating the total-p-capture and current-p-capture variables) so the amount of time was reduced. However, I later discovered the real issue was with how BehaviorSpace was importing the frozen world and running it in the experiment. I discuss this issue more in the Frozen World subsection of the Model Extensions section of Chapter 8.

CONSIDERING THE IMPLICATIONS OF VARIOUS FROZEN WORLD SCENARIOS

Obviously, the difficulty is how to determine which of the possible scenarios created

by this method is the best frozen world to use. Here I will discuss some of the possible

scenarios for a frozen world which would then be imported as the starting point for further

experimentation. I will then describe the actual process I used to make this selection.

Figure 7-21 provides an example of a model run with an ECO value of 7 and a

Reward of 250,000 stopped after 500 time-steps (ticks).
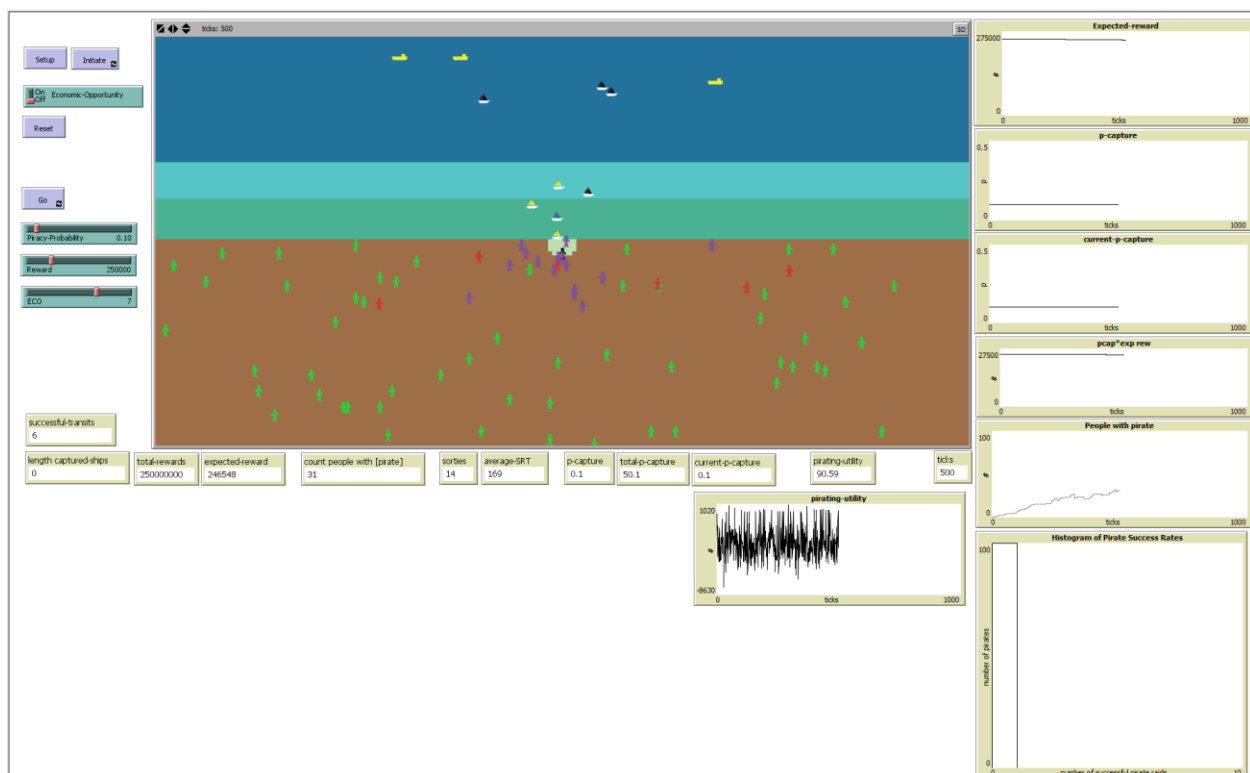
Figure 7-21. Model run 1 with ECO = 7, Reward = 250,000, and Ticks = 500 (Exported World)

In the model run displayed in figure 7-21, there were 14 sorties but no successful

captures. The dynamic values for average SRT and reward are functioning; however,

current-p-capture is still using its seed value since p-capture does not become dynamic

until a ship has been captured. For this reason, this would not be a good scenario to use as

a starting condition for model runs where we want to see all of the dynamic values

functioning from the start. Therefore, this scenario was discarded.
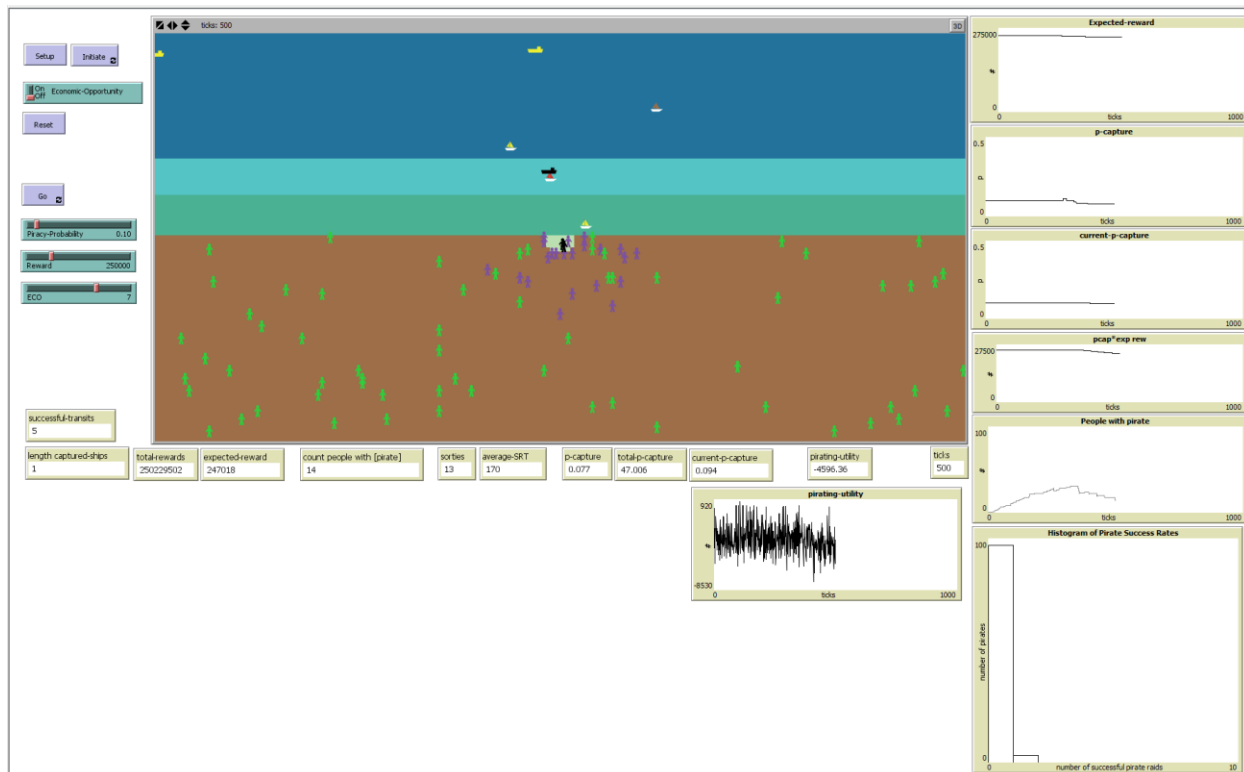
Figure 7-22. Model run 2 with ECO = 7, Reward = 250,000, and Ticks = 500 (Exported World)

Figure 7-22 displays another example of a model run with the same variable

settings as figure 7-21. In this case, the first vessel was captured with 9 skiffs out. The p-

capture value became dynamic and shifted to 0.111 (1 divided by 9). The current-p-

capture, which averages all values of p-capture over time, remains at 0.100 since the

simulation was approximately 300 time-steps along when the capture got tallied in the

port. By the end of 500 time-steps there have been 13 sorties and the current-p-capture

has dropped to 0.077 (1 divided by 13) and the current-p-capture has become 0.094. One skiff is returning to port with a captured ship.

If this world is imported as a common starting point, the p-capture will jump to 0.154 when the ship arrives in the port, which will also cause a gradual increase in current-p-capture, even as p-capture gradually declines. The next successful capture will again cause a jump in p-capture and current-p-capture will continue to gradually increase. This pattern will continue as long as the utility function continues to cause more people to pirate. As the simulation continues to run, the impact of each successful capture is less than the earlier ones.

Figure 7-23 displays the results of the simulation, after approximately 2000 time-steps, using the figure 7-22 frozen world as a starting point, with the same variable settings.
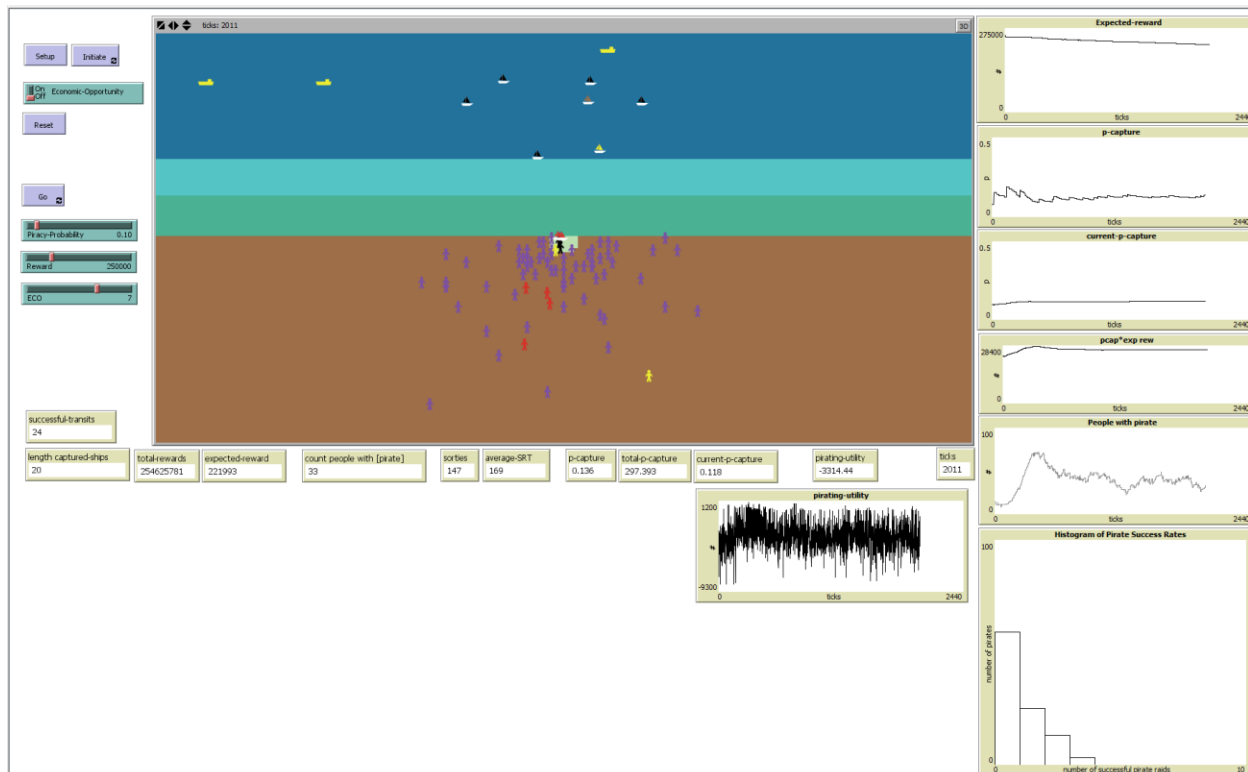
Figure 7-23. Model run 3 (Imported World) with ECO = 7, Reward = 250,000, and Ticks = ~2000

The p-capture variation is most significant when the numbers used to determine it are relatively small. As the simulation runs, the impact of each new capture still drives an increase, but to a lesser extent. Meanwhile, current-p-capture has continued to gradually increase so that even with a general decline of the expected reward (caused by all the unsuccessful skiff runs) people are still deciding to pirate. This results in a sustained pattern of piracy for these variable settings. This is clearly illustrated by figure 7-24 which displays the model after approximately 10,000 time-steps.
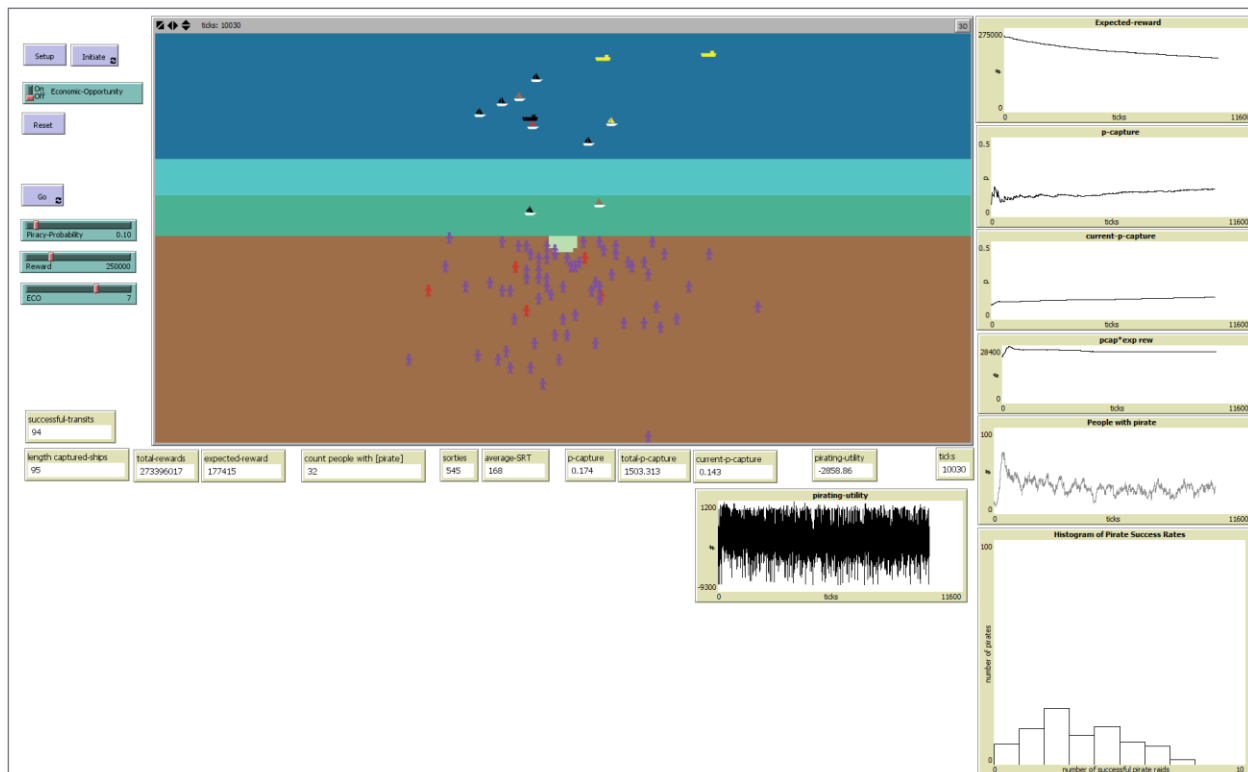
Figure 7-24. Model run 3 (Imported World) with ECO = 7, Reward = 250,000, and Ticks = 10,000

If the model were allowed to continue to run, it is logical to assume that at some point the product of the gradually increasing current-p-capture and the gradually decreasing expected-rewards would not be sufficient to maintain this pattern of piracy since there is a slight downward trend in the graph which displays this product.

Figure 7-25 shows yet another example of a frozen world after 500 time-steps. It was also created from a model run with an ECO value of 7 and a Reward of 250,000. In this scenario, there are 14 pirate sorties and one captured ship. This results in a p-capture value of 0.071 (1 divided by 14). At the time the scenario freezes, there are 14 pirates. Twelve pirates are on four different skiffs; one is returning to port with low fuel and three are on pirate operations. Two additional pirates are making their way to the port. The

current p-capture value is 0.095, which is high enough for people with low opportunity to decide to pirate.
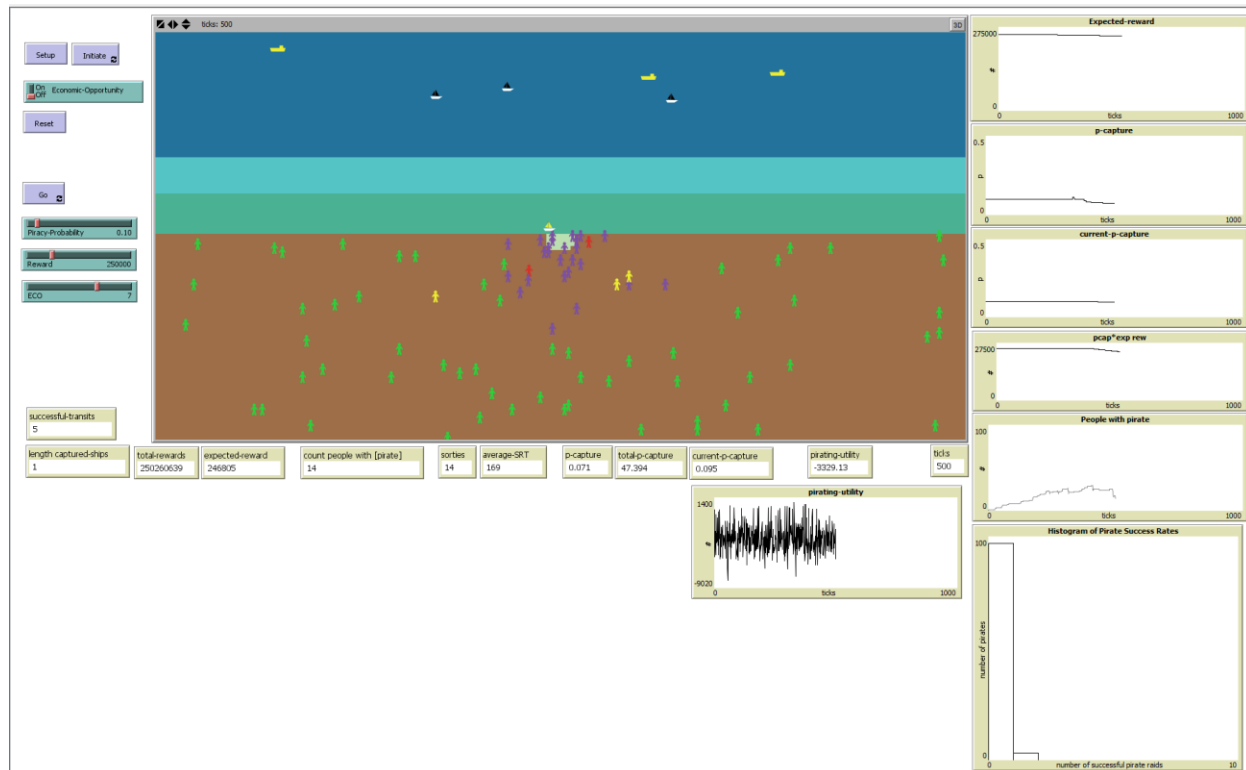
Figure 7-25. Model run 4 with ECO = 7, Reward = 250,000, and Ticks = 500 (Exported World)

If none of those skiffs return successful, it is possible no one else will decide to pirate. Alternatively, it is possible that one person will make the decision to pirate before current p-capture gets too low. This would allow just one more skiff to sail. At that point p-capture is 0.067 and current p-capture is gradually decreasing. If that 15th skiff is unsuccessful, by the time it returns to port the current p-capture value will have dropped to at least 0.087 and it is highly unlikely anyone else will decide to pirate. Figure 7-26 shows the status following the unsuccessful return of the 15th skiff.
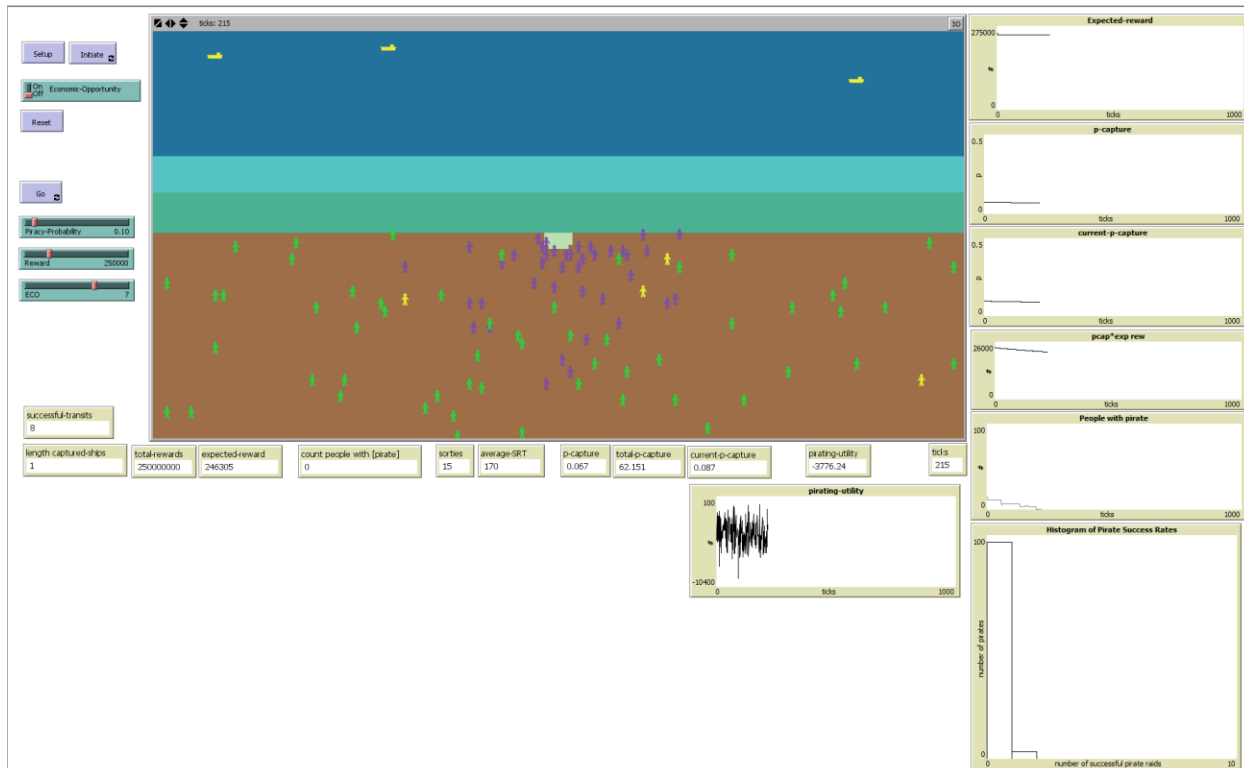
Figure 7-26. Model run 5 (Imported World) with ECO = 7, Reward = 250,000, and Ticks = 215

Alternatively, if there is a 15th sortie and it succeeds, at that point p-capture will increase to 0.133 (2 divided by 15) and current p-capture will begin to increase, encouraging others to pirate. This increase in p-capture is significant enough to keep sending more skiffs out and the model will keep producing pirates. As many as 30 sorties can occur without another successful capture. In that case, p-capture will have again decreased to 0.67. Figure 7-27 shows the results of a simulation with the 15th skiff successful, but then no additional successful captures until the 30th skiff (the 30th skiff is waiting to re-sail and will be successful).
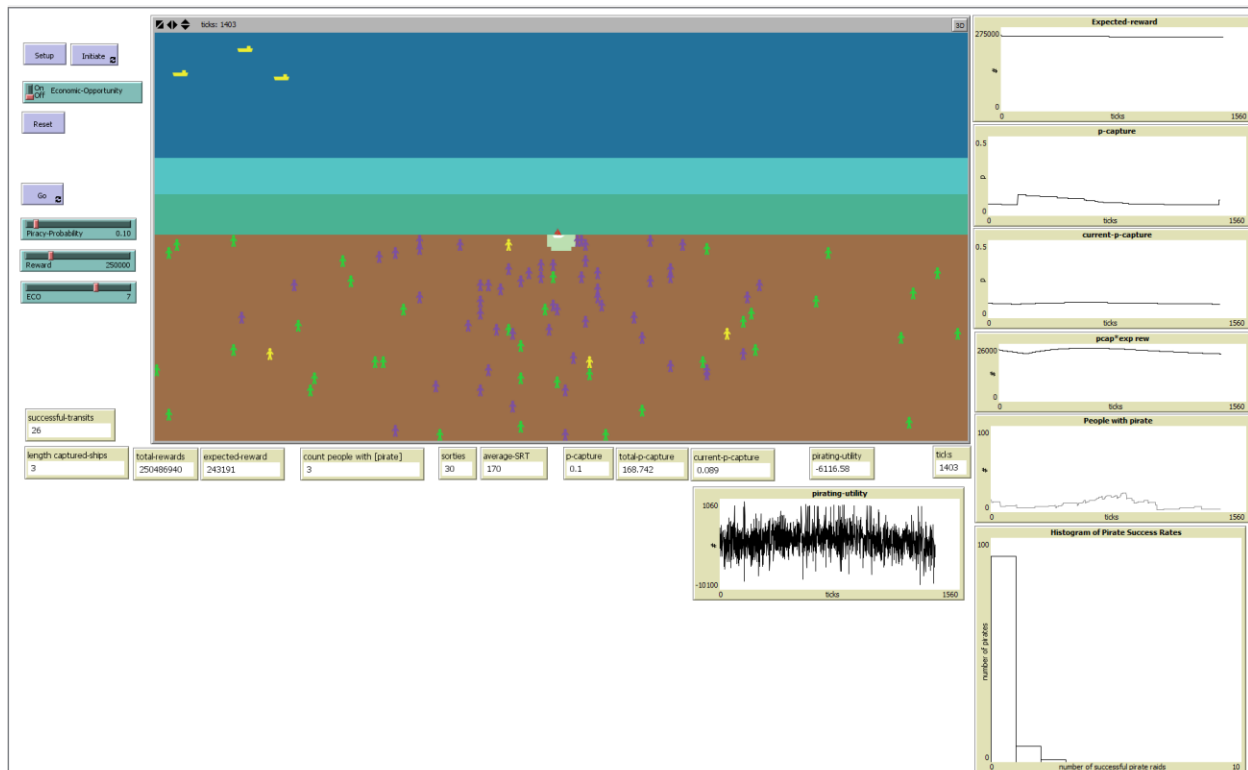
Figure 7-27. Model run 6 (Imported World) with ECO = 7, Reward = 250,000, 30 Sorties

At this point, when the captured ship arrives in the port, p-capture will increase to 0.100 (3 divided by 30) and current p-capture has decreased to 0.089 but will begin to again increase. So long as that skiff is successful when it sails again, the model will keep producing more pirates. With sortie 31 succeeding, p-capture will increase to 0.129 (4 divided by 31) and even more people will decide to pirate as current p-capture continues to increase. Figure 7-28 displays the situation shortly after sortie 31 returned to port. Alternatively, if sortie 31 is not successful, it is unlikely any more people will pirate as the current p-capture and expected reward will have continued to decrease.
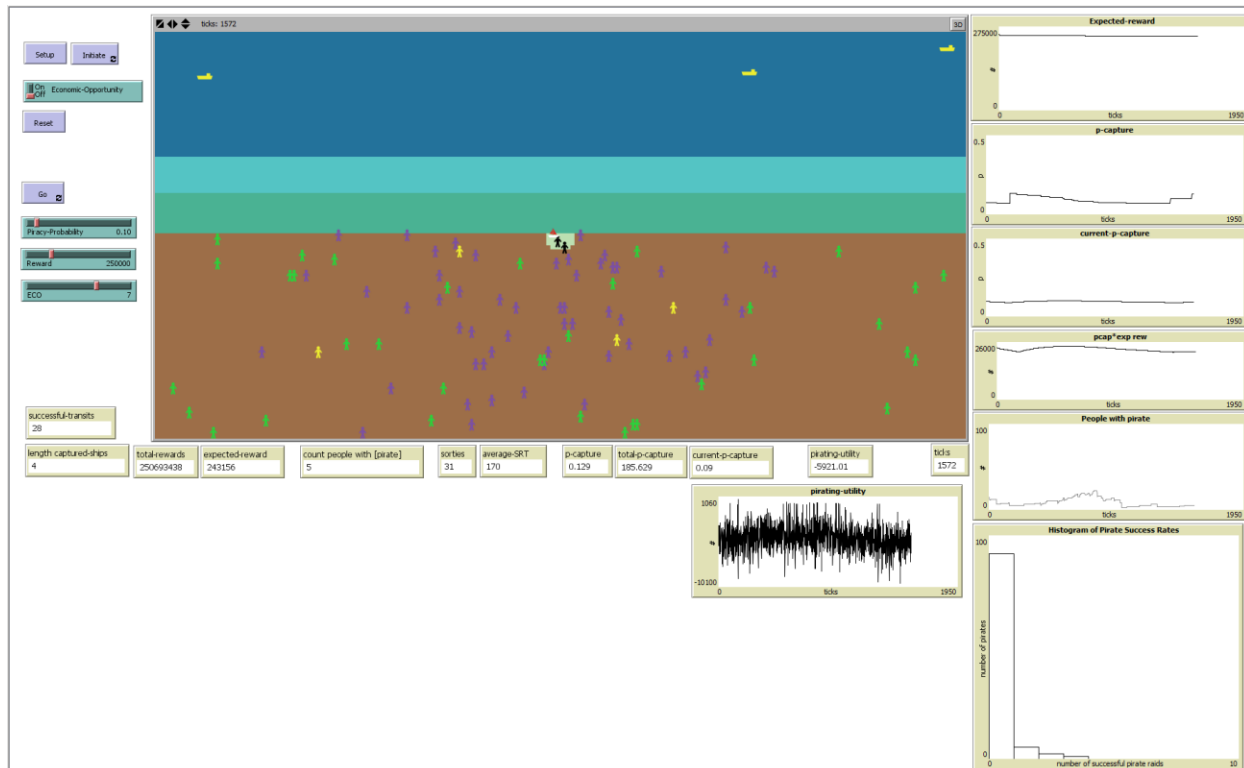
Figure 7-28. Model run 6 (Imported World) with ECO = 7, Reward = 250,000, 31 Sorties

All these scenarios are created by maintaining the same variables of ECO 7 and Reward 250,000. The frozen world can also be used to explore other ECO and Reward levels. A BehaviorSpace experiment, similar to the earlier experiment to determine the effect of varying the ECO and Reward values, can be run starting each model run with the same frozen world. While this reduces the stochasticity caused by model initiation, we do not know if it is a better representation of real life.

DETERMINING A LOGICAL PROCESS FOR FROZEN WORLD SELECTION

Earlier experimentation had determined that at low levels of reward, piracy only occurred with weak economic opportunity, such as would be found in the more fragile states. At the higher levels of reward, piracy occurred at most levels of economic

opportunity except for those with the highest levels of economic opportunity. However, it was more pervasive with lower economic opportunity. The goal of freezing the world and exporting it to be a starting point for future experiments is to ensure all variables initially assigned a seed value are now dynamic variables. This means piracy must be occurring at the time the model is stopped and the world is exported.

A series of BehaviorSpace experiments were run varying the ECO value from 7 to 8 and the Reward level from 200,000 to 250,000 with 100 iterations for each pair of variables. The target pairs were ECO 7 with Reward 250,000 and ECO 8 with Reward 200,000. As indicated in figure 7-3, ECO 7 is the environment in which piracy becomes pervasive for Reward level 250,000. This similarly occurs for ECO 8 with Reward 200,000. It was reasonable to expect plenty of frozen worlds with on-going piracy in these variable ranges. For each set of 100 exported worlds, the median numbers for pirates after 500 ticks were analyzed to determine the most frequent value. Then, those worlds with that number of pirates were evaluated, using the considerations discussed above.

For example, looking at table 7-2, the most common occurrence for the median number of pirates was 21, which occurred in 15 out of 100 exported worlds.

Table 7-2. Median Number of Pirates in 100 Exported Worlds with ECO 7 and Reward 250,000

Median	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	32
Occurrence	2	2	4	5	12	13	15	11	13	7	5	2	5	1	1	2

Each of these 15 exported worlds, with a median number of pirates equaling 21, were then individually evaluated. First, any without at least one captured ship were eliminated since

the p-capture variable would not be dynamic. Then, by comparing the standard deviation

and variance for the number of pirates at the time the world was exported, the worlds with

the lowest values were used for additional experimentation.

Figure 7-29. Initial model-reset for model 20B with imported world 178D[11]

In the world illustrated in figure 7-29, there were a total of 14 sorties which

resulted in one captured ship. Five ships successfully transited the shipping lane. A

maximum of 29 people pirated and at the time the world was exported 14 of them were

pirates. Twelve of the pirates are out in four skiffs, three of which are active in the shipping

lane, while the last one is returning to the port with a low fuel status. The other two pirates

are making their way to the port. The p-capture value is 0.071 while the current-p-capture

value is 0.095. The expected reward is 246,805 and the SRT value is 169. This is not to say

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[11] World 178D was the world produced by model run number 178 of 400 in the fourth BehaviorSpace
experiment to evaluate exported worlds.

that this is absolutely the best exported world for further experimentation; however, this does explain the logic behind the selection that was made.

Using this world, 178D, as a starting point for further experimentation, the BehaviorSpace experiment was repeated, varying the ECO and Reward values.[12] The experiment results showed similar trends between the various variable settings for ECO and Reward when compared with the results from the experiment with random world starts. The caveat to this is that the minimum numbers for the variables produced by the model (the number of pirates, sorties, successful transits, and captures) were established by the imported world.

As expected, the mean values for the standard deviation and variance across the two data sets were reduced by beginning with the same imported world for each run of the model. The mean standard deviation went from 13.891 with the randomly setup worlds to 9.888 for the imported world starts. Mean variance dropped from 309.820 to 151.668. Summaries of the data from these experiments are provided in Appendix D.

Table 7-3 provides a more detailed look at the data for the median number of pirates by ECO and Reward values. The experiment with Model 20A used random initialization as the starting point. The experiment with Model 20B imported the frozen exported world (1787D), so each model run began with that as its starting point. As discussed above, world 178D has twelve pirates. Importing this frozen world as the starting condition for future experimentation means that the minimum number of pirates for each of the model runs is 12.   With this as a given, we would expect the values of the imported world experiment to be equal to or higher than the values from the earlier

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[12] ECO values were varied from 4 to 10. Reward values were varied from 200,000 to 400,000.

experiment. However, a review of the data produced by the experiment, shows exceptions

to this for some of the ECO and Reward level combinations. The most dramatic example of

this is highlighted with a box in the table. For ECO 8 and Reward 200,000; the mean of the

median number of pirates was greater than 24 in the original experiment. For the

imported world experiment, it was less than two. The lower starting value for current

p-capture might explain this, but there also might be something else going on which would

require further experimentation to determine. As we saw in the earlier experiments, there

is a threshold or tipping point that causes swarming to occur. When this happens, the

competition crowds out pirate success. Instead of more pirating, we get less pirating.

Table 7-3. Comparison of Model 20A (random initialization) to Model 20B (Frozen World 178D) for 100 iterations per variable pair

Mean of Median Number of Pirates						
ECO	Model	200000	250000	300000	350000	400000
4	20A	0.0	0.0	0.0	15.5	19.6
	20B	0.0	2.0	5.6	15.1	29.5
5	20A	0.0	0.0	3.1	24.1	27.8
	20B	0.0	2.0	8.5	34.9	37.3
6	20A	0.0	0.8	29.0	24.4	43.0
	20B	0.0	2.0	18.2	40.9	54.1
7	20A	0.3	34.8	31.1	38.7	61.0
	20B	0.0	7.5	42.1	57.3	66.1
8	20A	24.1	35.8	45.1	64.3	72.1
	20B	1.7	41.4	54.8	65.9	76.6
9	20A	40.8	44.8	63.9	75.5	84.5
	20B	35.3	58.5	66.6	75.6	87.0
10	20A	50.6	60.4	76.2	83.8	88.4
	20B	54.1	68.5	76.8	86.1	90.8

Figure 7-30 provides a comparison of the box plots for reward level 400,000 from

the two BehaviorSpace experiments. These make it easier to see the reduction of the

standard deviation and variance in the experiment that used an imported world as the

starting point for each of the model runs.
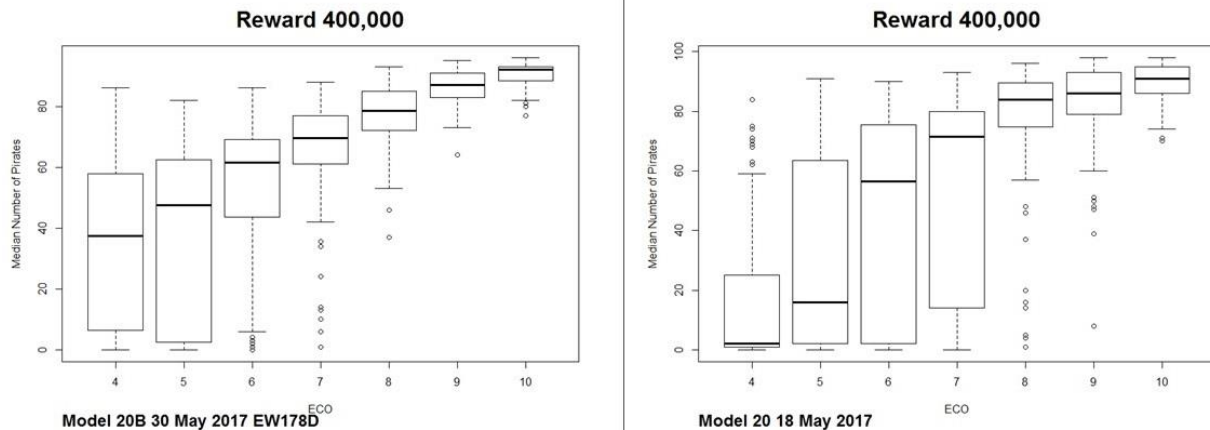
Figure 7-30. Box Plots of the median number of pirates for Reward 400,000 for 30 May 2017 BehaviorSpace experiment with Model 20B importing Exported World 178D for simulation initialization compared to 18 May 2017 BehaviorSpace experiment with Model 20 using random simulation initialization

IMPROVING HOW ECONOMIC OPPORTUNITY IS DEPICTED

Since the primary purpose of the model is to gain insight into the relationship

between the socio-political variables on the land and piracy at sea, an improvement was

made to the model, intended to bring refinement to the land portion of the model.

Specifically, how the people encounter their economic opportunity. There are many

refinements which could be made to the merchant ship flow and other aspects of the water

portion of the model. However, since, the purpose of the water side is to just provide the

necessary feedback to the land side with either the success or failure of the pirates, a

simplistic representation is adequate and no changes were made to the water side.

In the basic model, each patch of the land environment was randomly assigned an economic opportunity value during the set-up of the model, with the range of these values determined by the ECO slider on the model interface. The resultant random patterns of opportunity values across the land were depicted in figure 6-3 for ECO 1 and figure 6-4 for ECO 10. While this served as an abstract representation of economic opportunities available to the people, the representation can be improved by smoothing out the landscape to create a pattern that better represents *areas* of varying economic opportunity, with more gradual changes between the areas. This is done by diffusing[13] the initial random values assigned to the land. Figure 7-31 shows how the environment is displayed with ECO 1. The variations are smoothed out and while the economic opportunity values still vary from 91 to 100, the landscape appears much more uniform.

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[13] In Netlogo the diffuse command "Tells each patch to give equal shares of (*number* * 100) percent of the value of *patch-variable* to its eight neighboring patches. *number* should be between 0 and 1. Regardless of topology the sum of *patch-variable* will be conserved across the world. (If a patch has fewer than eight neighbors, each neighbor still gets an eighth share; the patch keeps any leftover shares.) Netlogo Dictionary. Accessed September 4, 2017, http://ccl.northwestern.edu/netlogo/docs/dictionary.html#D.

Figure 7-31. Initial Model setup with a diffused economic environment – ECO =1, Economic Opportunity on

Meanwhile figure 7-32 shows how the landscape is depicted when the ECO value is set at the other end of the scale at ECO 10. Here it is easier to see the variation, but much of the stochasticity has been reduced. Now when a person roams and experiences economic opportunity the values do not create drastic swings with each move.
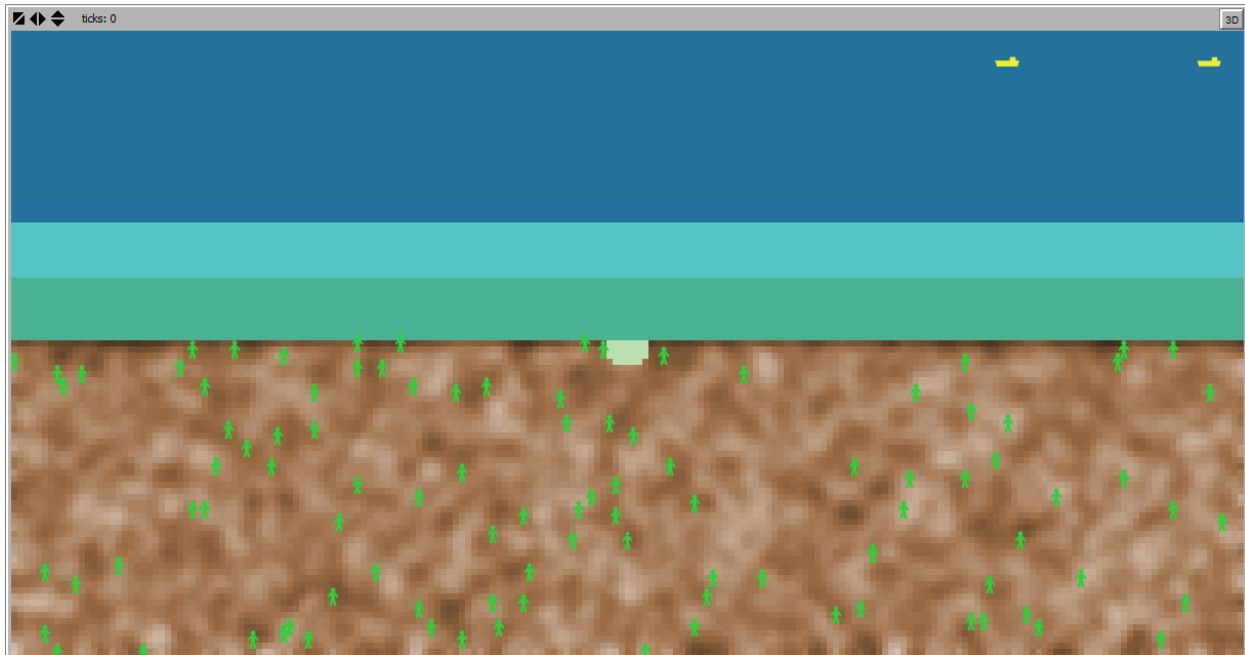
Figure 7-32. Initial Model setup with a diffused economic environment – ECO =10, Economic Opportunity on

REPEATED SIMULATIONS WITH A DIFFUSED ECONOMIC ENVIRONMENT

Once the model code was adjusted to diffuse the economic environment, similar BehaviorSpace experiments were conducted to compare the model performance between these two model variations. First, a BehaviorSpace experiment was done starting with the initial seed values of the model. Next an experiment was completed to provide a variety of exported worlds. These worlds were evaluated in the same manner as the exported worlds for the earlier model version. Then another BehaviorSpace experiment was conducted using one of these worlds as the initial conditions (starting with an imported world).

The world which was selected to be imported for the initial conditions was again a world resulting from an ECO setting of 7 and a Reward value of 250,000. At the time the world was frozen, there were a total of eight sorties which resulted in one captured ship. Six ships had successfully transited the shipping lane. A maximum of 18 people pirated and

at the time the world was exported there were eight pirates. Six of the pirates are out in

two skiffs, one of which was active in the shipping lane, while the other was waiting in the

port to re-sail. Of the other two pirates, one was making his way to the port and the other

pirate was waiting in the port for two more to man a skiff. The p-capture value is 0.125

while the current-p-capture value is 0.1. The expected reward is 248,227 and the SRT

value is 170. Figure 7-33 provides a visual of the frozen world.
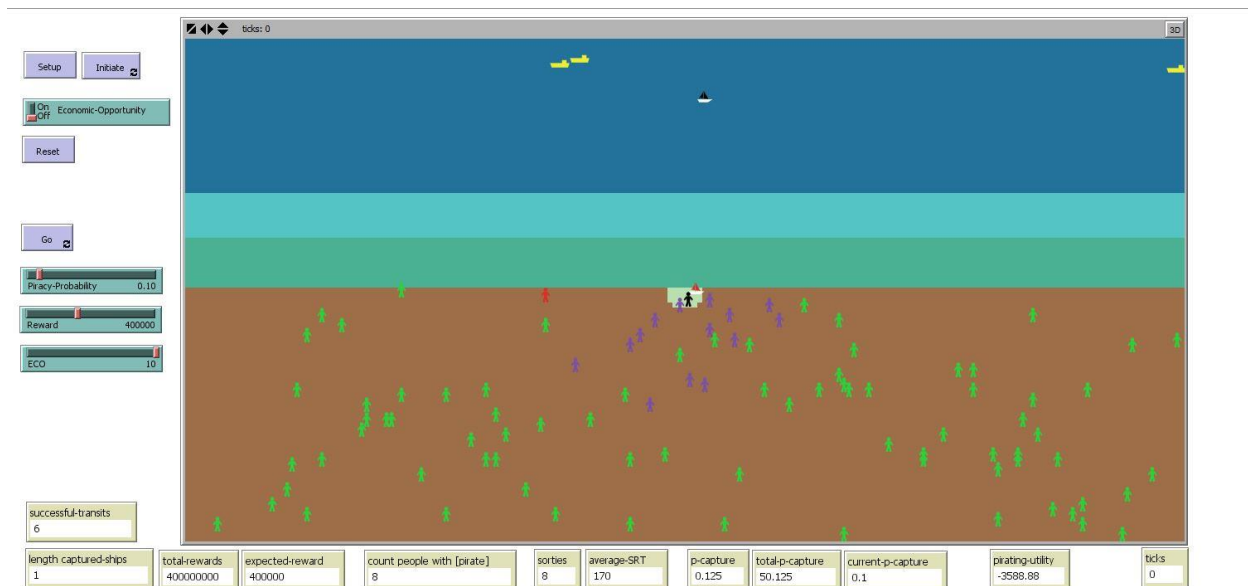
Figure 7-33. Initial model reset for model 21A with imported world 339E[14]

The expected result of running the model with the diffused environment was a

reduction of the stochasticity. While people were still roaming to determine their

opportunity, the eco-op values they encountered changed more gradually from patch to

patch. However, the results of the BehaviorSpace experiment with the diffused

[14] World 339E was the world produced by model run number 339 of 400 in the fifth BehaviorSpace experiment to evaluate exported worlds.

environment resulted in greater standard deviation and variance, not less. The mean value

for the standard deviation across the complete data set for the experiment, which used

Exported World 339E as the initial starting condition for each model run, was 14.494. In

comparison, the standard deviation for the non-diffused environment experiment, which

used Exported World 178D as initial starting conditions for each model run, was 9.888.

Mean variance was 327.4 as opposed to 151.668. Summaries of the data from these

experiments are provided in Appendix D.

Figures 7-34 and 7-35 provide a comparison of the box plots of the median number

of pirates for reward level 200,000 and reward level 400,000 from the two BehaviorSpace

experiments. These show that the increases in standard deviation and variance are not

consistent across all the ECO values. Given, that these results were not what was expected,

further experimentation is warranted. It is possible that the model code is not functioning

as intended. Alternatively, something unexpected may be occurring with this environment.
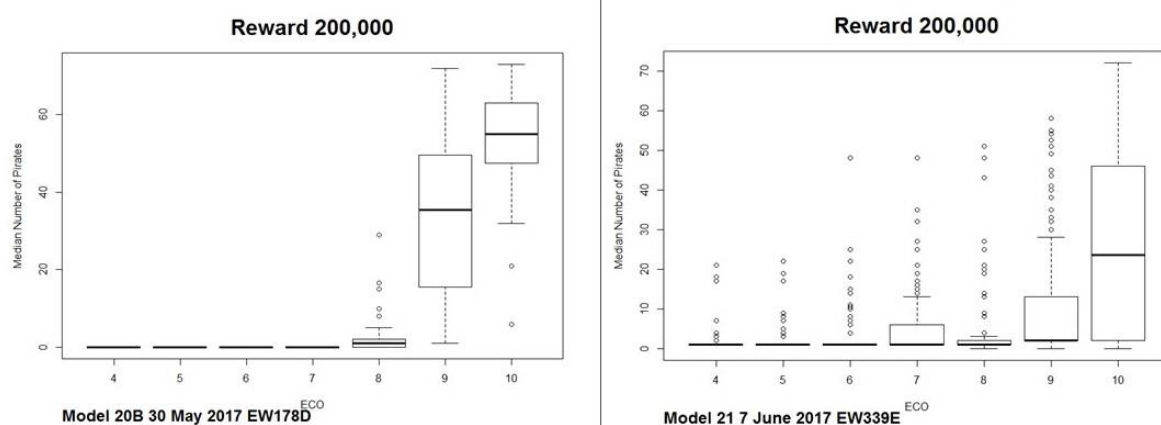
Figure 7-34. Box Plots of the median number of pirates for Reward 200,000 for 30 May 2017 BehaviorSpace experiment with Model 20B importing Exported World 178D for simulation initialization compared to 7 June 2017 BehaviorSpace experiment with Model 21 (Diffused Environment) importing Exported World 338E for simulation initialization
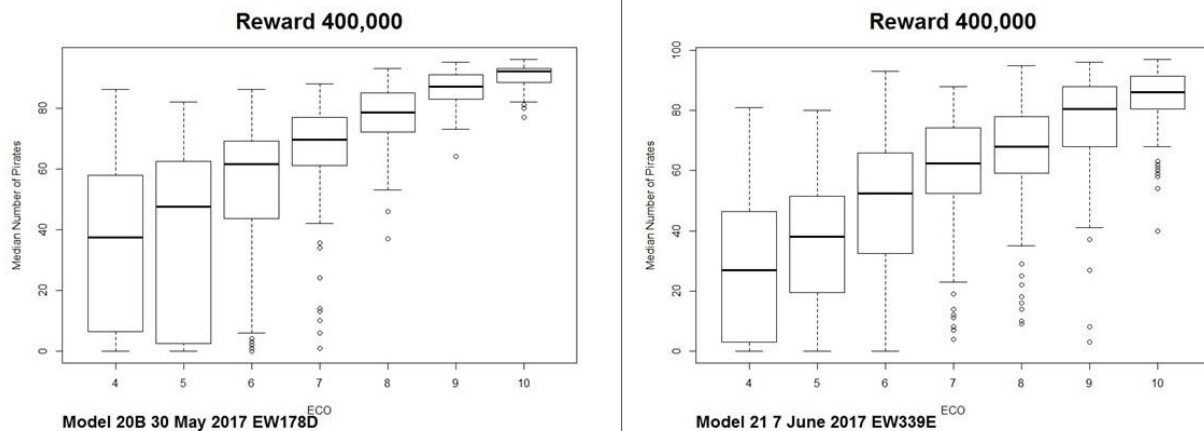
Figure 7-35. Box Plots of the median number of pirates for Reward 400,000 for 30 May 2017 BehaviorSpace experiment with Model 20B importing Exported World 178D for simulation initialization compared to 7 June 2017 BehaviorSpace experiment with Model 21 (Diffused Environment) importing Exported World 338E for simulation initialization

Table 7-4 provides a more detailed look at the data for the median number of

pirates by ECO and Reward values for the two experiments conducted with a frozen world

as the starting condition. The experiment that used the diffused landscape generally

produced a lower number of pirates, with some exceptions at the lower ECO values and

reward levels.[15] Typically, the mean of the median increases as the ECO values increases.

This was always true when the landscape was random (Model 20B). However, the data

from the diffused environment (Model 21A) provides two anomalies to this.[16] These data

anomalies also support the need for additional experimentation. A logical next step would

be to repeat the BehaviorSpace experiments; but switch the frozen worlds used as the

starting condition (use 339E for Model 20B and world 178D for Model 21A). This would

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[15] There 10 occurrence of Model 21A producing MORE pirates than Model 20B: At ECO 4 it occurs for Reward levels 300000, 350000, and 400000, for ECO 5 it occurs at Reward levels 300000 and 350000, for ECO 6 it occurs at Reward levels 250000 and 300000, for ECO 7 it occurs at Reward levels 200000 and 250000, and for ECO is occurs at Reward level 200000.

[16] For Model 20B the mean of median number of pirates DECREASED as the ECO value increased at Reward level 300000 (going from ECO 7 to ECO 8) and at Reward level 350000(going from ECO 6 to ECO 7).

allow for additional comparisons between the two models, starting with the same frozen

world.

Table 7-4. Comparison of Model 20B (random ECO values) to Model 21A
(diffused ECO values) for 100 iterations per variable pair. Model 20B used
frozen world 178D. Model 21A used frozen world 339E

ECO	Model	Mean of Median Number of Pirates
		200000	250000	300000	350000	400000
4	20B	0.0	2.0	5.6	15.1	29.5
	21A	0.0	0.0	13.9	29.7	40.2
5	20B	0.0	2.0	8.5	34.9	37.3
	21A	0.0	0.4	22.3	35.9	32.3
6	20B	0.0	2.0	18.2	40.9	54.1
	21A	0.0	6.2	25.9	34.2	40.2
7	20B	0.0	7.5	42.1	57.3	66.1
	21A	0.1	19.7	38.2	34.0	53.5
8	20B	1.7	41.4	54.8	65.9	76.6
	21A	2.2	26.1	36.6	48.2	59.8
9	20B	35.3	58.5	66.6	75.6	87.0
	21A	11.9	37.1	39.2	59.8	68.5
10	20B	54.1	68.5	76.8	86.1	90.8
	21A	25.8	37.5	52.1	69.3	79.4

SUMMARY

Let us review the motivation for the Piracy Opportunity Model and some of the main

efforts that went into its development. First the motivation; while there were other piracy

models, none of them focused on the sociological factors that motivate piracy. This model

offers a different approach from currently existing models. It explores how conditions on

land impact maritime piracy. Only by focusing on the socio-economic and socio-political

variables that encourage piracy can the true complexity of the issue be understood.

Because the data available to address this issue is very limited, an ABM provides a way to

critically think about the problem. The purpose of this model is not to predict future pirate

attacks or even piracy trends, but rather to illuminate core dynamics between the sociological conditions on the land and the piracy at sea.

The model was intentionally developed with light agents. By simplifying the details of certain aspect of the model, the focus is placed on the issues at the heart of the problem. As D. Scott Bennett has said, "Large models may run the risk that fundamental patterns will become lost as the parameter space for evaluations grows, and the effects of other assumed parameters become large, possibly concealing the possible dynamics of interest."[17] For this reason, just one of the possible sociological variables associated with piracy was selected. The model uses economic opportunity on land, specifically the individual agents' experience of this variable, to represent possible economic conditions that would motivate piracy. This allows for a parsimonious model that focuses on the specific relationship between the economic opportunity on land and the reward of pirating at sea. This does not mean that other sociological variables are not important. This model provides a baseline that can be easily extended in further work to explore those other variables.

The model takes a unique two models in one approach. It is comprised of two primary submodels; a land model and a water model. The land model uses a deductive approach that models the economic opportunity in a highly abstract manner. The water model, the primary function for which is to provide feedback to the land model, uses a more inductive approach by using the work already done in other piracy models, but in a simplified manner. There are no specific units assigned to the parameters in the model, these are kept generic. Relationship between units are relative with respect to time,

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[17] Bennett, 1.12.

distance and value. This allows for the model to remain non-specific, with utility across

many regional domains.

In many ways, the model is simple. However, this does not mean that designing the

model was a simple task. Much of the early part of the model development was focused on

getting the right relative relationships between the agents and variables. For example,

both the ships and skiffs operate at various speeds depending on the current operational

situation. These speeds are increments of their max speed. Yet the max speed for a ship is

2, while the max speed for a skiff is 3. This allows a skiff to travel faster than a large

merchant ship, and in the real world, this is in fact true. Another example is the amount of

fuel the skiffs start with. Each skiff has 100 units of fuel, which is decreased at a rate

related to the speed it operates at. However, the amount of fuel is clearly related to how

successful the skiffs are, as it determines how long they can remain at sea. Assign too much

fuel and the pirate success rate will increase; assign too little and none of the skiffs will

capture a ship. What these examples point to is the need for generic values to be balanced

such that the model performs in a way that represents realistic basic behaviors.

Once this was accomplished, we could see what kind of interactive dynamics are

generated from the simple rules the agents use to make decisions. While we could

anticipate a clear interaction between the ECO values and Reward levels, it is the

distinctive patterns that emerge from these interactions which are interesting. For each

reward level, a similar trend of increasing rates of piracy occurred with increases in the

ECO value. However, at lower reward levels the ECO value had a more dramatic effect on

the trend; while at higher reward levels the ECO value effect was more gradual. The

simulations suggest an ECO value tipping point at which the system moves from a state that

can sustain piracy, to one in which pirating competition drives down pirate activity. The implications of the model experimentation results are discussed in further detail in the Chapter 8.

Obviously, there is no lack of interesting potential additions to the current model. Some of these are relatively simple changes, that might need just a bit of experimentation to verify that the model changed as intended. Other additions could lead to far more interesting experiments. Even in the model's current relatively simple form, there is a great deal more that could be looked at and evaluated. Additionally, the model provides a base for far more complex modeling efforts.

CHAPTER 8

IMPLICATIONS AND FUTURE WORK

By keeping the model generic and relatively simple, the model utility is expanded. Unlike other models of maritime piracy, the parsimonious model developed in this work has utility across many specific regional domains. Model simulations suggest a clear interaction between the ECO value and the Reward level as figures 8-1 and 8-2 show.
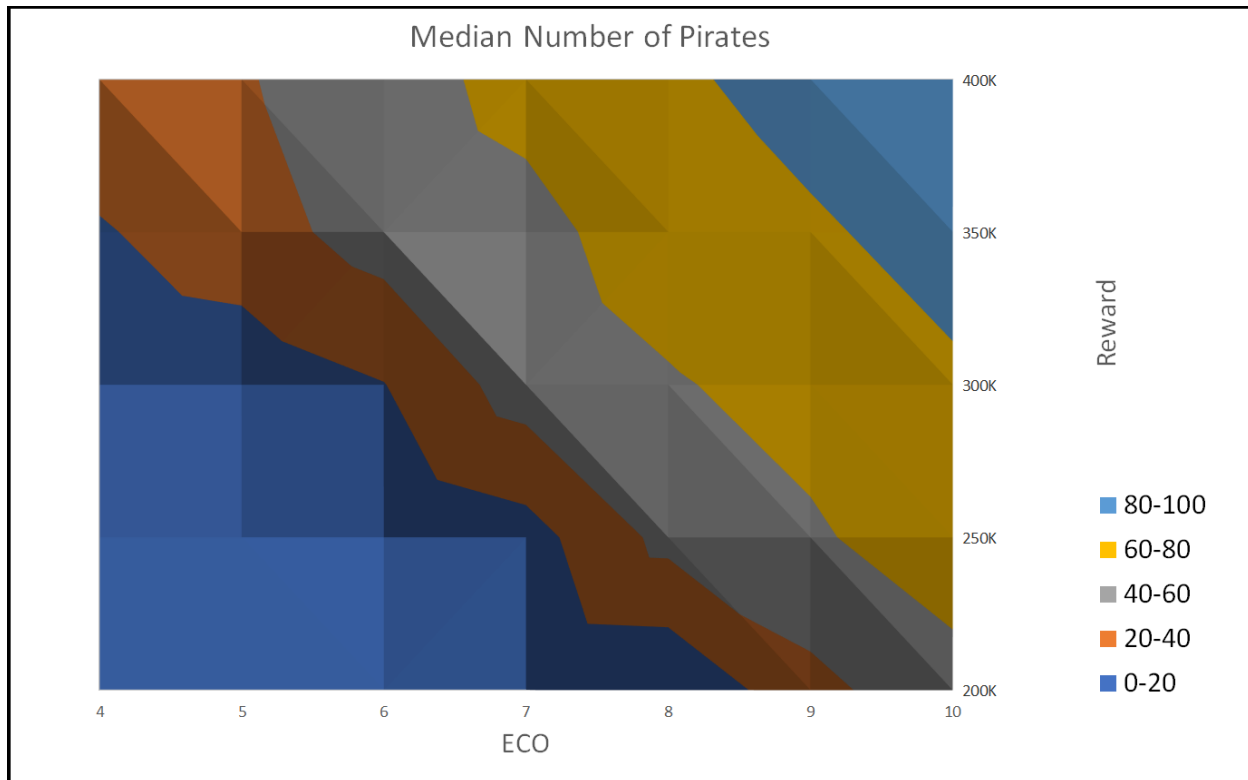
Figure 8-1. Median Number of Pirates for Model 20B 30 May 2017 BehaviorSpace Experiment

There are relatively stable regions of interaction between the variables, as measured by pirate population produced, at both ends of the tested spectrum (Low ECO

value with low reward level, and high ECO value with high reward level). These relatively

stable regions reinforce the expectation of the relationship between opportunity and

pirating. In the middle ranges of the interactions, there is a lot of volatility, with apparent

thresholds for the transition from the stable to volatile ranges. It is here, in these areas of

dynamic interaction, where we find the more interesting results of the model.
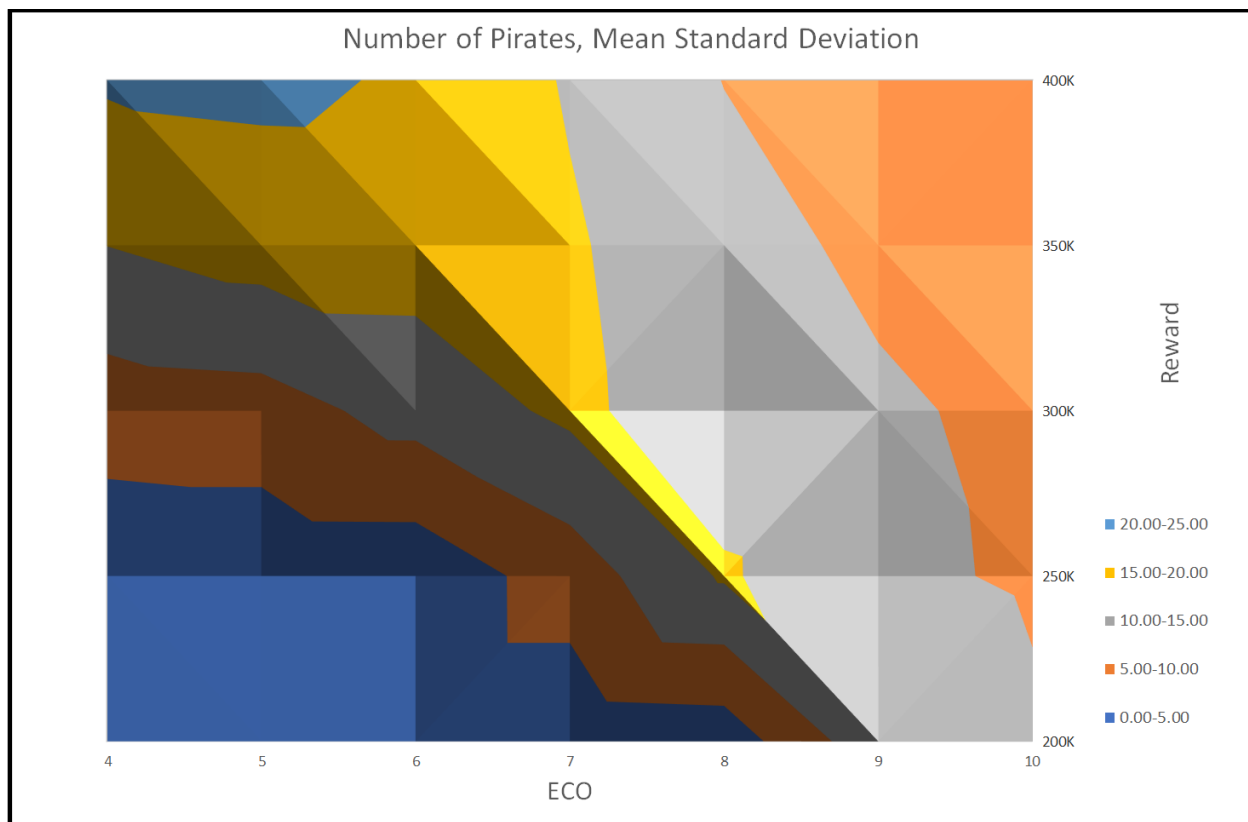
Figure 8-2. Mean Standard Deviation for Number of Pirates for Model 20B 30 May 2017 BehaviorSpace
Experiment

IMPLICATIONS

These results have important real-world implications. When the ECO value is low,

the economic opportunities are very good. In an environment with a healthy economy, it

makes sense that a low reward for piracy would have little or no pull. Thus, we see no

piracy occurring in these ranges. Alternatively, when the ECO value is high, the economic

opportunities are poor. In a weak economic environment, the model shows a lot of piracy

with the highest incidences of piracy at the high reward levels. However, the transition

across the range of values is not linear. The system dynamics which are occurring in

between these two alternatives are the most interesting.

For each value of ECO, there is a range of low reward values where no piracy occurs.

This implies conditions where the reward for piracy is not adequate to compensate for the

risks, including the cost, of pirating. As the reward level increases, there is a point at which

a few people become willing to pirate. At this threshold, the model is very sensitive to the

outcome of the initial pirate sorties. If the first few pirate skiffs fail to capture a ship, no

one else will pirate. If the first few skiffs are successful, others will decide to pirate. If

some of these skiffs succeed in capturing a ship a stable pattern of piracy will emerge. The

sensitivity of the model to the success or failure of the initial skiffs suggests that a strong

international response, early in the development of pirate activity in a region, may be

particularly critical. Counter-piracy operations which stop or at least limit the initial

successes are likely to play an important role in preventing the development of an

entrenched pirating culture in a region.

The simulations suggest the existence of an ECO value tipping point. Below this

point the model produces stable patterns of on-going piracy. Between the threshold for

piracy and this tipping point, the number of people who decide to pirate generally

increases as the ECO value increases (indicating progressively poorer economic

opportunities). The ECO value at which this tipping point occurs increases in conjunction

with the reward level. Once this tipping point is passed, the number of people who decide

to pirate is significantly decreased. This implies that when the system crosses this tipping

point, the system cannot support the level of piracy pulled by the expected reward. Pirate

competition creates a crowd-out effect which dampens the system and the success rate of

the skiffs significantly decreases.

The real-world implications of this are that a crowd-out effect can significantly

reduce the overall success rate of pirating. This provides a possible explanation for why

there was a decrease in the percentage of successful attacks during the height of the Somali

pirate crisis (See figure 5-1). From 2009 through 2011, the success rate of global pirate

attacks dropped to approximately 50 percent from the average of 70 percent (See table 5-

2). The data for just the Horn of Africa, where the Somali pirate crisis occurred, also

supports the idea of competition crowding out the success rate of pirate attacks. The data

is provided in table 8-1. From 2004 to 2007, the success rate was about 30 percent.

 Starting in 2008, the number of attacks began to really spike. Initially the success rate

increases, but then in 2009 the total number of attacks more than doubles. The number of

successful attacks remains almost steady. With a significant increase in the number of

failed attacks (attempted attacks) the success rate drops. The number of attacks more than

doubled, while the success rate was nearly cut in half. In 2010, the success rate

temporarily improved. This can be attributed to the extended range of the pirate attacks as

discussed in Chapter 2.[1] The number of attacks continued to rise in 2011, and we again see

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[1] The Piracy Opportunity Model has a fixed generic area for the attacks. Skiffs currently have a standard amount of fuel which limits their range. An increase the fuel could simulate extending the skiff's range.

a drop in the success rate. After 2011 all the numbers trend downward, but we know there was a variety of counter-piracy operations being conducting at that time.[2]

Table 8-1. Actual and Attempted Pirate Attacks for the Horn of Africa 2004-2016[3]

ATTACKS	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
ACTUAL	3	16	6	12	44	48	65	48	16	2	0	0	0
ATTEMPTED	7	29	14	32	67	167	152	189	59	13	11	0	2
TOTAL	10	45	20	44	111	215	217	237	75	15	11	0	0
% successful	*30*	*35*	*30*	*29*	*40*	*22*	*30*	*20*	*21*	*13*	*0*	*0*	*0*

It should, however, be noted that the parameters used to test the model might be amplifying this emerging behavior. Both the ECO value and Reward levels are integer values. We therefore do not have continuous data. It is possible that what appears to be a tipping point is brought on by the integer nature of the variables. Additionally, while the increment between the ECO values is as small as possible at one, the increment between the Reward levels is 50,000. This means there are many untested variable combinations between the values the BehaviorSpace tool sampled. Further experimentation should be done to test small increments of Reward levels.

When stable patterns of piracy emerge, there are oscillations in the quantity of pirates that resemble the patterns produced by a predator-prey model. These patterns

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[2] It is necessary to again emphasize the limitation of available piracy data. We do not know what percent of all attempted attacks were reported. It is also possible that the increased risk of a pirate attack, in conjunction with the presence of operating maritime security forces, provided added incentive for reporting attempted attacks.   If so, this would skew the trend by amplifying the decrease in pirate success rates.
[3] This data was compiled from the ICC IMB Annual Reports from 2004-2016.

emerged despite the model limiting the ships to a constant population of three. It would be interesting to further investigate the predator-prey relationship of piracy.

The model was not designed to predict occurrences of piracy. Yet, when thinking about these implications, the critical question is whether real-world patterns of maritime piracy can be reproduced from a simulated environment that begins with socio-economic and socio-political conditions ashore? Can we grow piracy? The decision to use the Fragile State Index variables was encouraged by the ability to later compare the model results with real-world piracy data. The model could be run using a specific state's index values and the results compared to the data for that region. But we should hold that thought for now.

The real value of a parsimonious model is its ability to elegantly portray the relationship between the fewest possible predictor variables. Since I was thinking I needed to represent the various socio-economic and political variables that influence piracy I began looking for data sources to support the process which would later help me validate the model's performance. When I needed to simplify the parameters, I selected the variable that I felt had the most influence on the issue. As Murphy says, "unless there is money to be made piracy will not happen."[4] Therefore I selected the economic opportunity variable to start with.

By this very process I was biasing my model design and limiting the opportunity variable to being "economic" opportunity. In reflecting on the results of the model and the possible broader applications, I realize the variable, as abstract as it is, could simply represent opportunity. Without the bias of thinking it represents economic opportunity the variable becomes more powerful. Simple, generic opportunity can represent the wider

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[4] Murphy, 2012, 509.

variety of variables. It can represent economic opportunity as intended in my model, but it can also represent a permissive legal environment that allows piracy to happen and the limitations imposed by the physical environment due to demographic pressures.

For this reason, further work should be done with the model to explore this more general opportunity variable. (The broader interpretation of the variable would be considered when making changes to how opportunity is represented in the world environment.) An important reason for modeling is to illuminate the core dynamics of the system. These dynamics should be further explored without the bias of the variable being limited to economic opportunity. As the saying goes – even the best models are wrong because they are after all just a model. But as Epstein has emphasized, "Simple models can be invaluable without being 'right' in an engineering sense… They are illuminating abstractions."[5] These thoughts will be expanded on in the future work portion of the chapter.

Now we return to the thought about the expansion of the model to possibly predict piracy. The model developed for this dissertation uses just the one economic variable. Since we know that there are multiple variables that contribute to piracy we should not expect to find good results when comparing this model with real-world data. By that I am referring to trying to compare the amount of piracy produced from the model at specific ECO values to the amount of piracy resulting from states with similar ECO values. The reasons for this are twofold. First, the current model uses an abstraction that does not allow for the variable to quantified, and as just discussed, this means it may better represent generic opportunity than economic opportunity. Secondly, we know that

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[5] Epstein, 2008, 1.12.

extracting just one of the indicators from the FSI does not allow us to represent a particular

state very accurately. Rather, the current model should be considered a baseline model

which can be expanded to include other sociological variables. Then the model results for a

particular combination of variable setting for ECO, DP, SEC and SL could be compared with

the amount of piracy attributed to a state with that same combination of variable values.

Bayes' analysis can be used to think about how adding other sociological variables to the

model would affect the decision to pirate or not-pirate.

BAYES' ANALYSIS

Bayes' analysis allows us to think about conditional probabilities. From the baseline

model, we could calculate the probability that a person will decide to pirate or not-pirate

based on the ECO value and Reward level. This would result in a series of utility functions;

one for each ECO value which estimate the probability for pirating at each possible reward.

Then when we have additional information about the environment, we would want to

update our expectations with that new information. To do this we can use Bayes' theorem:

$$P(A|B) = \frac{P(A)P(B|A)}{P(B)}$$

The theorem states the probability of A given outcome B, is the probability of A

times the probability of B given outcome A, divided by the probability of B. It is primarily

used to apply new information to revise probabilities based on old information. The

probability of A occurring can be updated with what we know about the occurrence of B.

These probabilities are often referred to by these terms: *P(A)* is the prior probability;

P(B|A) is the conditional probability, sometimes referred to as the likelihood; *P(B)* is the

marginal probability; and   *P(A|B)* is the posterior probability.

The total probability law allows for us to consider multiple prior probabilities such

that:

$$P(B) = \sum_{i=1}^{n} P(A_i)P(B|A_i)$$

Applying this to Bayes' rule we get:

$$P(A|B) = \frac{P(A)P(B|A)}{\sum_{i=1}^{n} P(A_i)P(B|A_i)}$$

Thus, "Bayes' rule provides a means for computing posterior probabilities from the

known prior probabilities *P(A)* and the conditional probabilities *P(B|A₁)* for a particular

situation or experiment."[6] With an understanding of Bayes' rule we can next consider the

technique of Baysesian inference. This technique allows us to update the validity of a

hypothesis (*H*) as we gain additional evidence (*e*) related to the hypothesis:

$$P(H|e) = \frac{P(H)P(e|H)}{P(H)P(e|H) + (1 - P(H))(P(e|H'))}$$

Where *P(e|H)* is the probability for the evidence if the hypothesis is true and *P(e|H')* is the

probability for the evidence being observed if the hypothesis is false. The values assigned

to *P(e|H)* and *P(e|H')* are values based on expert judgement. [*P(e|H)* + *P(e|H')* does not

have to equal 1]

As described by Pinto and Garvey in their book *Advanced Risk Analysis in*

Engineering Enterprise Systems, the hypothesis and evidence can be thought of as nodes.

Figure 8-3 depicts the evidence node *e₁* acting on the hypothesis node *H*. The equation can

be rewritten to specifically reflect *e₁*:

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[6] Pinto and Garvey, 57.

$$P(H|e_1) = \frac{P(H)P(e_1|H)}{P(H)P(e_1|H) + (1 - P(H))(P(e_1|H'))}$$
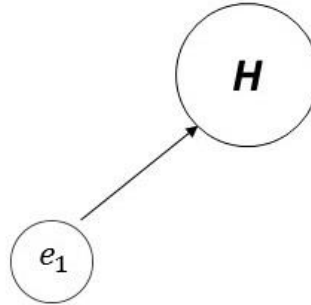
Figure 8-3. Evidence acting on Hypothesis

As additional evidence presents itself the equation can be updated to reflect the impact of that evidence. This is depicted in figure 8-4.
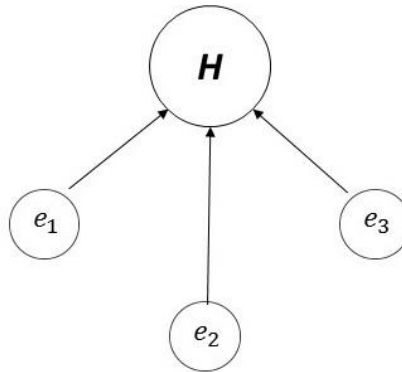
Figure 8-4. Additional evidence acting on Hypothesis

The equation can first be updated to reflect the impact of e_2:

$$P(H|e_1e_2) = \frac{P(H|e_1)P(e_2|H)}{P(H|e_1)P(e_2|H) + (1 - P(H|e_1))(P(e_2|H'))}$$

And again, to reflect the impact of e_3:

$$P(H|e_1e_2e_3) = \frac{P(H|e_1e_2)P(e_3|H)}{P(H|e_1e_2)P(e_3|H) + (1 - P(H|e_1e_2))(P(e_3|H'))}$$

Additional evidence nodes can be added by following this pattern.

This can be used to help us think about how the environmental conditions could impact a person's decision to pirate. Let us return to the additional socio-economic and socio-political variables from the Fragile State Index that were discussed above. Take an individual living in a coastal state who is deciding if they should turn to piracy. Let us assume that the individual is initially ambivalent about the decision so there is a 50% chance they will decide to pirate and 50% chance that they will not pirate. Instead of the generic H for hypothesis we can substitute a p to represent the probability of pirating. Therefore, the $P(p)$ is 0.50 and the $P(p')$ is 0.50, where p represents pirating and p' represents not-pirating.
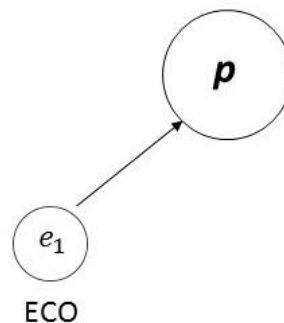
Figure 8-5. Environmental conditions acting on piracy probability

However, the conditions in that state present the individual with certain challenges which would influence that decision. Evidence of a worsening economic condition (ECO) could be judged to impact the individual decision such that $P(e_1|p)$ is 0.90 and $P(e_1|p')$ is

0.25. With this information, we can calculate the revised probability that the individual will decide to pirate using the equation above for $P(p|e_1)$.

$$P(p|e_1) = \frac{P(p)P(e_1|p)}{P(p)P(e_1|p) + (1 - P(p))(P(e_1|p'))}$$

$$P(p|e_1) = \frac{(0.50)(0.90)}{(0.50)(0.90) + (1 - 0.50)(0.25)}$$

$$P(p|e_1) = 0.783$$

Next let us consider the impact of demographic pressures (DP). The individual sees evidence of climate change which is reducing his ability to earn a decent living. In this case perhaps *P(e₂|p)* is 0.85 and *P(e₂|p')* is 0.30. Using the equation for $P(p|e_1e_2)$ we calculate:

$$P(p|e_1e_2) = \frac{P(p|e_1)P(e_2|p)}{P(p|e_1)P(e_2|p) + (1 - P(p|e_1))(P(e_2|p'))}$$

$$P(p|e_1e_2) = \frac{(0.783)(0.85)}{(0.783)(0.85) + (1 - 0.783)(0.30)}$$

$$P(p|e_1e_2) = 0.911$$

Last let us consider the impact of a weak state security apparatus (SEC) such that an individual does not think there will be legal repercussion for engaging in piracy. Here we will assume *P(e₃|p)* is 0.75 and *P(e₃|p')* is 0.10. Using the equation for $P(p|e_1e_2e_3)$ we calculate:

$$P(p|e_1e_2e_3) = \frac{P(p|e_1e_2)P(e_3|p)}{P(p|e_1e_2)P(e_3|p) + (1 - P(p|e_1e_2))(P(e_3|p'))}$$

$$P(p|e_1e_2e_3) = \frac{(0.911)(0.75)}{(0.911)(0.75) + (1 - 0.911)(0.10)}$$

$$P(p|e_1e_2e_3) = 0.986$$

From this we can see that an individual who is initially ambivalent about pirating, can, with mounting evidence of a lack of alternatives, be nearly sure to make the decision to pirate.
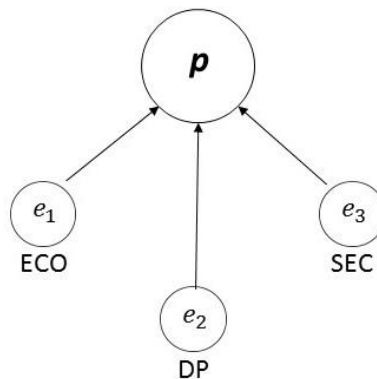
Figure 8-6. Multiple factors acting on piracy probability

Obviously, this merely an illustrative example since we do not have real values for each of these situations. More importantly, each individual would likely have different values for each of these evidence nodes based on their own personal values and their estimation of the risks involved in the situation. Still, this mental exercise illuminates how various environmental variables could have a cascading impact on individual's probability of turning to piracy. In the example described here each of the nodes increased the probability that a person would decide to pirate. Improving conditions could instead decrease the probability. To think about this situation, we would simply use the appropriate probabilities in the conditional probability equation. Just imagine that node e_1 provides evidence of an improving economic condition (ECO) such that $P(e_1/p)$ is only 0.25 and $P(e_1/p')$ is 0.80. With this information, we would calculate the revised probability that

the individual will decide to pirate, just as we did before, using the equation above for

$P(p|e_1)$.

$$P(p|e_1) = \frac{P(p)P(e_1|p)}{P(p)P(e_1|p) + (1 - P(p))(P(e_1|p'))}$$

$$P(p|e_1) = \frac{(0.50)(0.25)}{(0.50)(0.25) + (1 - 0.50)(0.80)}$$

$$P(p|e_1) = 0.238$$

In the scenario of a weakened economy the probability went from 50 percent to

nearly 80 percent, while in the improving economy scenario the probability dropped to just

a little more than 20 percent.

ENHANCING CURRENT RESULTS

On the simple side of future work, more experimentation could be done to improve

the evaluation of the trends that emerged from the given parameter space. This should be

done with the consideration of a more generic meaning for opportunity. There are three

methods for expanding the experiments already done on the model. These would allow for

more precise analysis of the sensitivity of the model by more fully exploring the parameter

space of the model. First, the model produced clear trends despite the amount of variation

between the runs of the BehaviorSpace experiments. It is possible that the amount of

variance would be more precisely quantified if the experiments are conducted with a

higher number of iterations per variable pair. Second, most of the BehaviorSpace

experiments were conducted with a 2000 time-step limit. Since many of the model runs

still had pirate activity occurring at this time, it would be useful to expand the time-step

limit to evaluate how long the system can sustain pirate activity. For efficiency purposes, a

stop condition could be added to the model code to end a simulation when pirate extinction occurs. This would allow only the simulations with active pirating to continue and would aid in evaluating the conditions which sustain piracy. Third, the increments between the Reward levels could be reduced to provide a more complete set of data. This would be useful for better understanding the apparent thresholds and tipping points in the frequency of piracy.

Lastly, the focus of this work was on the number of pirates produced by the economic opportunity conditions of their environment when evaluating the relative risk and reward of piracy. This may not be the best parameter to concentrate on. Alternatively, the individual skiffs might provide a better indication of the emerging dynamics. Table 8-2 provides the mean of the captured ships data from three separate BehaviorSpace experiments. The data from model 20A was done with random initial starting conditions. model 20B used exported world 178D as the initial starting condition. Exported world 339E was used as the initial starting condition for the diffused environment produced by model 21A.

Table 8-2. Comparison of capture data

Mean of Captures

Model 20A 13 Sep 2017

ECO	200000	250000	300000	350000	400000
4	0.0	0.0	0.0	7.4	9.2
5	0.0	0.0	1.6	10.9	11.9
6	0.0	0.1	12.6	10.6	16.5
7	0.1	12.4	12.8	15.4	21.8
8	11.3	15.5	17.5	23.5	24.5
9	18.3	17.6	23.2	25.7	27.8
10	20.7	22.1	26.4	27.8	28.4

Model 20B EW178D 13 Sep 2017

ECO	200000	250000	300000	350000	400000
4	1.0	1.0	4.5	9.4	14.2
5	1.0	1.0	5.2	16.3	16.1
6	1.0	1.1	8.8	17.6	22.4
7	1.0	3.9	18.5	23.9	26.4
8	1.5	18.5	23.3	26.3	28.3
9	17.7	24.9	26.3	27.3	29.6
10	23.6	27.8	27.8	29.9	30.3

Model 21A EW339E 8 June 2017

ECO	200000	250000	300000	350000	400000
4	0.0	0.0	7.4	14.0	18.4
5	0.0	0.1	10.9	16.4	14.7
6	0.0	3.2	12.4	15.1	17.1
7	0.0	10.0	17.2	15.5	20.1
8	1.3	12.5	15.7	19.0	22.2
9	5.9	16.6	16.6	22.6	24.2
10	11.5	15.6	20.3	24.6	26.5

Looking at capture data emphasizes the effect of beginning the simulation with a world that already has three active skiffs. We see ships captures in zones where we previously had none. Generally, each zone also had more captures; however, there are exceptions. For example, with Reward 200,000 there were just over 11 captures for ECO 8

with the random starts. With the imported world, there were less than 2 captures for that same reward level. Comparing the results for the model with the diffused landscape (model 21A) to the earlier model 20 results emphasizes the generally lower rate of captures, but again, a reminder that further experimentation is warranted for model 21 to verify that it is operating as intended.

Since the focus of the modeling effort was to provide insights into the dynamics occurring on the land, we should be cautious about shifting the focus to the skiffs. The focus should remain on the people/pirates but could be expanded to include consideration of the skiff success rate. This would also lay the ground work for exploring different skiff manning requirements and different types of piracy.

MODEL IMPROVEMENTS

There are two types of improvements that can made to the model.   The first are what I like to call housekeeping improvements. These are improvements that tweak the model code to clean-up various items which were not accounted for, or to allow for additional testing of the model as it now exists. The second kind of model improvements would expand the scope of the model or increase the utility of the model. These can be thought of in terms of model extensions.

Housekeeping Improvements

Port Deadtime: As discussed in Chapter 6, the time a pirate waits in the port for other pirates to man a skiff is not accounted for. Since three pirates are required to man the skiff, this time varies depending on which one of three pirates is waiting. The first

pirate to arrive waits the longest while the third pirate does not wait at all. Because this waiting time is not accounted for, the utility function that people use to determine if they are going to pirate ignores this issue. This could be accounted for by creating a variable that measures how many time-steps (ticks) a pirate roams around the port until they are assigned to a skiff. Similar to the variable SRT, that measures how long a skiff is gone from the port on a sortie, this new variable, call it Port Deadtime (PDT), could be averaged and then added to average-SRT.

Recall the equation for pirating utility:

$$U_p = \frac{R*p}{m} - (O * t)$$

Where t is the average-SRT value. Now we would have t = (average-SRT + average-PDT). The average-PDT would need to be seeded with an initial value, just like average-SRT was. This would require running some basic experiments while measuring PDT, calculating the average of these values, and using that to seed the model. An artificial average would initially be used until the first skiff is manned. At that time, the value could shift from static to dynamic and be continually updated with each pirate's real-time wait to man a skiff. This improvement would decrease the pirating utility. How much effect it would have on the functioning of the model would depend on how significant the value of this new variable, PDT, turns out to be.

Related to the issue of time spent waiting for a skiff, there is no limit to how long a pirate will wait. This is unrealistic. Once the data is gathered to determine what an average wait time is, a reasonable limit could be established. If a pirate is in the port beyond this amount of time, they would simply return to roaming on the land without ever

going on a pirate sortie. A pirate is apt to wait in the port an excessive amount of time if they arrive just before a skiff returns from an unsuccessful sortie. The failure to capture a ship drives the pirating utility below what is need for people to decide to pirate. If there are other sorties in progress, this might be a temporary situation – until a capture drives the pirating utility back up. If, however, it is the last sortie, or there are no future captures, it will be a permanent issue and pirating activity will cease for that model run. In this case imposing a limit on how long a pirate will wait in the port is academic and would have no real effect on how the model simulation runs. In the former situation, where the low pirating utility is only a temporary situation, a limit on port wait time would prevent the average-PDT variable from becoming skewed by the few pirates who would be waiting in the port an excessive amount of time. Alternatively, preventing a pirate from lingering in port for an indefinite amount of time would make it more difficult for the model to recover from a near extinction scenario, because it would be unlikely for three pirates to accumulate over an extended amount of time.

Additional Sliders: The current model is set up to provide the same number of people (100) and the small number of ships in the shipping channel (3) for each model run. Each of these could instead be determined by a slider switch on the model interface which would allow for a range of values for these variables to be explored. It is reasonable to consider modifying the model to allow this since these two values were arbitrarily selected. Similarly, a slider could be added to the model interface to determine the minimum manning requirement for the pirate skiffs. In the current model, this is set to three as this seemed to be a reasonable number for a small skiff. A slider would allow for exploration of the impact of other manning levels.

Model Extensions

The development of the diffused world was an extension to the basic model. As discussed in Chapter 7, the initial results of testing this environment call for further experimentation. Since it would be useful to shift between the two models, with and without the diffused environment, a slider could be added to the interface to allow this. Four other potential model extensions will be discussed in this section. All these extensions build on the current model without significantly changing its basic design. Each of them is focused on the people/pirates. Extensions to the water side of the model will be discussed in the section about model expansions.

Pirates Returning to Roaming: An easy extension could add a variable that tracks the individual people's status as pirate or non-pirate. This would allow analysis of the conditions under which they are most influenced by the changing risk associated with pirating. Currently, pirates continue to assess their opportunities as they make their way to the port. If the situation changes while they are headed to the port, they can return to a non-pirate status and go back to roaming on land. The model does not track the frequency with which people flip back to non-pirates before they reach the port. This phenomenon is readily visible when the model is running. People, originally green, turn red when they decide to pirate and black once they reach the port. If they decide not to pirate before they get to the port and flip back to roaming, they turn yellow. (Pirates who return to port after an unsuccessful sortie turn purple when they return to roaming.) Thus, the model clearly depicts this behavior of flipping from pirate to non-pirate but does not provide a way to easily quantify it or assess it. This ability could be particularly illuminating in evaluating

the model with the diffused landscape as it should highlight the impact of different landscape values on the piracy dynamics.

Pirates Learning: A second extension to the model would allow pirates to learn. In the current versions of the model, the pirates gain no advantage from successful sorties. Yet we know that pirates do learn and become more successful as their tactics improve. A model extension that allows the pirates to adapt to their success would depict this advancement of pirate tactics. This could easily be simulated by increasing the amount of fuel the pirate skiff has, since that determines how long the skiff can hunt for a target. Having more time to patrol would increase the probability of finding a ship to attack. The success of each pirate is currently tracked by the variable "pirate-success." This variable keeps track of the number of successful pirate attacks each pirate is involved in. The sum of the variable for the pirates assigned to the skiff could be used along with some multiple to increment the amount of fuel the skiff has.

Interestingly, an increased amount of skiff fuel will impact the SRT value. Rather than remaining near the seed value of 170, it would gradually increase as skiffs are able to patrol longer. This in turn would impact the pirating-utility function. As SRT increases, the lost opportunity for pirating will increase. Therefore, the perceived reward for pirating would need to be greater for a person to make the decision to pirate. This would be a reasonable reflection of the fact that as individuals engage in a behavior, they often need to have increasing gains to continue with that activity.

Social Interaction: Third, people could have social networks. In the current model, people are assumed to be rational actors and are able to constantly assess the value of pirating. Each person acts individually, without directly considering what the other people

are doing. By endowing the people with social networks, the model would be able to account for the influence other people often have on a person's decisions. People who are networked would have greater influence than those that are not.

Frozen Worlds: The last extension returns to the issue of using a frozen world as a starting point for model experimentation. As described in the Exported World section, it is extremely difficult to determine which world is the best to use. A wide variety of potential frozen worlds exists. These worlds can be categorized by how many people decide to pirate and how successful they are. Adding a selector switch for multiple frozen worlds would allow more than one world to be evaluated and compared in the same experiment. This would allow for greater exploration of interesting initial model conditions.

Each frozen world would represent a possible scenario. They could be worlds which were frozen at different points in the boom and bust cycles the model typically traverses. In terms of the predator-prey model, one world could portray piracy on an upswing of the cycle and another world could portray piracy on a downswing. There could be a world selected relatively early in a simulation before the system had a chance to stabilize and a world which was frozen during a more stable phase of the simulation. Alternatively, the worlds could be classified by the success of the pirates up to the time the world was frozen, especially if this extension is combined with the extension to allow pirates to learn. This would allow a world with a few very successful pirates (pirates with advanced skills) to be compared to a world with more, but less successful pirates.

MODEL EXPANSIONS

Here I consider future work which would involve much greater changes to the basic model.

Predator-Prey: The model produced patterns of piracy similar to those of the predator in a predator-prey system. This occurred despite the lack of ability of the ship (prey) quantity to adjust to the pirate attacks. Real-world factors impact the shipping density along designated sailing routes and shipping lanes. Adding a dynamic flow of shipping traffic[7] would allow the predator-prey relationship between the pirates and ships to be further explored. Such a model would have to account for more of the economic variables that impact a ship's decision concerning what route to sail. Some of these variables might be the cost of marine insurance, cost of added counter-piracy measures, the presence or lack of maritime security units along the route, as well as the availability of alternative routes. A cost-based analysis of these factors, versus the risk of a pirate attack, would determine if the ship sails through that shipping channel or not.

To fully explore this relationship, sliders should be added for the population of people and the quantity of ships considering transit of the shipping lane. Additionally, since the current model uses a static representation of opportunity, the predator-prey exploration should be combined with further refinements to how opportunity is portrayed such that opportunity is consumed and restored at varying rates.

Additional Fragile State Index Variables: As already discussed in the implications section, more than one sociological variable influences a person's decision to pirate. The current model was reduced to one variable for simplicity. This was a necessary step in the

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[7] This sort of simulation for shipping traffic was discussed in some of the models reviewed in Chapter 3.

development of the model. Following more sensitivity testing of the current model,

additional variables could carefully be added one at a time.   Some of these variables, such

as demographic pressures could be added to the patches. Other variables, like state

security, would be better represented as another agent set. Each additional variable adds a

layer of complexity to the model and exponentially expands the model's parameter space.

Agent Enhancements: This model assumes the agents are rational actors and that

they all perceive risk in the same way. Clearly this also is a simplification of reality. In the

real-world how people view risk varies from person to person. Some are risk averse while

others are more willing to take risks. Adding a risk perception trait to the people would

allow for this dynamic to be explored. Not only would this impact the individual decisions

to pirate or not, but the risk perceptions of the skiff crews could be factored into the

decision of the skiff to go after a particular target. In real life, pirates likely go through a

decision process on whether they should attack a particular ship. In a model where each

ship has its own risk profile, based on the type of ship and its preparedness, some ships

would be riskier targets than other. The pirates might be better off waiting for an easier

capture or higher reward.

We also know that while it is easier to think about people being rational actors who

make logical decisions, real people make emotional decisions. Joshua M. Epstein has done

work to create agents with greater cognitive realism.[8] He calls these Agent_Zero; they are

endowed with passion as well as reason. Each Agent_Zero develops their own relationship

between these entities as a result of their social interactions. This description simplifies

Epstein's work which is based on neurocognitive research of human behavior. The point is

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[8] Epstein, 2008.

that as work such as Epstein's continues to advance, agents such as his Agent_Zero could be used to evaluate which conditions on land *grow* piracy.

Water Model Enhancements: Much could be done to enhance the waterside of the model. As already discussed in some of the other enhancements, real world shipping volume is not static. A more sophisticated method for providing ships (not just a quantity slider) could be added to the model to make the flow of ships more realistic. Ships could vary by their type, flag, readiness etc., each presenting their own unique risk profile. Currently, the ships only vary in their reward value. An even more sophisticated enhancement would account for the pressures to the system that result from increasing insurance rates. The ship's ability to detect the pirates could be improved, allowing for evasive actions to occur. In this event, the water model depth delineations would take on new meaning as ships would be more limited in where they could go than the skiffs.

Another way to enhance the water model would be to put maritime security forces back into the model. These could be added with a selector switch determining if they are present or not. The addition of security forces would be particularly interesting in evaluating the predator-prey relationship since this would add an additional factor to the system. When piracy is intense, this should attract naval units which will drive down the reward of piracy, but when piracy is less intense, naval units are likely to be redeployed away, creating more opportunity for piracy.

Ultimately, the model could evolve to the extent that it will provide a risk assessment of the piracy potential for a given region based on the socio-economic and socio-political variables for that state. This information could be used as an additional

factor to assess overall risk profile of a ship.[9] Only by understanding the whole picture, to

include what motivates the pirates, can a merchant vessel truly assess its piracy risk.

ADDITIONAL THOUGHTS ON MODEL ENHANCEMENTS

Great care should be taken before embarking on the process to include any of the

above-mentioned enhancements. Clear goals should be defined for the enhancement. Once

that is done, the enhancement should be implemented in an incremental process that

allows verification that each added element is performing as intended.   As Wilensky and

Rand advise: "Start simple and build toward the question you want to answer."[10]

Throughout this work one should remember that "simple explanations are better than

complicated ones if both are equally good at explaining."[11] The more that gets added to a

model, the more difficult it is to focus on the basic relationship between the essential

elements of the system. Eventually, the model will reach what is sometimes referred to as

the paradox of enrichment. At this point, an increase is resources no longer improves the

system; instead the system becomes less stable.[12]

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[9] Chapter 4 discussed maritime risk assessment processes used by ships.
[10] Wilwensky and Rand, 196.
[11] Gilbert, 32.
[12] This idea is developed from the Leigh Van Valen's "Red Queen Hypothesis" (1973).

CHAPTER 9

CONCLUSIONS

The focus of this dissertation is on a small subsystem of a larger complex system. By concentrating on the impact of maritime piracy on the international shipping enterprise, a gap in our understanding of the motivation for piracy was identified. The purpose of the model developed in this work is to help us study the impact of socio-economic and political variables on incidences of maritime piracy by providing insights into the relationship between specific variables. The model serves as a proof of concept. Rather than trying to account for all the elements of this issue, the model focuses on core components of the relationship we want a better understanding of. The insights gained here can then be applied back to the larger system to improve our overall understanding of maritime safety and security.

The research design for this work borrowed from the emerging discipline of engineering enterprise systems. Maritime piracy is a complex problem that impacts a complex enterprise system. Given these complex dimensions, the challenge was to determine how we can improve our understanding of the piracy problem. The goal of the research was to provide an enriched understanding of pirate activity which can be used to inform relevant policy making. The critical question, for dealing with maritime piracy: Is it more effective to concentrate efforts on land than to expend limited resources on added maritime security?

The research began by surveying existing models of maritime piracy. This highlighted the fact that all the models are focused on the dynamics of piracy that occur on

the water. None of the models consider what motivates piracy in the first place. To develop a more holistic understanding of the social, political, and economic environments associated with maritime piracy, its history and evolution were reviewed. The concept of risk was next considered with a multidisciplinary approach. Enriched with this background, I set about to develop a model which would provide new insight into the problem of maritime piracy.

By keeping the Piracy Opportunity Model generic and relatively simple, the model utility is expanded. Unlike other models of maritime piracy, the parsimonious model developed in this work has utility across many specific regional domains. Model simulations suggest a clear interaction between the ECO value and the Reward level. These results have important real-world implications. The transition across the range of values which allow incidences of piracy to increase is not linear. The model is very sensitive, at threshold values, to the outcome of the initial pirate sorties. This suggests that an international response, early in the development of pirate activity in a region, may be particularly critical.

Most importantly, the simulations suggest the possible existence of tipping points and crowd-out effects. While the basic findings from the model reinforce the static implication that poverty and lack of governance drive piracy. The dynamic findings illuminate the non-linear relationship between the variables. Further research to better understand the sensitivity of this issue should be conducted. This would begin to allow policy makers to determine if it is better to expend limited resources on humanitarian efforts ashore or on counter-piracy operations at sea. Better insight into these dynamics could identify when it is better to focus on improving conditions on the shore and when it

is necessary to reduce, and if possible eliminate, pirate capabilities ashore.   These two

options represent the proverbial carrot and stick methods of dealing with the problem.

The model indicates that there are situations when one method would be better employed

than the other and vice versa.

As already stated, maritime piracy is a complex problem. We know that there are

multiple variables associated with the issue. Economic opportunity is just one of these

variables. There is value in further exploring the dynamics produced by the model with a

more generic interpretation of opportunity. While in some ways it may appear that the

parsimonious model produced by this work is overly simplistic with its focus on simple

piracy, I argue that this is exactly what we need to do with complex problems. They need

to be dissected into digestible bites. A parsimonious model may appear simple, but they

are not simple to construct and fully test. Their elegance is revealed by the basic

relationships they illuminate. These relationships are typically hidden from us by all the

chaff in a complex system.   Therefore, the Piracy Opportunity Model is a small, but

important, step in the process of fully understanding maritime piracy.

The model has broader application for other security issues where actors decide to

engage in illegal activities because of a lack of other opportunities and/or the high payoff

for the activity. Drug running and transiting of migrants are examples of other activities

that could be similarly modeled.   Additionally, while this work is explicitly concerned with

maritime security, there are broader implications for security studies in general. Complex

problems lend themselves to being thought of in terms of a system. That system is part of a

larger, more complex system. When dealing with a specific issue, expanding the scope of

consideration can provide new insights. Cross-disciplinary approaches are particularly

well suited to this since they offer varying approaches to the problem under consideration, highlighting information which would have been overlooked by a narrower approach.

Of course, it is necessary to conclude by pointing out some of the other attributes of maritime piracy, which some may consider critical, that are not present in this model. For example, there is no agent identity in terms of ethnicity or tribal relation, political or religious affiliation. Yet, I have made the argument in Chapter 2 that maritime piracy has strong cultural connections. The role of the media is ignored. The amount of media attention incidences of piracy get may directly impact the perception of how high the risk of an attack is. Conversely, media coverage of the judicial consequences of pirate apprehension may impact the pirate's risk calculations. The role of insurers is not considered, but we know it adds another layer of complexity to the problem.

In closing, I would like to circle back, one more time, to the distinction between dangers and risks which Beck makes. Dangers are caused by nature, while risks are caused by people. Maritime piracy is a man-made issue. It is a risk we can trace back to ancient times. It emerged as a contemporary security issue in the first modernity, but now must be considered in light of the characteristics of the second modernity. Underemployment and global risks such as climate change and financial market crashes have a role in defining our 21st century risks. If we want to address the risk of maritime piracy more effectively, we must expand our understanding of the problem. We must consider the issue with an understanding of the pluralization of modernity and account for the socio-economic and socio-political variables involved.

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APPENDIX A

PIRACY OPPORTUNITY MODEL CODE

This appendix provides the final version of the computer code for the Piracy Opportunity Model. It has been annotated to make it more understandable.

GENERAL NOTES ABOUT NETLOGO CODE

NetLogo automatically color codes portions of the model code, those color codes have been used with this code:

Green – Keywords [breeds, end, globals, patches-own, to, to-report, turtles-own]

Blue – Primitives: Commands and reporters that are built into NetLogo.

Commands are actions for the agents to carry out. Reporters carry out some operation and report a result either to a command or another reporter.

Red – Inputs: Values that the command or reporter uses in carrying out its actions.

Purple – Built-in variables

Semicolons are used to add comments to the program. These comments can make the code easier to read and understand.   To simplify this appendix those semicolons have been removed and the comments are italicized. The exception to this are lines of code which have been commented out – those are still preceded with a semicolon.

GENERAL NOTES PRIOR TO THE ACTUAL CODE

- The world is set to be 200x100 with the origin in the center.
- Patch size is 6.

- Wrapping is turned off.
- Updates are set to happen on ticks.
- Water patches are shaded to represent a shipping lane with shallower water on the landward side (bottom).
- Land patches CAN be shaded by their eco-op value IF economic-opportunity is turned on. *The patch values are not affected by the switch.*
- There are three breeds of agents: people, (pirates), skiffs, ships (Merchant ships aka pirate targets).
- The shape for "merchant ship" was created with the shape editor while "boat" and "person" shapes were imported from the library for skiffs and pirates.

ABM CODE

globals
[
 threshold
 land - *patches that are land*
 port - *patches that make up the port (they are also land patches)*
 port-pirates - *list of pirate's turtle numbers that made it to the port*
 minimum-manning - *number of pirates it takes to man a skiff*
 successful-transits - *number of times a merchant makes a successful crossing*
 captured-ships - *list of merchants captured*
 pirating-utility - *value for pirating, calculated using Piracy-Probability, reward and opportunity*
 p-capture - *probability of successful piracy*
 total-p-capture - *sum of the p-capture values for each tick*
 current-p-capture - *total-p-capture divided by ticks*
 total-rewards - *total value pirated*
 expected-reward - *average payoff*
 sorties - *number of skiff sorties*
 victory-party - *amount of time that a skiff remains in port after a successful capture*
 SRT-list - *list holding skiff run times, to be used in earlier version to determine the seed value of average-SRT*
 total-SRT - *total of all skiff at sea time*
 average-SRT - *average number of ticks a skiff is at sea - initially seeded with historical data and then dynamically determined*
 number-of-pirates - *list consisting of the number of people with pirate Boolean true each tick*
 average-number - *mean of number-of-pirates*
  ]
- Globals with Capital First Letters are set on the interface
- Reward is a slider on the interface to set the initial/seed value of pirating reward
- Economic-opportunity is a switch on interface, used to display the land in shades of brown depending on the value of eco-op

- ECO is a slider on the interface to adjust the opportunity of land patches

patches-own
 [
  eco-op - *random number related to ECO slider that people use to compute expected value of wandering*
  land-patch - *a Boolean to make it easier to keep the wandering people on land patches*
 ]

turtles-own []

breed [people person]
people-own
 [
   opportunity - *average of the last ten eco-op values they have encountered by wandering.*
   pirate - *Boolean which determines if they will pirate or not, false - no pirating, true - make way to port and pirate.*
   assigned-to-skiff - *Boolean*
   skiffnumber - *ID of skiff person is assigned to (this is not being used, for now the skiff keeps track of the pirates-on-board)*
   experience - *pirate's experience goes up for successful captures, down for empty cruises*
   pirate-success - *count of the times a person successfully pirates*
   decision-list - *a list of eco-op values obtained as person wanders to different patches. The decision-list is initially seeded with values using the same equation used to assign values to patches.*
 ]

breed [skiffs skiff] *(Pirates in small boats)*
skiffs-own
 [
   opmode - *operating mode of skiff*
   maxspeed
   speed
   max-fuel
   fuel
   attack-range - *this is a combination of how far the skiff can see and the range where it decides to attack*
   course
   patrol-range - *distance from port that the skiff travels before it starts patrolling*
   prey *when a merchant is detected, it is assigned as the current 'prey', in case there is another merchant nearby*
   return-to-port-tick - *remembers the tick when the skiff returned port after a cruise*
   pirates-on-board *pirates on board is a list of the turtle numbers of people associated with that skiff*
  at-sea-ticks - *measures how many ticks a skiff spends at sea*
 ]

```
breed [ships ship] (Ships - Pirate targets)
ships-own
 [
   maxspeed
   speed
   eastbound (Boolean)
   captured (Boolean)
   captor - ID of skiff that made attack
   successful-passage
   payoff
 ]
```

Main Setup

```
to Setup
  clear-all
  setup-global-values
  setup-patches
  setup-people
  setup-ships
  reset-ticks
end
```

```
to setup-global-values
  set sorties 0 - running total of pirate sorties (normally would be in setup skiffs, but that is
not called during setup)
  set victory-party 50 - skiff stay-in-port time after a successful capture, in ticks
  set successful-transits 0
  set captured-ships [] - initial list contains nobody
  set expected-reward Reward - seed until first capture
  set minimum-manning 3 - sets the crew size of a skiff, skiff cannot sail without full crew
  set number-of-pirates []
  set p-capture 0.1
  set total-p-capture p-capture
  set current-p-capture p-capture - this is set because the calculation doesn't start until there
are ticks and current-p-capture would otherwise initially be ZERO
  set SRT-list [] - used to get some data for SRT to get initial seed value
  set total-SRT 170000 - total Skiff at sea time, starts large to mitigate initial swings
  set average-SRT 170 - initial seed value of SRT
end
```

```
to setup-patches
   set land (patch-set patches with [pycor < 1]) - land is at the bottom
   set port (patch-set patches with [(distancexy 0 0) < 4 and (pycor < 1)]) – the port is
located around the origin
```

```
  ask patches - Water patches are colored to create a shallow zone toward the land, half of the
world is land
  [
   if pycor < 11 and pycor > 0 [ set pcolor 76 ]  -  shallow water near land
   if pycor > 10 and pycor < 21 [ set pcolor 85 ]  - territorial water
   if pycor > 19 [ set pcolor 94 ] - international water/shipping lane
   set land-patch false - used to test for land when people are moving to neighbors
  ]
 ask land
  [
   set pcolor 35
   set eco-op (100 - (ECO * random 10)) - assigns an eco-op (economic opportunity) value to
each land patch INCLUDING THE PORT - based on the ECO value selected on the slider on the
Interface.
   set land-patch true
  ]
  ;; repeat 5 [diffuse eco-op 0.5]  This is the code used to diffuse the land patches if desired
  if economic-opportunity
    [ ask land [set pcolor scale-color brown eco-op 0 100 ]
    ] - displays eco-op values in shades of Brown - somewhat chaotic looking.
 ask port
  [
   set pcolor 58
   set eco-op 100
  ]
end

to setup-people
  set port-pirates [] - a list of the people that are pirates in the port area, but not assigned to
a skiff.  Available for crew
  create-people 100
  ask people
  [
  move-to one-of land with [not any? turtles-here]
  set shape "person"
  set color lime
  set size 3
  set pirate false
  set assigned-to-skiff false
  set skiffnumber -1
  set experience 0
  set pirate-success 0
  set decision-list n-values 10 [100 - (ECO * random 10)] - this seeds the initial values of
'decision-list' with numbers similar to those assigned to land patches
  ]
end
```

```
to setup-ships (Merchant ships)
 create-ships 3
 ask ships
 [
   set shape "merchant ship"
   set size 6
   set color yellow
   set maxspeed 2
   set speed (.5 * maxspeed)
   set successful-passage false
   set captured false
   set captor nobody
   set payoff random-normal Reward 30000
   ifelse random 2 = 1 (coin flip)
    [set eastbound true
     set heading 90
     set xcor (-99 + random 40)
     set ycor 40 - random 3]
    [set eastbound false
     set heading 270
     set xcor (99 - random 40)
     set ycor 46 - random 3]
 ]
End
```

*** Main Loop***

```
to Initiate
 move-people
 move-ships
 move-skiffs
 calculate-intercept-probability
 if ticks = 500 -  amount of ticks prior to exporting the world: can be changed
  [
   export-world "ECOpiracy.cvs"
   stop
  ]
 tick
end
```

```
to Reset
 let tempECO ECO
 let tempreward reward
 import-world "ECOpiracy.cvs" - the file name can be changed to import a specific world
 reset-ticks
```

```
  clear-all-plots
  random-seed new-seed
  set ECO tempECO
  set reward tempReward
  ask skiffs
  [
  set return-to-port-tick 500 - return-to-port-tick - this accounts for the ticks getting reset to
0 so the resail happens at the right time for skiffs already inport; it will set the variable to 500
for skiffs at sea but that will get set to the current tick if they return with prey
  ]

  update-variables
end

to update-variables
  setup-patches
  set total-rewards Reward * 1000 – reduces model sensitivity to the first few skiff runs
  set expected-reward Reward - seed until first capture
  set number-of-pirates []
end

to Go
  move-people
  move-ships
  move-skiffs
  calculate-intercept-probability-forIW - Uses the calculation for the imported world
  tick
end
```

Main loop subroutines

```
to move-people
  analyze-pirate-statistics
  ask people
  [
Check pirate status
    if not pirate
      [
      if any? neighbors with [(not any? people-here) and land-patch] - check to make sure
adjacent land patches are not all occupied
        [
         move-to one-of neighbors with [(not any? people-here) and land-patch] - move to a
random empty neighboring patch, making sure that it is on land
        ]
      set decision-list fput eco-op but-last decision-list - update decision-list with new eco-op
and drop off 10th value
```

```
    set opportunity sum decision-list / 10 - calculate average of decision-list,
    set pirating-utility (expected-reward * current-p-capture / minimum-manning) -
(opportunity * average-SRT)
    if pirating-utility > opportunity - compare opportunity to reward for pirating
     [
      set pirate true
      set color red
     ]
    ]
The rest of this loop controls the people that have 'pirate' set to true
   if (pirate and color = red)
    [
      face one-of port
      forward 1
      set pirating-utility (expected-reward * current-p-capture / minimum-manning) -
(opportunity * average-SRT)
      if pirating-utility < opportunity - compare opportunity to reward for pirating, may
change decision while on the way to the port
      [
       set pirate false
       set color yellow - so we can see when someone changed decision to pirate on the way to
the port
      ]
     ]
   if (pirate and (member? patch-here port)) - arrived at the port
    [
      set color black
      if (not assigned-to-skiff and not member? who port-pirates)
      [set port-pirates lput who port-pirates] - add turtle ID to back end of list that contains
all the available pirates in the port area
     ]
   if (pirate and color = black)
    [
      face one-of port - mill around port
      forward 1
      if count people with [(pirate and not assigned-to-skiff) and color = black] >= minimum-
manning - enough unemployed pirates in port, hatch a skiff and associate skiff with these
pirates
      [
       let crew sublist port-pirates 0 minimum-manning - crew is the first group of pirates
available in the port (accounts for two or more pirates arriving during same tick)
       hatch-skiffs 1 [orient-skiff self crew] - send the skiff turtle number and the crew to the
subroutine
        foreach crew
```

```
        [ask turtle ?   - sets boolean for each pirate onboard outbound skiff, then hide them, so
they don't show in the port. They will be unhidden if the skiff returns to port unsuccessful so
they can return to roaming
          [set assigned-to-skiff true
            hide-turtle
          ]
        ]
      set port-pirates sublist port-pirates minimum-manning (length port-pirates)
 - removes the pirates (crew) from the list port-pirates
      ]
    ]
]
  end

to orient-skiff [skiff crew] - initializes the new skiff
  ask skiff
  [
    set shape "boat"
    set color black
    set size 4
    set xcor random 4 - 3
    set ycor 0
    set opmode 1 - transiting out to patrol area opmode, skiff's sail color changes with most
changes of status
    set prey nobody
    set course random 100 - 50
    set heading course
    set patrol-range 39
    set maxspeed 3
    set speed (.3 * maxspeed)
    set max-fuel 100 - seems to affect p-capture greatly
    set fuel max-fuel
    set attack-range 6
    set pirates-on-board crew - assigns the turtle numbers of the 'crew' to this skiff
    set sorties sorties + 1 - counter for total number of skiff cruises
    set at-sea-ticks 0
  ]
end

to move-ships (Merchant ships)
  ask ships
  [ - check to see if merchant reached the edge of the map
   if ((xcor = 100 or xcor = -100) and not successful-passage)
   [
    set successful-passage true
    set successful-transits successful-transits + 1
```

```
    hatch-ships 1 [orient-ship self]
     hide-turtle - hide the ship, hatch a new one
    ] - now check to see if any skiffs close by
    ifelse any? skiffs in-radius 7 and not captured
     [
       set speed maxspeed – try to outrun the skiff
       set color red
     ]
     [
       set speed .5 * maxspeed
       set color yellow
     ]
    if captured - test to see if captured
     [
       set color black - merchant follows pirate back to port
       set heading towards captor
       set speed ([speed] of captor)
     ]
     forward speed - continue on course
    ]
end

to orient-ship [ship] - initializes the new merchant ship
  ask ship
  [
   set shape "merchant ship"
   set size 6
   set color yellow
   set maxspeed 2
   set speed (.5 * maxspeed)
   set successful-passage false
   set captured false
   set captor nobody
   set payoff random-normal Reward 30000
   ifelse random 2 = 1 (coin flip)
    [
     set eastbound true
     set heading 90
     set xcor -99
     set ycor 40 - random 3
    ]
    [
     set eastbound false
     set heading 270
     set xcor 99
     set ycor 46 - random 3
```

```
    ]
  ]
end

to move-skiffs
- opmode 1 is transiting from the port to a patrol area; generally black sail
- opmode 2 is loitering on patrol
- opmode 3 is chasing a target ship; sail turns gray
- opmode 4 is when a target is captured; sail turns red
- opmode 5 is attacked a target - but target not captured; sail turns blue for repelled attack
- opmode 6 is low fuel status - transiting back to port; sail turns yellow
- opmode 7 is inport; sail turns brown when skiff resails after "victory party" (50 ticks)

  ask skiffs
  [
    let attack-failed false - temporary boolean to flag deterred or repelled attacks
    if ((opmode = 1 or opmode = 2 or opmode = 3) and fuel - 3 < (distancexy 0 0)) - running
out of fuel, return to port
      [ set opmode 6
        set color yellow
        set speed (.3 * maxspeed)
        set course towards one-of port
      ] - now test for each opmode and conditions needed to shift opmodes
    if opmode = 1 and (any? ships in-radius attack-range with [not captured]) - merchant
detected while in transit
      [chase]
    if opmode = 1 and ((distancexy 0 0) > patrol-range) - made it to patrol distance, shift to
opmode 2 loiter
      [
        set opmode 2
        set speed (.05 * maxspeed)
        set course one-of [90 270]
      ]
    if opmode = 2 and (not any? ships in-radius attack-range) - loiter/patrol
      [
        if ycor < 30 [set course 320 + random 80] - stay out where ships are
        if ycor > 46 [set course 140 + random 80] -  stay away from northern edge of world
        if not can-move? 1 [set course (course + 100 + random 100)] - turn away from east-
west edge of world and perform patrol wiggle
        set course course + random 20
        set course course - random 20
      ]
    if opmode = 2 and (any? ships in-radius attack-range with [not captured]) - merchant
detected while loitering
      [chase]
    if opmode = 3 and (not [captured] of prey) - opmode 3 is chasing mode
```

```
    [
      set course towards prey
      let templist1 list (maxspeed) (1.4 + distance prey)
      set speed min templist1
    ]
    if (opmode = 3 and ([captured] of prey) and (([captor] of prey) != self))
     [ set opmode 1 - merchant is captured by someone else, return to patrolling
     ]
    if opmode = 3 and distance prey < 2 and (not ([captured] of prey)) - this tests to make
sure skiff caught up to; also checks to make sure the ship has not been captured by another
skiff
      [
        if random 10 < 4 -  3 in 10 chance that the merchant repels attack, based on 70% real-
world success rate
          [
           set attack-failed true
           set color blue
          ]

         ifelse attack-failed
         [
           set opmode 5 - attack failed or was deterred, return to port
           set speed (.3 * maxspeed)
           set course towards one-of port
           set prey nobody
         ]
         [
           set opmode 4 - successful capture, return to port, tell merchant to follow
           set color red
           set speed (.3 * maxspeed)
           set course towards one-of port
           ask prey
            [
             set captured true
             set captor myself
            ]
         ]
      ] - end of the big captured in opmode 3 if loop

    - opmode 4 and 5 tests
    if opmode = 4 and (member? patch-here port) - reached port with a prey, shutdown
     [
      set opmode 7
      set SRT-list lput at-sea-ticks SRT-list
      set total-SRT total-SRT + at-sea-ticks
      set average-SRT total-SRT / (1000 + sorties)
```

```
    ask prey
     [
      set captor nobody
      set captured false
      set captured-ships lput who captured-ships - update the list of those ships that have
been captured, for later analysis
      set total-rewards total-rewards + payoff
      set expected-reward total-rewards / (sorties + 1000) - adjustment for initializing
model sensitivity

      hatch-ships 1 [orient-ship self] - hatch new ship, call subroutine to initialize it
      die
     ]
    foreach pirates-on-board
    [ask turtle ?
      [
        set experience experience + 10  - crew get experience for successful capture – not
used in the current model.
        set pirate-success pirate-success + 1 – keeps track of how many times this pirate has
been successful.
      ]
    ]
    set speed 0
    set prey nobody
    set return-to-port-tick ticks - time holder, this skiff will sail after a cool-down
     ]
   if (opmode = 7 and (ticks > return-to-port-tick + victory-party)) - successful cruise, send
them back to sea
    [
     set opmode 1
     set color brown
     set prey nobody
     set course random 100 - 50
     set speed (.3 * maxspeed)
     set fuel max-fuel - consideration for future version - experienced skiffs carry more fuel?
     set at-sea-ticks 0
     set sorties sorties + 1 - counter for total number of skiff cruises
    ]
   if (opmode = 5 or opmode = 6) and (member? patch-here port) - reached port due to
repelled attack or low fuel - shutdown
    [
     set expected-reward total-rewards / (sorties + 1000) - adjustment for initializing
model sensitivity
    set SRT-list lput at-sea-ticks SRT-list
    set total-SRT total-SRT + at-sea-ticks  ;;
    set average-SRT total-SRT / (1000 + sorties)
```

```
     foreach pirates-on-board - send the crew back to roaming, in port, but colored violet,
opportunity should stay high inside port area
       [ask turtle ?
        [show-turtle
         set pirate false
         set color violet
         set assigned-to-skiff false
         set skiffnumber -1
         set experience experience - 5 – reduce experience after failed sortie
        ]
       ]
      Die - kill this skiff, no reason to keep it
      ]
    set heading course
    forward speed
    set fuel fuel - speed
    set at-sea-ticks at-sea-ticks + 1
   ] - end of ask skiffs loop
end

to chase - skiff sighted a merchant, gives chase
 set opmode 3
 set prey one-of ships in-radius attack-range
 set speed maxspeed
 set course towards prey
 set color gray
end

to calculate-intercept-probability
  let total-ships length captured-ships
  let total-time ticks + 1 -  this accounts for the 0 tick and the divisor is never zero when
calculating current-p-capture
   if (ticks > 0) and (total-ships >= 1) - there has be a ship captured before p-capture will
become dynamic
   [
    let ideal-p-capture total-ships / sorties - this is the actual value based on captures, but we
can't tolerate rapid jumps.  Also, it changes when a skiff leaves port, not when it returns - pros
and cons to this.
    ifelse (ideal-p-capture - p-capture > .03)
    [
     set p-capture p-capture + .01
    ]
    [ - small change, use the new ideal
     set p-capture ideal-p-capture
    ]
   ]
```

```
   if ticks > 0
   [
    set total-p-capture total-p-capture + p-capture
    set current-p-capture total-p-capture / total-time
   ]
end

to calculate-intercept-probability-forIW - calculation used for "to Go" with an inported world
  let total-ships length captured-ships
  let total-time ticks + 501 - this account for the 0 tick and the 500 ticks of the inported world
  if (ticks > 0) and (total-ships >= 1) - there has be a ship captured before p-capture will
become dynamic
   [
    let ideal-p-capture total-ships / sorties  - this is the actual value based on captures
     set p-capture ideal-p-capture
   ]
   if ticks > 0
   [
    set total-p-capture total-p-capture + p-capture
    set current-p-capture total-p-capture / total-time
   ]
end

to analyze-pirate-statistics
  set number-of-pirates lput (count people with [pirate]) number-of-pirates
  set average-number mean number-of-pirates
end
```

APPENDIX B

MODEL CODE WITH DEVELOPMENT NOTES

This appendix provides expanded computer code which shows the process of

evolution for the Piracy Opportunity Model. Lines of code which are "commented out"

using semicolons remain to show how the code evolved. The lines of code that are

highlighted show aspects of the model which were totally deleted when the model concept

was significantly changed or simplified. The same general notes found in Appendix A about

NetLogo color coding of the computer code pertain. General comments which remained in

the final version of the model have been italicized to distinguish them from the older

commented out code and to simplify the code presented here.

GENERAL NOTES PRIOR TO THE ACTUAL CODE

- The world is set to be 200x100 with the origin in the center.
- Patch size is 6.
- Wrapping is turned off.
- Updates are set to happen on ticks.
- Water patches are shaded to represent a shipping lane with shallower water on the landward side (bottom).
- Land patches CAN be shaded by their eco-op value IF economic-opportunity is turned on. *The patch values are not affected by the switch*
- There are three breeds of agents: people, (pirates), skiffs, ships (Merchant ships aka pirate targets)
- The shape for "merchant ship" was created with the shape editor while "boat" and "person" shapes were imported from the library for skiffs and pirates.

RECORD OF WORKING PROTOTYPES

The following notes reflect the model's evolution:

The _1 version sets up the patches with colors for shipping lane and does initial set-up of pirates, ships and units

The _2 version only made minor changes

The _3 version adds in a variable for the number of security units

The _4 version begins to add set-up details

The _5 version starts to work with fragility and corruption. Fragility come from the Fragile State Index where 0 = most stable. Corruption comes from Transparency International's Corruption Perception Index - lower score is more corrupt

The _6 version expands the world to 200 x 100 and moves the origin to the center. This allows for half of the world to be "land" represented by brown patches - this is where pirates will begin

The _7 version shifts the orientation from vertical to horizontal to account for the added complexity of having the breed of people. Pirates are changed to skiffs and are hatched when there are enough pirates (people who decide to pirate)

The _8 version only made minor changes

The _9 version solved the issue of assigning specific people (turtle ID) to a hatched skiff using the list port-pirates and the sublist command

The _10 version shifts the variables from Fragility and Corruption to individual indicators from the fragile state index:
>   Demographic Pressures (DP)
>   Poverty and Economic Decline (ECO)
>   State Legitimacy (SL)
>   Security Apparatus (SEC)

The _11 version incorporated skiff, ship, and unit operation from an earlier project

The _12 version incorporates calculations for the utility of wandering on land and compares that to utility of pirating

The _13 version incorporates the utility function for pirating. This function uses the piracy-probability, reward and the individual's opportunity value to determine the value of pirating.

The _14 version adjusts the utility function for pirating to use dynamic values for total-rewards and p-capture. Since the utility function will not work with zeros these variables are given initial values and do not become dynamic until after the first ship is captured.

The _15 version includes the skiffs resailing after a successful cruise (with a victory-party delay). Unsuccessful skiffs discharge their crews (violet) and die. Still working on the pirating utility equation

The _16 version adds a variable to measure how long a skiff is at sea, another variable is added for the averageSRT (skiff-run-time), averageSRT is seeded with historical data but becomes dynamic when the model is run and is used to calculate loss opportunity. This version also makes corrections to the utility function used to calculate pirating utility.

The_17 version adds people variable for pirate-success which counts the number of times the agent successfully pirates. This data is captured in a histogram on the interface.

The _18 version corrects an error in the code for orient-ship and sequentially numbers the opmodes 1-7. This version also deletes the code for maritime security units.
> 18A version changes the ship reward distribution by a factor of 100.

The_19 version exports and imports the world. This is done with "Setup" and "Initiate" to get the exported world; then reset and go. The multiple for the initial total reward was adjusted from 100 to 1000 to decrease the sensitivity of the expected reward

The-20 version makes a correction to how p-capture is calculated to account for time. It introduces two new globals: "total-p-capture" and "current-p-capture."
> 20A has a separate calculate-intercept-probability for "Go"
> 20B adds code to the Reset loop to allow temp values so BehaviorSpace Experiments will run properly.

The 21_version adds code to the patch setup for diffusion of the economic opportunity values. Also adjusts the reset code to adjust the report-to-port-ticks for any skiffs

The 22_version removes the slider for piracy-probability and hard codes it to 0.1

ABM CODE

globals
[
 threshold
 land - *patches that are land*
 port - *patches that make up the port (they are also land patches)*
 port-pirates - *list of pirate's turtle numbers that made it to the port*
 minimum-manning - *number of pirates it takes to man a skiff*

successful-transits - *number of times a merchant makes a successful crossing*
captured-ships - *list of merchants captured*
pirating-utility - *value for pirating, calculated using Piracy-Probability, reward and opportunity*
p-capture - *probability of successful piracy*
total-p-capture - *sum of the p-capture values for each tick*
current-p-capture - *total-p-capture divided by ticks*
total-rewards - *total value pirated*
expected-reward - *the average payoff*
sorties - *the number of skiff sorties*
victory-party - *amount of time that a skiff remains in port after a successful capture*
naval-deterrence-range ;; *range that a security unit has to be within to deter a skiff attack*
SRT-list - *list holding skiff run times, to be used in earlier version to determine the seed value of average-SRT*
total-SRT - *total of all skiff at sea time*
average-SRT - *average number of ticks a skiff is at sea - initially seeded with historical data and then dynamically determined*
number-of-pirates - *list consisting of the number of people with pirate Boolean true each tick*
average-number - *mean of number-of-pirates*
 ]
Globals with Capital First Letters are set on the interface
Reward is a slider on the interface to set the initial/seed value of pirating reward
Economic-opportunity is a switch on interface, used to display the land in shades of brown depending on the value of eco-op
ECO is a slider on the interface to adjust the opportunity of land patches
Maritime-Security is a switch on interface, turns maritime security forces on and off
Number-of-security-units is a slider on interface
Piracy-Probability slider, the probability of pirating before there are any sorties

patches-own
 [
  eco-op - *random number related to ECO slider that people use to compute expected value of wandering*
  land-patch - *a Boolean to make it easier to keep the wandering people on land patches*
 ]

turtles-own []

breed [people person]
people-own [
 risk-aversion   ;; 0-1 but currently not in use
 perceived-hardship ;; 0-1 but currently not in use
 opportunity - *average value of the last ten eco-op they have encountered by wandering. The decision-list is initially seeded with values using the same equation used to assign values to patches.*

  pirate - *Boolean which determines if they will pirate or not, false - no pirating, true - make way to port and pirate.*
  assigned-to-skiff - *Boolean*
  skiffnumber - *ID of skiff person is assigned to (this is not being used, for now the skiff keeps track of the pirates-on-board)*
  experience - *a pirate's experience goes up for successful captures, down for empty cruises*
  pirate-success - *count of the times successfully pirate*
  decision-list - *list of eco-op values obtained as person wanders to different patches*
  ;;pirating-utility - *value for pirating, calculated using Piracy-Probability, reward and opportunity (moved to globals 10/24/16 so it could be seen on a monitor)*
 ]

breed [skiffs skiff] *(Pirates in small boats)*
skiffs-own [
  opmode - *operating mode of skiff*
  maxspeed
  speed
  max-fuel
  fuel
  attack-range - *this is a combination of how far the skiff can see and the range where it decides to attack*
  course
  patrol-range - *distance from port that the skiff travels before it starts patrolling*
  prey *when a merchant is detected, it is assigned as the current 'prey', in case there is another merchant nearby*
  return-to-port-tick - *remembers the tick when the skiff returned port after a cruise*
  pirates-on-board - *pirates on board is a list of the turtle numbers of people associated with that skiff*
  at-sea-ticks - *measures how many ticks a skiff spends at sea*
 ]

breed [ships ship] *(Ships - Pirate targets)*
ships-own [maxspeed speed eastbound captured captor successful-passage payoff]
eastbound and captured are Boolean; captor is ID of skiff that made attack

Main Setup

to Setup
  clear-all
  setup-global-values
  setup-patches
  setup-people
  setup-ships
  reset-ticks
end

```
to setup-global-values
  set sorties 0 - running total of pirate sorties (normally would be in setup skiffs, but that is
not called during setup)
  set victory-party 50 - skiff stay-in-port time after a successful capture, in ticks
  set successful-transits 0
  set captured-ships [] - initially list contains nobody
  ;; set total-rewards Reward    set total-rewards Reward * 1000 ;; model is too sensitive at
iniation to the first few skiff runs
  set expected-reward Reward - seed until first capture
  set minimum-manning 3 - sets the crew size of a skiff, skiff cannot sail without full crew
  set number-of-pirates []
  set p-capture 0.1 - changed from slider value to 0.1 (8/22/17)
  set total-p-capture p-capture
  set current-p-capture p-capture - this is set because the calculation doesn't start until there
are tick and current-p-capture would otherwise initially be ZERO
  set SRT-list [] - used to get some data for SRT to get initial seed value
  set total-SRT 170000 - total Skiff at sea time, starts large to mitigate initial swings
  set average-SRT 170 - initial seed value of SRT
end


to setup-patches
  set land (patch-set patches with [pycor < 1]) - Land is at the bottom
  set port (patch-set patches with [(distancexy 0 0) < 4 and (pycor < 1)]) - Port is located
around the origin
  ask patches - Water patches are colored to create a shallow zone toward the land, half of the
world is land
  [
   if pycor < 11 and pycor > 0 [ set pcolor 76 ]   - Shallow water near land
   if pycor > 10 and pycor < 21 [ set pcolor 85 ]  - Territorial water
   if pycor > 19 [ set pcolor 94 ] - International water/shipping lane
   set land-patch false - Used to test for land when people are moving to neighbors
  ]
  ask land
  [
   set pcolor 35
   set eco-op (100 - (ECO * random 10)) - assigns an eco-op (economic opportunity) value to
each land patch INCLUDING THE PORT - based on the ECO value selected on the slider on the
Interface.
   set land-patch true
  ]
  ;; repeat 5 [diffuse eco-op 0.5]  - This is the code used to diffuse the land patches if desired
  if economic-opportunity
    [ ask land [set pcolor scale-color brown eco-op 0 100 ]
    ]  - Displays eco-op values in shades of Brown - somewhat chaotic looking.
  ask port
  [
```

```
    set pcolor 58
    set eco-op 100
  ]
end

to setup-people
  set port-pirates [] - list of the people that are pirates in the port area, but not assigned to a
skiff.  Available for crew
  create-people 100
  ask people
  [
   move-to one-of land with [not any? turtles-here]
   set shape "person"
   set color lime
   set size 3
   set pirate false
   set assigned-to-skiff false
   set skiffnumber -1
   set experience 0
   set pirate-success 0
   ;; set decision-list (list ([eco-op] of patch-here) ([eco-op] of neighbors))
   ;; set decision-list []
   set decision-list n-values 10 [100 - (ECO * random 10)] - This seeds the initial values of
'decision-list' with numbers similar to those assigned to land patches
  ]
end

to setup-ships (Merchant ships)
 create-ships 3
 ask ships
 [
   set shape "merchant ship"
   set size 6
   set color yellow
   set maxspeed 2
   set speed (.5 * maxspeed)
   set successful-passage false
   set captured false
   set captor nobody
   set payoff random-normal Reward 30000        ;; this may need to be adjusted  -- adjusted
by factor of 100 4/12/17
   ifelse random 2 = 1 (coin flip)
    [set eastbound true
     set heading 90
     set xcor (-99 + random 40)  ;; check for other ships within 20?
     set ycor 40 - random 3]
```

```
    [set eastbound false
     set heading 270
     set xcor (99 - random 40)
     set ycor 46 - random 3]
  ]
end
```

*****Main Loop*****

```
to Initiate
  move-people
  move-ships
  move-skiffs
  calculate-intercept-probability    ;; don't call this every tick?, changes with sorties
  if ticks = 500 - The amount of ticks prior to exporting the world: can be changed
   [
    export-world "ECOpiracy.cvs"
    stop
   ]
  tick
end

to Reset
  let tempECO ECO
  let tempreward reward
  import-world "ECOpiracy.cvs" - the file name can be changed to import a specific world
  reset-ticks
  clear-all-plots
  random-seed new-seed
  set ECO tempECO
  set reward tempReward
  ask skiffs
  [
  set return-to-port-tick 500 - return-to-port-tick - this accounts for the ticks getting reset to
0 so the resail happens at the right time for skiffs already inport; it will set the variable to 500
for skiffs at sea but that will get set to the current tick if they return with prey
  ]

  update-variables
end

to update-variables
  setup-patches
  set total-rewards Reward * 1000 - model is too sensitive at initiation to the first few skiffs
runs
  set expected-reward Reward - seed until first capture
```

```
 ;; set p-capture current-p-capture          ;; if you reset the p-capture there will be a jump
downward in value because the first calculated ideal-p-capture isn't buffered in the
current-p-capture calculation
 ;; set total-p-capture current-p-capture
  set number-of-pirates []
end

to Go
  move-people
  move-ships
  move-skiffs
 calculate-intercept-probability-forIW - Uses the calculation for the imported world
ADJUSTMENT MADE 23 May 2017
 ;;calculate-intercept-probability
  tick
end
```

Main loop subroutines

```
to move-people
  analyze-pirate-statistics
  ask people
  [ - Check pirate status
   if not pirate
    [
     if any? neighbors with [(not any? people-here) and land-patch] - Check to make sure
adjacent land patches are not all occupied
     [
      move-to one-of neighbors with [(not any? people-here) and land-patch] - Move to
empty neighboring patch, making sure that it is on land
     ]
     set decision-list fput eco-op but-last decision-list  - Update decision-list with new eco-op
and drop off 10th value
     set opportunity sum decision-list / 10  - Calculate average of decision-list,
     ;; if (risk-aversion + perceived-hardship) > 1.6 ;; this number is just for testing, and
doesn't change (yet)
     ;; set pirating-utility (Piracy-Probability * Reward) - ((1 - Piracy-Probability) *
opportunity)
     ;;set pirating-utility (total-rewards * p-capture) - ((1 - total-rewards) * opportunity)
;; I think this equation is wrong see next line
      ;; set pirating-utility (total-rewards * p-capture) - ((1 - p-capture) * opportunity)        ;;
This doesn't work because as soon as there is at least one tick p-capture gets set, but there
are no total ships yet and so it become ZERO
     ;; set pirating-utility (expected-reward * p-capture) - ((1 - p-capture) * opportunity *
average-SRT)  ;;
```

```
    ;;set pirating-utility (expected-reward * p-capture / minimum-manning) - (opportunity
* average-SRT)  ;;
    set pirating-utility (expected-reward * current-p-capture / minimum-manning) -
(opportunity * average-SRT)  ;; change made 18 May 2017
   if pirating-utility > opportunity  - Compare opportunity to reward for pirating
   [
    set pirate true
    set color red
   ]
  ]- The rest of this loop controls the people that have 'pirate' set to true
  if (pirate and color = red)
 [
   face one-of port
   forward 1
   ;; set pirating-utility (total-rewards * p-capture) - ((1 - total-rewards) * opportunity)
   ;; set pirating-utility (Piracy-Probability * Reward) - ((1 - Piracy-Probability) *
opportunity)
   ;; as they move toward port, still need to check pirating utility
   ;; set pirating-utility (total-rewards * p-capture) - ((1 - p-capture) * opportunity)
not working-- should be average payoff
   ;; set pirating-utility (expected-reward * p-capture) - ((1 - p-capture) * opportunity *
average-SRT)
   ;;set pirating-utility (expected-reward * p-capture / minimum-manning) - (opportunity
* average-SRT)
   set pirating-utility (expected-reward * current-p-capture / minimum-manning) -
(opportunity * average-SRT) - change made 18 May 2017 to average_SRT as a factor
   if pirating-utility < opportunity   Compare opportunity to reward for pirating, may
change decision while on the way to the port
   [
    set pirate false
    set color yellow - So we can see when someone changed decision to pirate on the way to
the port
   ]
  ] - Moves pirates ahead towards port as long as pirating-utility > opportunity
  if (pirate and (member? patch-here port)) Arrived at the port
  [
   set color black
   if (not assigned-to-skiff and not member? who port-pirates)
   [set port-pirates lput who port-pirates] - Add turtle ID to back end of list that contains
all the available pirates in the port area
  ] -  Reached the port
 if (pirate and color = black)
 [
   face one-of port - mill around port
   forward 1
```

```
    if count people with [(pirate and not assigned-to-skiff) and color = black] >= minimum-
manning
      ;; enough unemployed pirates in port, can hatch a skiff and associate skiff with these
pirates
    [
      ;;show "made it to 3"  ;; testing note, delete from final code
      let crew sublist port-pirates 0 minimum-manning - Crew is the first group of pirates
available in the port (accounts for two or more pirates arriving during same tick)
      ;; show crew ;; testing note, to show those pirates on the skiff, delete from final code
      hatch-skiffs 1 [orient-skiff self crew] ;;send the skiff turtle number and the crew to the
subroutine
      foreach crew
       [ask turtle ?  - Sets boolean for each pirate onboard outbound skiff, then hide them, so
they don't show in the port. They will be unhidden if the skiff returns to port unsuccessful so
they can return to roaming
         [set assigned-to-skiff true
          hide-turtle
         ]
        ]
      set port-pirates sublist port-pirates minimum-manning (length port-pirates)
    ] - Removes the pirates (crew) from the list port-pirates
   ]
]
  end

to orient-skiff [skiff crew] - Initializes the new skiff
  ask skiff
 [
    set shape "boat"
    set color black
    set size 4
    set xcor random 4 - 3
    set ycor 0
    set opmode 1 - transiting out to patrol area opmode, skiff's sail color changes with most
changes of status
    set prey nobody
    set course random 100 - 50
    set heading course
    set patrol-range 39
    set maxspeed 3
    set speed (.3 * maxspeed)
    set max-fuel 100 - seems to affect p-capture greatly
    set fuel max-fuel
    set attack-range 6
    set pirates-on-board crew - assigns the turtle numbers of the 'crew' to this skiff
    set sorties sorties + 1 - counter for total number of skiff cruises
```

```
    set at-sea-ticks 0
    ;; calculate-intercept-probability  ;; seems to get less swarming when called every tick,
than each sortie
  ]
end

to move-ships (Merchant ships)
  ask ships
 [ - Check to see if merchant reached the edge of the map
  if ((xcor = 100 or xcor = -100) and not successful-passage)
  [
   set successful-passage true
   set successful-transits successful-transits + 1
   hatch-ships 1 [orient-ship self]
   hide-turtle Hide the ship, hatch a new one
  ] - Now check to see if any skiffs close by
   ifelse any? skiffs in-radius 7 and not captured
  [
    set speed maxspeed
    set color red
   ;; call for naval vessel help?  this something that still needs to be developed
   ;; it would get the navy to the area that the pirates are operating in
   ;; even if they didn't arrive in time to help the one that called for help
  ]
  [
    set speed .5 * maxspeed
    set color yellow
   ] - Test to see if captured,
  if captured
  [
    set color black - Merchant follows pirate back to port
    set heading towards captor
    set speed ([speed] of captor)
  ]
   forward speed - Continue on same course
  ]
end

to orient-ship [ship] - Initializes the new merchant ship
  ask ship
  [
   set shape "merchant ship"
   set size 6
   set color yellow
   set maxspeed 2
   set speed (.5 * maxspeed)
```

```
    set successful-passage false
    set captured false
    set captor nobody
    set payoff random-normal Reward 30000 - altered by a factor of 100 on 4/12/17
    ifelse random 2 = 1 (coin flip)
     [set eastbound true
      set heading 90
      set xcor -99
      set ycor 40 - random 3]
     [set eastbound false
      set heading 270
      set xcor 99
      set ycor 46 - random 3]
  ]
end

to move-skiffs
opmode 1 - transiting from the port to a patrol area; generally black sail
opmode 2 - loitering on patrol
opmode 3 - chasing a target ship; sail turns gray
opmode 4 - when a target is captured; sail turns red
opmode 5 - attacked a target - but target not captured; sail turns blue for repelled attack
opmode 6 - low fuel status - transiting back to port; sail turns yellow
opmode 7 - inport; sail turns brown when skiff resails after "victory party" (50 ticks)

   ask skiffs
   [
     let attack-failed false - Temporary Boolean to flag deterred or repelled attacks
     if ((opmode = 1 or opmode = 2 or opmode = 3) and fuel - 3 < (distancexy 0 0)) - running
out of fuel, return to port
       [
        set opmode 6
        set color yellow
        set speed (.3 * maxspeed)
        set course towards one-of port
       ] - now test for each opmode and conditions needed to shift opmodes
     if opmode = 1 and (any? ships in-radius attack-range with [not captured]) - Merchant
detected while in transit
       [chase]
     if opmode = 1 and ((distancexy 0 0) > patrol-range) - Made it to patrol distance, shift to
opmode 2 loiter
       [ set opmode 2
        set speed (.05 * maxspeed)
        set course one-of [90 270]
       ]
     if opmode = 2 and (not any? ships in-radius attack-range) - loiter/patrol
```

```
    [
      if ycor < 30 [set course 320 + random 80] - stay out where ships are
      if ycor > 46 [set course 140 + random 80]  - stay away from northern edge of world
      if not can-move? 1 [set course (course + 100 + random 100)] - turn away from east-
west edge of world and perform patrol wiggle
      set course course + random 20
      set course course - random 20
    ]
  if opmode = 2 and (any? ships in-radius attack-range with [not captured]) - merchant
detected while loitering
    [chase]
  if opmode = 3 and (not [captured] of prey) - opmode 3 is chasing mode
   [
     set course towards prey
     let templist1 list (maxspeed) (1.4 + distance prey)
     set speed min templist1
     ; even with the speed cap, still getting some overshoots when prey is at 45 relative,
     ; results in a sawtooth chase pattern which continues until pirate needs to return to
port for low fuel state.
     ; To avoid, test for this case, then shorten one leg of the saw to change relative
bearing
     ;;let fortyfive (course + 45) mod 90 ; tests for all 4 situations where target angle about
45
     ;if distance prey < 2 and (fortyfive < 10 or fortyfive > 80) ; within 10 degrees of target
angle 45
     ;  [set speed 1.5]; should end up astern of target, now just eat him with speed, or not if
experience low
    ]
  if (opmode = 3 and ([captured] of prey) and (([captor] of prey) != self))
   [ set opmode 1 - merchant is captured by someone else, return to patrolling
    ;;show "breaking off, already captured"  ;; this is a testing report, remove from final
code
    ]
  if opmode = 3 and distance prey < 2 and (not ([captured] of prey)) ;; this tests to make
sure skiff caught up to,
    ;;but also checks to make sure the ship has not been captured by another skiff
   [
    ;;show "within 2" ;; this is a testing report, remove from final code
     if random 10 < 4 - 3 in 10 chance that the merchant repels attack, based on 70% real-
world success rate
       [
         set attack-failed true
         set color blue
       ]

       ifelse attack-failed
```

```
  [
  ;; show "attack deterred or repelled"  ;; this is a testing report, remove from final
code
    set opmode 5 - attack failed or was deterred, return to port
    set speed (.3 * maxspeed)
    set course towards one-of port
    set prey nobody
  ]
  [
    set opmode 4 - successful capture, return to port, tell merchant to follow
    set color red
    set speed (.3 * maxspeed)
    set course towards one-of port
    ;;show "successful capture"          ;; this is a testing report, remove from final code
    ask prey
      [set captured true
       set captor myself
      ]
    ]
  ] - end of the big captured in opmode 3 if loop


  opmode 4 and 5 tests
  if opmode = 4 and (member? patch-here port)  ; reached port with a prey, shutdown,
  [
   set opmode 7
   set SRT-list lput at-sea-ticks SRT-list
   set total-SRT total-SRT + at-sea-ticks  ;;
   set average-SRT total-SRT / (1000 + sorties)
   ask prey
   [
    set captor nobody
    set captured false
    set captured-ships lput who captured-ships  - update the list of those ships that have
been captured, for later analysis
    set total-rewards total-rewards + payoff
    ;;let total-ships length captured-ships
    ;;set expected-reward total-rewards / (total-ships + 1)
    ;;set expected-reward total-rewards / (sorties + 1)  ;; this accounts for there being no
reward for an unsuccessful skiff run
    set expected-reward total-rewards / (sorties + 1000) - adjustment for initializing
model sensitivity
    hatch-ships 1 [orient-ship self] - hatch new ship, call subroutine to initialize it
    ;;hide-turtle                      ;; hide the old ship  (should it die?)
    die
   ]
  foreach pirates-on-board
```

```
    [ask turtle ?
      [
        set experience experience + 10 -  crew get experience for successful capture – not
used in the current model.
        set pirate-success pirate-success + 1 - crew get credit for successfully pirating.
      ]
     ]
    set speed 0
    set prey nobody
    set return-to-port-tick ticks - time holder, this skiff will sail after a cool-down
     ;;  calculate-intercept-probability  ;; update p-capture
    ]
    if (opmode = 7 and (ticks > return-to-port-tick + victory-party)) - successful cruise, send
them back to sea
    [
     set opmode 1
     set color brown
     set prey nobody
     set course random 100 - 50
     set speed (.3 * maxspeed)
     set fuel max-fuel - Consideration for future version - experienced skiffs carry more fuel?
     set at-sea-ticks 0
     set sorties sorties + 1 - counter for total number of skiff cruises
    ]
    if (opmode = 5 or opmode = 6) and (member? patch-here port) - reached port due to
repelled attack or low fuel - shutdown
    [ ;;set opmode 5   ;; delete after sure we are going to die
     ;;set speed 0   ;;; delete after sure we are going to die
     ;;set prey nobody  ; delete after sure we are going to die
     set expected-reward total-rewards / (sorties + 1000) - adjustment for initializing
model sensitivity
     set SRT-list lput at-sea-ticks SRT-list
     set total-SRT total-SRT + at-sea-ticks  ;;
     set average-SRT total-SRT / (1000 + sorties)
     foreach pirates-on-board - send the crew back to work, in port, but colored violet,
opportunity should stay high inside port area
     [ask turtle ?
      [show-turtle
       set pirate false
       set color violet
       set assigned-to-skiff false
       set skiffnumber -1
       set experience experience - 5
      ]
     ]
    die - kill this skiff, no reason to keep it
```

```
      ;; calculate-intercept-probability   ;;update p-capture
      ]
    set heading course
    forward speed
    set fuel fuel - speed
    set at-sea-ticks at-sea-ticks + 1
  ] end of ask skiffs loop
end

to chase - skiff sighted a merchant, gives chase
  set opmode 3
  set prey one-of ships in-radius attack-range
  set speed maxspeed
  set course towards prey
  set color gray
end

to calculate-intercept-probability
  let total-ships length captured-ships
  let total-time ticks + 1 - this accounts for the 0 tick and the divisor is never zero when
calculating current-p-capture below ADJUSTMENT MADE 18 May 2017
  if (ticks > 0) and (total-ships >= 1) - There has be a ship captured before p-capture will
become dynamic
  [
    let ideal-p-capture total-ships / sorties - This is the actual value based on captures, but we
can't tolerate rapid jumps.  Also, it changes when a skiff leaves port, not when it returns - pros
and cons to this.
    ifelse (ideal-p-capture - p-capture > .03)
    [
      set p-capture p-capture + .01
      ;; show "p-capture increase limited"
    ]
    [ ;; small change, use the new ideal
      set p-capture ideal-p-capture
    ]
  ]
  if ticks > 0
  [
   set total-p-capture total-p-capture + p-capture
   set current-p-capture total-p-capture / total-time
  ]
end

to calculate-intercept-probability-forIW  - Calculation used for GO with an inported world
  let total-ships length captured-ships
  let total-time ticks + 501 - This account for the 0 tick and the 500 ticks of the inported world
```

```
  if (ticks > 0) and (total-ships >= 1) - There has be a ship captured before p-capture will
become dynamic
   [
    let ideal-p-capture total-ships / sorties  - This is the actual value based on captures
     set p-capture ideal-p-capture
   ]
  if ticks > 0
  [
   set total-p-capture total-p-capture + p-capture
   set current-p-capture total-p-capture / total-time
  ]
end

to analyze-pirate-statistics
  set number-of-pirates lput (count people with [pirate]) number-of-pirates
  set average-number mean number-of-pirates
end
```

APPENDIX C

EXPERIMENT DATA SET SUMMARIES

Table C-1. Behavior Space Experiment Run #1 on Model 18A (18A adjusted the normal distribution for ship reward)

14 April					
	Max Number	Mean Number	Median No.	Stand Deviation	Variance
Min	0	0	0	0	0
1st Quarter	6	1.909	0	1.345	1.808
Median	98	15.267	3	18.718	350.355
Mean	69.69	25.160	20.83	16.327	386.776
3rd Quarter	100	44.716	42	25.271	638.620
Max	100	86.433	87	36.751	1350.662

Table C-2. Behavior Space Experiment Run #2 on Model 18A

16 April					
	Max Number	Mean Number	Median No.	Stand Deviation	Variance
Min	0	0	0	0	0
1st Quarter	5	1.722	0	1.301	1.692
Median	98	13.630	2	19.114	365.352
Mean	68.72	21.779	16.77	16.535	399.352
3rd Quarter	100	38.556	34	26.039	678.046
Max	100	81.933	82	38.135	1454.250

Table C-3. Behavior Space Experiment Run #3 on Model 18A ECO 1-10 (5000 observations)

11 Sept							
	Max No.	Mean No.	Median No.	Std Dev	Variance	Sorties	Captures
Min	0	0	0	0	0	0	0
1st Quarter	0	0	0	0	0	0	0
Median	61	6.776	1	11.28	127.2	16	1
Mean	49.34	15.780	12.37	11.77	282.0	51.33	6.308
3rd Quarter	100	28.442	24	22.76	518.2	91.25	12
Max	100	80.388	80	37.68	1419.6	285	39

Table C-4. Behavior Space Experiment on Model 20 (20 Adjusted how p-capture is calculated)

18 May					
	Max Number	Mean Number	Median No.	Stand Deviation	Variance
Min	0	0	0	0	0
1st Quarter	8	3.103	1	1.823	3.325
Median	96	35.178	31	13.687	187.323
Mean	68.7	37.885	35.94	13.891	309.820
3rd Quarter	100	68.226	71	22.718	516.125
Max	100	97.469	98	42.768	1829.113

Table C-5. Behavior Space Experiment Run on Model 20B (uses 178D imported world as initial conditions)

30 May					
	Max Number	Mean Number	Median No.	Stand Deviation	Variance
Min	14	0.355	0	1.221	1.491
1st Quarter	15	2.423	2	3.131	9.806
Median	80	45.801	47	8.727	76.158
Mean	63.89	40.121	39.90	9.888	151.668
3rd Quarter	98	69.449	70.62	14.644	214.436
Max	100	95.210	96	31.729	1006.727

Table C-6. Behavior Space Experiment Run #2 on Model 20B (uses 178D imported world as initial conditions ECO 7 Reward 250K)

24 May									
	Max	Mean	Median	Std Dev	Variance	P-cap	C-P-cap	Sorties	Captures
Min	14	0.358	0	1.280	1.639	0.02174	0.03720	14	1
1st Qtr	15	2.420	2	2.954	8.725	0.07143	0.07607	17	1
Median	79	44.130	44	8.712	75.891	0.09641	0.08412	168	19
Mean	63.27	39.373	38.99	9.786	148.596	0.09440	0.08696	153.2	16
3rd Qtr	98	69.015	70	14.392	207.126	0.11321	0.09839	261.0	28
Max	100	95.726	96	33.306	1109.288	0.18750	0.14060	379.0	42

Table C-7. Behavior Space Experiment Run #3 on Model 20B (uses 178D imported world as initial conditions ECO 7 Reward 250K)

13 Sep									
	Max	Mean	Median	Std Dev	Variance	P-cap	C-P-cap	Sorties	Captures
Min	14	0.358	0	1.276	1.629	0.02041	0.03588	14	1
1st Qtr	15	2.419	2	3.049	9.294	0.07143	0.07607	17	1
Median	79	43.848	44	8.718	75.997	0.09677	0.08433	167	19
Mean	63.25	39.308	38.88	9.735	145.801	0.09466	0.08723	152.8	15.92
3rd Qtr	98	68.259	69.25	14.256	203.240	0.11278	0.09871	258.0	27
Max	100	95.025	96	33.811	1143.197	0.19231	0.14053	370.0	41

Table C-8. Behavior Space Experiment Run on Model 21 (uses 339E imported world as initial conditions ECO 8 Reward 250K)

7 June									
	Max	Mean	Median	Std Dev	Variance	P-cap	C-P-cap	Sorties	Captures
Min	8	0.829	0	1.427	2.038	0.02128	0.03851	9	1
1st Qtr	14	3.789	2	3.600	12.957	0.10000	0.09317	16	1
Median	79	35.219	32	12.807	164.030	0.11111	0.10687	130	17
Mean	63.52	35.444	33.97	12.712	236.740	0.11462	0.10591	331.7	15.28
3rd Qtr	100	59.388	60	19.266	371.161	0.12839	0.11461	218	25.25
Max	100	69.035	97	37.126	1378.374	0.27273	0.19266	364	40

Table C-9. Behavior Space Experiment Run on Model 21A – FUSION (uses 339E imported world as initial conditions ECO 8 Reward 250K)

8 June									
	Max	Mean	Median	Std Dev	Variance	P-cap	C-P-cap	Sorties	Captures
Min	0	0.000	0	0	0	0.0200	0.02535	0	0
1st Qtr	15	6.042	2	3.286	10.8	0.1000	0.09131	16.76	1
Median	86	28.603	21	15.195	230.9	0.1020	0.10000	99	12
Mean	63.51	33.004	30.91	14.494	327.4	0.1058	0.09865	115.68	12.79
3rd Qtr	100	56.573	57	23.240	540.1	0.1221	0.11076	201.00	23.00
Max	100	97.651	98	41.318	1707.2	0.3333	0.14930	359.00	40

Table C-10. Behavior Space Experiment Run on Model 20A – Just Setup & Go – just done to compare p-capture etc.

8 June									
	Max	Mean	Median	Std Dev	Variance	P-cap	C-P-cap	Sorties	Captures
Min	0	0.000	0	0	0	0.01370	0.02197	0	0
1st Qtr	7	2.62	1	1.661	2.762	0.09091	0.08176	5.75	0
Median	96	36.24	32	13.897	193.124	0.10000	0.09859	123.5	14
Mean	69.02	38.36	36.46	13.857	306.566	0.09814	0.09106	13387	13.74
3rd Qtr	100	68.54	71	22.508	506.632	0.11042	0.10000	244.00	25.00
Max	100	97.38	98	41.894	1755.103	0.50000	0.14297	362.00	41.00

Table C-11. Behavior Space Experiment Run on Model 20A for Expanded ECO Range 1- 10

13 Sep										
	Max	Mean	Median	Std Dev	Variance	P-cap	C-P-cap	Sorties	Captures	Transits
Min	0	0	0	0	0	0.01282	0.02289	0	0	4
1st Qtr	0	0	0	0	0	0.09840	0.08809	0	0	15
Median	63	12.10	1	6.79	46.11	0.10000	0.10000	32	1	29
Mean	49.46	27.22	25.76	10.04	223.42	0.09855	0.09373	94.78	9.742	23.3
3rd Qtr	100	56.23	58	18.88	356.51	0.10246	0.10000	196.00	22	30
Max	100	97.45	98	40.61	1649.35	0.50000	0.14205	365.00	39	30

APPENDIX D

INDIVIDUAL ILLUSTRATIVE MODEL RUNS

These figures show the state of each of the model runs used in the model scenarios described in Chapter 7, at tick 2000 when the model stopped. The selector switches on the left side of the model world indicate the model settings for the run. In addition to the graph of "People with pirate," which was already provided in Chapter 7, graphs of "Expected reward," "p-capture," "current-p-capture," "pcap*exprew" (current-p-capture times the expected reward), and "pirating utility" provide additional information about the model run history. A histogram of the pirate success rates shows number of pirates with various success rates. At the beginning of a model run, the histogram shows 100 pirates with zero success. When the first skiff returns to port with a capture, it updates to 97 pirates with zero success and three pirates with one success. Each capture will result in an update of the histogram. Early in a model run this is typically in increments of three; however, later when the pirates that man a skiff might have different individual success rates, the updates are less predictable. Monitors below the model world provide individual variable values.

While it is difficult to determine exactly what occurred during the model run from just the end state snapshot, the figures do provide quite a bit of insight. In addition to the information we get from the graphs and monitors, we visually see how many pirates there are, what state they are in (heading to the port (red), waiting in the port (black), or in a skiff). The color of the skiff's sail indicates its status as described in table 7-1. The color of the people indicates their status. Any green people have never decided to pirate. Purple people have returned to roaming after an unsuccessful pirate run. Finally, any yellow

people indicate a person decided to pirate, but then changed their mind before getting to

the port.
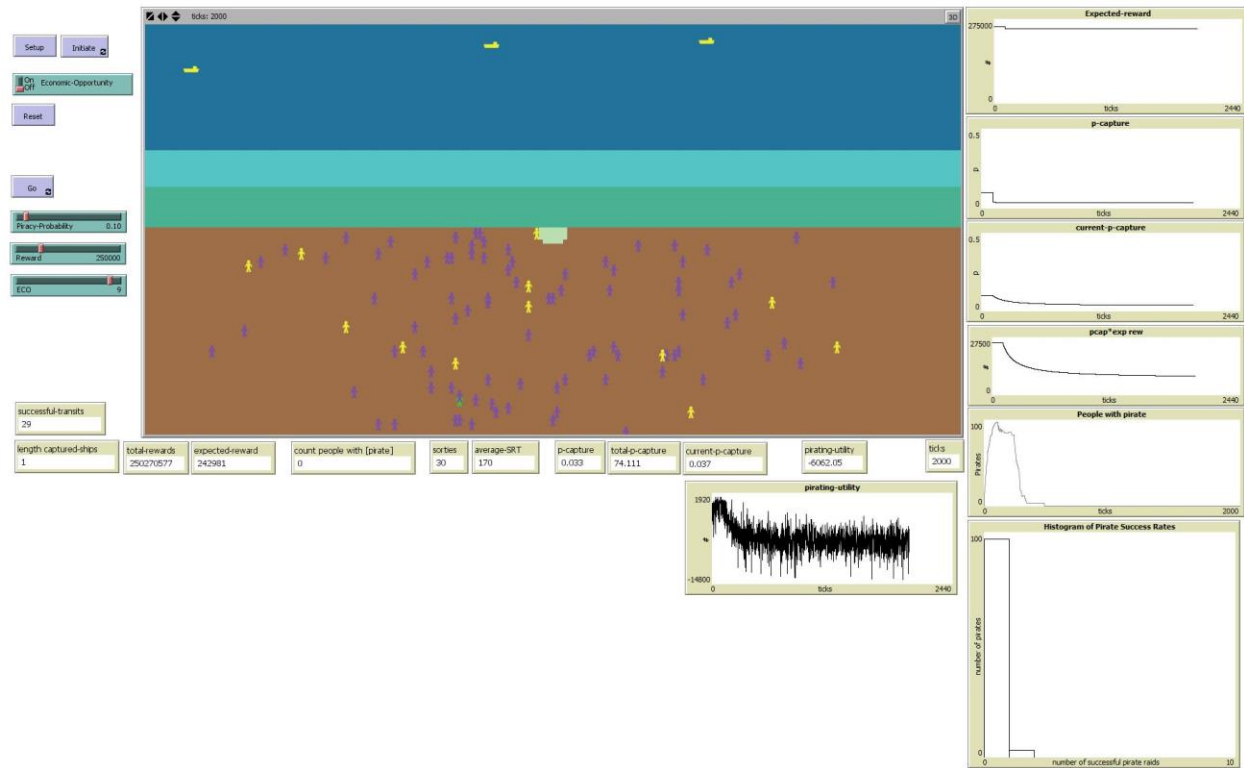
Figure D-1. Scenario 1: Model 20, Reward = 250,000, ECO = 9.
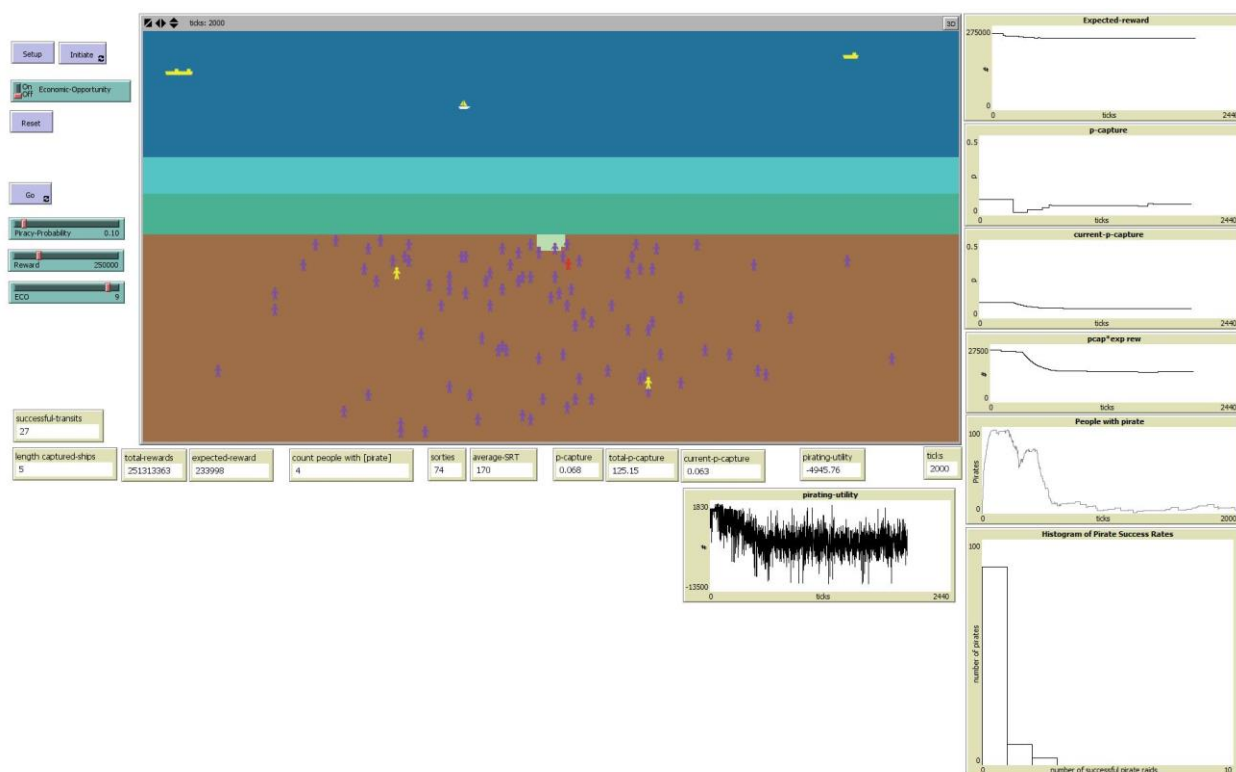
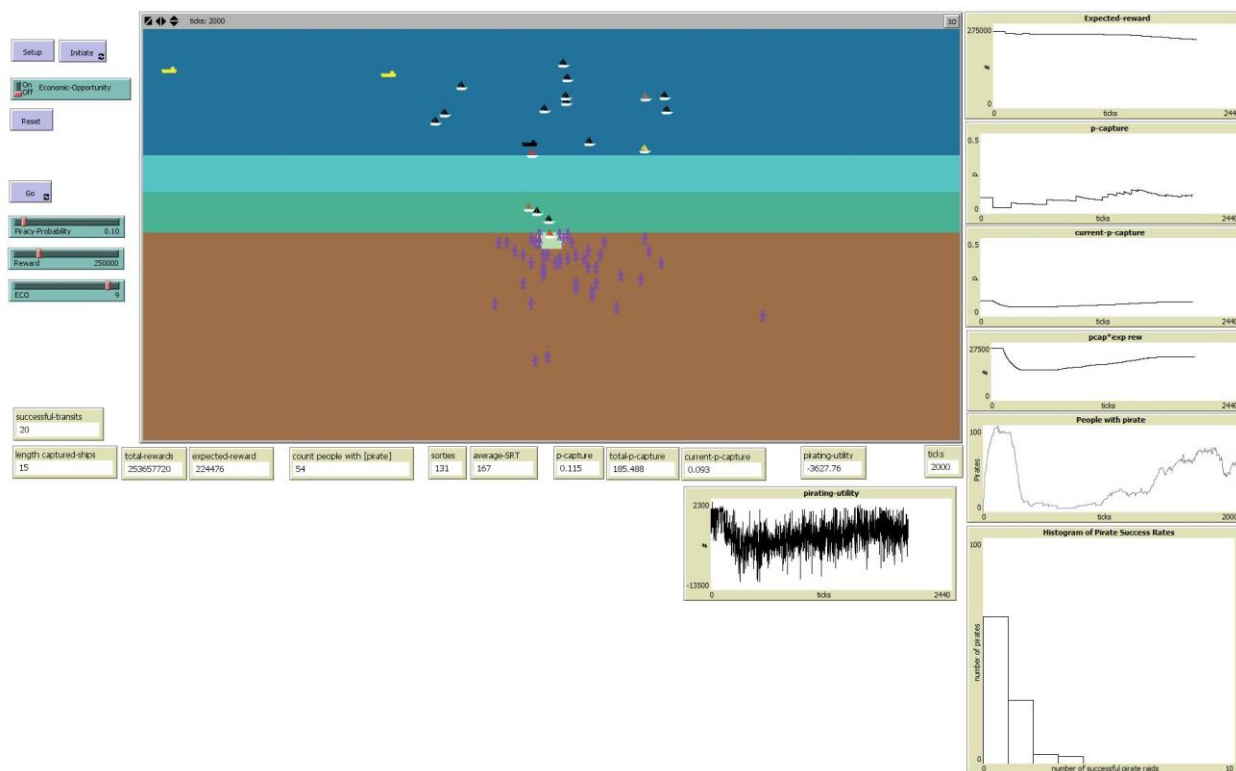Figure D-2. Scenario 2: Model 20, Reward = 250,000, ECO = 9.

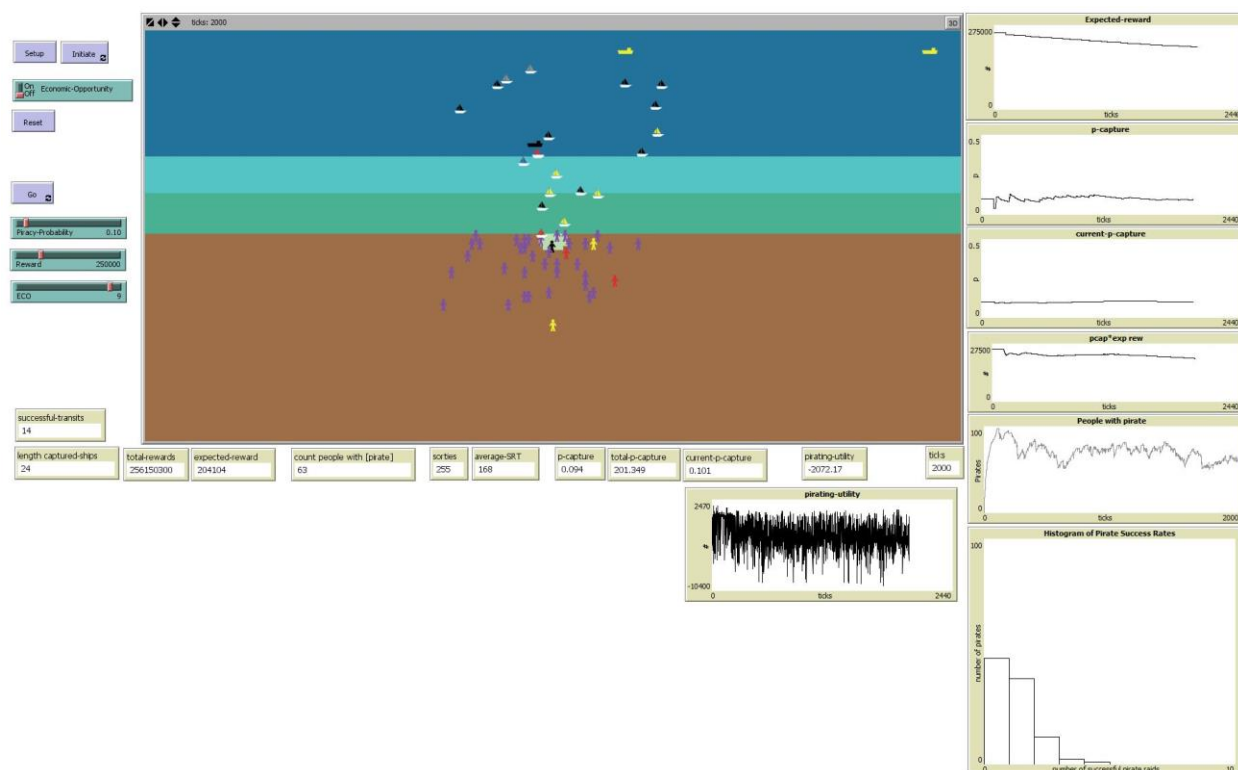Figure D-3. Scenario 3: Model 20, Reward = 250,000, ECO = 9.

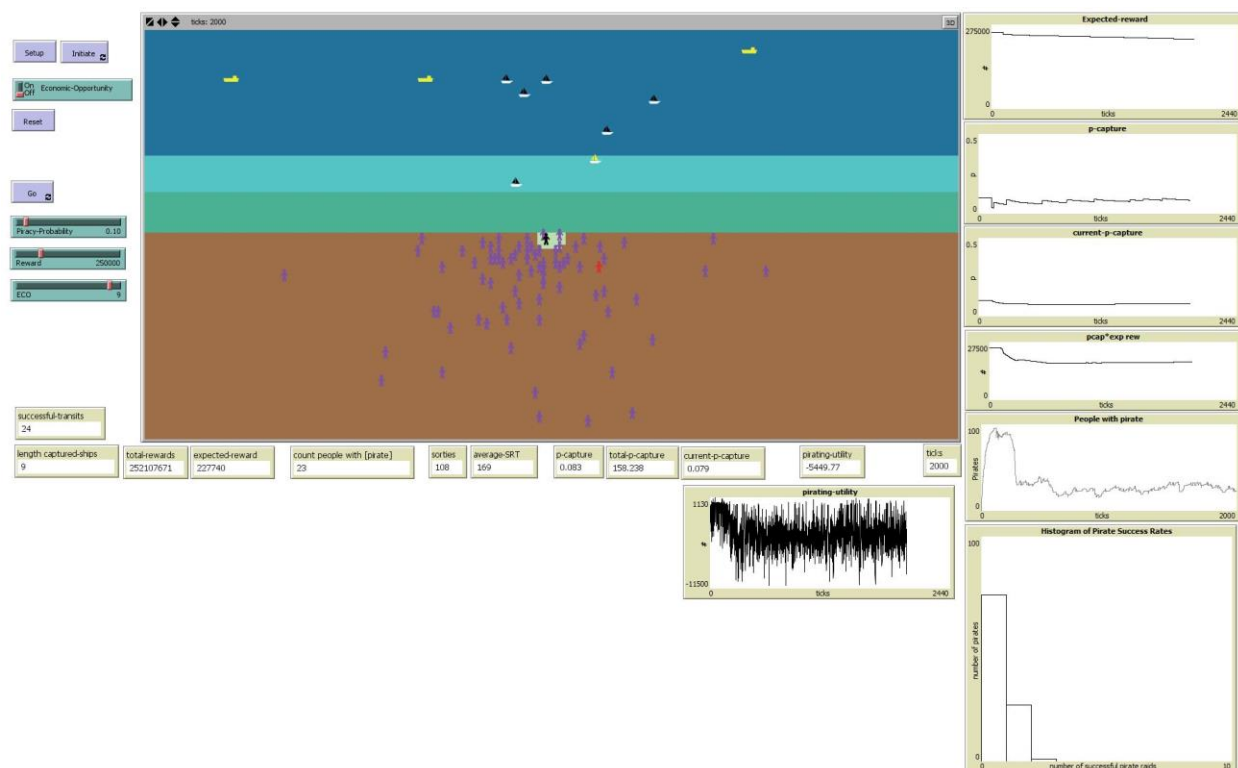Figure D-4. Scenario 4: Model 20, Reward = 250,000, ECO = 9.

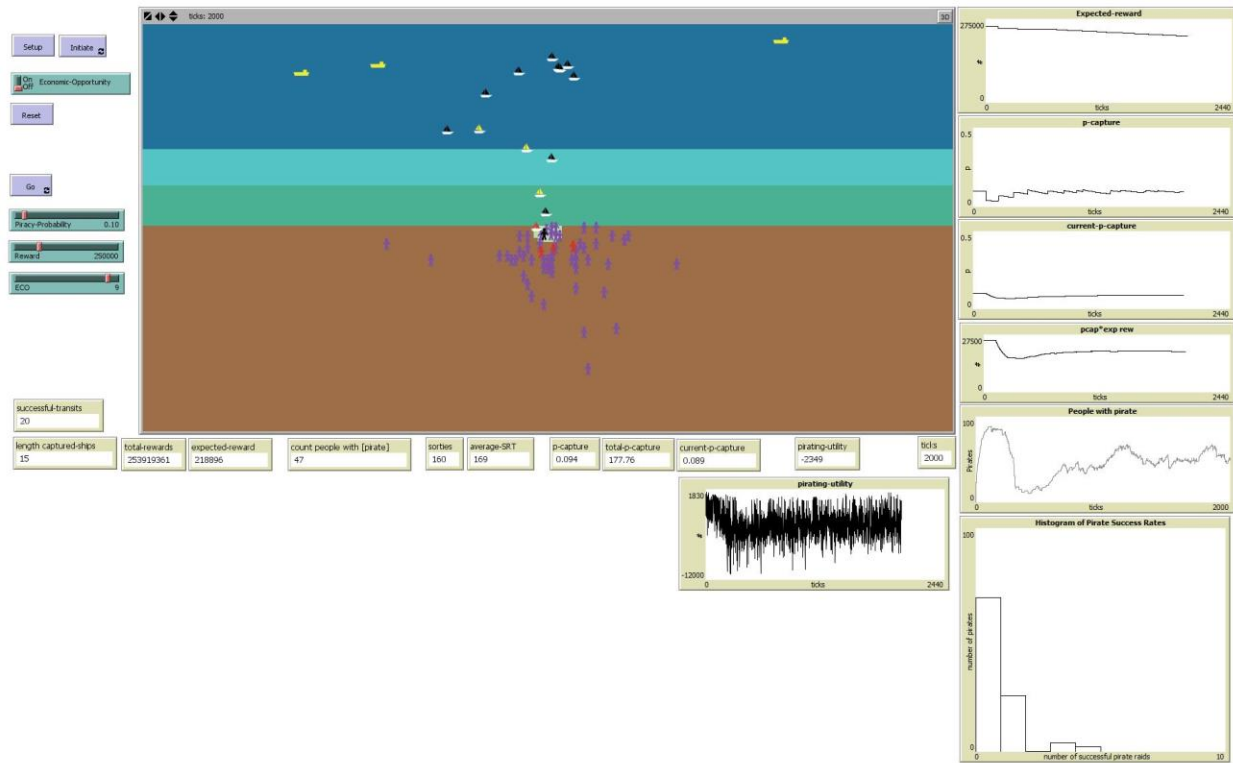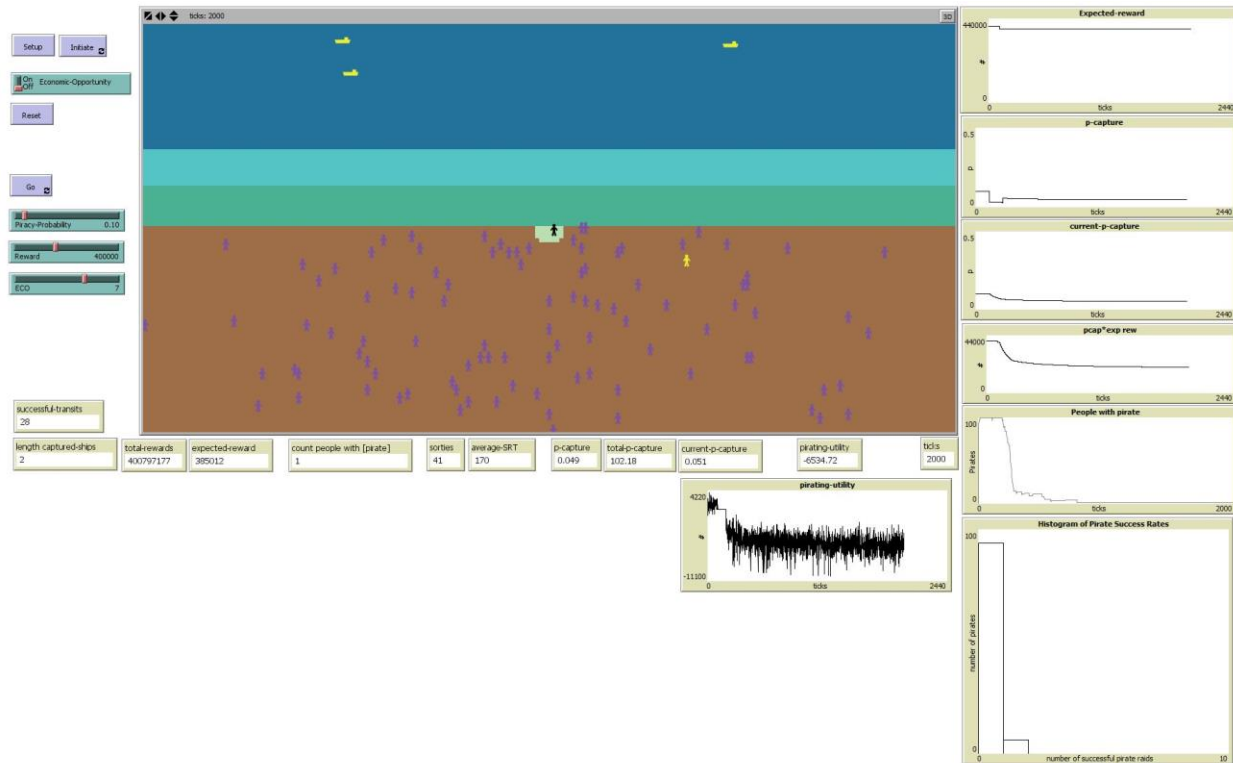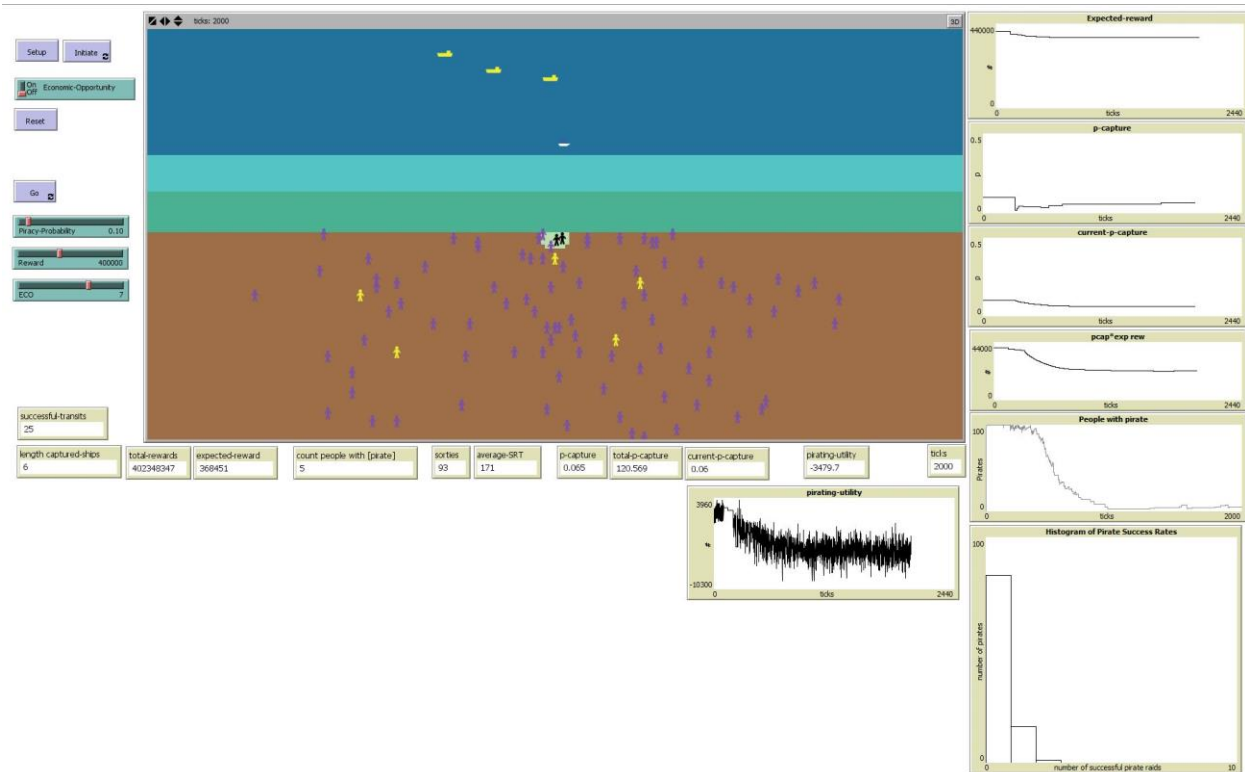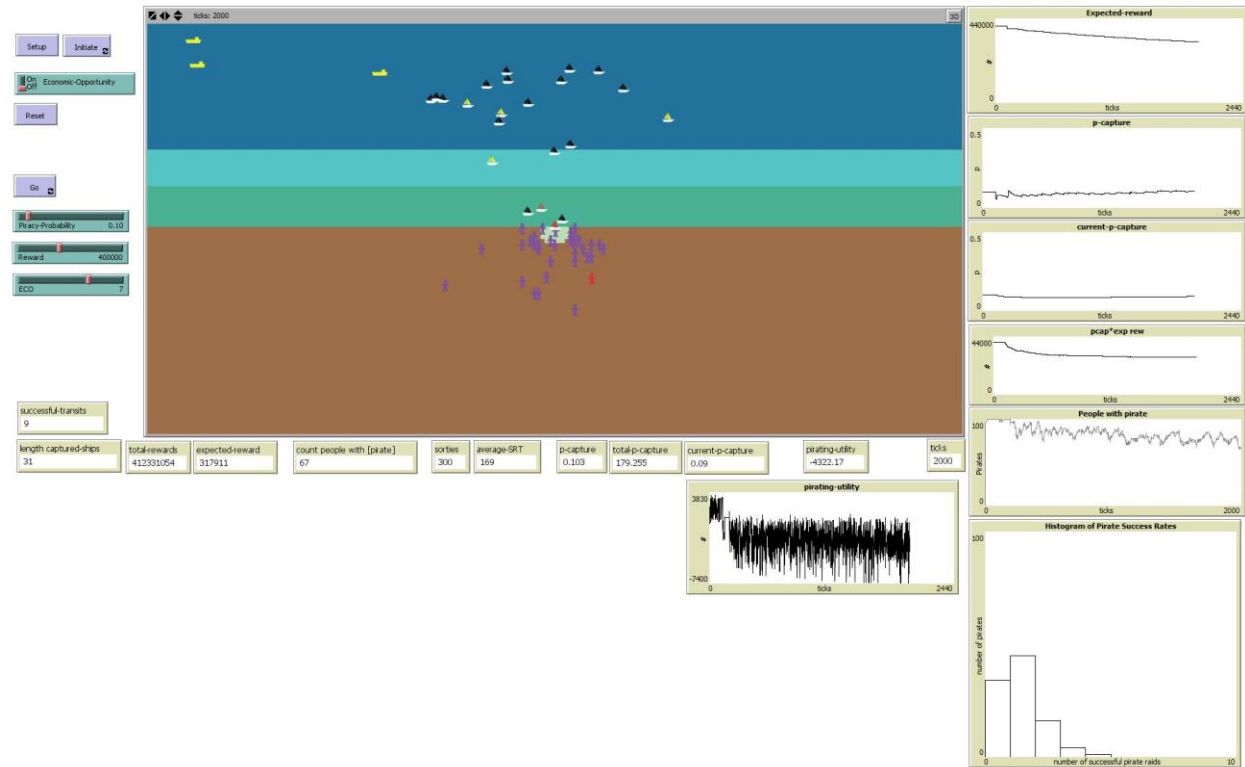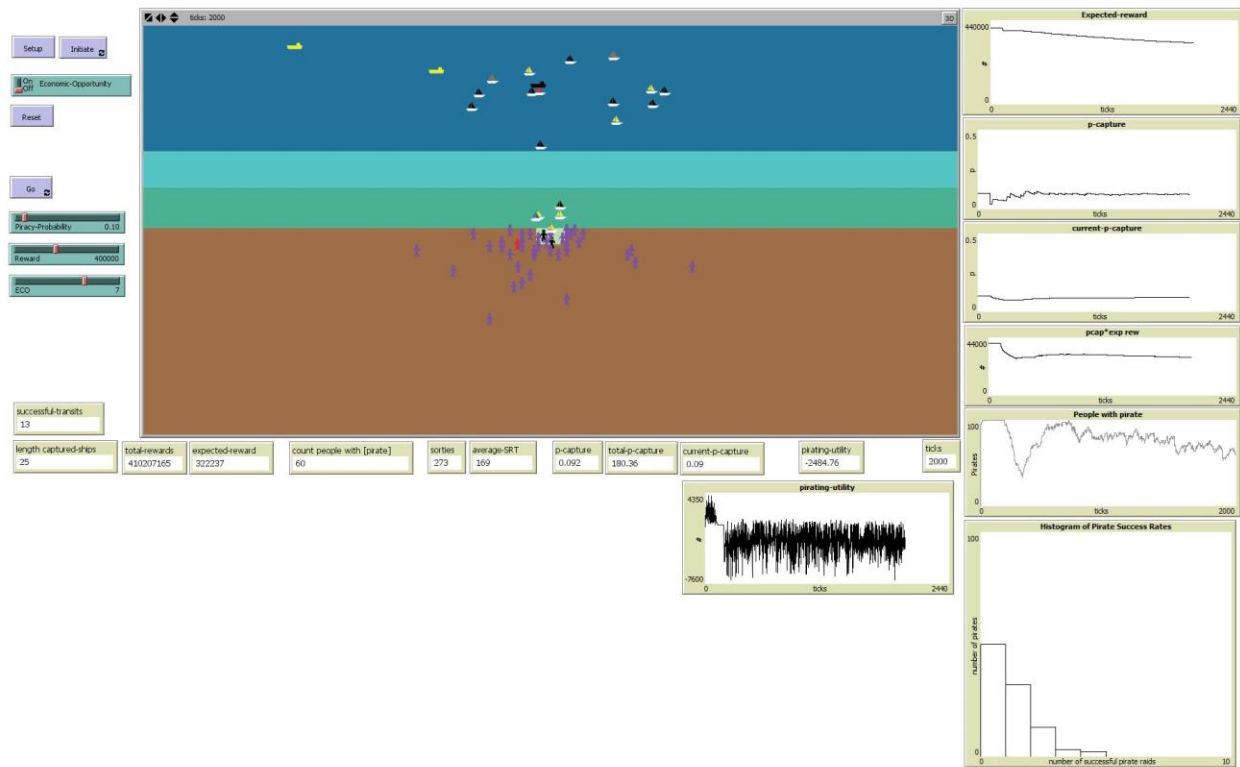Figure D-5. Scenario 5: Model 20, Reward = 250,000, ECO = 9.

Figure D-6. Scenario 6: Model 20, Reward = 250,000, ECO = 9.

Figure D-7. Scenario 7: Model 20, Reward = 400,000, ECO = 7.

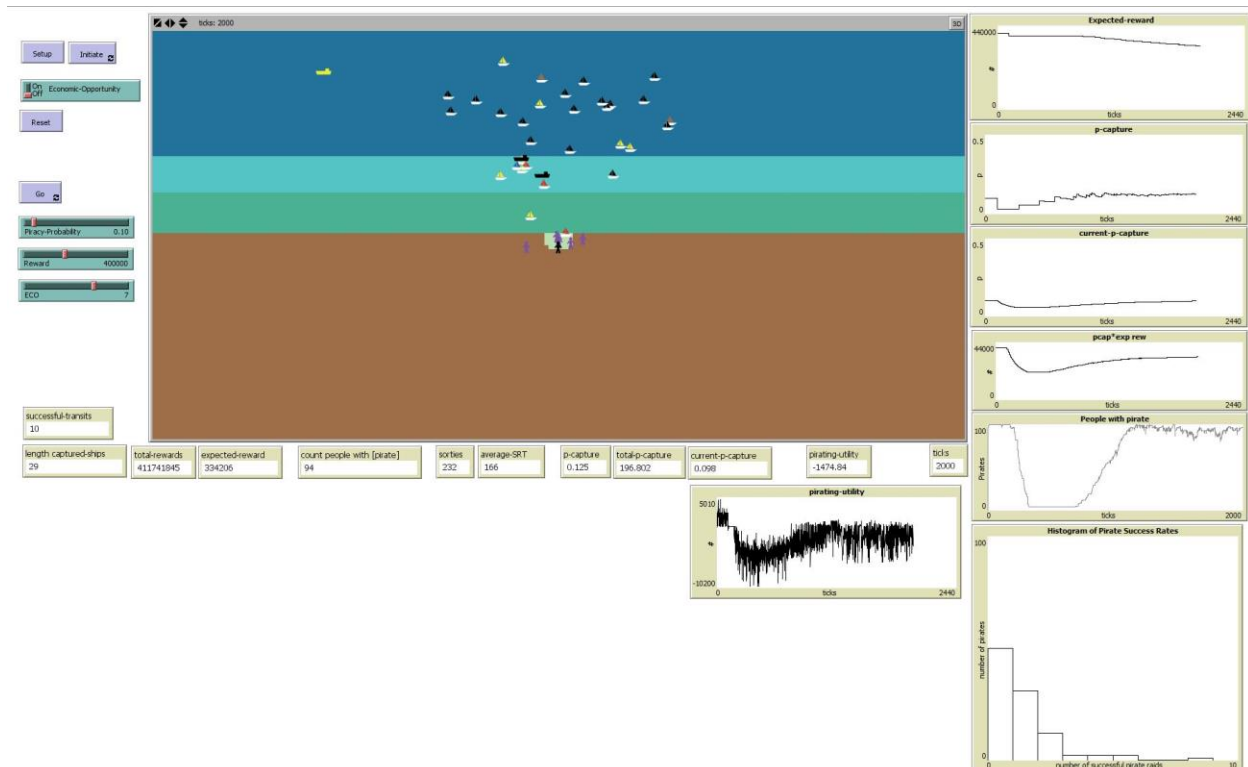Figure D-8. Scenario 8: Model 20, Reward = 400,000, ECO = 7.

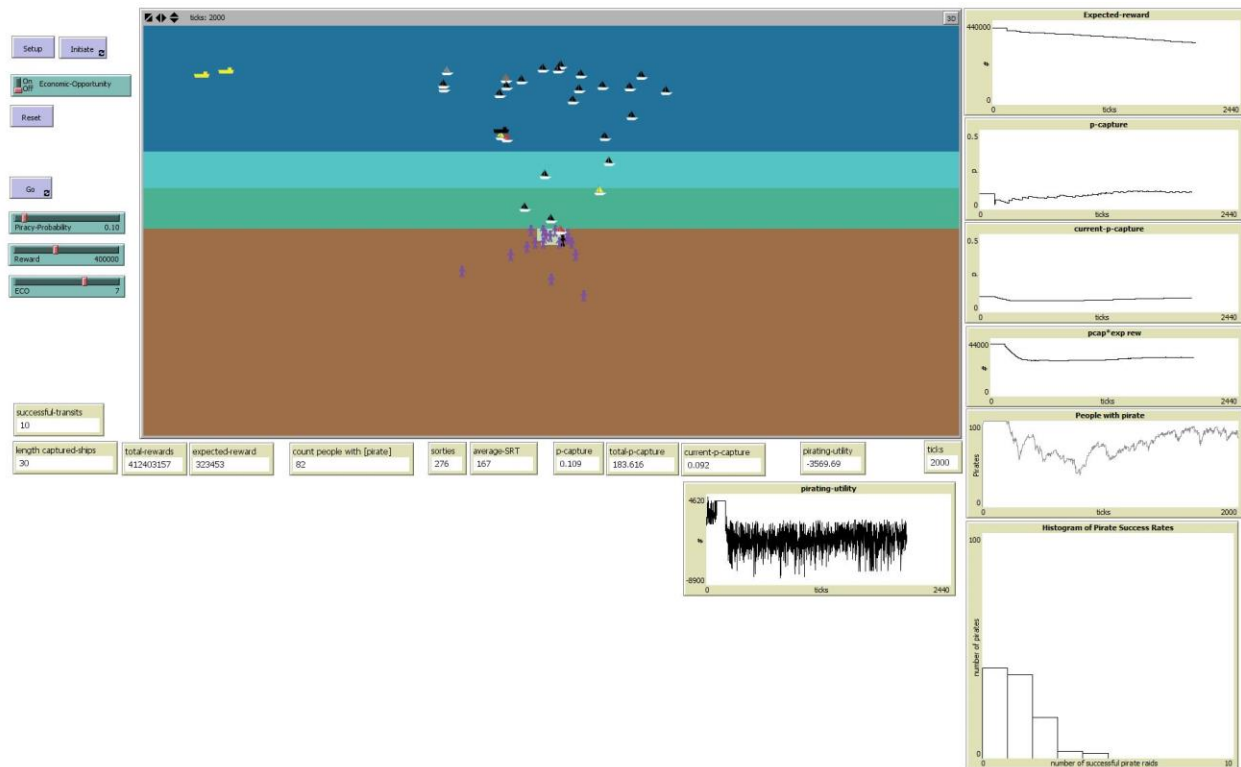Figure D-9. Scenario 9: Model 20, Reward = 400,000, ECO = 7.

Figure D-10. Scenario 10: Model 20, Reward = 400,000, ECO = 7.

Figure D-11. Scenario 11: Model 20, Reward = 400,000, ECO = 7.

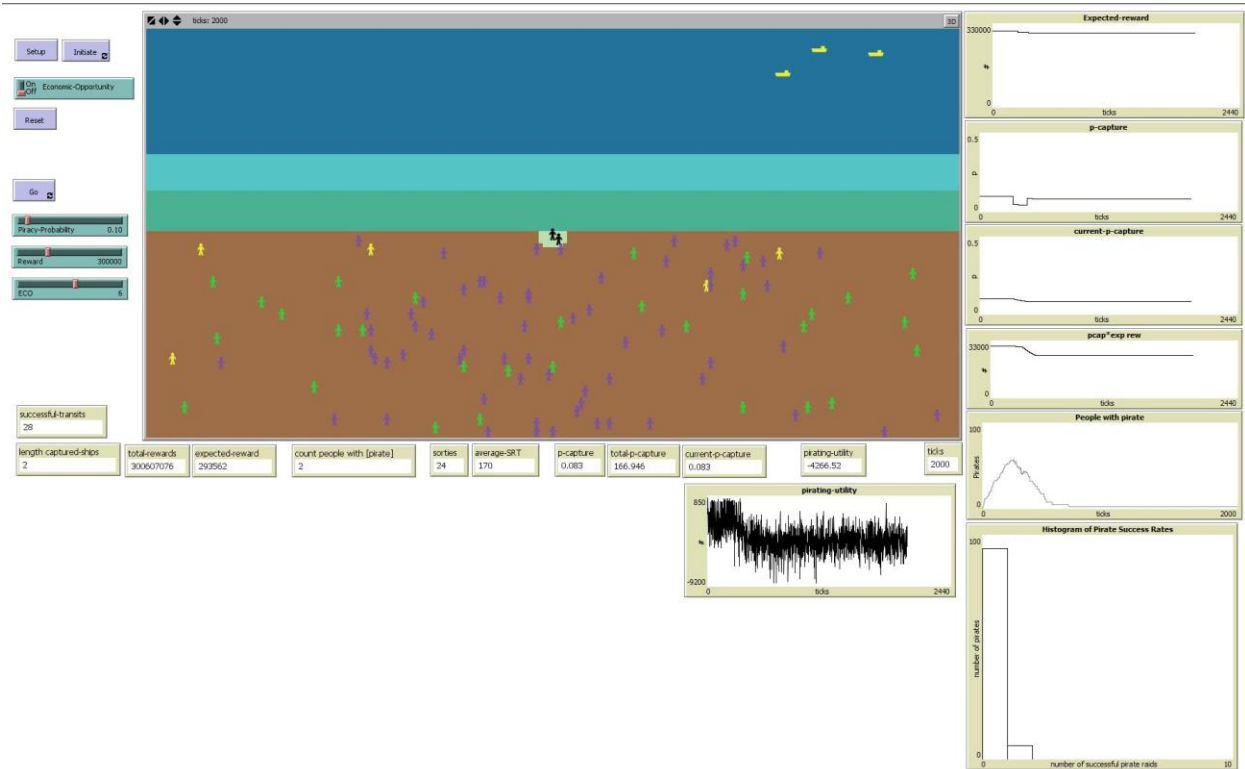Figure D-12. Scenario 12: Model 20, Reward = 400,000, ECO = 7.

Figure D-13. Scenario 13: Model 20, Reward = 300,000, ECO = 6.
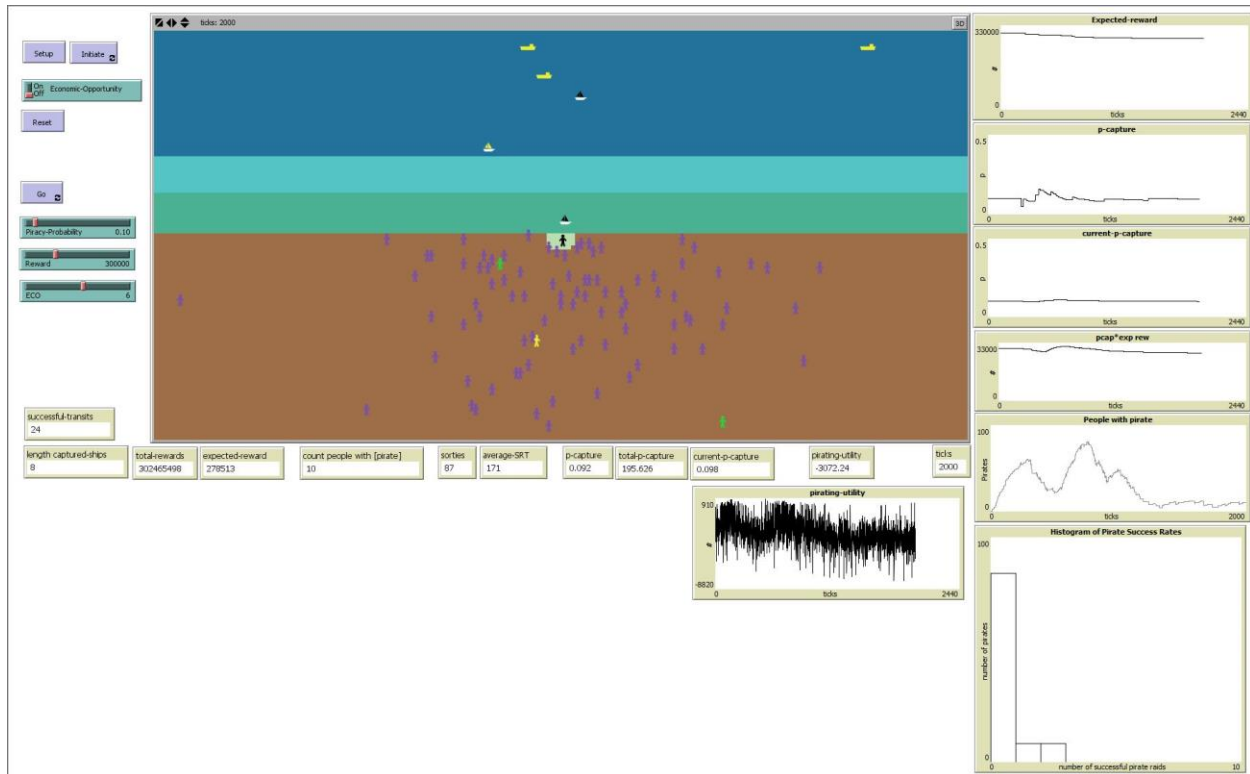
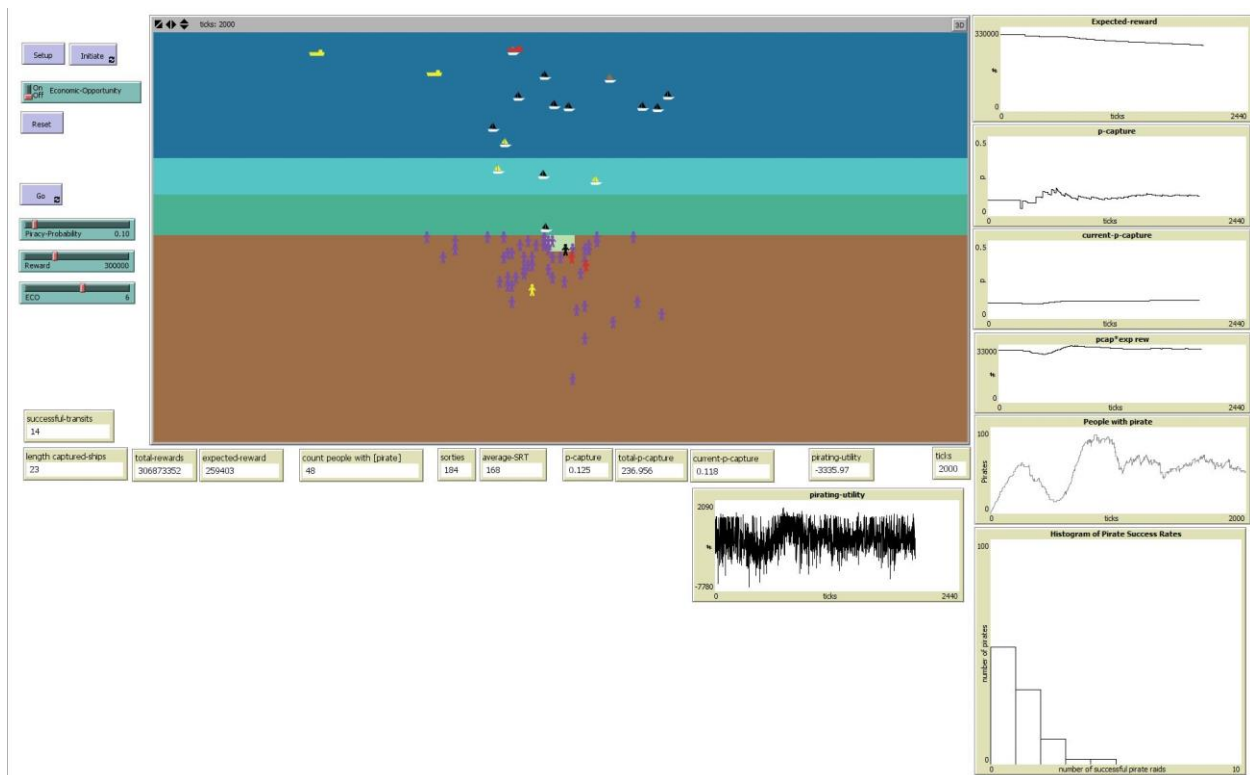Figure D-14. Scenario 14: Model 20, Reward = 300,000, ECO = 6.

Figure D-15. Scenario 15: Model 20, Reward = 300,000, ECO = 6.

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