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A CONCEPT OF OPERATIONS FOR AN UNCLASSIFIED COMMON OPERATIONAL PICTURE IN SUPPORT OF MARITIME DOMAIN AWARENESS

by

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13. ABSTRACT (maximum 200 words)

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The purpose of this thesis is to establish a concept of operations (CONOPS) that will provide an unclassified maritime common operational picture (COP) with the capability to produce near-real-time shareable information from which all authorized interested parties can benefit. The research focuses on utilizing available unclassified commercial-off-the-shelf (COTS) capabilities to create a scalable and extensible platform that provides intelligence analysts and decision makers the ability to gain additional situational awareness and gather actionable information that can be quickly and easily shared with other services and international partners. Additionally, in an effort to prove the proposed CONOPS will work, the process was attempted utilizing some of these technologies.

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LIST OF ACRONYMS AND ABBREVIATIONS

AIS	Automated Identification System
AOI	Area of Interest
AOR	Area of Responsibility
AWS	Amazon Web Services
C2	Command and Control
C4ISR	Command, Control, Communications, Computers and Intelligence, Surveillance and Reconnaissance
C5F	Commander Fifth Fleet
C6F	Commander Sixth Fleet
C7F	Commander Seventh Fleet
CAMTES	Computer-Assisted Maritime Threat Evaluation System
CNN	Convolutional Neural Network
COCOM	Combatant Command
CONOPS	Concept of Operations
COP	Common Operational Picture
COTS	Commercial-off-the-Shelf
CSII	Cooperative Situational Information Integration system
CTAR	Coalition Tactical Awareness and Response
DOD	Department of Defense
DOT	Department of Transportation
EO	Electro-Optical
EOC	Emergency Operations Center
EV-WHS	Enhanced View-Web Hosting Service
FTP	File Transfer Protocol
GB	Gigabytes
GCCS	Global Command and Control System
GCCS-M	Global Command and Control System–Maritime
GeoTiff	Geostationary Earth Orbit Tagged Image File Format
GSD	Ground Sampling Distance
HTTPS	Hypertext Transfer Protocol Secure

IC	Intelligence Community
IMO	International Maritime Organization
ISR	Intelligence, Surveillance and Reconnaissance
IT	Information Technology
JIATF-S	Joint Inter-Agency Task Force - South
JWICS	Joint Worldwide Intelligence Communications System
LRIT	Long Range Identification and Tracking
MDA	Maritime Domain Awareness
MSI	Maritime Security Initiative
MSSIS	Maritime Safety and Security Information System
NGA	National Geospatial–Intelligence Agency
NIEM	National Information Exchange Model
NIPRNET	Non-Classified Internet Protocol Router Network
NITFS	National Imagery Transmission Format Standard
NOAA	National Oceanic and Atmospheric Administration
OODA	Observe, Orient, Decide, Act
OPNAV N2N63	Chief of Naval Operations for Information Dominance
PKI	Public Key Infrastructure
S-AIS	Satellite-Based AIS systems
SAR	Synthetic Aperture Radar
SCS	South China Sea
SIPRNET	Secret Internet Protocol Router Network
SME	Subject Matter Expert
SPAWAR	Space and Naval Warfare Systems Command
SPOTR	Surveillance Persistent Observation and Target Recognition
TCPED	Tasking, Collection, Processing, Exploitation, Dissemination
U.S.	United States
UNCLOS	United Nations Convention of the Law of the Sea
USB	Universal Serial Bus
USN	United States Navy
VMS	Vessel Monitoring Systems
VOI	Vessel of Interest

I. INTRODUCTION

The Naval Postgraduate School Information Science Department has proposed a two-year campaign of integrated thesis research designed to explore and develop ideas relating to the development of an unclassified maritime domain awareness (MDA) concept of operations (CONOPS). U.S. forces are able to detect and monitor the maritime domain in support of maritime interests around the world, but often lack the ability to provide actionable information in a shareable, usable manner. This issue, in particular, is an ongoing Commander Seventh Fleet (C7F) topic of interest due to the complex MDA issues present in their area of responsibility (AOR). The intent of this thesis is to take the first step in the development of a fully implementable CONOPS that leverages recent developments in unclassified commercial-off-the-shelf (COTS) intelligence, surveillance and reconnaissance (ISR) capabilities to build a comprehensive common operational picture (COP). The overarching goal of the COP is to provide the who, when, what and where for maritime vessels of interest (VOIs) adaptable to specific areas of interest (AOIs) so that operators and intelligence analysts, who will infer the why and how, can make informed actionable decisions and/or share data with interested parties.

MDA is defined as "the effective understanding of anything associated with the maritime domain that could impact the security, safety, economy, or environment of the United States" (White House, 2013, p. 2). It encompasses "all areas and things of, on, under, relating to, adjacent to, or bordering on a sea, ocean, or other navigable waterway, including all maritime-related activities, infrastructure, people, cargo, vessels, and other conveyances" (White House, 2013, p. 2). What is happening in the waterways around the world is becoming an increasing concern. Technological advances in recent decades have provided an environment that has allowed the global capital market to grow and open new economic opportunities via complex commerce pathways. The global supply chain is becoming increasingly dependent on interconnected waterways to support these expanding opportunities and, as a result, they have become essential to the United States' national economy, commerce and security. However, the increasing number of countries and vessels moving freely through these waterways is creating complex security issues.

Harmful and unlawful acts within this increasingly important domain can cause the disruption or destruction of a physical and economic nature to the United States and its partners (White House, 2012). There is no shortage of these threats to national security and economic interests. These include terrorism, criminal activities, piracy, environmental destruction, illegal immigration, and human and drug trafficking to name a few (White House, 2013). The core principles of effective MDA promote a unity of effort through proper information sharing and safeguarding in order to facilitate informed decision making to ensure the safe and timely movements of legitimate commerce (White House, 2013).

When the need arises, U.S. forces are able to identify and track VOIs in support of these maritime interests. However, the means by which this data is collected and processed often does not result in information quickly or in a form that is easily shareable, which can result in lost opportunities. The data often comes from classified sources. Additionally, data persistence is difficult to maintain because it is either too expensive to sustain continuous operation of the sensor and/or there are too few personnel or resources to commit to data and information gathering objectives. This creates a reactionary environment for data analysts and decision makers who would prefer to know and act on the threat before the damage is done.

A. PURPOSE

While the United States Navy (USN) is the lead agency primarily concerned with MDA, each of the combatant commands (COCOMs) is assigned a different AOR that results in different concerns and mission requirements. This has led to various technology and information silos that do not easily share information of interest with other U.S. agencies and foreign partners. However, increases in public domain information on vessel tracking and the quality and periodicity of open-source commercial satellite imagery as well as improvements in feature recognition software suggest that a non-classified capability to recognize and track VOIs in the areas of USN operations may be possible.

The purpose of this thesis is to addresses some of these issues inherent in the current MDA construct by reviewing both the purpose of MDA and the current policies governing it. Then, the current tools available with the capability to collect, process and display unclassified maritime data are explored to determine how they might be integrated to enhance MDA within this construct. The role of trust and classification is also explored to determine the viability of such an unclassified MDA information system.

B. RESEARCH INTENT

In an attempt to better understand the relationship between the numerous variables related to MDA in C7F and other COCOM AORs, this research attempts to determine if the highly sought-after qualities in actionable MDA data, such as information shareability, accuracy, reliability, frequency and quality, can be achieved solely via unclassified means. Four specific issues were addressed. First, specific C7F MDA objectives were clarified. Second, the value of non-classified MDA technical approaches now and in the near future were determined. Specifically, whether or not data persistency can co-exist with the ability to develop tracks on cooperative and non-cooperative VOIs. Third, if an unclassified MDA CONOPS could be utilized to develop maritime behavioral models that could deduce specific maritime activities, such as fishing, illegal fishing, smuggling, military action and other activities of potential national interest. Finally, broader strategic opportunities were investigated. To address these issues, the following questions were specifically addressed:

1. What are the current MDA processes in C7F and other AORs?
2. What emerging capabilities and practices could improve C7F MDA?
3. Can these capabilities be integrated in a way to build increased situational awareness and sharing capacity?
4. What effects would an unclassified, sharable MDA construct have on strategic relations within the AOR?

This thesis will expand on existing MDA policies and procedures and introduce new practices and operational concepts to enhance the current MDA warfighting concept, expose issues and identify potential solutions. On the surface, while numerous policies and architectures have been suggested, it does not appear that the United States, and C7F in particular, have been able to fully leverage current unclassified MDA capabilities.

C. SCOPE AND LIMITATIONS

The scope of this study is considerable and encompasses numerous agencies and classification levels. Some limitations included a lack of experience on the part of the researchers at the operational level of command within the MDA enterprise to fully understand the nuances involved. Additionally, the information sought for this research was not always priority number one for staffs who are overworked and undermanned. These concerns were mitigated by patiently gaining access to numerous individuals who have worked and are currently working at the strategic, operational and tactical levels in multiple AORs whose concerns mirrored the scope of this thesis.

D. METHODOLOGY

A qualitative approach toward research was performed to best identify gaps in the current MDA policies and procedures and generate applicable recommendations. Research was conducted to collect data on current MDA systems and workflows to determine what might be leveraged or changed for future operations. This included historical research, observation and discussion of current practices with operational subject matter experts (SMEs) assigned to applicable AORs as well as those working in research and development for new and future capabilities. Real world scenarios were analyzed to determine what MDA tasks are normally completed, what priority they are given, who was generally involved, what applications were generally used and how they communicated with outside interested parties. Shortcomings and inefficiencies were noted.

Working with the C7F sponsors and other stakeholders, a detailed analysis of their particular processes was completed to establish possible solutions and process changes to create operational improvements. Based on those findings, possible technological and process improvements utilizing COTS products and capabilities were explored in an attempt to optimize data collection, processing and integration into an unclassified and shareable COP and a general workflow process model was developed and tested. Finally, the research provides some future modification possibilities and uses as well as challenges for the road ahead. Notably, if these capabilities can be leveraged and integrated, the technical, operational and strategic implications must be determined before practical implementation can occur. Concerns will exist over how much of this data and derived information can and should be shared with coalition and allied partners.

E. ORGANIZATION OF THE RESEARCH

Chapter II provides a comprehensive literature review. This includes a thorough explanation as to the importance of global MDA. Then, the recent improvements and advances in ISR technology that could be utilized to build an unclassified COP are discussed in detail. Chapter III breaks down the current methods of MDA utilizing Leavitt's diamond model to determine the gaps in the four major components of the MDA enterprise and how possible solutions will affect each of them. A CONOPS is proposed for a new method to achieve MDA via unclassified sources, processes and displays along with examples of possible uses cases where this method would be applicable. Chapter IV describes the testing methods that were used to validate the proposed CONOPS to include examples of the data received and how it could be employed to increase situational awareness and decrease workload throughout the MDA enterprise. Finally, Chapter V presents conclusions based on the analysis and testing of the suggested CONOPS and recommendations for future work and research.

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II. LITERATURE REVIEW

A. MARITIME DOMAIN AWARENESS

The maritime domain is an area of significant strategic concern to the United States and its allies. It is the global common ground where commodities are exchanged, wealth realized and, consequently, an area of opportunity for our enemies to threaten national security and/or prosper from unlawful activities. It is where those seeking to gain from illicit opportunities have the greatest chance of success. To properly confront these threats extensive situational awareness will be required to enable effective decision making (Bush, 2005). In order to monitor and prosecute illegal activities over such a vast global area, concerned entities are becoming increasingly dependent on technology to collect, process and share actionable data within this environment. The capability to build a comprehensive COP with real-time and reliable data enables effective decision making and appropriate action by the law enforcement, military and civilian entities involved.

1. The Importance of MDA

Admiral Mahan (1918) first suggested and codified “scouting” as one of the key elements to successful naval engagements. This crucial requirement has not changed in the intervening years, just the methods to achieve this goal. Ever since the devastating attacks on September 11, 2001, the Federal Government has continued to develop and revise domestic and foreign policies to combat the new and evolving threats posed by irregular warfare and an increase in illicit activates occurring near and through our borders. Previous to this, various departments exercised separate strategies that were effective enough to provide a comfortable layer of security. However, in 2004, in response to those attacks and other developing security concerns, President Bush directed the Secretaries of Defense and Homeland Security, via the National Strategy for Maritime Security, to lead an effort to develop a new national strategy for maritime security that would integrate disconnected public and private departmental strategies into one cohesive and effective national maritime strategy. This strategy, released in 2005, called for the alignment of federal, state, local and private sector entities to form a more cohesive and effective Maritime Strategy (Bush, 2005). In response, all the departments that play a role in maritime security developed supporting plans to cover their specific concerns and challenges. Each entity concentrated on a different aspect of MDA that fell within their mission focus and developed a new strategy that could fit within the general scope of a larger all-encompassing strategy that includes all the others (Boraz, 2009). For this strategy to be successful, an increased willingness and capability to share information across services, departments, agencies and national boundaries needs to exist.

2. Information Sharing Basics

According to Vice Admiral Morgan, Deputy Chief of Naval Operations for Information, Plans and Strategy at the time, there are two key requirements needed to build an effective COP, information and intelligence (Morgan & Wimmer, 2005). Both are required fundamental components for improving maritime security, but with these components come various operational, policy and legal ramifications (Klein, 2011). A clear propagation and understanding of these rules and ramifications against strategic initiatives are required to determine what can be shared and with whom. Using the term "intelligence" often leads to the assumption of military interests and, with respect to MDA, exclusivity in regards to the use of the oceans. However, MDA in the general sense is more about the use of information regarding a common interest to promote secure borders and safe international trade through secure shipping practices (Klein, 2011). The international understanding of this need is evident in the adoption of United Nations Convention on the Law of the Sea (UNCLOS) in 1982 by over 160 parties and its further revisions (Hong, 2012). UNCLOS defines the rights and responsibilities of nations with respect to the development and sustainment of the world's oceans. It accomplishes this by outlining various guidelines and specific obligations imposed on states in regards to the management of marine natural resources and vessel safe passage. Among these specific obligations is the duty to share relevant information that can assist in security issues relating to a state's borders or the conduct of safe passage (Hong, 2012).

Unfortunately, national security issues and the capabilities used to collect information in reference to them will likely trump information sharing that does not directly benefit the gatherer. This can cause delays in action that result in lost opportunities. Collaborative approaches to information exchange need to be formally endorsed in recognition of global needs to properly achieve MDA. The Obama administration (2012) hoped to build on the Bush era strategies mentioned previously by fostering an information sharing and safeguarding environment with nations who possess a valid need and have met all access requirements. The expectation, outlined in the National Strategy for Information Sharing and Safeguarding, is to enable accurate and confident decisions and responses as well as further partnerships that promote and facilitate MDA safeguarding and integration (Obama, 2012). Advances in information technology (IT) can make this a reality by allowing information to flow freely across jurisdictional and organizational boundaries. With access, however, comes vulnerabilities.

The challenge lies in forming a single comprehensive capability that can receive and fuse all the information coming from different sources into a common system that will not overwhelm the user while meeting the security needs of all participating agencies and allies. Additionally, in order to use the information most effectively a certain degree of collaboration that provides the ability to share information quickly and effectively to enhance operational support needs to exist (Morgan & Wimmer, 2005). Essentially, the ability of analysts to collect and access relevant data, monitor their AOR, and allow a flow of information between agencies and allies that can lead to effective communication to detect and prevent illicit activities is of utmost importance for effective MDA.

3. Role of Trust

Knowledge is power and any gain in information will give the receiver added advantage so there will always be a level of risk associated with any sharing of information. The more handled, inconsistent, or fragmented the information shared the higher the risk to national security. However, with well-defined and executed policies and standards, comprehensive training and effective governance and accountability via performance management and compliance monitoring, risk can be mitigated and a culture of responsible sharing can be fostered (Obama, 2012). Realizing that sharing and safeguarding information do not have to be mutually exclusive is important to increase transparency, a requirement to foster trust, while enabling the appropriate confidentiality.

The advantage of utilizing unclassified tools for surveillance, detection, classification, identification, location and tracking at the operational and tactical levels is that the data derived, even when fused from multiple sources, does not divulge any specific operational details beyond routine maritime surveillance. This creates a wealth of easily accessible and shareable data, information vice intelligence, for use by national and coalition partners while meeting national security objectives. Information moving between data providers and consumers via defined common standards and protocols can not only make this possible, but improving information gathering and dissemination processes to provide products that are useful in various defined MDA mission sets.

Another benefit of an unclassified means to an end is the advantage of expedited access to information by authorized users by removing the numerous roadblocks in information sharing that currently exist due to the inherent over-classification of MDA data. Often a by-product of the increasing demands on the intelligence community's (IC) time and effort due to big data, it has become the cultural norm to over-classify information. Rather than doing the due diligence of appropriately marking information sources, it is much easier to revert to a higher classification. The classification of information from national technical means sources is in direct conflict with information sharing. The United States and its allies have much to gain from the information sharing and collaboration that could result from reversing this trend (Grimes, 2009). This will require a shift from working in a culture of secrecy to a culture of sharing; a concept the IC is likely to push back on due to various policies and procedures already in place that can be difficult to navigate. The United States is normally bound by numerous bilateral and multilateral agreements which can make knowing when and with whom information can be shared difficult. These agreements permit the United States to share certain classifications of data with other countries and no two agreements are the same. These conflicting agreements pose significant problems in a classified COP architecture because it requires unique data sets for each agreement that has been established. The Department of Defense (DOD) Information Sharing Implementation Plan mentioned earlier was developed specifically to help overcome these information-sharing challenges (Grimes, 2009). With input on sharing requirements and concerns from the COCOMs, military departments and multiple defense agencies, this plan was developed to help these agencies overcome differences in culture, governance, policy, resources and technology. The plan also addresses management, operations and classification processes while acknowledging the unprecedented capabilities to exchange information in a variety of ways across the globe with today's technology. It also touches on the issues of improper and over-classification as impediments to the timely sharing of time-sensitive information. This has eased concerns and paved the way for COCOMs to begin buying into and adopting unclassified portals with foreign partners in their AORs to meet specific mission needs (Grimes, 2009). An unclassified COP remedies this situation by keeping the data and information assessable via collection and processing, but allowing partners to analyze information themselves to derive their own actionable intelligence that may or may not be shareable.

4. The South China Sea Problem

While all areas of naval operations offer complex MDA situations, the current issues within the C7F AOR, particularly in the South China Sea (SCS) region, provide a great example of the continuing need for effective MDA. Sovereignty disputes and land reclamation among the six nations that rim the resource-rich SCS are becoming increasingly common. This is creating greater tension and intensifying conflict in an already volatile area of the world (Jackson, Rapp-Hooper, Scharre, Krejsa, & Chism, 2016).

According to the DOD's Asia-Pacific Maritime Security Strategy (2015), the United States engages in many complicated bilateral relationships where the presence of China, and their territorial views on the SCS, makes MDA particularly important. The White House (2015) confirmed the United States' interests in the SCS in 2015 when it released a fact sheet entitled "U.S. Building Maritime Capacity in Southeast Asia" which outlined funding commitments, security programs and the need for increasing cooperation and coordination with allies in the region, including the Philippines, Vietnam, Indonesia and Malaysia. This document also reaffirms the United States' commitment to improving maritime security capabilities in Southeast Asia by developing credible maritime capabilities and seeking new opportunities for collaboration. Other United States' funded maritime capacity building efforts are contained in the general foreign military financing program and via other specific departments or bureaus. For example, the U.S. State Department's Bureau of International Narcotics and Law Enforcement Affairs designated $25 million to develop the Southeast Asia Maritime Security Law Enforcement Initiative (Parameswaran, 2016).

Announced in June 2015, the Southeast Asian Maritime Security Initiative (MSI) reinforced collaboration efforts by calling for a focus on building a regional capacity through ally and partner maritime capabilities to better address numerous maritime challenges (Cronin, 2016). At the forefront of these challenges is China's increasing aggression in the SCS area. A five-year, $425 million DOD-funded project, MSI's primary goal is to enhance MDA through detection, understanding and sharing maritime information in the SCS so that all interested parties share a common picture. Specifically, it aims to create enhanced regional capabilities that can regularly update a COP that will enhance the Southeast Asian states' capacity to detect, analyze, respond to and share valuable information about maritime activities in the SCS (Cronin, 2016).

Within the C7F AOR, it will be challenging to build this level of capacity. MDA collaboration between the United States and Southeast Asian governments in the C7F AOR is currently very limited. On top of each country having their own ISR capabilities, numerous bilateral and multilateral relationships exist, like Singapore's Information Fusion Center and multilateral cooperative endeavors such as the Malacca Straits patrols, which makes cooperation difficult (Parameswaran, 2016). Because the extent of these capabilities varies widely and there is very limited participation from external sources in local networking, numerous gaps continue to exist between actual and desired capabilities (Jackson et al., 2016). For instance, a crucial Filipino armed forces security gap identified in the Sulu and Celebes Seas resulted in over eighty percent of MSI funding to be focused on bridging that one specific gap (Cronin, 2016). Gaps like this and others create obstacles in the ability and desire of entities within the region to share information. Taking advantage of the recent advances in technology, however, if implemented correctly, could bridge those gaps and create a more robust complete MDA COP to enable persistent collaboration opportunities within the C7F AOR and beyond.

Even if the technology gaps inherent in the current information sharing processes are overcome, readily available data and imagery shared throughout such an unsteady AOR will have a strategic impact. In his book, *Asia's Cauldron*, author Robert Kaplan (2014) paints a portrait of considerable shared distrust of Chinese intentions by other SCS nations. Despite shared concerns, there has been very little collaboration between these nations to address this intent. Building a shared COP that includes maritime awareness and shared ISR data is attainable, but the two need to be viewed together in balance in order to reach an attainable solution.

Beyond the mistrust between the nations surrounding the SCS, the perceptions of United States led initiatives, such as MSI and ongoing relationship building strategies in the region, are not always positively received. Some may view MSI as a U.S.-led effort directed against China, which could compromise relationships individual countries have with Beijing. In order to be successful, the United States will have to convince countries involved to commit to their initiatives. Not all participants may be so willing to share their information not only with the United States but amongst their neighbors due either to a lack of trust or pre-existing rivalry. For example, Malaysia and Indonesia still refuse to join 20 other Asian states in the Regional Cooperation Agreement on Combating Piracy and Armed Robbery Against Ships in Asia based partly on a disagreement in the Singapore location of the information sharing center headquarters (Parameswaran, 2016). Working together with various agencies and foreign partners to develop transparent, comprehensive and cooperative strategies will go a long way to foster confidence and trust (Walker, 2013).

With such a broad variety of concerns and mission sets within the maritime domain, the goal, then, is to produce an easily accessible COP using a limited amount of resources. The enhanced joint awareness this system will provide gives commanders and decision-makers timely, accurate information with which to direct forces confidently and effectively. Technology can provide a means to share information by monitoring activities, but decisions and processes will still have to be determined via policy. This research intends to determine which technical capabilities exist that can make an unclassified COP a reality, identify what remaining technical roadblocks exist that might hinder these emerging capabilities from achieving the desired result, and finally, discover the possible operational and strategic issues identified by such a capability and how to best address them. Successful integration of commercial technological advances to enhance maritime domain awareness that can transcend international boundaries has already been proven on a limited basis and will be discussed more in depth in Chapter III.

B. POTENTIAL UNCLASSIFIED MDA TOOLS

Technology improvements in the ISR field have accelerated rapidly over the past two decades. These developments have become an increasingly important strategic requirement for those who require actionable intelligence for the protection and security of their borders, economic activities and maritime traffic. There is an unprecedented amount of resources feeding increasing amounts of data into networks on various systems for end users to analyze. This data, when properly integrated into the current MDA construct, can increase the speed and quality of information produced. Some examples include long-range over the horizon radars, high altitude, long-dwell unmanned aerial vehicles, oceanic surveillance buoys, acoustic systems and an ever-growing fleet of military and commercial satellites. However, few of these have afforded the United States a means to collect rapidly actionable unclassified data that can be shared between independent agencies, multinational allies and law enforcement agencies (Mugridge, 2012).

Advances in technology, particularly analytical processes and tools, available in the commercial sector could be leveraged to make MDA data more accessible, effective and available at a faster rate. This could significantly shorten the observe, orient, decide and act (OODA) loop, allowing commanders and analysts more time to focus on mission-critical tasks. This thesis will only assess open-source unclassified technologies and their capabilities that can be leveraged in order to determine their value to provide the end user with actionable, shareable data from collection to display.

1. Data Collection

With all the new and enhanced commercially available technology available, there are numerous tools that can be leveraged to gather data for input into a COP that can be accessed and updated by a multitude of authorized users. These tools encompass a wide range of assets from orbiting satellites to earth-bound radar and sensors to numerous onboard and off board vessel tracking systems. These systems have become so advanced and prolific that they can provide a constant stream of information to aid in tracking both cooperative and uncooperative vessels.

a. Satellites

The biggest increase in the accessibility of data in recent years is due to the evolution of the satellite market. Recent advances in technology have allowed engineers to transition from the large, costly, complex satellites to smaller, less complex cheaper versions. Additionally, it has become cheaper and easier to launch satellites into orbit. This has led to a notable increase in the number of small private organizations putting their own vehicles in space (Baylis, Kroll, & Madon, 2016). Based on a report released by the Tauri Group (2016), the number of satellites launched per year from 2011–2015 increased 36% over those launched in the previous five years. Consequently, there are 1,381 operational satellites in orbit, an increase of 39% since 2011 (Tauri Group, 2016). This data provides a unique view that is unmatched in any technological sector on the ground. As a result, commercial companies are able to sell an increasing amount of open-source data from their satellites. Previously, imagery and access to these satellites that has been available to only a small number of organizations, such as government space agencies and research institutions, but it is now becoming widely available to the public for a fee (Baylis, Kroll, & Madon, 2016).

Most useful to the maritime domain is a satellite's ability to observe and record the earth's surface. Currently, there are two observation technologies, electro-optical (EO) and synthetic aperture radar (SAR), which can generate vessel tracking imagery.

These payloads are carried on different systems and can be stand alone or work together. Each system has its advantages and disadvantages which will ultimately determine its usefulness for different mission sets. The full-color EO imagery is flashier and has been around quite a bit longer, but requires daylight and clear weather to prove useful. At a high resolution, it can provide a wealth of information beyond mere detection; providing such details that may lead to classification and identification of a vessel to include course and speed. Typically, these satellites have been primarily used for environmental monitoring, meteorology and map making. SAR, however, can provide useful information regardless of weather or time of day which guarantees data will be received within the AOI, but is limited to the presence of an object, its location and possibly, the direction of motion (Parker, 2012).

Earth imagery and analysis has become big business. For years, only a limited number of companies offered earth observation services, but new competitors and partnerships have emerged with funding no longer being driven by the space industry, but increasingly by the IT sector. DigitalGlobe, Airbus Defense & Space, TerraBella and ImageSat International are just a few notable companies that provide EO and SAR imagery and analysis (Tauri Group, 2016). Not only have the number of satellites increased, but the technology to take pictures from space has advanced significantly, with leading-edge imagery now less than 0.3m-resolution (DigitalGlobe, 2014). Prior to 2014, the U.S. Government banned commercial companies from publicly releasing images with a pixel resolution greater than 0.5m for national security reasons. According to DigitalGlobe (2014), concerns of a significant loss in market share due to rapid advances by non-U.S. earth observation companies has led the U.S. Department of Commerce to grant them and others permission to sell their highest-resolution photographs, up to 0.25m panchromatic and 1.0m multispectral ground sample distance (GSD) to the public in 2014. At this resolution, you can not only see a car, but determine its make (DigitalGlobe, 2014).

This preponderance of available imagery creates large data sets, which when analyzed correctly, are already solving extensive problems in environmental conservation, natural resource management, humanitarian aid and human migration

(Baylis, Kroll, & Madon, 2016). Once imagery processing is streamlined, actionable imagery and its accompanying metadata can be available within hours (Baylis et al., 2016). To help organizations handle the dramatic increase in incoming data, satellite companies are now offering storage, data mining and analysis services by means of manual and automated machine learning for a fee. Companies that provide such data analysis include DigitalGlobe, Orbital Insight, Descartes Labs and Tellus Labs, but none have developed an automated maritime imagery recognition capability that has been advertised.

b. Coastal Radar Systems

Radar imagery is not only produced from space, but also on the ground. With increasing maritime security concerns, ground radar and acoustic surveillance systems have become more common. Coastal radar systems, such as STYRIS CSS, utilize various sensors built along the coast. These sensors acquire data and feed into the company's database where it is fused with other data feeds to create a maritime picture providing increased command and control (C2) capabilities (Signalis, 2015). Also of note, passive acoustic methods which detect ships based on the detection of sound are becoming an increasingly effective maritime sensor. For example, the Stevens Passive Acoustic System can detect and classify ships via simultaneous acquisition and analysis of acoustic signals (Sutin et al., 2010).

c. Vessel Tracking Systems

There is also an assorted array of vessel tracking systems operated by various organizations for different purposes; the most often cited being maritime safety and security. The commercially available Automatic Identification System (AIS), Long-Range Identification and Tracking system (LRIT) and Vessel Monitoring System (VMS) are the three prominent tracking systems used globally.

AIS is an open, non-proprietary communications system sanctioned by the International Maritime Organization (IMO) to promote safety and transparency in maritime traffic. It is mostly used to supplement marine radar, the primary method of collision avoidance for water transport. Effective December 2004, IMO required all ships of 300 gross tonnage and upwards in international waters, cargo ships of 500 gross tonnage and upwards not engaged on international voyages and all passenger ships irrespective of size to carry AIS systems (IMO, n.d.). The AIS system, when used properly, transmits and receives information via an onboard transponder that passes a wealth of information to other ships and shore-based facilities including ship identification, type, position, speed, course, status and various other safety related information (IMO, n.d.). This information can and is shared freely at the unclassified level. Numerous websites already exist for anyone with account access to view AIS track information such as marinetraffic.com, vesselfinder.com and fleetmon.com. However, the level of vessel information displayed is often fee dependent.

There are limitations to AIS. Traditional AIS signals have to be routed back to a shore-based receiving station. This can be done directly if the vessel is within close range to shore or via a relay system built into the AIS transceiver. When vessels are beyond the acceptable range, far out to sea, the AIS signal cannot be received. A satellite-based AIS system (S-AIS) embedded in micro-satellites that is able to detect and process AIS information transmitted from vessels beyond the range of traditional AIS receivers has been developed to mitigate this issue. This, however, requires a cost to upgrade the system on the vessel, so it may not be cost-effective for the ship to utilize the upgraded system (Thomas, 2013). Companies such as ORBCOMM, ExactEarth, Spacequest and Spire are currently deploying this technology. Other issues include spoofing, hijacking, availability disruption and general voluntary compliance. Beyond the aforementioned regulations, there is no standard of how the system is used. Individual vessels are able to input fraudulent information (Balduzzi, Pasta, & Wilhoit, 2014). Therefore, while it provides an unclassified and shareable platform, used alone, AIS is an ineffective system to achieve effective MDA. The information derived from AIS will need to be validated and/or fused with other sensors, databases and displays that are unclassified and shareable to be considered reliable and valuable.

In contrast to AIS, primarily a short-range collision avoidance system, LRIT is a system specifically designed for long range operations. Initiated by the IMO in 2006, it is a satellite based communication system for vessel identification and tracking built primarily for ship types engaging in international voyages, including all passenger ships, high-speed craft over 300 gross tonnage, cargo ships and mobile offshore drilling units (Chen 2013). The IMO requirement states that these ships must report to their flag administration four times a day. The use of LRIT on vessels follows the same characteristics as AIS, but there are a few key differences. AIS has more information categories in its database providing more information on a vessel. Also, LRIT, unlike the passive AIS system, requires active participation via a two-way link between ship and shore offering a higher degree of credibility (Chen, 2013). While AIS and LRIT are used for different purposes and slightly different capabilities, they are complementary and can be used in conjunction with one another to provide more reliable information.

The third system, VMS, is a satellite-based, closed, proprietary system used in the commercial fishing industry and managed by the National Oceanic and Atmospheric Administration. According to the program website (NOAA, n.d.), unlike AIS and LRIT, VMS is merely a one-way transceiver that is installed on vessels that leverages satellite communications in order to pass information back to ecological and fishery regulatory organizations for tracking and monitoring purposes. The transceiver sends position reports that include vessel identification, time, date and location about once an hour or more often if the vessel is approaching an environmentally sensitive area. The system is typically used to observe vessels operating in the territorial waters and 200-nautical mile exclusive economic zones of many countries in order to increase the control and sustainability of the maritime environment by verifying proper fishing procedures and deterring illegal fishing activities (NOAA, n.d.).

While all these systems provide information and benefits for different purposes, the real advantage for maritime authorities and MDA intelligence analysts lies in the comparison of information reported in these systems. Data received from these various systems can be compared to verify that correct information is being reported by a particular vessel and provide a wealth of unique data to identify specific vessel activity to build a reliable snapshot of a particular AOI. For MDA analysis, the use of this information is particularly useful to build historical tracks and a more comprehensive COP to determine any abnormal behavior.

2. Data Processing

The proliferation of data caused by the boom in the satellite imagery industry that is making high-resolution imagery readily available also comes with big challenges (Baylis et al., 2016). The bandwidth, storage, computer processing power and expertise required to process high-resolution imagery and big data analysis becomes the next hurdle. Information received from various ISR sensors is generally received in a raw data format that is not suitable for interpretation and analysis. Processing this data into a usable and meaningful format so that it can be analyzed is a greater challenge. Traditionally, information gained from satellite imagery has been processed manually due to the need for high accuracy in deriving the information necessary for the level of decision making required (Baylis et al., 2016). However, this requires highly skilled analyst and a considerable amount of time to complete data and image processing tasks. As more data is becoming available at increasingly high rates, this process is becoming unmanageable for most intelligence analysts. Not only is it time-consuming, but manual classification is subject to bias (Baylis et al., 2016). So, this approach is increasingly unfeasible.

With these challenges in mind, many of the commercial satellite imagery providers have developed processing-intensive imagery analysis platforms to handle the incoming data directly. Automatic detection through the use of advanced computer algorithms, including machine learning capabilities in some cases, can sift through large amounts of data in a fraction of a second compared to human users, saving time and money. Because this technology is still in its infancy, few organizations within the DOD use these methods for two reasons, the lack of computer processing capabilities and qualified data engineering expertise (Baylis et al., 2016). Commercial companies, however, seeing the benefits of enhanced machine learning algorithms to extract intelligence from big data, are directing considerable resources towards acquiring this capability. This allows them to automatically extract useful information from large data sets that would impossible to replicate manually. Google, DigitalGlobe and Orbital Insight, as well as a few smaller startup companies, already offer such services and have proven successful in a number of instances, including tracking human rights violations and migration patterns (Baylis et al., 2016).

Currently, all of the commercial systems and companies mentioned have their own ground station downlinks, including the military, for their particular satellites. They do not, however, possess the capability to talk to each other, so for the present time, any imagery being processed and delivered to DOD systems will incur a delay as it is routed through the commercial company's infrastructure first. However, capabilities exist to inexpensively format data for use in a standards-based downstream processing chain or transform it to be compatible with legacy DOD IT infrastructures to meet real-time requirements, an important capability for making data shareable throughout the DOD and its foreign partner's various systems.

With commercially available imagery of sufficient resolution now available, it is possible to apply advanced feature recognition techniques within the MDA construct to detect and possibly classify and identify vessels anywhere in the world (Bannister & Neyland, 2015). Progeny Systems, located in Manassas, Virginia, is currently developing their feature recognition tool, known as Surveillance, Persistent Observation and Target Recognition (SPOTR), for use in the maritime domain. Similar to facial or biometric recognition tools, SPOTR is a suite of image processing, computer vision and pattern recognition tools that use machine learning and feedback mechanisms to create more intelligent and adaptable techniques for classification and identification of objects (Faltemier, Steinhaeuser, Miller, & Paradis, 2016). By analyzing commercial satellite imagery with near-real-time processing, it can detect, classify and identify ships at sea and in port using these capabilities. With an extensive vessel library to draw from, detection and classification can occur in less than a minute and is still improving. Additionally, it can be further suited to a particular task based on a smaller search space (Faltemier et al., 2016). In time this capability could augment or completely replace the human in the loop required in current MDA operations (see Figure 1). While completely automated classifications are preferred to save time and money, manual classifications, in the short term, can aid machine learning algorithms, thereby increasing automated classification accuracy and efficiency. This will result in reduced identification time and cost in the long run and should not be dismissed.

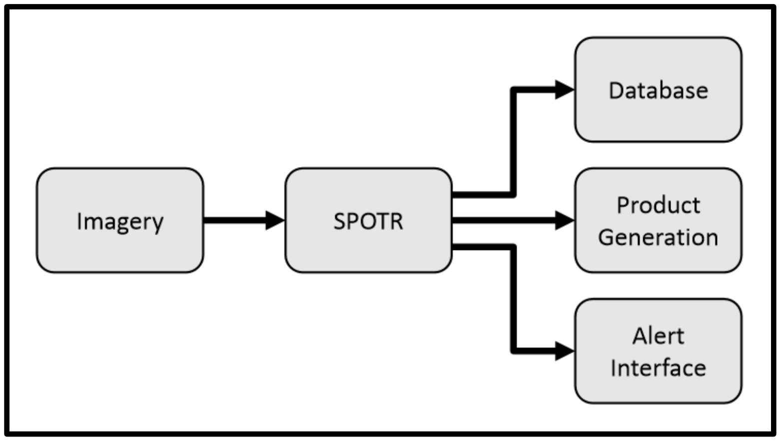


Figure 1. SPOTR Supporting Product Generation. Source: Faltemier et al. (2016).

Beyond imagery and vessel tracking systems there are opportunities for other sources to be incorporated into the COP as they become available. Some of these technologies are currently being tested while others are still in development. These data sources include passive sonar detection, coastal radar and full motion video. As these data sources become available they can be fused into the COP via a standard, agreed upon message format, to make it even more reliable and complete.

3. COP Display

Unifying the overarching strategy, built around these aggregate capabilities, can produce, a comprehensive, reliable and shareable COP. How the information is displayed on the COP is very important. It will determine the usability and adoptability to the user. This is one of the limiting factors in the current MDA architecture. Due to the nature of how data is collected, received and/or stored, it is often only displayable via classified applications. There are numerous COTS unclassified COP applications available, such as Sensor Island, iCommand and probably most well-known, Google Earth (Naval Postgraduate School, 2013). These COP applications have non-military uses such as Emergency Operation Centers (EOC) for wildfires or hurricane relief. Most notable and applicable to this MDA strategy is SeaVision, an unclassified COP application that is sponsored by the Office of the Chief of Naval Operations for Information Warfare (OPNAV N2N63) and is being primarily developed by the U.S Department of Transportation's (DOT) Volpe Center, of Cambridge, Massachusetts, in conjunction with the Space and Naval Warfare Systems Command (SPAWAR) Data Engineering Sciences Center, SPAWAR Systems Center Pacific and U.S. Fleet Forces Command (SeaVision, n.d.b).

SeaVision (n.d.b) is a web-based unclassified maritime data management and visualization tool built with the intent to boost maritime security and build relationships within the maritime community for Public Key Infrastructure (PKI) and non-PKI users. SeaVision creates a common maritime picture via a Google Maps-based interface allowing the user to see, filter and track near-real-time vessel location information as well as receive notifications on specific VOI based on user-defined rules. Currently, SeaVision only leverages terrestrial AIS, S-AIS, and some coastal radar systems for input data. However, the system's open architecture is designed to support multi-source data giving the system room to grow and include more inputs as they become available. For instance, testing has begun to determine if EO, full motion video and SAR imagery track data can be supported within the architecture. Most importantly, SeaVision is adopting and implementing the maritime data exchange formats described in the National MDA Architecture Plan and the National Information Exchange Model (NIEM)-Maritime (SeaVision, n.d.b). Any organization complying with these predefined user attributes and security controls will be able to access and manage the maritime information sharing environment and NIEM-compliant maritime data (Tweed-Kent, 2014).

Ultimately, SeaVision is an attractive application because it not only provides situational awareness, but it can be automated to provide a user or group of users with alerts based on a variety of conditions or filters that allows the user to better manage their time and energy. Though current capabilities only allow the embedding and fusing of cooperative and EO derived tracks, the potential to fully exploit this capability is promising. Incorporating non-cooperative tracking capabilities, such as the unclassified EO and SAR satellite data, into the system means that the SeaVision COP can be complete and accurate for all authorized users with access. With user-defined options for source selection, display data and alerts, the system is extremely flexible making it easily adoptable by any COCOM to build a COP specific to their mission sets and AOR concerns. Further, as a web-based application, there is no requirement for additional hardware or equipment installations.

C. IMPLEMENTATION

No matter the tools that are used to develop this new unclassified operational capacity, implementing this new process will face significant challenges. Users are often critical of change. Effective testing and proof of concept will be required to ease the transition process from the current stove-piped MDA systems to the theoretical architecture and infrastructure required to meet current and future national interests and MDA policy. The challenges and benefits, along with their effects on the relationships within the enterprise, will need to be clearly defined to facilitate a smooth transition from the old processes to the new unclassified CONOPS. A successful proof of concept will assure stakeholders that the new process is well thought out and the benefits will outweigh the challenges to implementation.

D. CHAPTER SUMMARY

MDA can provide a significant strategic advantage if information can be collected and disseminated quickly and effectively. To date, there are no completely unclassified means in which this can accomplished. However, the recent advances in COTS ISR technology potentially make this possibility a reality. The challenge lies in utilizing these new capabilities in a cohesive, low-cost, easy-to-use way that all interested agencies and partners can leverage. In order to determine a viable unclassified solution to MDA, the current methods must be deconstructed to gain an understanding of their flaws and how to best address them.

III. RESEARCH METHODOLOGY

A. UNDERSTANDING THE CURRENT SOLUTIONS

The purpose of this thesis is to establish a CONOPS that will provide an unclassified maritime COP with the capability to produce near-real-time shareable information from which all authorized interested parties can benefit. The first step in creating this new process is to address how MDA is currently achieved and by what means. From there, it can be determined where the gaps exist and properly implement solutions to bridge those gaps. Due to varying threats and concerns around the world, the current MDA processes are broad in scope. This is the result of the many socio-technical aspects of the commanders, staff and information systems involved. To address this complexity, this chapter provides a high-level systematic analysis of current systems in place that provide MDA, the gaps that exist and finally, the improvements that can be employed to better the current process.

1. Analysis via Leavitt's Diamond

Due to a number of different complex mission sets and concerns that reside within the maritime domain, Leavitt's diamond framework, an integrated approach to change, is used to identify and describe the critical components of the MDA enterprise and how they affect each other. Leavitt's diamond (see Figure 2) is a model that proposes every organizational system is comprised of four critical components: structures, tasks, people and IT (Leavitt, Dill, & Eyring, 1973). A thorough analysis of these components and their relationships within an organization will identify issues in the organization and determine how best to initiate change by revealing how specific changes will impact the organization as a whole (Pearlson & Saunders, 2013). This framework captures the organizational, control and cultural variables in a holistic way to analyze the current methods used to achieve MDA, to assess what is missing and to determine what options are available for use to fill those gaps. Therefore, it is appropriate to use each aspect of Leavitt's diamond to describe the current solutions available in the MDA enterprise.

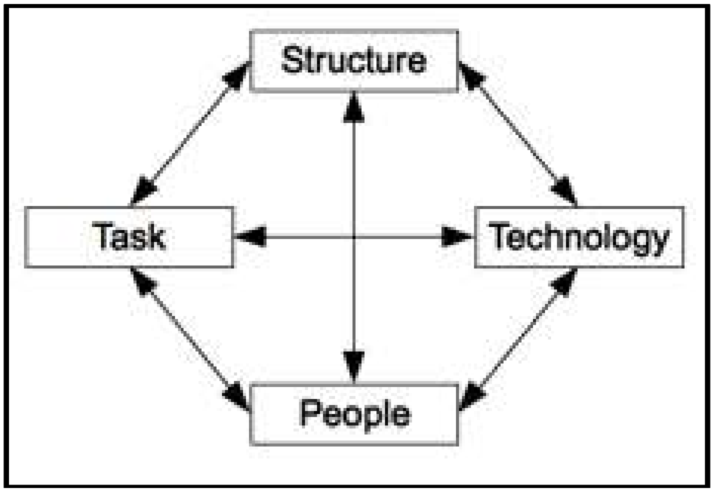


Figure 2. Leavitt's diamond. Adapted from Leavitt et al. (1973).

a. Structure Analysis

The first aspect of the Leavitt diamond is structure. This includes the hierarchical structure as well as the relationships and communication patterns throughout the organization (Leavitt et al., 1973). The USN is the lead agency responsible for achieving maritime superiority at home and abroad where national interests are affected. The expansive nature of the global maritime environment coupled with a dwindling defense budget prevents the USN and supporting agencies from being able to physically monitor all of the world's waterways continuously. Currently, monitoring and tasking in the MDA arena fall to each of the COCOMs separately to operate as they see fit within their AOR. They each have different concerns and mission requirements. This has led to various information silos, both classified and unclassified, that do not easily share information of interest with other COCOMs, U.S. agencies and foreign partners. To best achieve effective global MDA, a comprehensive COP is required so the United States can, at a minimum, proactively monitor vessels throughout the world virtually and take action when and where as necessary.

b. People Analysis

Another aspect of Leavitt's framework is people, which can be characterized as individual actors, subunits, or organizations as a whole. It is not just the users of the processes and data, but their skills, productivity and efficiency to address their COCOMs needs and concerns (Leavitt et al., 1973). Each of the numbered fleet commanders have different concerns within their particular maritime AOR, and therefore, require different MDA information to meet their needs. For example, Commander, Fourth Fleet's main concern in the waters around South America where their primary concern is the trafficking of humans, weapons and illicit narcotics. Commander Sixth Fleet (C6F), whose AOR focus is the Mediterranean Sea and along the African coast where they are in a constant battle against piracy, illegal fishing and immigration. Commander Fifth Fleet (C5F), concerned with the Indian Ocean and the Persian Gulf, shares many of these concerns as well as operating as an active participant in the War on Terror. Finally, C7F is focused on a wide array of threats including the proliferation of nuclear weapons, Chinese aggression and sovereignty disputes in and around the SCS, as well as illegal, unlicensed and unregulated fishing. Based on different mission sets and requirements, their budgets and manpower resources vary greatly. Regardless of the perceived area of focus and the resources they employ, the ability to achieve MDA is imperative to recognizing and prosecuting those threats before they can do irreparable damage. As the operational sponsor to this research, C7F's command and control structure was given primary focus. However, recognizing the common need and taking into account that each COCOM has a different perspective, operational requirements requiring different skill sets and relationships with other agencies and countries, will play a large part in finding an acceptable global solution.

As discussed, C7F is not as affected by terrorism or everyday immigration issues like the other COCOMs. Because C7F's concerns, such as Chinese aggression and island building activities, tend to reveal themselves slowly over time, innovation has not occurred as rapidly. C7F still maintains a cold war type posture using old cold war tactics to monitor China and other South East Asian threats. Due to the sheer size and dynamic nature of their AOR, C7F lacks the time and resources to focus on MDA as much as they would like. This results in a reactive approach to MDA. Their personnel are doing the work manually via separate computer systems to analyze incoming data and spreadsheets to track it. The information they collect must then be integrated or fused with existing disparate technologies. Currently, derived MDA data is uploaded manually for delivery to the IC via the Joint Worldwide Intelligence Communications System (JWICS). This limited data exchange is cumbersome and sometimes inaccurate causing unnecessary delays. JWICS is a classified intelligence system so when the information is used, regardless of classification level prior to input, it retains the classification of the JWICS network and must go through a cross-domain solution, or a complicated declassification process, to be shared. These aspects combined with technology limitations across country and agency boundaries create a sluggish MDA environment which limits C7F's ability to operate proactively.

c. Task Analysis

The tasks, or processes and goals, of achieving MDA are primarily a command and control function that requires a socio-technical solution. The goal is a complete view of the battlespace and how well that goal is achieved is crucial to operating effectively within it. For this thesis, the maritime domain is the defined battlespace that concerns the USN with regards to MDA. While commanders are faced with many different mission requirements within this complex battlespace, all require some aspect of command and control. The commander's ability to perform command and control is constrained by the speed in which they can cycle through the OODA loop. This concept is pivotal in the achievement of any given mission set, especially MDA (Hutchins et al., 2008). Figure 3 is an example of an MDA workflow, representing C5F, which accurately depicts the immense complexity of command, control, communications, computers and intelligence, surveillance and reconnaissance (C4ISR) processes involved in MDA and how it relates to the entities and people involved. Typically, commanders and their staff rely on various data sources, processes and displays to gather information and build situational awareness within their AOR. This situational awareness is usually viewed via some COP which supports the first two aspects of the OODA loop, observe and orient. Not only is it important to appreciate that interactions like these take place, it is also key to understanding what questions are being asked and how they are answered to improve the process.

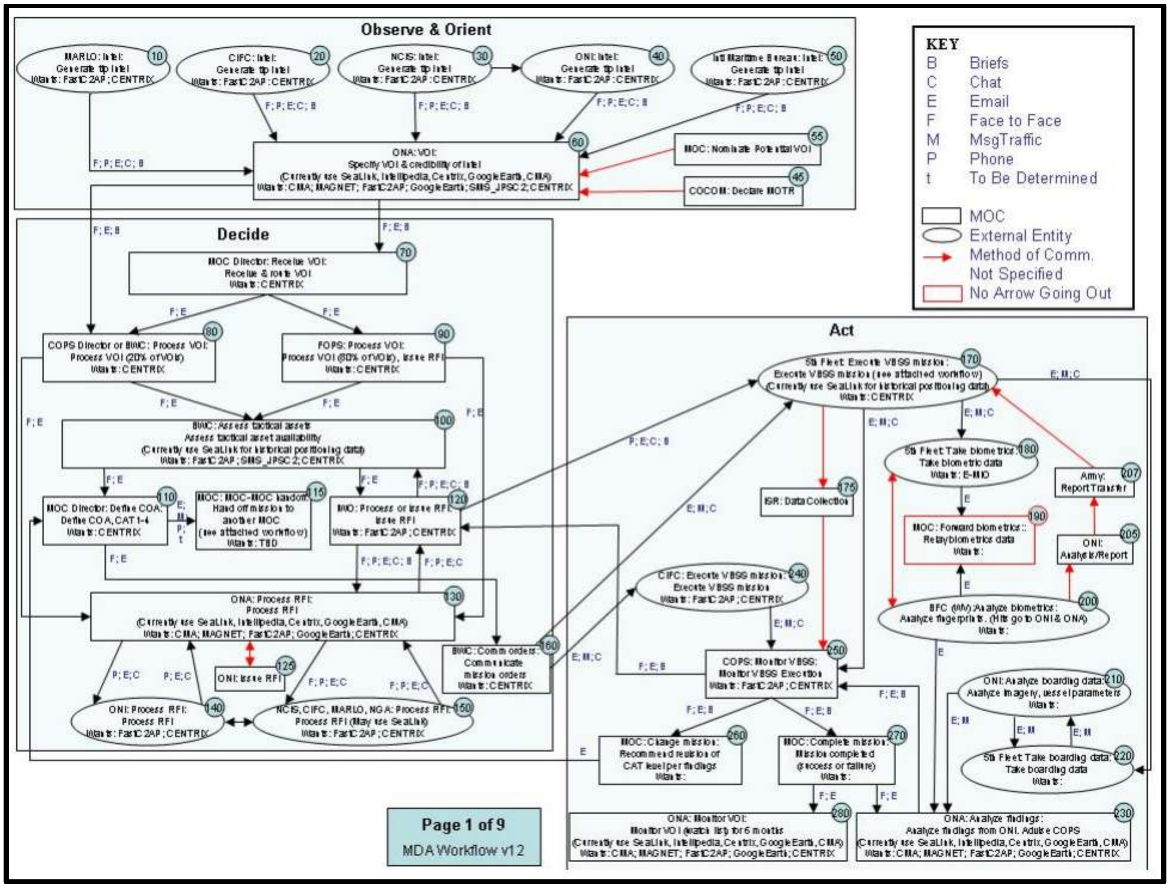


Figure 3. MDA OODA Workflow. Source: Hutchins et al. (2008).

In the C7F MDA workflow, information is derived reactively by using a linear tasking, collection, processing, exploitation and dissemination (TCPED) process to locate and verify a VOI, process that information and await feedback. This slow, labor intensive, man-in-the-loop process cycle consumes critical time and manpower. Additionally, C7F often liaisons and interacts with foreign partner intelligence, the Combined Intelligence Fusion Center, the Office of Naval Intelligence (ONI) and the Naval Criminal Investigative Service based on the information they collect. These entities may benefit from or be able to add to the information collected, but not all these agencies have access to the same systems or information sources so collaboration is difficult and can further slow the OODA loop process. If the information can be automatically collected, inputted, fused and correlated with other independent unclassified sources, it becomes more increasingly reliable. New and interesting advances, discussed in Chapter

II, can enhance the COP by making the system more automated while reducing costs, resources and people needed to process, analyze and track the information. Ultimately, any process or system that can decrease the amount of time it takes to execute an OODA loop will aid every fleet's ability to execute command and control.

d. Technology Analysis

The final aspect of Leavitt's diamond is technology. This is the component of the enterprise which facilitates people to perform the tasks. It is the actual infrastructure, hardware, software, network and data that enable information to flow throughout the enterprise (Pearlson & Saunders, 2013). Technology is the key enabler of MDA and the ability for commanders to rapidly execute the OODA loop. Most commands develop a specific maritime COP to address their specific AOR's maritime threat concerns. According to the U.S. Joint Chiefs of Staff (2010), a COP is defined as a single, tailorable display, which provides consistent significant information that can be shared by multiple commands. This information is used to foster combined planning and provide situational awareness to all levels of an organization. The term COP does not mean that everyone sees the same display, but rather has access to the same data sources (Board, 2006).

While it is generally accepted that MDA is best achieved through a COP, there is no universally established solution or system currently in place that provides a standard approach to building a COP for MDA (Ochs, 2015). Each U.S agency, COCOM and numbered USN fleet uses their own internally funded and developed system (Board, 2008). These systems range in classification from unclassified to Top Secret/Secret Compartmentalized Information and generally do not communicate with each other. Since COPS exist at both the classified and unclassified levels involving different technological approaches, they will be discussed separately.

(1) Classified Technology Approach to MDA

Within the USN, the most common tool for building a COP is the Global Command and Control System-Maritime (GCCS-M), which is typically run at a classified level (Wilson et al., 2016). GCCS-M is the maritime component of the GCCS family of systems and has been installed on nearly every Navy ship and over 65 ground stations (Board, 2006). It is a system consisting of hardware, software and numerous applications built around common processes and standards. It facilitates global connectivity at all levels of command (Wilson et al., 2016). GCCS-M receives information from multiple sources and correlates, fuses, filters and ultimately produces the COP, depicted in Figure 4, which displays multi-source track information (The Office of the Director, Operational Test & Evaluation, 2011). This helps to achieve MDA by allowing analysts to view data input from multiple sensor sources that is fused together and displayed as tracks on a map. The information derived by the analyst monitoring the COP is passed to the commander as necessary for decision and action.

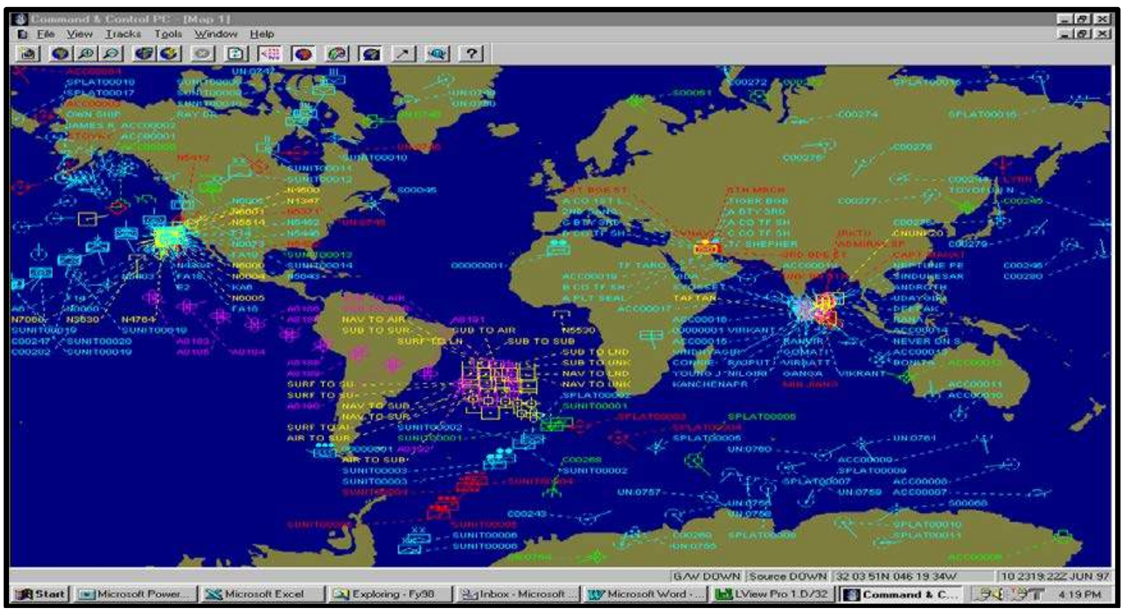


Figure 4. GCCS-M COP Display. Source: MR Popovich and Company (2010).

While the GCCS-M COP accomplishes the observe and orient portion of the OODA loop, it still requires users to actively engage the systems throughout the process and to communicate across different classification levels. While most variants of GCCS can be used at the unclassified level, the GCCS-M version is primarily used only at the classified level for two reasons. The sources of input data are often classified and there are significant bandwidth limitations onboard Navy vessels (Ochs, 2015). In regards to the latter, the ship’s unclassified networks often compete with ships company communications and the Non-Classified Internet Protocol Router Network (NIPRNET) administrative processes, limiting remaining bandwidth for operational and tactical uses. Alternatively, higher classification networks have a higher capacity because they are mission essential, and therefore, given more bandwidth priority. SIPRNET networks ensure that the minimum bandwidth requirements for GCCS-M are met (MR Popovich and Company, 2010). The classification of GCCS-M limits the ability to share information among partner nations and agencies that do not have a direct connection to the system.

(2) Unclassified Technology Approach to MDA

Realizing that data contained within an unclassified COP is easier to share, steps have been taken to utilize more unclassified methods to produce usable MDA information. For more than a decade, the DOD has taken steps to exploit COTS solutions to create and leverage unclassified data sources which has resulted in numerous unclassified COP applications being developed (Board, 2008). Some of these products have been developed for the individual use of services, agencies and/or numbered fleets based on their specific operational needs. For example, U.S Northern Command uses the Situational Awareness Geospatial Enterprise and Risk assessment, Planning and Incident Decision Support as unclassified COP (U.S. Joint Chiefs of Staff, 2015). For years, U.S. Southern Command used the Cooperating Nations Information Exchange System, but has recently transitioned to the Cooperative Situational Information Integration system (CSII), demonstrated in Figure 5, as a method for achieving MDA in Central and South America (Marina, 2013). C6F has had success using the previously mentioned SeaVision application with their African partner nations to track and combat illegal fishing (McLean, 2013).

Figure 5. Cooperative Situational Information Integration System (CSII) COP. Source: Marina (2013).

Outside of the DOD, numerous commercially developed COP applications exist for domestic and civilian use. These include iCommand, SensorIsland and Google Earth. These and other products like them have been used successfully in EOCs for earthquake response and forest fire management (Naval Postgraduate School, 2013). International partners have also developed their own versions of unclassified COPs. In an effort to meet the needs of partner nations that rim the SCS, the Changi C2 Centre in Singapore utilizes the COP application in Figure 6 which combines information broadcast by AIS-reporting vessels with data received from coastal radars to achieve regional domain awareness (Board, 2008).

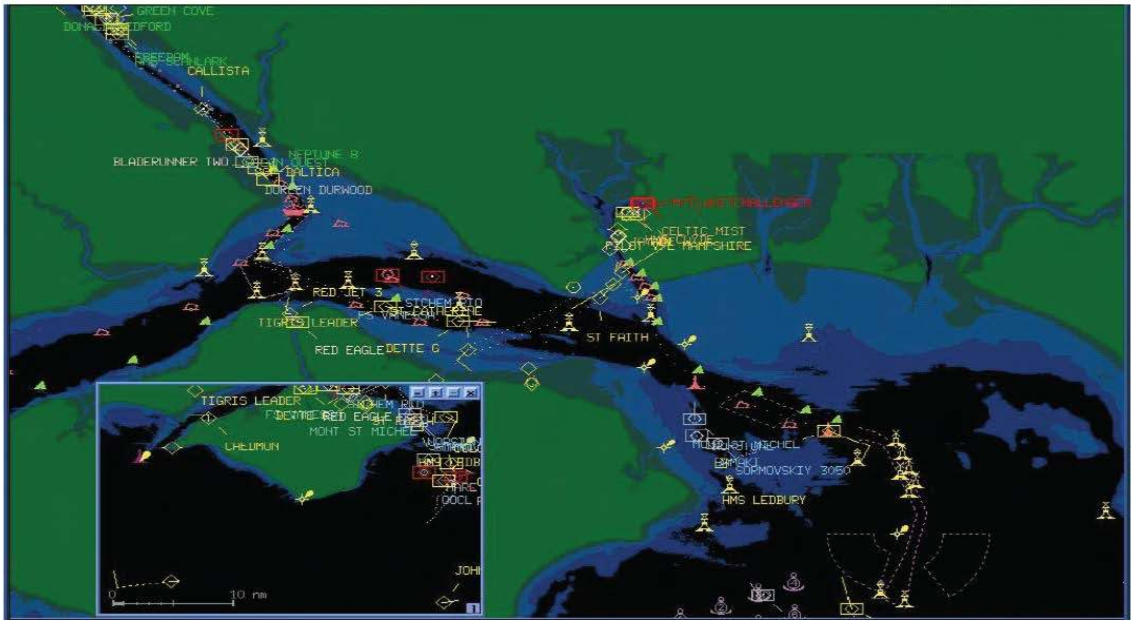


Figure 6. Singapore Unclassified COP. Source: Board (2008).

Beyond these examples, there have been numerous other systems that have been developed, used and eventually abandoned for various reasons. Due to the limited number of unclassified sources and the joint and international feasibility of the systems developed, many unclassified COPs only display limited information and have not been fully adopted. While all these COPs have been successful in some form, overall they are inadequate to meet the needs to produce effective MDA for all occasions.

2. Problems and Limitations

The breakdown of the MDA enterprise utilizing Leavitt's diamond exposed some issues within the four main components. Both the classified and unclassified approaches to achieving MDA have room for improvement if they are to keep pace with evolving capabilities, threats and partnerships. While this thesis aims to create a CONOPs for an unclassified COP to increase ease of use and create a more favorable sharing environment, lessons can be learned by analyzing the common limitations contained within both approaches of MDA to avoid building them into another unusable product. The problems and limitations are broken down in the following subsections.

a. *Shareability and Disclosure Problems*

The most notable issue with current COP processes is that they do not produce information in a way that can be easily shared. As discussed in the previous section, the primary system in use to build a maritime COP on the classified side is GCCS-M. GCCS-M has been the backbone of the USN COP for nearly 30 years. It is a dated system whose display and functionally has not kept pace with today's technology standards thereby limiting the user's ability to exploit the information they receive in an effective way (Wilson et al., 2016). GCCS-M is a hardware intensive system that is further complicated by its mixed use of sources and displays that have different classification requirements. On a typical USN warship, there will be multiple instances of GCCS-M running simultaneously to accommodate various data sources and controlled space classification requirements (Ochs, 2015). Beyond the ship, data sharing conditions are subject to various bilateral and multilateral agreements and the geopolitical conditions of coalition partners. This may require the vessel to run separate instances of GCCS-M COPs at various classification levels for each participant. For example, if Japan and South Korea are participating in an exercise, a USN ship may need to run an instance of GCCS-M releasable to Japan and GCCS-M releasable to South Korea because the two countries have entered into separate bilateral agreements with the United States. This is just a small example, but communication complications only increase as the number of parties involved increases. Adding to the complication, each additional instance of a COP requires extra hardware, manpower and bandwidth to run increasing the potential for human error, system failures and breaches of sensitive information. To solve the communication and classification issues, some systems use replication and duplication approaches, but often these techniques may overwhelm or confuse the user with excess unnecessary information. Modernization and increased system automation are essential.

b. *Lack of Automation*

GCCS-M does provide situational awareness to the commander. However, in the age of highly advanced computers, big data and machine learning, GCCS-M lacks the automation most users would expect. At its most basic premise, GCCS-M essentially tracks and maps the input data requested by the users (Wilson et al., 2016). However, GCCS-M is prone to data inaccuracies which require extensive oversight and upkeep on the part of watch standers. Consistent track correlation and picture maintenance through diligent housekeeping is required (Ochs, 2015). As a system of systems, GCCS-M has over 75 inputs (Wilson et al., 2016). These inputs are not always fused which creates unnecessary duplication which clutters the display (Ochs, 2015). For example, when multiple ships, sensors, or systems all report data on the same VOI, it is not always automatically correlated and fused. This creates multiple tracks relating to the same VOI to appear on the COP and it is incumbent upon the user to actively manage the tracks on the picture (Ochs, 2015). Additionally, some inputs just indicate that something is present in an AOI with no amplifying information. The analyst has to then take extra steps to try and determine what is present and if it is important. The track management task is extremely time-consuming and if not done correctly will give the commander an inaccurate picture of reality. As a result, utilizing GCCS-M, and similar systems, to produce a usable COP is a complicated process, which requires extensive user training to become proficient (Board, 2006).

c. Reliability

The biggest issue with unclassified approaches in building an effective COP is the lack of unclassified data sources and processing capabilities. Most unclassified COPs rely on AIS and coastal radar inputs. While AIS is a profound advancement in maritime safety and security, it has significant weaknesses. As discussed in Chapter II, not every vessel is required to use AIS and even if it does, the reporting information that an AIS subscriber can enter is completely discretionary. There is little standard or regulatory oversight as to what data is entered in the AIS transponder onboard the vessel so false information can easily be transmitted. Finally, the use of AIS, and similar reporting services, is subject to the crew. It is a known phenomenon that ship captains frequently turn off their AIS terminals when they are in an area known for piracy to protect their crew and cargo (Balduzzi et al., 2014). The use of satellite imagery has also been sparingly used, but to date, it can only report the presence of an object, but not generally who or what it is, thereby creating more work for the user vice less. Coastal radar, as a standalone system, does produce usable tracks, however, the system has limited range and the tracks must be correlated.

d. Lack of Adoption

In order to mitigate the issues that agencies have sharing the information they acquire, many have turned to COTS products to try and replicate the classified COPs on the unclassified side. However, as Leavitt's diamond suggests, with a change in structure and tasks, other components will need to change as well. All stakeholders must buy into the new system for it to be successful. Those affected by the system have to gain value from it and trust the system. If the system is not easy to use or reliable, the user will not adopt it. And to date, the attempts to build an unclassified COP have not been fully adopted for these reasons and continue to be only utilized when needed. For instance, the Computer-Assisted Maritime Threat Evaluation System (CAMTES), which gained the interest of some commanders in specific AORs, was eventually discontinued for a lack of sustainment funding (McLean, 2013). Because CAMTES and programs like this have been abandoned before their potential was fully realized, new programs are met with caution and disinterest by fleet commanders who do not want to waste resources integrating something that is incomplete or not fully funded.

Another adoptability issue stems from a lack of communication with regard to unclassified COP best practices. As mentioned previously, the COCOMs are each using disparate systems. If one common system was in place, funding could be streamlined and the COP could be fully developed and sustained over time. Bottom line is that unclassified approaches to achieve MDA have lacked staying power because they are not programs of record and tend to be incomplete due to a lack of maturity and little follow through.

Based on the analysis of the MDA enterprise using Leavitt's diamond framework, changes are required to meet the evolving global needs to effectively manage and utilize relevant information to achieve effective MDA. It is important to note, as Leavitt's diamond suggests, the gaps are threaded through all four components of the enterprise with a limitation in one affecting the others' ability to succeed. Analysis suggests that the recent advances in ISR technology, if properly implemented, will provide the most significant and positive impact on all components within the enterprise. The primary issues with producing an effective COP include communication difficulties that are the result of stove-piped systems that cannot communicate, difficulty creating a comprehensive picture due to cumbersome, resource intensive processes and an inability to reach across organizational boundaries with the information that is gathered. Taking advantage of newer COTS products could provide solutions to these shortcomings. However, changes to technology and the related MDA processes, will affect all the other components of the enterprise and they must be continually evaluated as new products and processes are implemented.

B. DEVELOPING THE TO-BE MODEL

Based on the general issues discovered during analysis, discussions were held with leadership and operators from various fleets around the world to determine the specific issues they have conducting MDA in their AOR. Their current challenges to the MDA process are many and varied, but a lot of common themes emerged that were similar to the results of our initial analysis. First and foremost, there is a need for a simpler, user-friendly MDA process that enhances information sharing capabilities. Also, there is reluctance to operate outside of classified systems. Users agreed that attempts to operate at a purely unclassified level have proven expensive and time-consuming. Furthermore, regardless of the systems in use, there is a general lack of resources, money, manpower and time to be able to conduct MDA at a level that would be advantageous, so MDA is often not the priority. It is also difficult to include national and foreign partners from a both a technical and policy standpoint. Ultimately, if the way MDA is done is going to be changed and accepted it has to work on board vessels as well as in command centers. Due to the constraints of vessels, the new operational method will need to be low bandwidth, low cost and easy to use and, above all else, the data needs to remain unclassified to provide actionable, shareable information in a timely and usable manner.

With these challenges in mind, this research attempts to determine what emerging technologies could be used to improve MDA at the operational level in a way that not only meets the needs of the warfighter, but is beneficial and convenient enough to be adopted. The CONOPS proposed attempts to automate the detection, classification, identification of VOIs from source to display for authorized users to access when and how they need it. For this process to work it must be able to successfully identify and track vessels on an unclassified application incorporating new and historical data fused from multiple sources. This should reduce the overall time required for an intelligence analyst to complete routine MDA tasks by automating the process of detection, classification and identification with multi-source correlation to increase confidence and trust in the system. It could also take advantage of other useful automated capabilities to decrease the time an analyst spends searching for information. These capabilities would include alerts and warnings based on anomaly detection set by the user with a low trade-off between false alarms and missing critical data, (e.g., boundary violations and user-defined management tasks and filters). Ultimately, it provides a real-time comprehensive COP to support proactive decision making at the operational and tactical levels with the capability to collaborate and share information between all interested parties.

In order to make this process a reality, numerous unclassified capabilities discussed in Chapter II were vetted for validity in this model. Numerous COTS capabilities exist that can provide unclassified data for input into the COP that are able to detect and identify cooperative VOI, such as AIS, LRIT, and VMS. Non-cooperative targets can be detected and tracked via coastal radar systems and image/video downloads from SAR and EO satellite sensors. Quick and effective capture of this information is required to useful. To accomplish this, data processing and analytics will need to occur near-real-time and with a high rate of success. Finally, the data will need to be displayed in a cohesive manner via an easy to use application. The concept behind this CONOPS does not drastically differ from other unclassified COPs that have been suggested in the past with one exception. This CONOPS aims to utilize the commercial satellite imagery already available coupled with advanced feature recognition software to derive tracks in conjunction with numerous other unclassified data sources. This data will populate a COP display that leverages an extremely automated and user-friendly interface.

1. CONOPS Vision

The overall principle of this CONOPS is to provide a process that can produce an unclassified COP to achieve effective MDA. It is built to provide analysts and decision makers with high reliability and automation in a way that is tailorable to an organization's specific needs. The vision is twofold. First, the concept provides a scalable platform to add and change unclassified data source inputs as ISR technology evolves over time. Second, the process is automated to the maximum extent possible to reduced manpower workload. This CONOPS provides a tailorable and filterable system that will alert analysts when certain user-specified criteria are met. For instance, the user can request an alert or warning when vessels of certain types or from specific countries or origins leave port, transit specific areas, or arrive at designated locations.

The CONOPS is broken down into three basic system components, data sources, processing and display. Figure 7 depicts the initial intended COTS systems proposed and how they interact. Data sources will include any standalone system that can generate data within the maritime domain, specifically in regards to cooperative and uncooperative vessels. The data produced will then be downloaded and processed as necessary with relevant information being sent to a correlator/fuser. Once fused, the information is stored in the COP database where it can be accessed via queries from the user's display interface as needed.

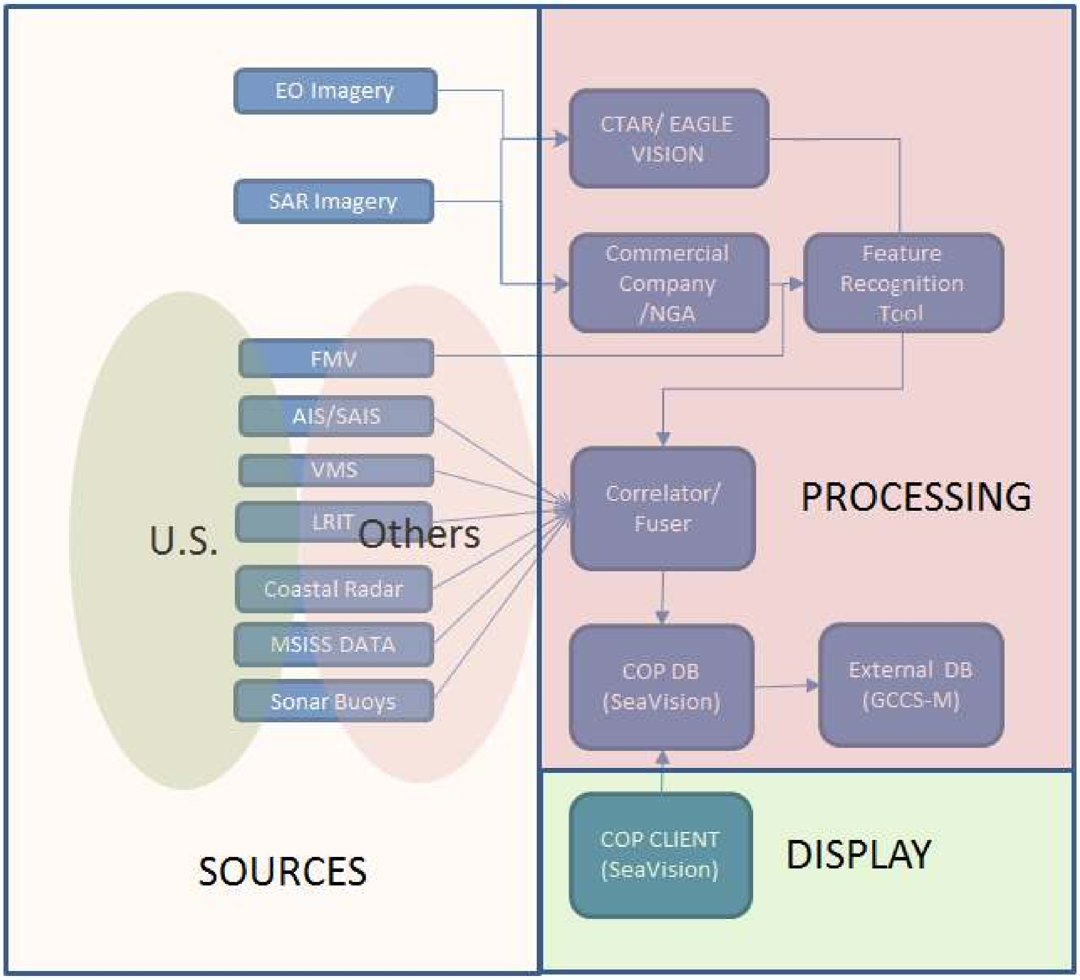


Figure 7. Unclassified Common Operational Picture: System View

2. Process Flows

The system view in Figure 7 describes the physical components and general flow of information through the proposed CONOPS. It leverages existing data sources, technologies and displays that were discussed in Chapter II with the addition of target tracks generated from commercial satellite imagery. Figure 8 illustrates a more detailed view of the complete workflow proposed. Unlike the TCPED process currently in use for MDA information gathering, this process is not linear, but recursive in nature. However, because the IC and targeted users understand the linear process, the CONOPS explanation is broken down in the same format keeping in mind that the system is continually operating.

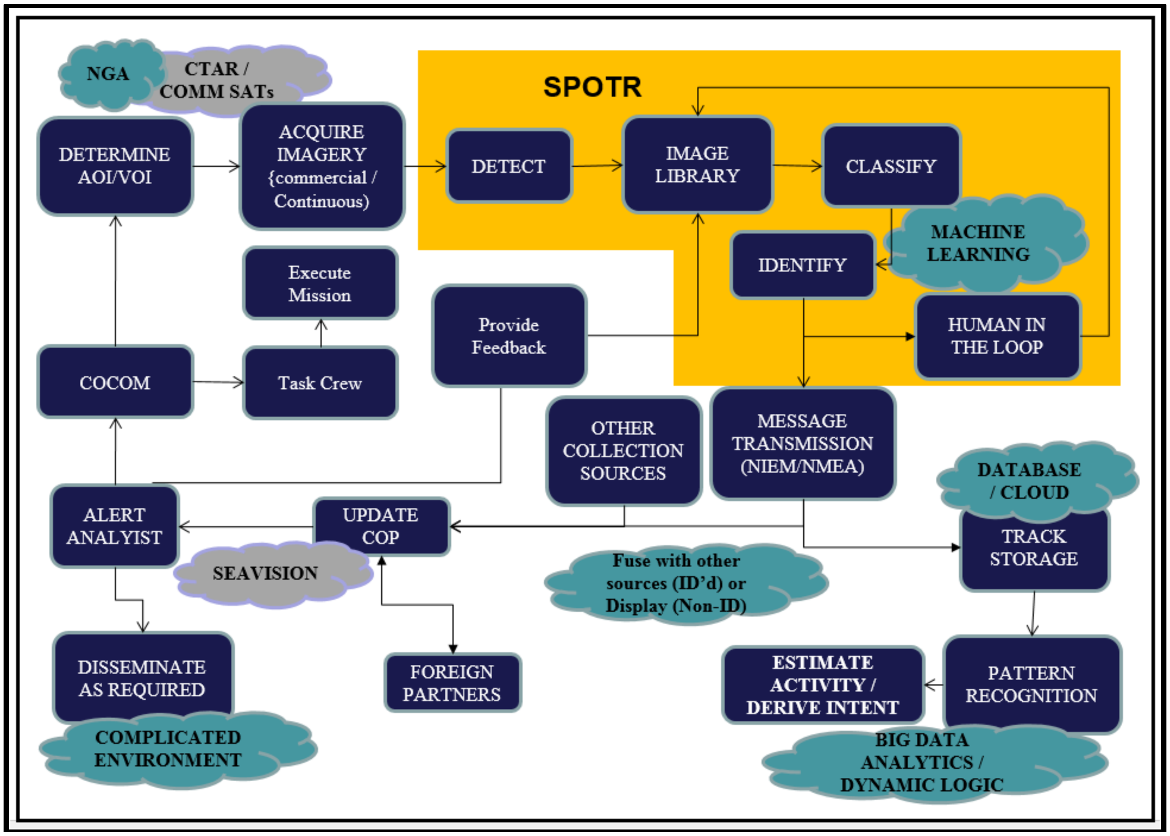


Figure 8. Unclassified Common Operational Picture: Workflow

a. Tasking

Effective MDA begins with an appropriate understanding of what is important to the user. The majority of data sources that feed the COP are automatically and continuously collecting data, therefore there is no need to specifically task or direct them unless a specific need arises. However, for the correct data to be delivered to the user later in the process it is important to know what information is important to them. In this step, the operational commander, either Combatant Commander, Fleet Commander, or Task Force Commander, will determine the AOI and/or VOIs. This determination will guide data collection, the priority of commercial imagery, and define the other data sources that can best provide the most optimal data to build the most effective COP.

b. Collection

Once the AOI and VOI are clear, data can be appropriately acquired and eventually displayed. One of the main benefits of this process is that data is being collected continuously regardless of the AOI and VOI, but with priorities established, the system can concentrate on the areas and vessels of most concern and archive the remaining data for use as needed. Numerous unclassified sources of data have already been successfully implemented in building COPs, including AIS, LRIT, VMS, coastal radars, sonar buoys and EO/SAR satellite imagery. This data is generated by both United States and foreign partner systems. But they have not yet been used in a way that builds a unique and comprehensive COP. All these inputs need to be compared and fused to create a system that is highly reliable to build user trust. The greatest gain to the system will be the addition of high-resolution commercial imagery. This will create an additional layer of track information to the system, ideally without user input. The National Geospatial-Intelligence Agency (NGA) already has contracts with a number of companies producing such imagery, including DigitalGlobe, Terra Bella, Black Sky and Planet Labs. These contracts provide the NGA, the DOD's primary broker for commercial satellite imagery, with access to all of their collected images. Due to the size and quality of the imagery and the amount of data they produce, it has not been feasible for use in a COP to date.

While commercial imagery has not yet been established as a data point in a COP, the use of this imagery has proven extremely beneficial to MDA operations. For rapid data acquisition, the Navy's process called Coalition Tactical Awareness and Response (CTAR) has been leveraged. CTAR is designed to serve as a tactical system giving a theater commander direct access to satellite systems to proactively collect and process SAR and EO imagery. The images taken are directly downloaded to a mobile ground station positioned near the theater of operations where they can be analyzed manually on the spot (Ochs, 2015). While this process is quicker than waiting for the satellite to pass a specific spot where it is in range to download its data, which could be hours or days later, it is still not a perfect system. Gaining access to task a satellite for a specific mission and maintaining and moving a mobile ground station is extremely expensive. If the massive library of data that the commercial imagery companies produce can be leveraged and analyzed automatically, the CTAR system could be prioritized for very specific, rapid acquisition needs. The information gained from those missions will benefit from the additional data that can be acquired from this CONOPS as well. However, CTAR has proven the need and successful use of commercial satellite in an operational capacity.

For this CONOPS, the more these commercial companies continue to launch increasingly advanced imaging satellites, the more the associated imagery library continues to expand, covering more of the globe with greater persistency. The images collected from these companies, or directly via satellite tasking, will be automatically ingested via downlink into the processing software. Once downloaded, it can be analyzed via highly advanced computer processing and algorithms to detect, classify and identify vessels and input into the unclassified COP for all authorized users to see. This would decrease the need for expensive and time-consuming processes to specifically task satellites. In order to fully exploit satellite imagery, it must be quickly downloaded and processed, to ensure the COP is as close to real-time as possible.

Finally, within this CONOPS foreign partners can be data contributors vice just data consumers. Partner nations often have their own satellites, coastal radars, sonar buoys and collected vessel tracking data which they can supply, with the correct messaging format and access rights, directly into the COP. For example, the Canadian company, MacDonald, Dettwiler and Associates, has a commercial RADARSAT constellation of satellites that collects SAR imagery. This could easily be included as a data source with the right data messaging formats (Ochs, 2015). This cooperation builds trust, aids in information sharing and contributes to an even more robust picture. Once all of the data has been collected, it will be automatically processed into information.

c. Processing

One of the biggest issues hindering the adoption of an unclassified COP is that the data acquired requires too much time and resources for proper analysis to be considered beneficial. A lot of manual analysis and track updating is required. This CONOPS aims to alleviate this issue. The uniqueness of this CONOPS lies within the processing capabilities which will automate a lot of the more time-consuming analysis and record keeping steps for the user. For this CONOPS, due to the variety of input sources, multiple types of processing occur throughout this phase. Therefore, the processing phase for description purposes will be generalized into three categories: acquisition and transport, feature recognition and fusion. The data from all input sources will be collected, transmitted and processed either remotely at the data source or further down the chain where data is correlated.

During acquisition and transport, the data from each source undergoes its own processing at its origin. For example, commercial SAR imagery that is collected by the Canadian RADARSAT is sent to OceanSuite, a tool which analyzes SAR imagery and detects ships (Ochs, 2015). Likewise, remote coastal radar systems generally conduct their own remote processing then send tracked target messages for input into the COP (J. Stastny, personal communication, October 24, 2016). While all types of data processing are important to and included in this CONOPS, this is not necessarily a new concept. The most critical new addition that makes this system really work is the application of feature recognition software to extract data from commercial satellite imagery quickly and accurately. It provides a solution to the gap in surveillance and analysis that prevents MDA from being truly a proactive mission.

Technological advances in computer vision and machine learning have created feature recognition software capable of detecting, classifying and identifying non-cooperative targets at long range. Facial and pattern recognition is already commonly used for a variety of reasons, however, in theory, this could be leveraged in unique ways to aid in MDA (Faltemier, et al., 2016). SPOTR, briefly discussed in Chapter II, is a suite of image processing, computer vision and pattern recognition tools that incorporate advanced algorithms, object detectors and machine learning to continually refine the 2D/3D models used for recognition. The more the system is used, the better it gets. Initially, humans are in the loop to provide review and correction feedback to the system as necessary (Faltemier et al., 2016). With time, this will take the analysis and product creation out of the hands of the user by automatically detecting vessels in overhead imagery, extracting its features and matching those features against known models leading to the identification of multiple vessels within seconds of download (Faltemier et al., 2016).

The process, depicted in Figure 9, is transparent to the user. The processing begins as images are streamed into the system in batches where the machine immediately analyzes them. When ship detections occur, target location, date and time and eventually the course and speed are extracted from the metadata of the supplied image. SPOTR then compares the metadata to a library of known 2D/3D models in an attempt to classify and identify the vessel (Faltemier et al., 2016). Classifications are termed by general ship type (e.g., military, fishing, transport etc.), and identifications are specific ship type and possibly with enough data, vessel name. Because all ships have key identifying features, SPOTR should be able to identify specific hull numbers if the reference library is populated with enough data on that particular vessel (Faltemier et al., 2016). SPOTR, or any feature recognition software capable of producing vessel target information can format the track data in the correct message format for ingestion and display in the COP.

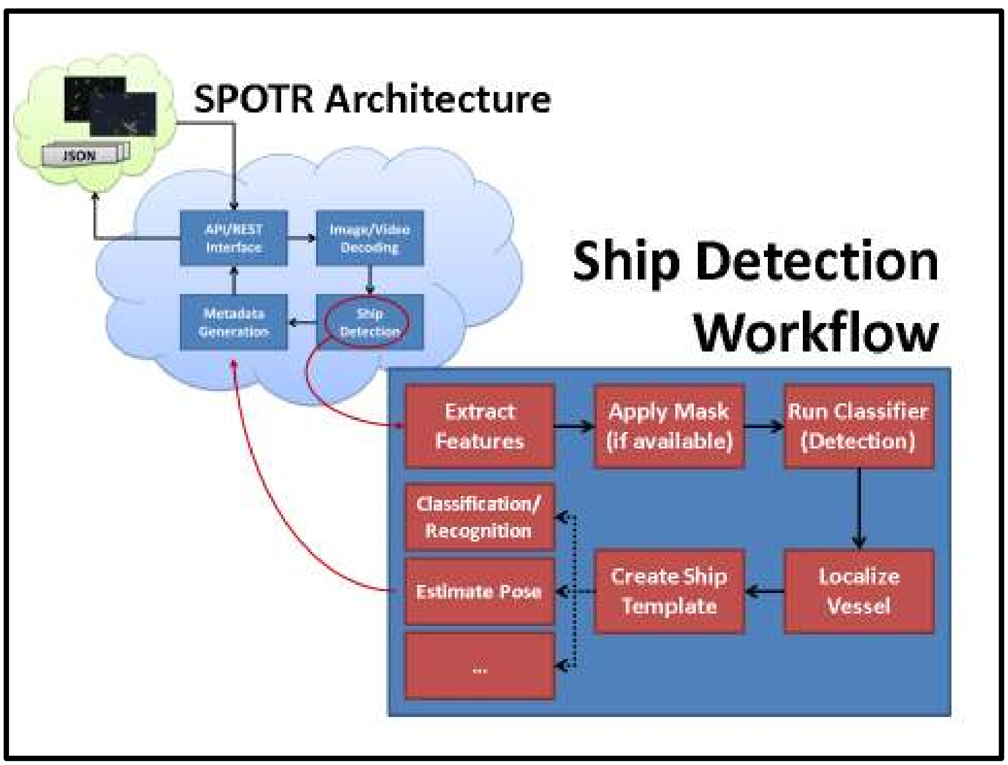


Figure 9. SPOTR: Operational View. Adapted from Steinhaeuser (2016).

Confidence in data output is key to the success of this system. Deep machine learning and convolutional neural networks (CNN) like Progeny's SPOTR, are using their proprietarily developed software and algorithms to detect, classify and identify sea-going vessels that are present in satellite imagery, but its use in mission specific scenarios or large real world applications is a relatively non-existent. CNN's like SPOTR have a known error rate of approximately 17% (Krizhevsky, Sutskever, & Hinton, 2012). Therefore, while SPOTR has shown impressive results in testing (e.g., a false target rate of less than 1%), if possible, blending different types of computer vision technologies together would produce more reliable results.

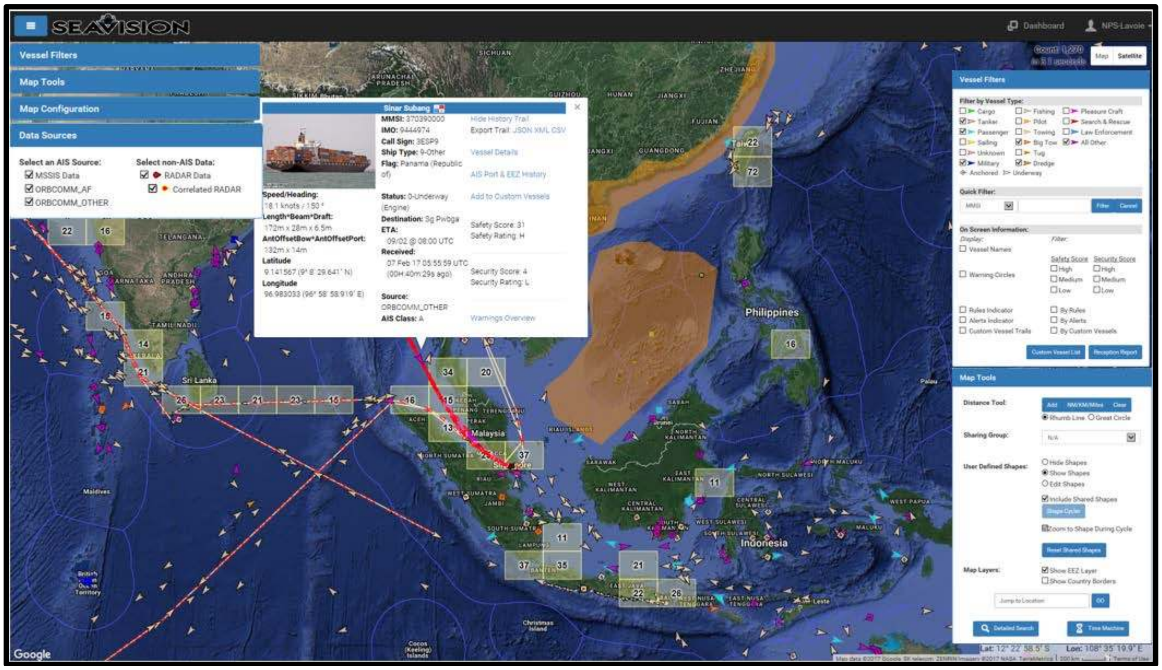
Finally, data fusion is also taking place during the processing step of this CONOPS. The resultant processed data ingested into the COP need to be aggregated, correlated and fused. The display will still be usable without this step, but it will require a lot of user time and input to decipher the clutter and gain actionable information. To minimize that problem, track data is fused, sent to the COP database for storage and the COP display is updated. The key enabler here is common data standards. In order for all these systems to input their data into the COP, common data standards are required to enable disparate systems to communicate and will facilitate the ultimate goals of collaboration and interoperability. This open architecture, with agreed upon standards, not only creates an agile and versatile system, but creates opportunities for information sharing between parties that were unable to contribute in the past. All authorized users will now be able to contribute thereby building a more comprehensive and reliable COP.

In SeaVision, the recommended COP application, the correlation of data is accomplished with Rapier Fusion, a time delayed data correlator (J. Stastny, personal communication, October 24, 2016). Rapier Fusion uses position, length/width and heading derived data from imagery-based sources and correlates them with separately reported electronic sources such as AIS/VMS/LRIT. The fused and correlated track now contains information from multiple data sources and is stored in SeaVision's database. This database serves as the COP's main data source. Additionally, this database and the information contained could be accessed by SPOTR to improve and reinforce its image model library. This process of fusion and correlation greatly enhances the confidence and reliability of the system while cutting the costs, resources and people needed to process, analyze and track the information.

The advanced identifications that SPOTR provides are extremely beneficially to MDA and future analysis, however, it is recognized that individual ship identification is not always possible. It should be noted that even limited ship detection information, (e.g., location, date and time), can provide valuable non-cooperative inputs to the COP. Theses inputs can be fused with others if correlation data exists or to just alert the user that something is there. Ultimately, by shifting the analysis and processing tasks to technology, analysts and decision makers will be more productive. They can spend more time on the important decide and act phases of the OODA loop and leave the busy work, observe and orient, to the automated MDA system processes. This capability, enabled by technology, and through conformance to technical standards, paves the way for all users to be involved in the processes from collection to display. The continuous cycle of tasking, collection and processing is constantly producing information that is present in the COP for exploitation.

d. Exploitation

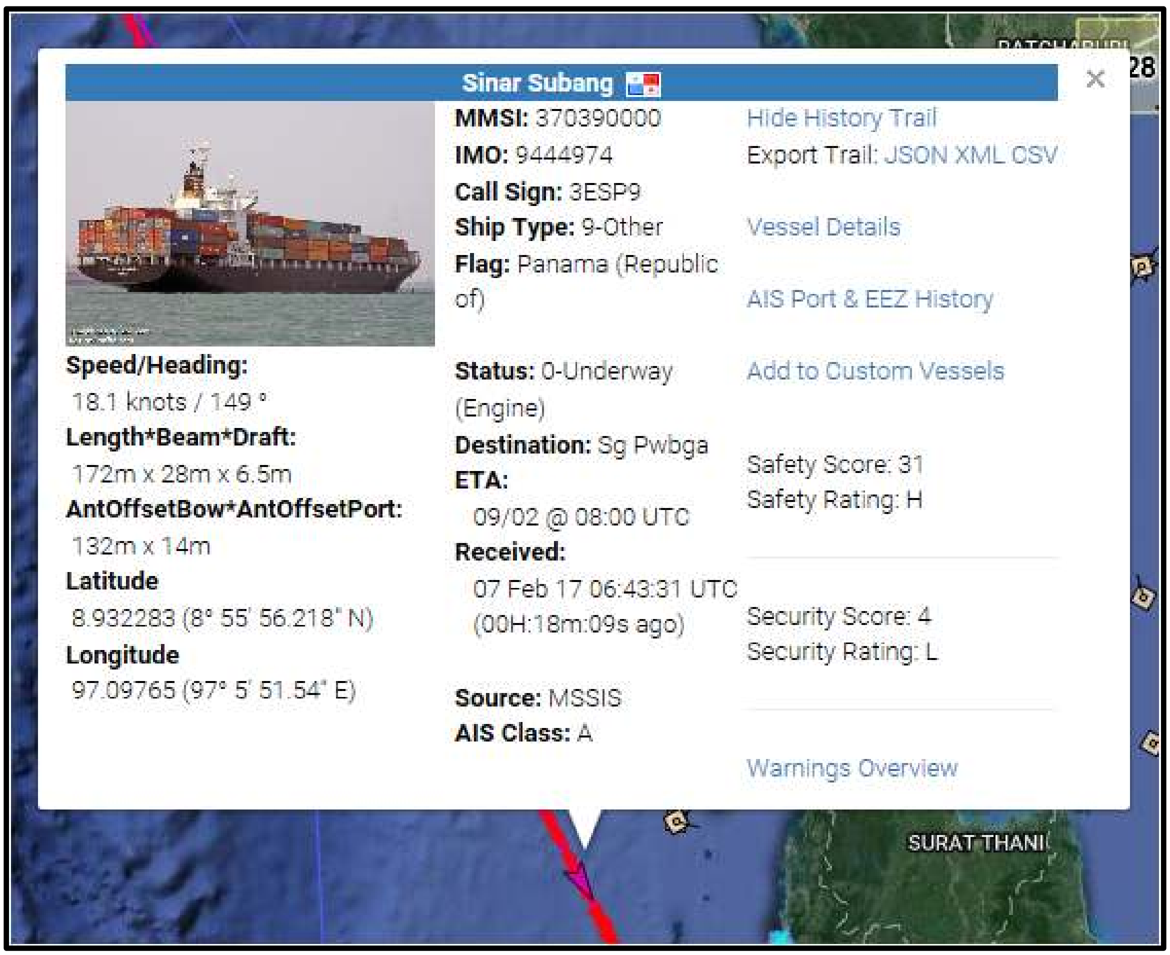
Once the data is processed and formatted, the information needs to be presented in a way that is usable and exploitable. During this stage, the information from multiple sources is now resident in the SeaVision database and is available for COP display, the physical manifestation of this CONOPS. Based on the options available, SeaVision is the display application that provided the best fit for this CONOPS (see Figure 10). SeaVision provides a user-friendly platform which is capable of displaying a broad spectrum of maritime information from multiple disparate sources. Most importantly, it uses the NIEM conformant data exchange allowing it to be highly scalable as new data sources become available. SeaVision's web-based interface, ease of use, automation, architecture and user tailorable features provide an excellence resource for the USN, U.S. Coast Guard, other federal agencies and partner nations. Unlike GCCS-M, SeaVision does not require any hardware installation or maintenance by the end-user; all processing and data fusion occurs upstream. Additionally, it provides a multi-tiered access capability that can be amended depending on the nature of data sharing needs with other agencies and foreign partners to limit or release different instances of data.



Screen capture from SeaVision, February 2017. See http://seavision.mda.gov/.

Figure 10. SeaVision COP Display

Once the data is uploaded to SeaVision from the database, the COP information can now be exploited in several ways. SeaVision gives the operator/analyst multiple options in how they choose to receive and use information. They can actively monitor the situation via the display shown (in Figure 10) and click on any available track to view the information related to it, including the source of the data (see Figure 11). Currently, SeaVision is limited to mostly cooperative tracking systems, but the scalability, extensibility and flexibility of the system make it a good candidate to accept data from the proposed imagery recognition software. The analyst can also choose to use a more automated method within SeaVision. The application also offers a high level of display customization via user defined pre-established rules. Using the SeaVision dashboard, the user can set multiple boundaries, warnings, rules and request alerts. When tripped, these alerts trigger an email or message to be sent to the analyst. Therefore, the analyst can concentrate on more immediate tasking and handle MDA situations as they are alerted. Per the suggested CONOPS, the analyst could also provide feedback at this stage to the CNN feature recognition system to further refine the machine learning algorithms. Finally, the information provided and the analyst's subsequent observations would then be forwarded to the appropriate commander for tactical action as required. This final action restarts the CONOPS process loop (in Figure 8). The decision makers, based on the information they received, decide and act by revising their AOI and VOIs to gather more data, execute a mission, or share the information with relevant parties.



Screen capture from SeaVision, February 2017. See http://seavision.mda.gov/.

Figure 11. SeaVision COP Display with Vessel Detail Selected

e. Dissemination/Sharing

The final step in the TCPED process has traditionally been dissemination however, in this CONOPS, the term sharing is used to differentiate between information and intelligence. Information refers to just the data itself whereas intelligence is a collection of relevant and actionable knowledge derived from information. Typically, classified methods have been used for achieving MDA. Using this unclassified CONOPS and display mechanism allows for an increased amount of sharable information options not previously available to fleet commanders. Historically, the “need to know” culture has impeded this information sharing process as intelligence professionals attempt to safeguard their sources and methods of intelligence-gathering with often overly cautious policies (Jones, 2007). Regardless of the culture of the intelligence communities, the unclassified COP is needed. It allows the commander the room needed for maneuver in the complicated geopolitical landscape. This means that while a sharing relationship of classified information may exist between the United States and a foreign country, this CONOPS will allow a new level of freedom in moving data between different agencies and partnerships as needed.

In the dissemination/sharing phase, while all input data is unclassified, there is a point at which the aggregation of information received could be considered classified and would require some level of control. SeaVision has various levels of authorized access. The individual commanders can determine which levels of access are appropriate for which users for those under their command and with whom they operate. Ultimately, the foreign disclosure officer is the local expert on classification procedures and relationships throughout their AOR and should be consulted to determine the best course of action regarding coalition partners in the collaborative MDA COP (Department of the Navy, 2007). Since SeaVision is a web interface and aspects of the COP can be tailored, partner nations will only receive the data that they are authorized to view. It will be incumbent upon their own intelligence staff to derive meaning from the data since only raw information is passed. The end result of this CONOPS is the ability to share unclassified information from a number of sources in the form of a tailorable, automated and comprehensive COP. This transparent effort will go a long way in building trust with foreign nations and will pay dividends with garnering foreign assistance and collaboration.

To highlight one example, since 2014 SeaVision has been successfully used by C6F in partnership with African countries to track and combat illegal fishing on the west coast of Africa. By combining forces, the USN and nine nations were able to manually use reported tracks in SeaVision with satellite imagery and coastal radar data to better track illegal fishing vessels, levy fines and protect their national resources (Beardsley, 2014). This example of information sharing and partnership is just the first step in achieving global MDA. Although SeaVision has not been completely adopted across the USN, its use is growing and with the incorporation of non-cooperative tracking capabilities via this CONOPS, the SeaVision COP will be complete and accurate.

3. Feedback Mechanisms

The USN does not have the resources or capability to cover the entire maritime arena. Participation from foreign partners with a common interest is critical in filling these gaps. Information sharing is built on trust and all participants should participate in building and maintaining the picture. Providing feedback ensures that all users are able to contribute to picture accuracy. Machine learning and computer vision technologies are only as good as the information provided to them. They require active feedback to consistently improve their computer algorithms to deliver accurate results. This can be accomplished with a direct link in alert and warning emails and messages or embedded in the track data reported on the display. If the track data is determined to be incorrect, (e.g., reporting a false positive), the user can directly correct the information via the link or send the data back to SPOTR for re-analysis by their system or a human in the loop. This process, where all participants play an active role in building the picture, creates a culture of trust that will build confidence in using the unclassified COP.

4. Potential Use Cases

This CONOPS, where information can be shared over a collaborative system by different agencies whereby they can collectively observe their respective AOI, can have immediate and far-reaching effects. The shareable COP ultimately connects all entities within an operational area and results in a common understanding of the maritime environment. Three examples of how this could be particularly useful are described in the following subsections.

a. Time-Critical Missions

Over the years, the DOD has been involved in humanitarian assistance and disaster recovery missions, search and rescue missions and Defense in Support of Civilian Authorities missions where hastily formed enterprises are created and DOD is required to share information with non-traditional partners. An unclassified CONOPS as described in Figure 8 could have a direct impact where all entities within the affected area can access the COP to gain or add situational awareness. This will dramatically increase the speed and efficiency of a response by means of a highly-coordinated effort.

b. Joint Inter-Agency Task Force-South (JIATF-S)

Joint Inter-Agency Task Force-South (JIATF-S) has a long history of multinational and interagency collaboration. It is a task force that flourishes due to the international relationships that it has spent years establishing and maintaining. While considerable U.S. assets have been employed in the AOR, the major key to success is the availability and willingness of host nation end-game or law enforcement assets to interdict narco-terrorists. Even though sharing relationships have been established, the flow of information could be enhanced. Utilizing the technologies proposed could enable increased host nation support by providing them improved situational awareness with access to the unclassified COP. This additional information sharing capability enables host nations the ability to prosecute targets without the delays in multi-step coordination through JIATF-S.

c. Piracy

Piracy exists in many AORs. In particular, the waters off the coast of Africa are largely ungoverned allowing piracy and other maritime crimes to occur regularly and with impunity. Reports of these incidents have risen steadily since the turn of the century (Till, 2016). Because of this threat, commercial ship captains frequently secure their electronic tracking systems, such as AIS, for their own security to ensure that they cannot be seen by potential harmful entities. However, with current technology, this means that they also disappear from all vessel monitoring systems which exist for their safety. If there is an issue and the vessel needs assistance, they will be hard to track. The multisource correlation and data fusion tools that exist in this CONOPS will allow for commercial vessels to be continuous tracked regardless of their AIS, VMS, or LRIT functionality. This will enable local law enforcement to protect these mariners as well as monitor other vessels that are exhibiting potentially nefarious profiles.

C. CHAPTER SUMMARY

This research established a CONOPS that provides a way forward in achieving effective MDA at the unclassified level. In order to determine if the CONOPS can provide the benefits the research suggests, it must be implemented and verified. In an effort to demonstrate that this CONOPS will work, the process was attempted as far as current technologies would allow. Although this CONOPS was developed to use all sources of commercial imagery and multiple CNNs for image processing, due to the lack of time and access to some resources, the test and evaluation was limited to archived DigitalGlobe imagery and Progeny's SPOTR feature recognition software. The results were instrumental in refining the CONOPS to its final state and demonstrating the potential of the proposed system.

IV. DATA ANALYSIS

A. CONOPS TEST METHODS

The goal of this thesis was to build an unclassified CONOPS strategy for use in the MDA arena in which intelligence analysts and decision makers can gain situational awareness, gather actionable information quickly and allow them the additional capability to share it with other services and international partners. The CONOPSs proposed in chapter III attempts to meet these needs via a new unclassified, low bandwidth, low cost and easy to use operational method. For this process to work and thereby increase the probability of adoption, it must be able to successfully identify and track vessels via an unclassified web-based application that incorporates new and archived track data fused from the multiple sources discussed in Chapter III. This should reduce the overall time required for an intelligence analyst to complete routine MDA tasks by automating the process of detection, classification and identification. Ideally, this will include multi-source correlation and data fusion to increase confidence and trust in the system by the users. Other useful capabilities built into the system would include user defined management tasks, filters, warnings and alerts, such as anomaly detection and boundary violations, with a low trade-off between missing critical data and false alarms. Finally, it will provide a real-time comprehensive COP to support proactive decision making at the operational and tactical levels with the capability to collaborate and share information between all interested parties.

In order to prove that this newly developed CONOPS meets these requirements for adoptability, an attempt to replicate the process was made using the same tools that were suggested in Chapter III. A successful test would conclude with the detection, classification and identification of non-cooperative vessels using the unclassified technologies suggested. For this test, an AOI and VOIs were selected and data was gathered from unclassified collection sources to include DigitalGlobe's imagery and SeaVision's available track data. Once imagery was collected it was sent to Progeny Systems in Manassas, Virginia for analysis by their imagery feature recognition software, SPOTR. The primary purpose of this analysis was to test SPOTR's ability to detect, classify and identify VOIs. Simultaneously, due to delays in receiving SPOTR results, attempts to emulate the TCPED process were conducted by processing and fusing the data manually. Success in manual processing demonstrates that the capability to detect, classify and identify VOIs using only unclassified means is possible. Eventually, proving the system could be automated is the ultimate goal, but due to time constraints, the process to make this a reality remains in development and will be discussed later.

1. Tasking

Based on C7F concerns and MDA requirements, it was determined that the operational area of focus for the testing effort would consist of the contested islands located in the SCS and some Chinese ports and shipbuilding yards within the Southern Theater of China. In all, 18 key locations were identified for analysis (see Figure 12). With the AOI and VOIs selected, the imagery collection process began. One of the key concerns within the SCS, as described in Chapter II, surrounds the perceived aggression of China and their island building activities. Therefore, dredgers and vessels involved in dredging activity were selected as the VOIs.

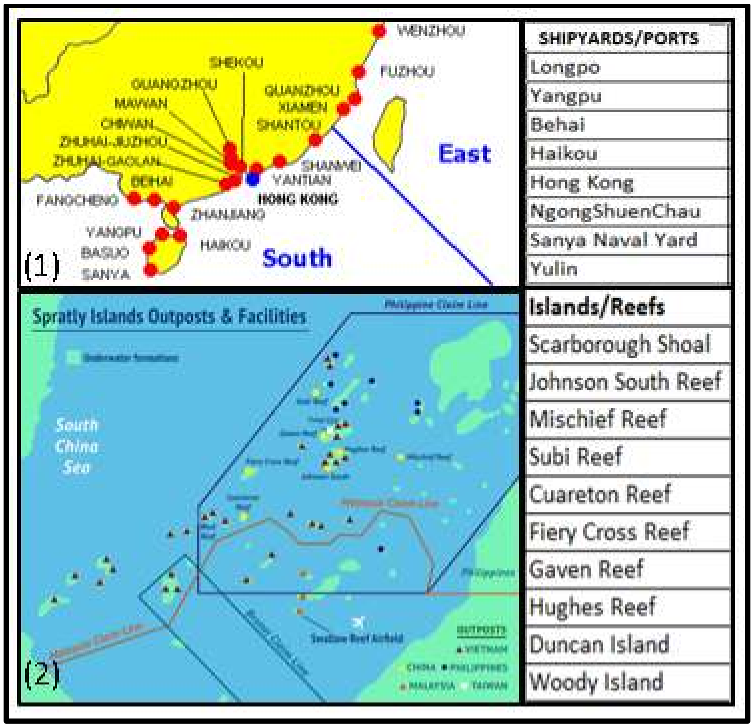
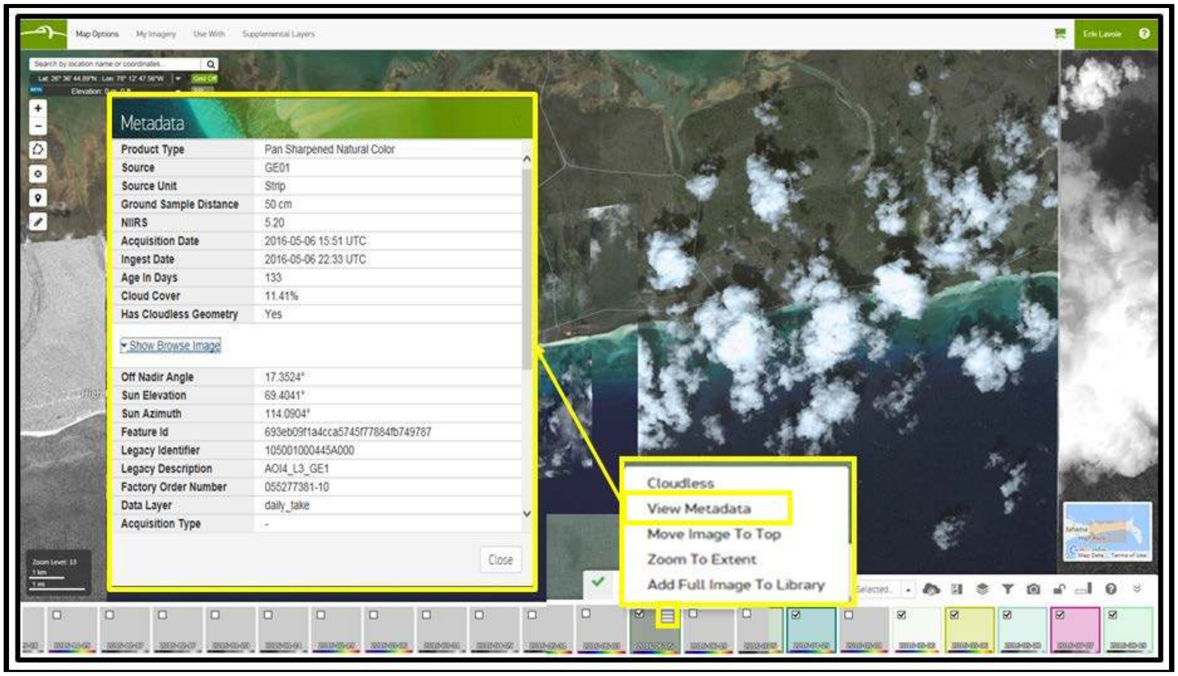


Figure 12. Defined AOIs for CONOPS Test. Adapted from (1) "Chinese Naval Bases" (n.d.) and (2) Roach (2015).

2. Collection

In order to start the data collection process, access to the data applications had to be obtained. Gaining access to track data in SeaVision was relatively simple. According to the SeaVision (n.d.a) FAQ web page, users are individually managed by a system administrator or community manager. To gain access, one just needs to send a request via the homepage. The request is then approved by a DOD or DOT civil service employee; however, the definitive authority authorizing users is the SeaVision Office of Primary Responsibility in OPNAV N2N6E3 (SeaVision, n.d.a). For the satellite imagery, initial attempts were made to secure direct access to DigitalGlobe's commercially-available open-source image archives so that images could be downloaded in bulk. This would have greatly reduced the time it took to gather enough images to commence the analysis process; however, the necessary approval for bulk data transfer was not granted. As a result, individual accounts to DigitalGlobe via https://evwhs.digitalglobe.com were requested and access to their Enhanced View-Web Hosting Service (EV-WHS) was granted. Access is available to anyone supporting a government mission with an active common access card (CAC). The EV-WHS account provides access to DigitalGlobe's online library, which is a subset of their entire archive. This level of access allows the user to select images, copy them to an individual DigitalGlobe user library and download them as necessary, but limitations to specific images, geographical areas and system features and functionality still existed. Specifically, the EV-WHS portal permitted access to approximately 800M km^2 of content, including full Global Digital Topography, foundation GEOINT mosaics and DigitalGlobe commercial "Global Base Map" mosaics (DigitalGlobe, n.d.b.). This was enough access to provide a wealth of images to fulfill the image acquisition requirements for this CONOPS test.

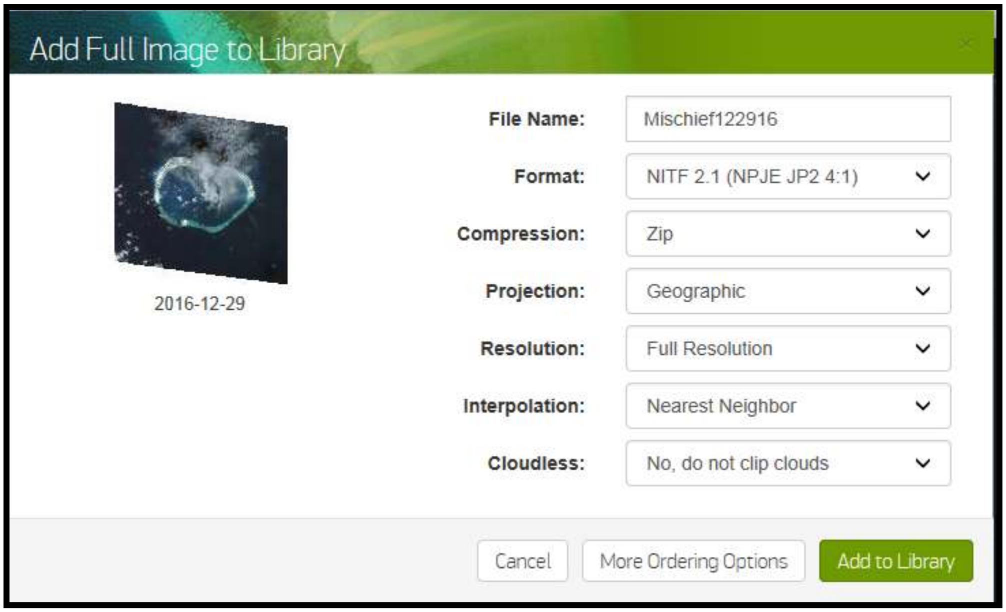
Next, the tedious process of locating the specific AOIs was initiated. This involved locating the specific islands and ports, then zooming in on each image set to determine which images were desired for download and processing. Each available image contained viewable metadata which provided information related to image properties, such as acquisition date and time, sensor type, GSD, sun elevation and cloud cover percentage (see Figure 13). This was useful in determining which pictures would be most beneficial for the initial round of manual processing, and later, for Progeny's automatic machine-learning algorithms. The images available for each AOI differed, but each had approximately 20–50 available ranging from 2012 to present day.



Satellite images and screen captures obtained from DigitalGlobe, August 2016. See https://evwhs.digitalglobe.com.

Figure 13. Screenshot of DigitalGlobe EV-WHS Interface Selections

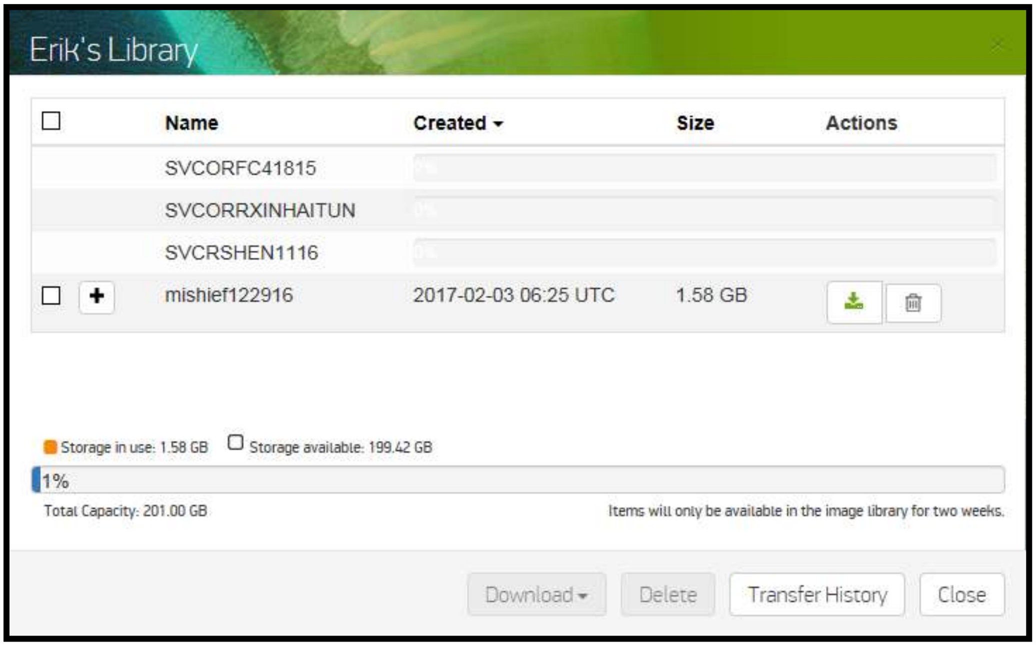
In order to download the imagery, the selected images had to be copied and transferred one at a time from DigitalGlobe's archive to the user's online library associated with their account. To do this, each image was selected and given a file name containing the location and date the image was taken. Other selectable options during transfer include file size, format and compression type (see Figure 14). The Geostationary Earth Orbit Tagged Image File Format (GeoTiff) was selected based on early discussions with Progeny for use with their image recognition software. However, months later, it was determined that the GeoTiff file format did not retain all the necessary metadata that would be required to establish track data, such as the date and time of image capture.



Satellite images and screen captures obtained from DigitalGlobe, February 2017. See https://evwhs.digitalglobe.com.

Figure 14. DigitalGlobe Image Download Process Options

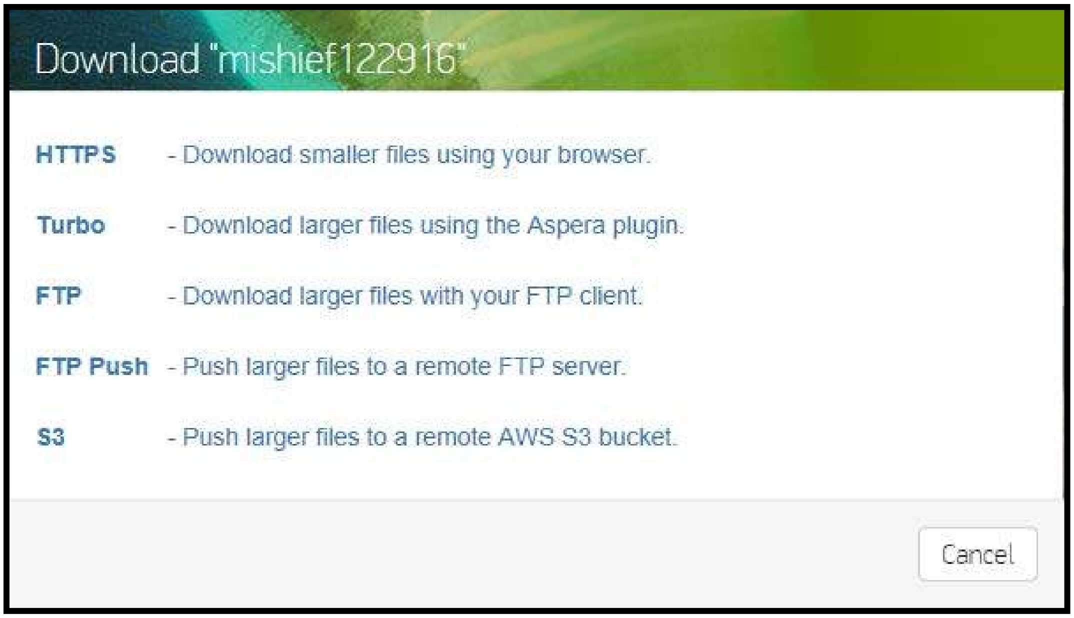
With the appropriate selections made, the image was copied and transferred to the user's individual online library. EV-WHS is a shared resource across all government entities, and therefore services, such as the image transfer and download process, share bandwidth (DigitalGlobe, n.d.a.). Because this is a first-in-first-out request queue, transfer time varied from five minutes to several hours depending on the time of day and DigitalGlobe's system demand and/or outages. The online user library limitations posed another time hurdle during the collection process. The user library storage bin is limited in two significant ways. First, it is limited to 200 gigabytes (GB) of data at any one time. Second, image files can only be saved for a maximum of 14 days at which time they will be automatically removed (see Figure 15). The 200GB limitation was circumvented by downloading the images to an off-line storage device and immediately deleting the file from the online library to make room for more. The download process will be explained later in further detail. It was also possible to cue numerous images for transfer to the library at once. The image size did not appear to count towards the storage limit until the file transfer process reached 100%. With this method, it was possible to have over 400GB of images in the library at once. However, once the library had reached capacity, no other images could be added until the library capacity fell below the 200GB threshold again. These limitations created a significant bottleneck while downloading images for the CONOPS test.



Screen capture from DigitalGlobe, February 2017. See https://evwhs.digitalglobe.com.

Figure 15. DigitalGlobe Image Library Transfer Interface

Once the image was copied and transferred to the online library, it could be downloaded in either a TAR or ZIP compressed format and saved on a local hard drive or removable device for use in the processing step. During compression, the image was broken down into multiple smaller files for download and becomes an image file set. The image file set contains the original photo broken down into 4–30 smaller image tiles depending on the size and resolution of the original. Post-download these tiles could be stitched back together to reform the original if desired. Also, included in the image set was a file that contained the metadata, the NextView Imagery End User License Agreement (see Appendix B) and other accompanying files determined by selections made when the file was chosen for download. At the time of imagery collection, there were four download options available; hypertext transfer protocol secure (HTTPS), turbo, file transfer protocol (FTP) and FTP Push (see Figure 16). Turbo, which would have been the fastest option, was not compatible with this test process because of the requirement for an Aspera plugin that was not present on the local workstations. Therefore, FTP offered the next highest download rate and was chosen for data transfer. The image files were downloaded one at a time to personal laptops. However, due to the large size of the image files, ranging anywhere from 2–17 GB each, storage quickly became an issue as the number of images downloaded increased. To make more room, the images were transferred to a removable universal serial bus (USB) flash drive and moved to a remote server for storage. Finally, access to a centralized server was granted and a virtual machine was created in the Naval Postgraduate Graduate School of Operations and Information Science lab for use. Remote access allowed users with the proper credentials to access the data fetcher on any computer running the VMware Horizon Client software. Now, images could be directly accessed and downloaded from the DigitalGlobe EV-WHS application straight onto a dedicated machine running a Linux operating system via remote access using the TIGHTVNC application. From that point on, the Linux machine had a dedicated 13 terabyte hard drive that served as the data storage warehouse for the images. Additionally, the Linux machine had a ten GB/second Ethernet internet connection which allowed for faster downloads. During FTP download, data transfer rates ranged from 1–10 megabytes per second for file sizes ranging from 2–27GB. A file progress meter could be observed during download; however, it was often inaccurate. The file would be fully downloaded while the progress bar still read 15% complete. However, due to security constraints and protocol, FTP was not allowed on the centralized Linux server.



Screen capture from DigitalGlobe, February 2017. See https://evwhs.digitalglobe.com.

Figure 16. DigitalGlobe Image Download Options

Left with no other options, HTTPS became the default method for image download. HTTPS data transfer rates were typically 900 kilobytes per second which actually slowed down the image downloading process. With a hard-wired 10 GB per second Ethernet connection to the server, it was initially thought that the download transfer rate would be improved, but it actually remained the same. This revealed that the bottleneck existed with the DigitalGlobe server and not the remote machine. Further delays occurred in the download process because the DigitalGlobe server only allowed for six simultaneous downloads per user at a time. Then, because the large files were downloaded in a compressed format, each file had to be extracted and viewed to ensure there were no complications during download. Often, the files were corrupted in the process and had to be relocated and downloaded a second time. During the manual test of the proposed CONOPS, the slow data transfer rates and file manipulations required for viewing were not ideal, but were acceptable. The Amazon Web Services (AWS) S3 bucket option seen in Figure 16 was not an option at the time of imagery download and will be discussed in more detail in Chapter V. In a real-world application, direct access to the archives and real-time satellite imagery would be required.

Once the files were determined usable for processing, they were saved to a folder corresponding to its location and date of capture. The download and organizational process was repeated several times to gather a large data set for use in the CONOPS test. In total, 105 high-resolution images comprised of 1,361 separate tiles were downloaded requiring over 800 GB of storage. In a real-world scenario, there would be no limit to the number of images that could be processed via Progeny's image recognition software. The image download process that took several weeks to accomplish manually, would take Progeny's SPOTR system mere seconds with a direct downlink pushing images directly from DigitalGlobe's image library.

3. Data Processing

Once the imagery collection was complete the image files were copied from the server to a remote USB hard drive and shipped to Progeny Systems to test SPOTR's ability to detect, classify and identify the selected VOIs. Progeny Systems was, at the time of this research, currently working on numerous other funded projects. Therefore, this project was not their top priority which caused significant delays in the processing of the imagery. While waiting for the SPOTR results, a manual analysis was simultaneously conducted on the imagery collected. The purpose of the manual analysis was to determine if it was possible to detect, classify and identify a VOI in the downloaded images with information correlated by the vessel tracking systems available within the SeaVision application. This would ultimately demonstrate the benefits of future fusion capabilities inherent in this proposed CONOPS.

B. TESTING RESULTS

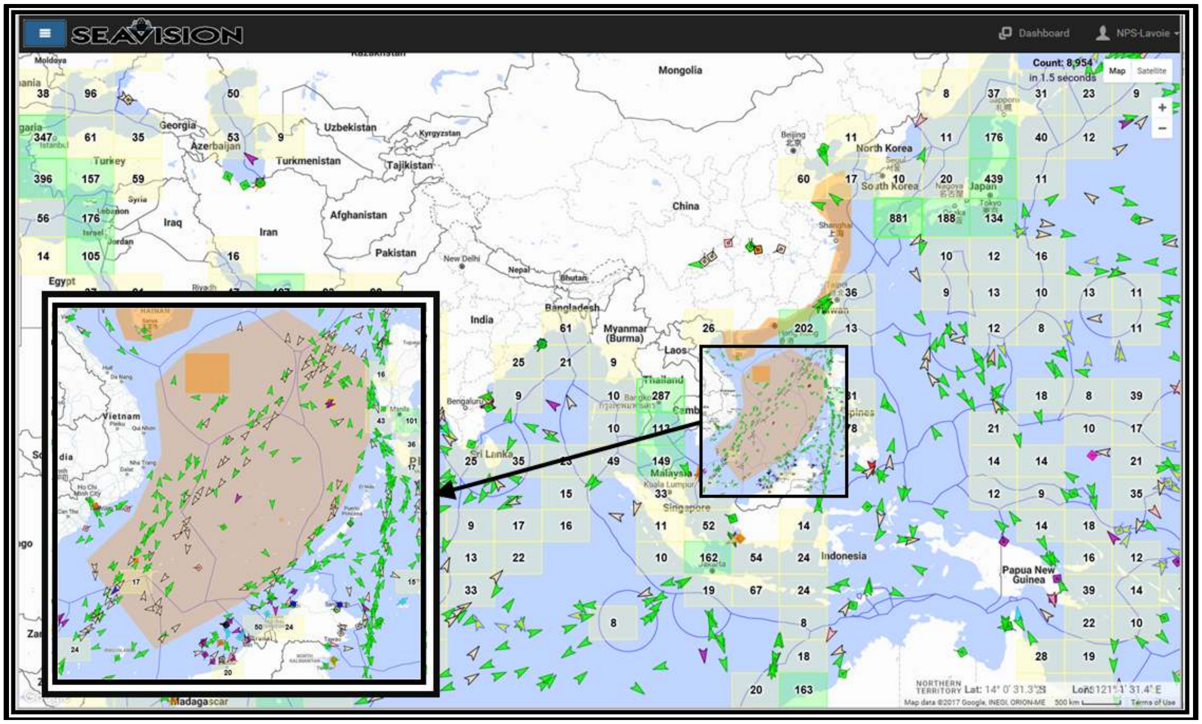
The following section covers the results of both the manual effort to emulate the TCPED process using only the unclassified data and processing steps suggested in the proposed model and SPOTR's automated feature recognition software. The results revealed interesting insights into the potential of the proposed CONOPS. The manual processing results demonstrate the capability to detect, classify and identify VOIs via an unclassified means is possible. SPOTR's results prove that the manual process could be automated. The results of both methods and their implications are discussed in detail in the following subsections.

1. Manual Vessel Detection

The manual analysis utilized unclassified sources to gain data on VOI in the SCS and mirrored the processing techniques described in the proposed CONOPS. Correlations between cooperative vessel tracking systems and DigitalGlobe's commercially available EO imagery was conducted to determine if insights into China's island building activities could be determined to include detecting, classifying and identifying specific vessels. Some of SPOTR's automated ship detection results are mentioned alongside the manual results where relevant for comparison purposes, but will be discussed further in the next section.

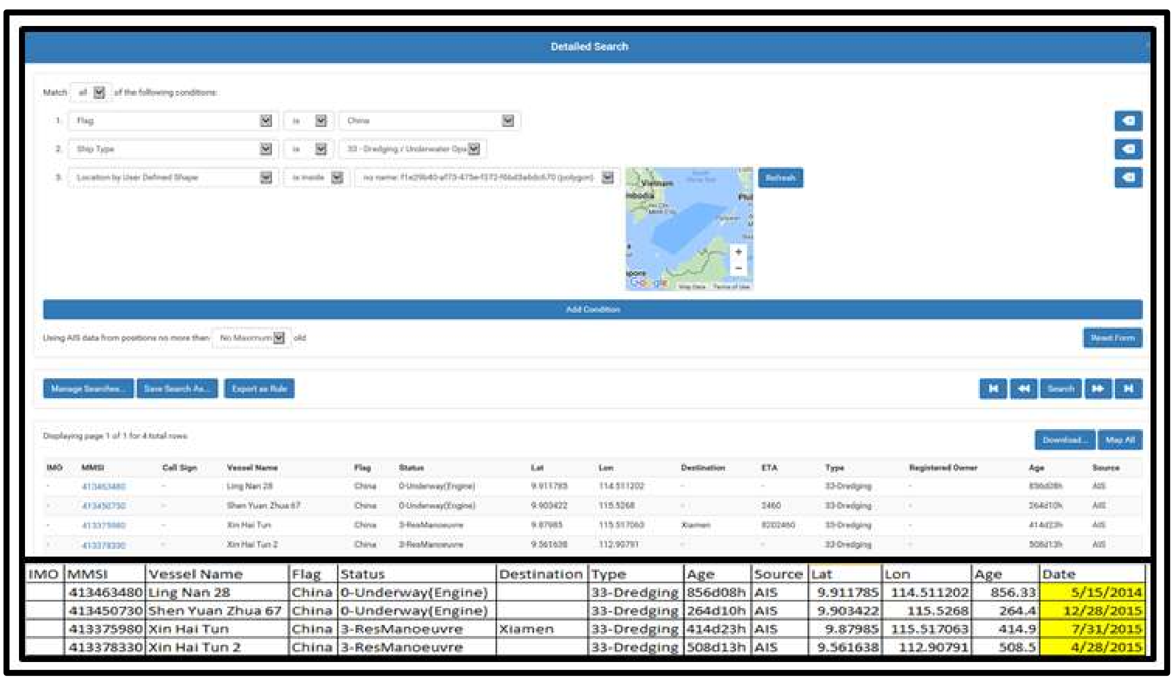
a. Correlations

Utilizing the current version of SeaVision, a user defined polygon was established covering the AOI, the SCS, to conduct a detailed search for the VOIs (see Figure 17). To limit the initial returns, Chinese dredgers were the only VOI selected in SeaVision's detailed search query. The query returned four contacts and their last AIS reported positions, which were subsequently downloaded to Excel for further analysis (see Figure 18).



Screen capture from SeaVision, February 2017. See http://seavision.mda.gov/.

Figure 17. SeaVision COP Display with User Defined Polygon over the SCS



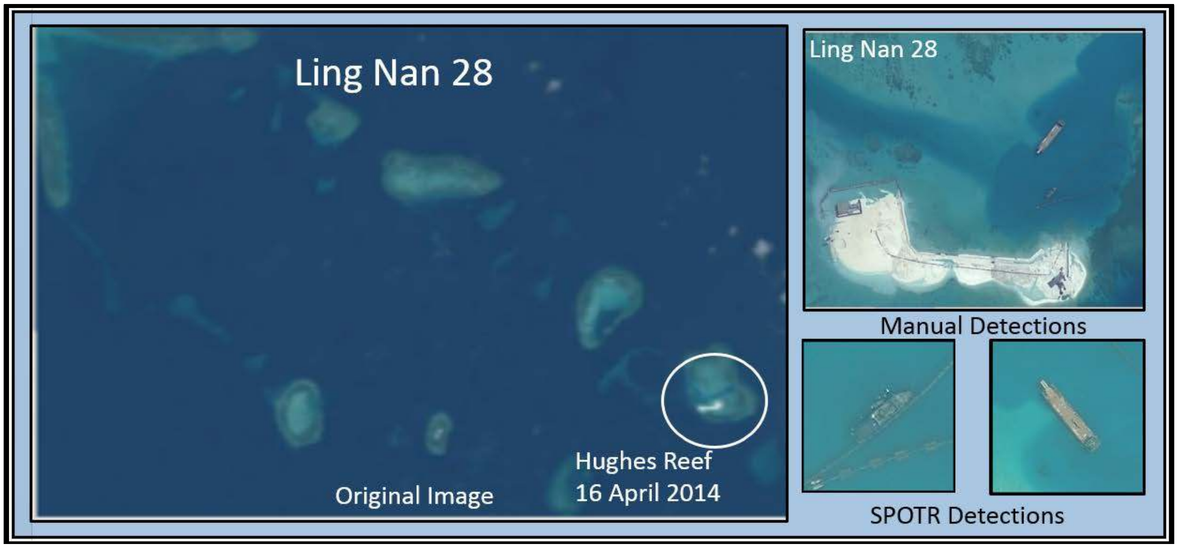
IMO	MMSI	Vessel Name	Flag	Status	Destination	Type	Age	Source	Lat	Lon	Age	Date
	413463480	Ling Nan 28	China	0-Underway(Engine)		33-Dredging	856d08h	AIS	9.911785	114.511202	856.33	5/15/2014
	413450730	Shen Yuan Zhua 67	China	0-Underway(Engine)		33-Dredging	264d10h	AIS	9.903422	115.5268	264.4	12/28/2015
	413375980	Xin Hai Tun	China	3-ResManoeuvre	Xiamen	33-Dredging	414d23h	AIS	9.87985	115.517063	414.9	7/31/2015
	413378330	Xin Hai Tun 2	China	3-ResManoeuvre		33-Dredging	508d13h	AIS	9.561638	112.90791	508.5	4/28/2015

Screen capture from SeaVision, August 2016. See http://seavision.mda.gov/.

Figure 18. SeaVision Detailed Search, Rules Filtering and Query Results

Using the vessel's last reported AIS time stamp and position coordinates reported by SeaVision, a search was conducted for corresponding imagery in DigitalGlobe's archive. Due to limited imagery availability through the EV-WHS service, exact time/date matches were not always possible to perform precise temporal coincident correlation. However, since operating dredgers often stay in one place for a lengthy period of time, there was a high level of confidence that images within a close temporal coincidence to the reported contact could be correlated to the AIS reporting vessel. The images in DigitalGlobe provided some enlightening information and highlighted the importance of using imagery and other means of vessel discovery for effective MDA.

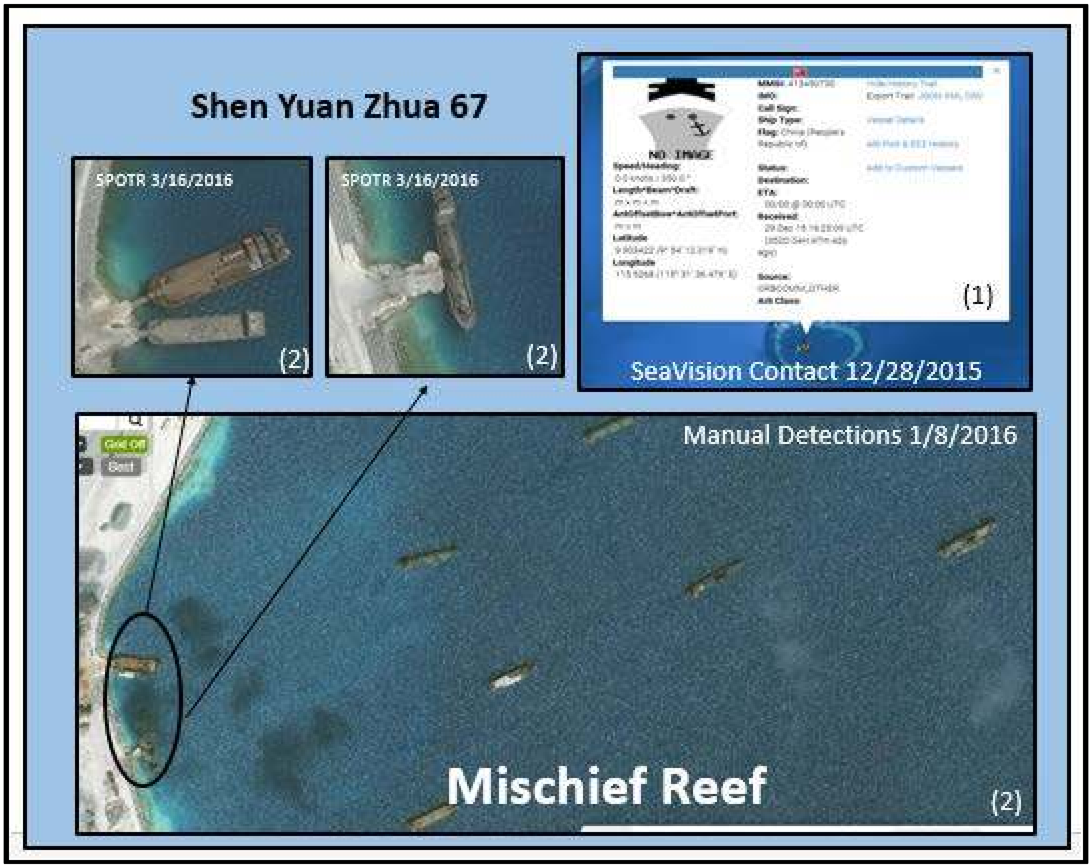
The first reported vessel listed was the Chinese dredger, Ling Nan 28 (in Figure 18). SeaVision reported the AIS contact in the area of Hughes Reef on 15 May 2014. A vessel, similar in appearance, was located in a DigitalGlobe image captured on 16 April 2014 (see Figure 19). This image shows two vessels engaged in dredging operations near Hughes Reef a month earlier. While one vessel is likely the Ling Nan 28, the second vessel in the picture did not report AIS data. Progeny's SPOTR software was able to detect 11 vessels around the island including the two visible here, while SeaVision only returned one AIS contact.



Satellite images obtained from DigitalGlobe, August 2016. See https://evwhs.digitalglobe.com.

Figure 19. Ling Nan 28 Correlation Process

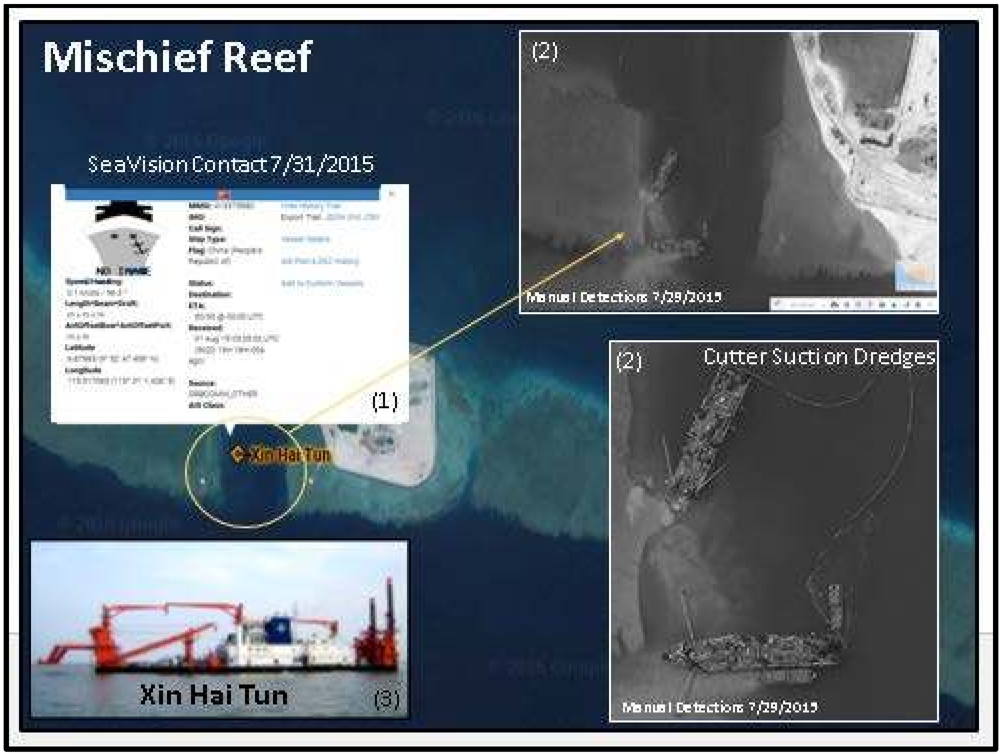
The second AIS contact reported in the SeaVision query is listed as the Shen Yuan Zhua 67 (See Figure 18). It reported its position while operating near Mischief Reef on 28 December 2015. This vessel correlated closely with a vessel discovered in a DigitalGlobe image captured of Mischief Reef on 08 January 2016, just ten days later (see Figure 20). Of note, an image captured on 16 March 2016 was analyzed by SPOTR where 42 total vessels were detected in the same area. Two of those vessels, in particular, resembled the same vessels that were present in the manually reviewed image captured three months prior.



Satellite images and screen captures obtained from (1) SeaVision http://seavision.mda.gov/ (2) DigitalGlobe https://evwhs.digitalglobe.com.

Figure 20. Shen Yuan Zhua 67 Correlation Process

The third AIS dredger contact reported via in SeaVision, the Xin Hai Tun, is a cutter suction dredger that was reported operating near Mischief Reef on 31 July 2015 (see Figure 21). The Xin Hai Tun was also found in an image captured by DigitalGlobe on 29 July 2015 of Mischief reef. This image, taken just two days after the AIS data was recorded, reveals two cutter suction dredgers. One vessel is likely the Xin Hai Tun, while the other does not appear to have reported its location. This highlights the need to add additional unclassified measures to detect non-reporting VOI. Relying solely on information that SeaVision currently provides will not provide a complete picture.



Satellite images and screen captures obtained from (1) SeaVision http://seavision.mda.gov/ (2) DigitalGlobe https://evwhs.digitalglobe.com (3) Shanghai Dredging Company www.dredgepoint.org/dredging-database/owners/cccc-shanghai-dredging-co-ltd.

Figure 21. Xin Hai Tun Correlation Process

The final AIS contact reported in the SeaVision query, the Xin Hai Tun 2, is another cutter suction dredger and sister ship to the Xin Hai Tun. The Xin Hai Tun 2 reported via AIS that it was operating near Fiery Cross Reef on 28 April 2015. Again, while only one vessel reported its position, in an image collected by DigitalGlobe on 18 April 2015, two vessels appear to be conducting dredging operations (see Figure 22). SPOTR analyzed an image dated 05 March 15 and returned a total of 25 vessels operating in the same area, including 4 dredgers.

Satellite images and screen captures obtained from (1) DigitalGlobe https://evwhs.digitalglobe.com (2) Shanghai Dredging Company www.dredgepoint.org/dredging-database/owners/cccc-shanghai-dredging-co-ltd (3) SeaVision http://seavision.mda.gov/.

Figure 22. Xin Hai Tun 2 Correlation Process

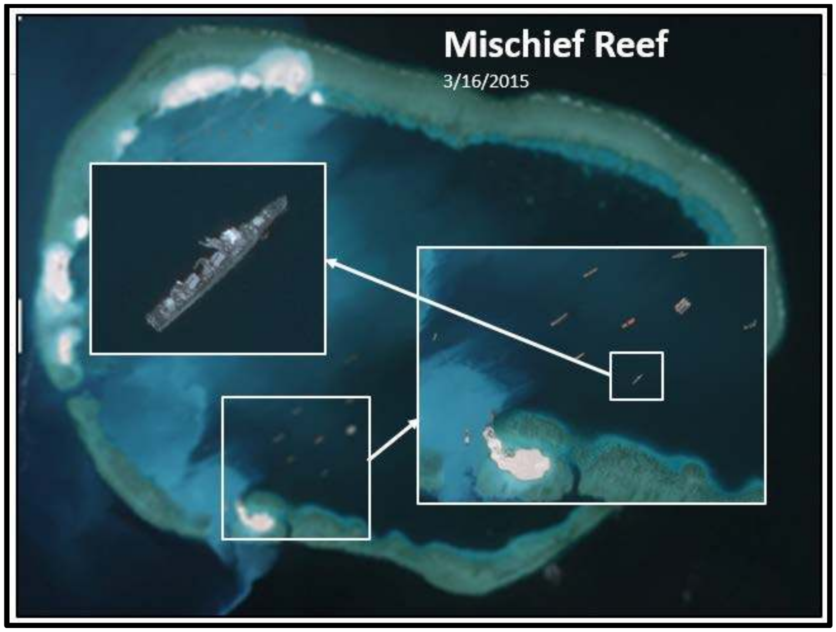
b. Island Building Observations

As images were downloaded and analyzed, C7F's concerns regarding China's aggressive island building and VOIs were kept in mind. Throughout the process, any VOIs that were discovered manually were logged. For example, in an image of Johnson South Reef taken on 22 January 2014, two vessels, a dredger and warship, were noted as VOI for further review. SPOTR detected these two ships as well as two others (see Figure 23).

Satellite images obtained from DigitalGlobe, August 2016. See https://evwhs.digitalglobe.com.

Figure 23. Johnson South Reef Island Building Operations

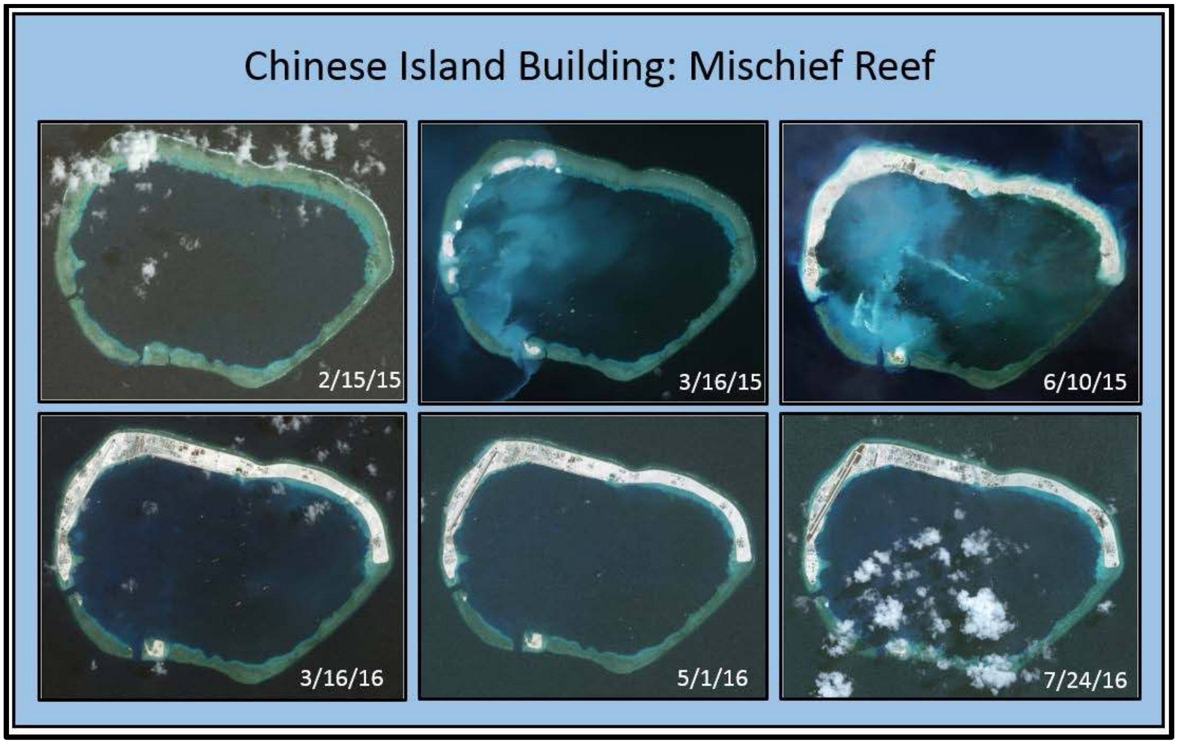
The same activity was seen occurring at Mischief Reef, the most recent Chinese island to be constructed. When the image dated, 16 March 2015, was downloaded, a military ship was noted in the vicinity. SPOTR detected the same military ship as well as 34 other vessels. Many appeared to be engaged in dredging and island building activities (see Figure 24).



Satellite images obtained from DigitalGlobe, August 2016. See https://evwhs.digitalglobe.com.

Figure 24. Building Operations on Mischief Reef

Another benefit noted is the ability of imagery recognition software to evaluate changes in topography known as change detection, (e.g., island building and land reclamation). Changes in the landscape as operations progressed can clearly be seen over time. Figure 25 depicts how imagery can be utilized to show the changes in topography over time by highlighting the progression of Chinese island building operations at Mischief Reef over the course of a year and a half. In 17 months, Mischief Reef was transformed from a barren reef to a fully functioning island base complete with an airfield.



Satellite images obtained from DigitalGlobe, August 2016. See https://evwhs.digitalglobe.com.

Figure 25. Time Lapse of Building Operations on Mischief Reef

2. Automated Results (SPOTR)

The results from Progeny's SPOTR system were received in two batches approximately two weeks apart. The results were sent via a spreadsheet that detailed each detected vessel's position in the latitude and longitude format and included the width and height of the bounding box in image pixels (see Table 1). The bounding box data could be used to derive a rough size estimate for the vessel, however, not a precise beam and width.

Table 1. Example of Progeny's Initial Results

x	y	width	height	latitude	longitude	crop_filename	source_filename
9641	14043	35	88	10.20987	114.3958	Feb14_R9C1_00000.png	Feb14/Feb14_R9C1.tif
2545	6138	58	58	15.1594	117.8085	Scarborough11NOV14_R2C3_00000.png	Scarlborough/Scarborough11NOV14Good/Scarborough11NOV14_R2C3.tif
1889	7310	95	151	15.19212	117.6311	Scarborough15JUN15_R2C1_00000.png	Scarlborough/Scarborough15JUN15Good/Scarborough15JUN15_R2C1.tif
14092	14376	123	81	15.08593	117.7544	Scarborough19APR14_R3C1_00000.png	Scarlborough/Scarborough19APR14attempt2Good/Scarborough19APR14_R3C1.tif
10534	4095	120	120	15.1321	117.8121	Scarborough19APR14_R3C2_00000.png	Scarlborough/Scarborough19APR14attempt2Good/Scarborough19APR14_R3C2.tif
5745	2585	58	57	15.17907	117.6908	Scarborough29JAN15_R2C1_00000.png	Scarlborough/Scarborough29JAN15Good/Scarborough29JAN15_R2C1.tif
11230	3409	38	46	15.17539	117.7154	Scarborough29JAN15_R2C1_00001.png	Scarlborough/Scarborough29JAN15Good/Scarborough29JAN15_R2C1.tif
209	14652	22	21	15.12485	117.7391	Scarborough29JAN15_R2C2_00000.png	Scarlborough/Scarborough29JAN15Good/Scarborough29JAN15_R2C2.tif
14	14932	24	21	15.12359	117.7382	Scarborough29JAN15_R2C2_00001.png	Scarlborough/Scarborough29JAN15Good/Scarborough29JAN15_R2C2.tif
8389	8754	80	21	15.07766	117.7032	Scarborough29JAN15_R3C1_00000.png	Scarlborough/Scarborough29JAN15Good/Scarborough29JAN15_R3C1.tif
7968	1951	54	50	15.10821	117.774	Scarborough29JAN15_R3C2_00000.png	Scarlborough/Scarborough29JAN15Good/Scarborough29JAN15_R3C2.tif
12949	10896	194	139	15.06776	117.7968	Scarborough29JAN15_R3C2_00001.png	Scarlborough/Scarborough29JAN15Good/Scarborough29JAN15_R3C2.tif
14384	4753	71	29	15.09565	117.8029	Scarborough29JAN15_R3C2_00002.png	Scarlborough/Scarborough29JAN15Good/Scarborough29JAN15_R3C2.tif
559	6007	103	138	15.08976	117.8145	Scarborough29JAN15_R3C3_00000.png	Scarlborough/Scarborough29JAN15Good/Scarborough29JAN15_R3C3.tif
604	6135	75	75	15.08933	117.8147	Scarborough29JAN15_R3C3_00001.png	Scarlborough/Scarborough29JAN15Good/Scarborough29JAN15_R3C3.tif
4922	6190	49	41	15.19545	117.712	Scorborough18MAY16_R2C1_00000.png	Scarlborough/Scorborough18MAY16Good/Scorborough18MAY16_R2C1.tif
13982	13600	41	42	15.1621	117.8264	Scorborough18MAY16_R2C2_00000.png	Scarlborough/Scorborough18MAY16Good/Scorborough18MAY16_R2C2.tif
15468	13312	40	25	15.16343	117.8331	Scorborough18MAY16_R2C2_00001.png	Scarlborough/Scorborough18MAY16Good/Scorborough18MAY16_R2C2.tif
1196	15732	47	46	15.15249	117.8426	Scorborough18MAY16_R2C3_00000.png	Scarlborough/Scorborough18MAY16Good/Scorborough18MAY16_R2C3.tif
10886	9708	42	32	15.10591	117.7388	Scorborough18MAY16_R3C1_00000.png	Scarlborough/Scorborough18MAY16Good/Scorborough18MAY16_R3C1.tif
16114	5065	83	54	15.12675	117.8361	Scorborough18MAY16_R3C2_00000.png	Scarlborough/Scorborough18MAY16Good/Scorborough18MAY16_R3C2.tif
12324	10756	40	52	15.10114	117.8189	Scorborough18MAY16_R3C2_00001.png	Scarlborough/Scorborough18MAY16Good/Scorborough18MAY16_R3C2.tif
8103	10405	50	43	15.10275	117.7999	Scorborough18MAY16_R3C2_00002.png	Scarlborough/Scorborough18MAY16Good/Scorborough18MAY16_R3C2.tif
270	12131	60	160	15.09471	117.7647	Scorborough18MAY16_R3C2_00003.png	Scarlborough/Scorborough18MAY16Good/Scorborough18MAY16_R3C2.tif
262	9257	134	109	15.10776	117.8386	Scorborough18MAY16_R3C3_00000.png	Scarlborough/Scorborough18MAY16Good/Scorborough18MAY16_R3C3.tif
6643	5970	18	19	15.23265	117.7605	Scorborough24AUG16_R1C1_00000.png	Scarlborough/Scorborough24AUG16Good/Scorborough24AUG16_R1C1.tif
5555	12936	73	62	15.2129	117.7575	Scorborough24AUG16_R1C1_00001.png	Scarlborough/Scorborough24AUG16Good/Scorborough24AUG16_R1C1.tif
15458	3346	28	30	15.19375	117.8317	Scorborough24AUG16_R2C2_00000.png	Scarlborough/Scorborough24AUG16Good/Scorborough24AUG16_R2C2.tif
9873	894	28	28	15.15438	117.7696	Scorborough24AUG16_R3C1_00000.png	Scarlborough/Scorborough24AUG16Good/Scorborough24AUG16_R3C1.tif
1211	467	39	35	15.15558	117.7914	Scorborough24AUG16_R3C2_00000.png	Scarlborough/Scorborough24AUG16Good/Scorborough24AUG16_R3C2.tif
15646	8431	91	120	15.13295	117.8323	Scorborough24AUG16_R3C2_00001.png	Scarlborough/Scorborough24AUG16Good/Scorborough24AUG16_R3C2.tif
1801	12514	104	90	15.12628	117.8357	scarbough18nov15_R2C3_00000.png	Scarlborough/scarbough18nov15/scarbough18nov15_R2C3.tif
11987	7682	86	225	15.074	117.8078	scarbough18nov15_R3C2_00000.png	Scarlborough/scarbough18nov15/scarbough18nov15_R3C2.tif

Along with the spreadsheet of information, Progeny returned actual images of each vessel detected. Overall, Progeny's results indicated that 11,870 vessels were detected in the 1,361 image tiles analyzed. See Appendix A for a specific breakdown of the results. The results were studied for accuracy and further analysis and interpretation. The advantages and limitations determined from the initial round of SPOTR imagery analysis are discussed in the following sections.

a. SPOTR Advantages

The SPOTR results yielded some impressive detection capabilities that have great potential for use in the proposed CONOPS. Numerous instances showed how SPOTR could be leveraged to automate the information collection and processing steps of the TCPED model. SPOTR's computer vision can be a force multiplier by providing an additional capacity to gather data beyond the capabilities of an intel analyst by detecting vessels that would be nearly impossible to see by the human eye alone. The following subsections describe these positive attributes in detail.

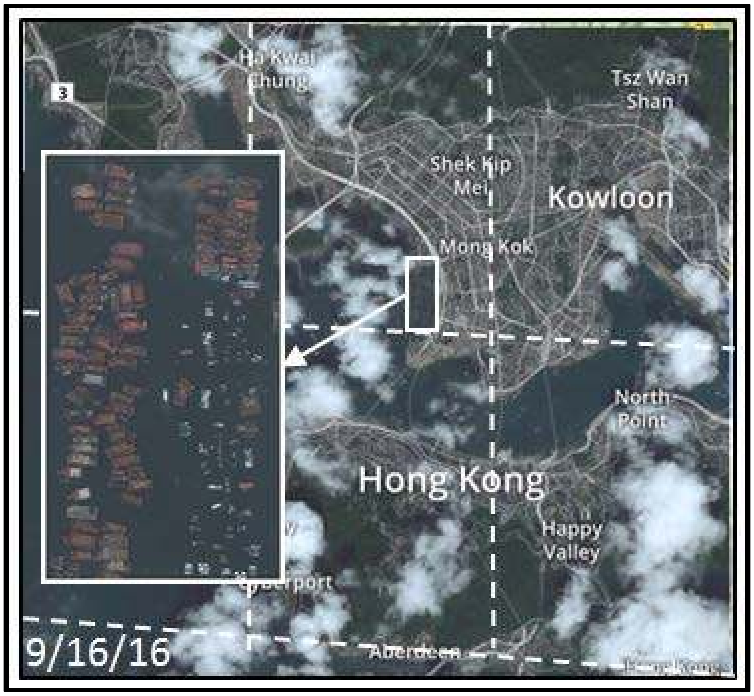
(1) Automated Detection

Although the process to get the imagery to Progeny was manually intensive, the results were significant. The images sent for analysis covered large sections of ocean; some over 400 square miles. Searching these images for a VOI, whose exact position is not known, would be near impossible for an intelligence analyst. It is unlikely that the human eye would be able to find all the results that SPOTR was capable of and certainly not as quickly. Furthermore, SPOTR was regularly able to break out vessels in situations where distractions and clutter would also make it difficult for the human eye. For example, the image of Scarborough Shoal captured on 15 June 2015 covers 230 square miles and contains 16% cloud cover. At first glance, it does not appear there are any vessels in the image. However, SPOTR did detect a single vessel as shown (see Figure 26).

Satellite images obtained from DigitalGlobe, August 2016. See https://evwhs.digitalglobe.com.

Figure 26. Image of Scarborough Shoal with Cloud Cover

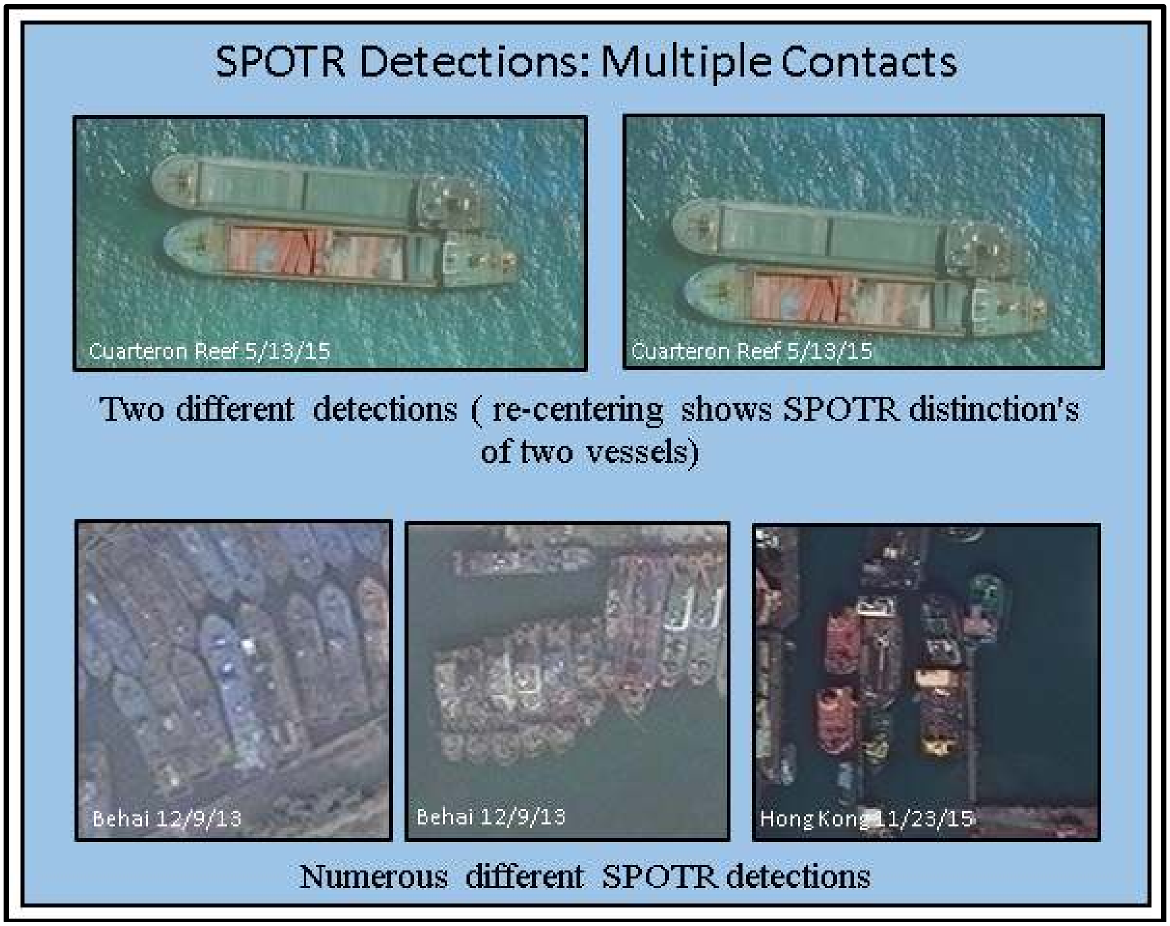
High-density ports also pose a significant challenge for intelligence analysts, especially when commercial and military activities are blended within the same environment. The image seen in Figure 27 was captured by the DigitalGlobe Worldview-3 satellite on 16 September 2016. The dashed lines represent how the image was broken down into smaller tiles when it was downloaded and analyzed. The enlarged portion shows an example of the magnitude of ships that can be present in just one small subsection of the image. Accounting for each vessel in this image would be an extremely time-consuming task for an analyst. SPOTR detected 881 total vessels in the 70 square miles covered by this image and returned a separate picture for each vessel it detected.



Satellite images obtained from DigitalGlobe, September 2016. See https://evwhs.digitalglobe.com.

Figure 27. Image of Hong Kong

There were numerous occasions where SPOTR positively detected individual vessels among substantial clusters especially in large ports such as Hong Kong. When multiple vessels were detected in close proximity SPOTR would account for each vessel with a unique detection report and cropped image centered on the detected vessel. For example, in Figure 28, two cargo vessels were detected near Cuarteron Reef that appear to be tied alongside each other. SPOTR returned two separate results, one for each of the vessels. In situations with dense maritime traffic, this individual vessel differentiation capability could be very helpful to automatically detect and account for each vessel, as well as changes in overall traffic patterns and port density. If SPOTR can detect what is in port on any given day, change detection algorithms could eventually be applied to recognize if a particular vessel is absent or a new one is present at that same location over time. This activity could trigger an alert and send a message to the analyst. The large number of the detection returns and limited time for analysis made it difficult to determine if every vessel among hundreds was accounted for, but in a small sampling, an initial examination showed that SPOTR's accuracy was very high.



Satellite images obtained from DigitalGlobe, August 2016. See https://evwhs.digitalglobe.com.

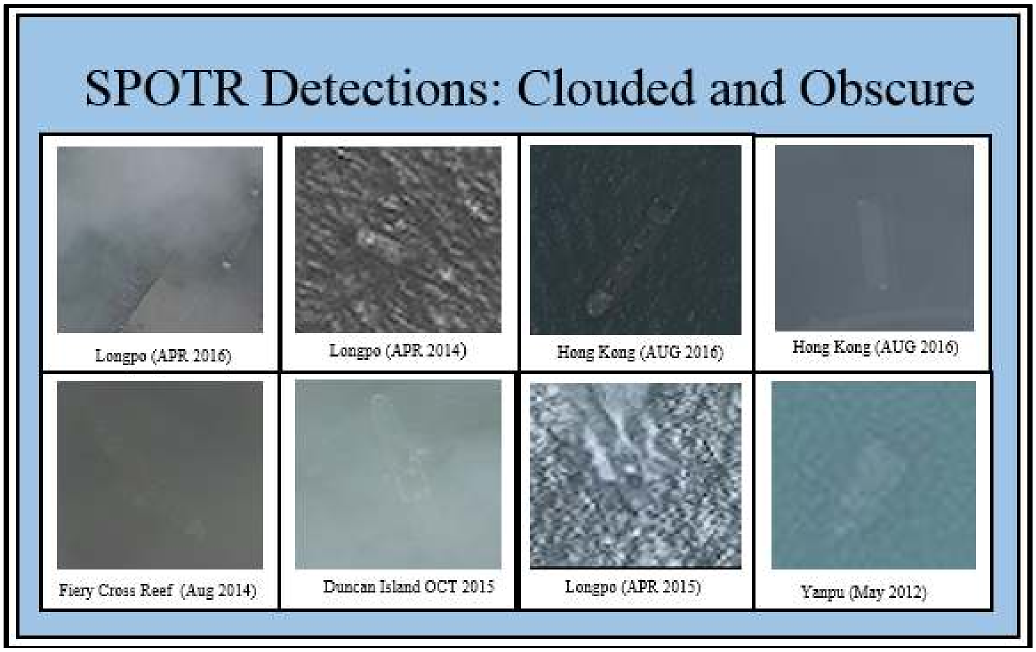
Figure 28. SPOTR's Detection of Multiple Contacts in Close Proximity

SPOTR's ability to detect extremely small vessels was also apparent. The images depicted in Figure 29 have been cropped and enlarged for display purposes, however they measure less than 30 feet in length. As mentioned in Chapters II and III, this type of detection capability might not interest C7F, but it would help in other AORs where combatting piracy or illicit trafficking activities is a high priority.

Satellite images obtained from DigitalGlobe, August 2016. See https://evwhs.digitalglobe.com.

Figure 29. SPOTR's Detection of Small Vessels

Another positive attribute was SPOTR's ability to detect images through challenging environmental or man-made conditions. Some vessels that SPOTR detected would be difficult to see due to cloud cover, lighting and background coloration. While the vessel is not intentionally attempting to evade detection, these conditions can easily obscure it from being spotted by the human eye. Figure 30 highlights SPOTR's ability to detect vessels in these problematic environmental conditions.



Satellite images obtained from DigitalGlobe, August 2016. See https://evwhs.digital globe.com.

Figure 30. SPOTR Detections in Obscure Environmental Conditions

Along with vessels potentially obscured by environmental conditions, some vessels can blend into piers and other man-made surroundings. This creates a camouflaged appearance and could pose problems to an intelligence analyst reviewing imagery of busy port areas. Figure 31 depicts various types of cargo vessels that SPOTR detected in port that appear to blend into to their environment.

Satellite images obtained from DigitalGlobe, August 2016. See https://evwhs.digital globe.com.

Figure 31. SPOTR Detections in Busy Port Areas

(2) VOI Tracking / Change Detection

Both military and civilian vessels are important factors that need to be accounted for in effective MDA. While this thesis covered dredging and other support vessels important to C7F's geopolitical concerns with other nation's movements and activity in the area, military leaders in every COCOM are concerned with the location and activities of other nation's military ships. In Figure 32, SPOTR's ability to locate both surface and subsurface combatants is demonstrated.

Satellite images obtained from DigitalGlobe, August 2016. See https://evwhs.digitalglobe.com.

Figure 32. SPOTR Detections of Military Vessels

Furthermore, change detection can be applied to military ports as well. SeaVision can leverage SPOTR's results by noting a change, either the absence or presence of a new ship at a particular location. In Figure 33, for example, it will be possible to determine that a submarine that has been pier side for two years is no longer present in the latest SPOTR data results. This will create a much more proactive MDA environment with exponentially less manual tracking needed by the intelligence analysts.

Satellite images obtained from DigitalGlobe, August 2016. See https://evwhs.digitalglobe.com.

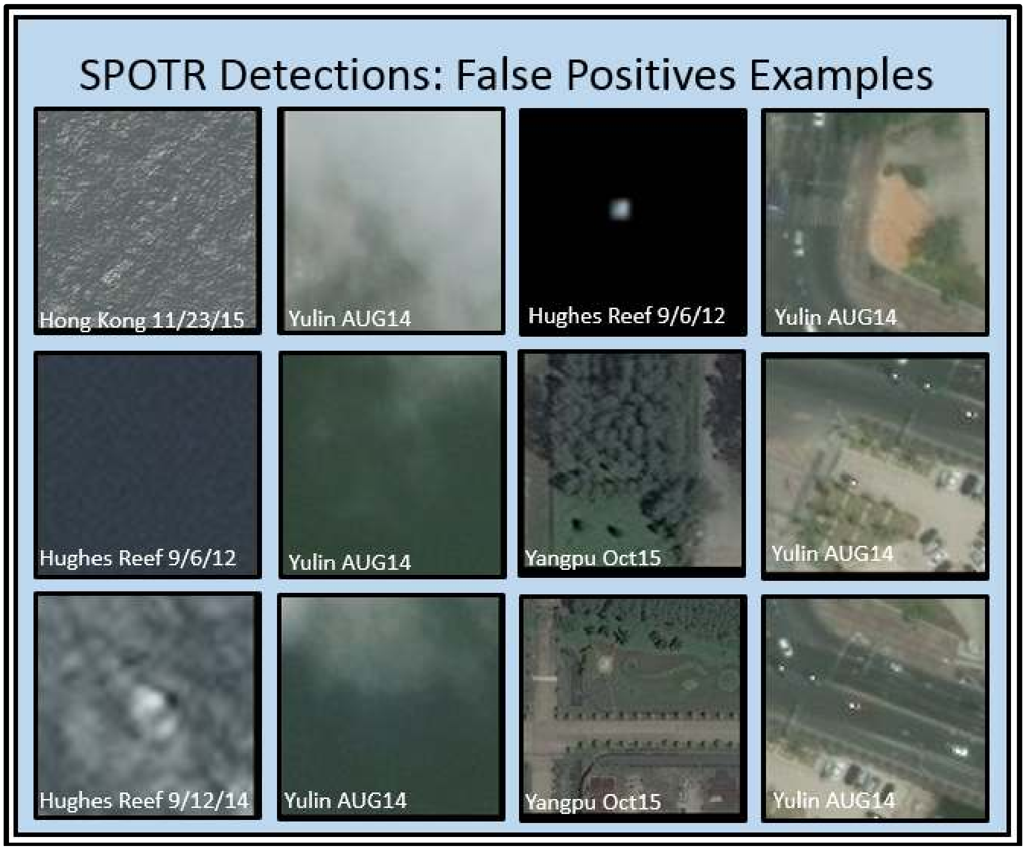
Figure 33. Future Capability: Change Detection

b. SPOTR Limitations

The SPOTR detection results were impressive and far beyond what the human eye could have found scanning the images one by one. It is clear that the inclusion of these results into a COP can be a vital part of this CONOPS and greatly enhance MDA. However, with any new complicated automated process improvements need to be made to gain the full range of benefits. These problems can be addressed with continuous feedback and process improvement. When reviewing the results, the following problems were noted.

(1) False Positives

While SPOTR returned 11,870 detections, it did return some images that did not appear to contain a vessel. An initial manual review of the returned images revealed that approximately 109, or 0.9%, were false positives. Those images either contained land or empty water. Some examples are included in Figure 34. This highlights the continuous need for feedback to refine SPOTR's computer vision algorithms to decrease the occurrence of these false positive in future results. However, despite SPOTR's use of complicated algorithms, a less than one percent false positive return is remarkable.



Satellite images obtained from DigitalGlobe, August 2016. See https://evwhs.digitalglobe.com.

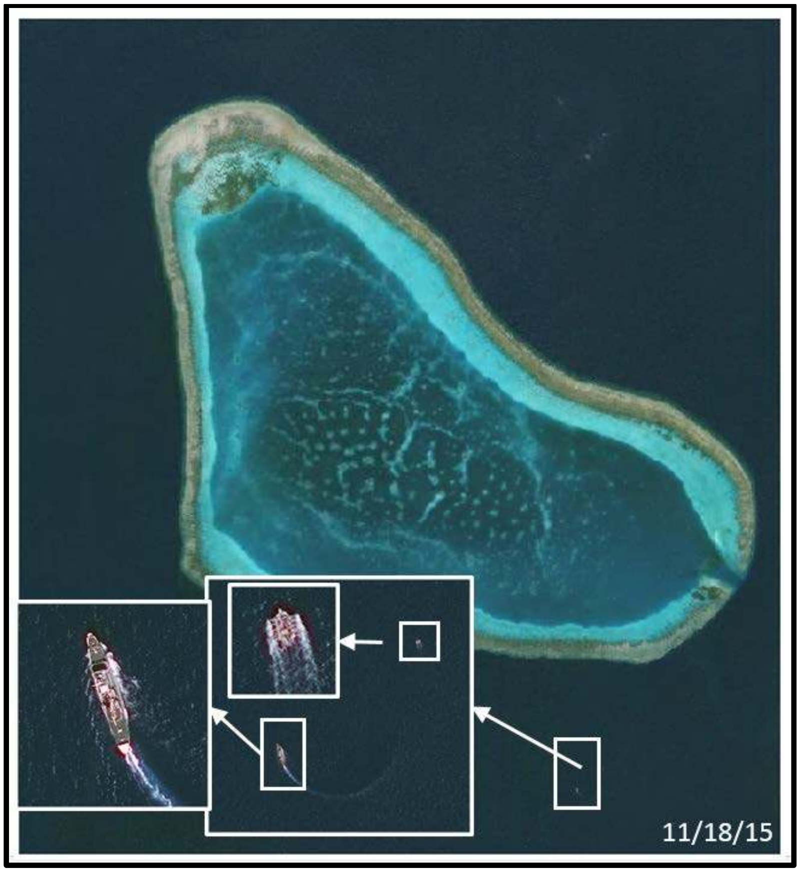
Figure 34. Examples of SPOTR's False Positive

(2) Detection Capability Only

SPOTR was unable to classify or identify specific vessels for the initial data set. Unfortunately, Progeny does not yet have a compatible vessel database for this region. Lacking that vessel library, SPOTR's functionality was limited to vessel detection only. For classification to occur, SPOTR requires an ontology/taxonomy with distinguishing characteristics of the VOIs to use as a standard. Further work with Progeny will be required to expand the capabilities of their technology to provide more value to the COP. However, even ship detections without the amplifying information can provide value to the COP. It can still be utilized to alert the analyst that something is present that may warrant their interest. The detected unknown vessel could also be overlaid with a known contact from another source with which it can be fused, adding confidence to the track.

C. CHAPTER SUMMARY

Overall, SPOTR's results show significant promise. There are indications that intrinsic value could be derived by an intelligence analyst using a system with these types of results included. As described previously, SPOTR is trained to locate, classify and identify vessels based on finely tuned algorithms. Once the results are input into SeaVision, it can alert the human analyst to investigate a contact more in depth. The COP only provides information such as the who, what, where and when as related to vessel movements. The IC still needs to determine the why, how and/or various implications of the picture. For example, SPOTR detected two vessels near Scarborough Shoal (see Figure 35). In time, it may also be able to determine that they are a Chinese Coast Guard Cutter and a Filipino fishing boat, for example. This data is input into SeaVision and an analyst is alerted. The analyst downloads the image and confirms the vessel classification is correct. The analyst will also note that the cutter is in a high-speed turn and maneuvering closer to the smaller fishing vessel. While this is just a fabricated example to show the system's promise, this is a type of situation that mirrors reality. There are numerous incidents that have been reported indicating that Chinese Coast Guard vessels have harassed Filipino fishermen around Scarborough Shoal (Maresca, 2015).



Satellite images obtained from DigitalGlobe, August 2016. See https://evwhs.digitalglobe.com.

Figure 35. Two Vessels near Scarborough Shoal

Both the manual and automated analysis of potential unclassified sources, processes and the SeaVision display application showed the potential benefits of an unclassified COP. Due to limited time and resources, only four vessels could be correlated using imagery results and cooperative AIS tracks in SeaVision, but with the number of other sources and processing capabilities available the potential is limitless. Adding processing technologies such as SPOTR will only automate and quicken the process giving intelligence analysts more time to complete intelligence tasks, vice gathering and tracking data. It will also provide leadership additional information and better situational awareness from which to make important decisions.

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V. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY OF RESULTS

The goal of this thesis was to construct an unclassified CONOPS strategy to meet the evolving needs of fleet and operational commanders in the execution of MDA. The CONOPS presented is the result of extensive research into current operational MDA methods and requirements and new or improved ISR technologies. Those findings were used to develop a CONOPS that could produce unclassified data fused from numerous input sources that is low-cost, low bandwidth and easy to use. Having developed a CONOPS that met those requirements in theory, it was tested to validate its feasibility and flush out the initial imperfections.

The testing methods simulated the recommended process by utilizing the same technologies for data retrieval, processing and display suggested in the CONOPS, DigitalGlobe, SPOTR and SeaVision respectively. The concept behind the initial attempt was to detect, classify and identify a set of non-cooperative vessels using only the unclassified technologies suggested. Due to time and access constraints, however, a complete test of the CONOPS was not possible. The classification, identification and data input steps of testing via the automated system was not completed. The manual method and automated detection results received did expose multiple strengths and weakness of the three subsystems used and the overall CONOPS processes that can be improved upon in future attempts to test and refine the process.

B. PROCESS IMPROVEMENTS

This CONOPS is still at a theoretical stage, but based on the research and initial testing, it could have far-reaching positive effects within the MDA enterprise. Unfortunately, most new processes and systems that are initiated often whither on the vine without proper support. The next steps following this research will be very important in moving towards process implementation. This research produced a thorough and workable CONOPS theory, but it must be further developed and continually refined. Some of the challenges and limitations that were encountered throughout the testing process were later resolved and should be applied to future attempts in proving the concept.

The single biggest improvement to this process would be to gain access to large batches of imagery for the AOI through assistance with the NGA and DigitalGlobe. If this is still not an option, there are a couple simple changes that will improve the download process. As mentioned in Chapter IV, the process to download and send images to Progeny was fairly lengthy. After the initial test run was complete, DigitalGlobe introduced a new way to download images via an AWS S3 bucket. AWS is Amazon's portfolio of cloud computing services and the S3 bucket is the cloud-based web storage service. This added service introduces a new and faster way to complete the transfer process. It allows for a direct bucket to bucket cloud-based storage and transfer which will exponentially decrease the time required to move images from DigitalGlobe's database to Progeny's from hours to seconds. Future download batches should utilize this method to alleviate the delays and glitches caused by download speeds, image consolidations, hard drive transfers and shipments.

Another important update to the process involves the file download format. As mentioned in Chapter IV, the initial batch of imagery delivered to Progeny was not in the best possible format. The initial format chosen, GeoTiff, does not preserve all of the original image metadata. In particular, the date and time of image capture and download were not included. This data is necessary to eventually derive specific information to aid in image detections and track information. While the GeoTiff formats were acceptable for the initial test run, the missing data will be critical for future iterations where track data can be input into SeaVision. Progeny recommended that the National Imagery Transmission Format Standard (NITFS) be used for future downloads to preserve all necessary data to create the appropriate message format for eventual data transfer to the SeaVision COP application.

As discussed, the initial SPOTR test was only successful in detecting vessels in the imagery. To improve SPOTR's classification and identification processes, it will be necessary to expand the image and model library that Progeny uses for classification and identification. SPOTR is an extremely powerful tool that is capable of making VOI identifications only if it is provided the appropriate seed gallery for image comparison. Building the initial seed gallery can be done a couple of ways. Human in the loop or crowdsourced data mining via AIS reports and other electronic tracking data feedback can assist the special and temporal machine learning process. For instance, future research can use SeaVision to collect a 90-day history of AIS data in a specific AOI and then collect a 90-day history of imagery of the same locations. SPOTR will detect vessels and provide information on date, time and location. Then correlations to identify the vessels can be performed as was done in the initial manual testing of this CONOPS. SeaVision's limited archive of AIS data precluded this step from being taken on the initial tranche of imagery analyzed by SPOTR. Once this seed gallery is created and refined, the full power of SPOTR will be realized. Unfortunately, as noted in this research, most vessels that SPOTR will detect are not all reporting their position and vessel information. The better, and perhaps faster solution, would be to gain access to or purchase images and 3D models of known ship types and VOI information from ONI or other collection agencies for direct input into the system. Once the SPOTR detections can be input into SeaVision, then steps can be taken to further automate the feedback process described above. Any SeaVision or manual AIS/SPOTR detection correlations could be sent back via a feedback loop to SPOTR for system refinement.

C. RECOMMENDATIONS FOR FUTURE RESEARCH

The research and preliminary tests of the proposed unclassified CONOPS demonstrated that the unclassified technology behind the concept is sound, but in order for the unclassified comprehensive COP to be a reality much more work must be done. More effort needs to be made to integrate the various technologies together to form the complete COP. The next steps should include importing the imagery-based SPOTR derived track data into SeaVision and maturing the SeaVision application as future capabilities become available.

1. Import Imagery Data into SeaVision

The most significant hurdle to making the COP a reality is transforming SPOTR derived track data into an acceptable message format for input into SeaVision real time.

Certain steps are required to import the current SPOTR contact and tracking information to the SeaVision COP. Along with using the correct image download format, NITFS, the speed of data acquisition and transfer must be increased. Initially, time can be saved by transferring the images to SPOTR via the AWS S3 bucket mentioned previously, but real world implementation of this CONOPS requires a direct imagery data downlink feed to SPOTR from the collection sources to reduce delay. This will provide the most up to date information as possible to the COP. However, the analyst is at the mercy of the daily scheduled imagery take from the satellite which may not meet their specific needs real time. In that case, when specific or more instantaneous imagery needs are required, the system can be supplemented with the CTAR process described in Chapter III. CTAR has the potential to allow analysts direct access to a commercial satellite. They can decide specifically what imagery is taken and when. The data will then be sent directly to their remote moveable ground station for immediate processing. This method is expensive, so will likely be used sparingly. It also requires further testing to determine its practicality as a means of data acquisition. This could potentially close the time gap from collection to display when the normal process may be too slow.

The next challenge to overcome is displaying the SPOTR data on the SeaVision COP. This will require the data to be input into the proper message format. One of the primary reasons SeaVision was selected for the COP display is because it is already built to allow NIEM conformant exchanges (Department of Transportation, n.d.). This means that SeaVision can quickly assimilate new data sources, including those from new services, other agencies and foreign partners. The Volpe Center built, deployed and continues to leverage the low-cost, unclassified, near-real time Maritime Safety and Security Information System (MSSIS) network which enables collaboration and data-sharing between government agencies and foreign partners (Volpe Center, n.d.). The new data source, SPOTR in this case, will need to transfer the data in a format compatible with the MSSIS network. Progeny supplied the initial results via datasets in both Comma Separated Value and JavaScript Object Notation formats. In the future, the data needs to be refined and put into the specific format for SeaVision to use. SeaVision uses the PVOL format to integrate satellite imagery detection data into MSSIS. This format applies four-corner point latitude and longitude coordinates, as well as contact course, speed, estimated size and sensor information (J. Stastny, personal communication, October 24, 2016). As SPOTR will likely provide additional details about the imagery detections that are not already common in the PVOL format, specifically classification and identification, new fields may be required so SeaVision can perform correlation and fusion with the more granular details provided by other sources. Due to the lack of time to fully develop target sets, this step could not be completed. Progeny and the Volpe Center will need to work together to build the proper protocols in order to establish data security, authenticity and availability as information passes from one to the other. Once this protocol is established a direct channel between SPOTR and SeaVision will allow the track data to be ingested directly into the COP.

2. Transition to Future Capabilities

This CONOPS is meant to allow for future growth and expansion providing capabilities beyond data display and correlation if desired. With the proper tools in place, it could be leveraged for social network analysis along with big data analytics and dynamic logic to go beyond the who, what, where and when, but start to answer the why and how. Most COPs in existence today fail to provide information beyond answering the questions of who and where (Arciszewski & De Greef, 2011). Recent advances in big data analytics could provide new ways to further exploit the information this COP provides. With high-level data abstractions and advanced fusion techniques, detection of VOI operating patterns may be detected. With a big data approach, the sources of the unclassified COP could be ingested into a distributed file system to derive big data solutions that recognize such patterns. Analysis of these patterns and social networks can provide suggestions on how monitored vessels match planned or predicted movements or actions. These patterns of life could aid in the determination of activity and intent which would be a breakthrough in data exploitation.

In the case of MDA, information including unit capabilities, status information, known movements between ports and various interactions can be projected as a data set to provide the commander information. The data sets could include unclassified information on vessels, such as port or registry, crew, builder and/or owner that is reported and verifiable, which can be used to build a multimodal network of commonalities to analyze. This information and analysis system will likely create an intelligence solution that will no longer fall into the unclassified domain, and is therefore, not a focus of this thesis, but is an interesting possible extension of the CONOPS presented.

D. CONCLUSION

New and evolving maritime threats and concerns require new and creative ways to conduct MDA. The CONOPS presented in this thesis is a simple yet powerful tool that creates a collaborative platform for all concerned entities to share information. It combines cooperative vessel tracking systems already in place with processed data derived from high-resolution commercial satellite imagery to provide data on vessel movements all over the world. Initial testing demonstrated that together these systems can provide a wealth of information in a fraction of the time and cost required by the cumbersome methods used currently. Further development will be required to move the CONOPS from theory to reality, but the capabilities to make the transition exist. Additionally, beyond the new and expanding COTS technologies suggested, the CONOPS provides an avenue for future growth because of its inherent flexibility, scalability and extensibility. Changes in the input sources to SeaVision, a service-orientated application, rarely affect the user. As long as the changes present the user with added benefits and remain easy to use, adoptability and acceptability will not be a concern.

As with any new information platform utilized by the operators and analysts, especially one which provides valuable information on the movements of national and foreign assets, there will be some pushback. This will arise from concerns as to the level of information the system provides and who has access to it. This CONOPS provides a means to gather and share public information via a platform that is unclassified from source to display. As long as the information presented in this platform remains of common interest to all users, such as securing borders and the freedom of movement, classification concerns should be minimal. It simply provides a single comprehensive capability that could allow the flow of useful unclassified information between agencies and allies to enable an effective MDA environment beneficial to all.

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APPENDIX A. THE COMPLETE LIST OF COLLECTED IMAGES

Imagery Catalogue					
Location – SCS AOI	Year	Month/ Day	Total Images	Tile Count	SPOTR Detects
Scarborough Shoal	2013	OCT 5		12	0
	2014	SEP 10		10	0
	2014	NOV 11		7	1
	2014	APR 19		16	2
	2015	JAN 29		11	11
	2015	JUN 15		15	1
	2015	NOV 18		8	2
	2016	MAY 18		13	11
	2016	AUG 24		13	6
Total			9	105	34
Johnson South Reef	2014	JAN 22		3	4
	2014	AUG 7		2	2
	2014	OCT 4		31	28
	2014	NOV 5		2	1
	2015	FEB 2		2	3
	2015	MAR 23		2	3
	2015	MAY 27		2	2
	2016	FEB 9		2	3
	2016	JUL 3		2	0
Total			9	48	46
Mischief Reef	2015	FEB 1		10	9
	2015	MAR 16		8	34
	2015	JUN 10		12	95
	2016	MAR 16		13	42
	2016	MAY 01		22	25
	2016	JUL 22		17	49
	2016	JUL 24		4	28
Total			7	86	282
Subi Reef	2014	MAY 12		1	0
	2016	MAY 1		20	60
	2016	JUL 24		4	46
Total			3	25	106

Imagery Catalogue					
Location - SCS AOI	Year	Month/ Day	Total Images	Tile Count	SPOTR Detects
Cuareton Reef	2014	FEB 21		10	1
	2014	MAR 08		1	0
	2014	AUG 29		19	10
	2014	SEP 24		1	3
	2014	NOV 22		10	0
	2015	APR 13		1	1
	2015	MAY 13		10	4
	2016	JUN 16		10	0
	2016	JUL 29		19	0
Total			**9**	**81**	**19**
Fiery Cross Reef	2014	FEB 21		10	27
	2014	AUG 29		19	3
	2014	NOV 23		13	11
	2015	JAN 07		7	19
	2015	FEB 14		13	25
	2015	MAR 05		10	25
	2015	JUL 13		10	20
	2015	AUG 12		5	29
	2015	APR		7	0
	2016	MAY 01		27	27
Total			**10**	**121**	**186**
Gaven Reef	2014	APR 08		37	4
	2014	AUG 25		16	5
	2014	NOV 11		7	6
	2015	JAN 04		8	1
	2015	MAR 17		2	3
	2015	MAY 27		2	11
	2015	DEC 28		34	4
	2016	JUL 24		7	1
Total			**8**	**113**	**35**

Imagery Catalogue					
Location - SCS AOI	Year	Month/ Day	Total Images	Tile Count	SPOTR Detects
Hughes Reef	2012	SEP 06		7	13
	2014	FEB 21		10	5
	2014	MAR 17		26	6
	2014	APR 16		7	11
	2014	SEP 12		9	17
	2014	OCT 04		2	5
	2014	NOV 19		7	14
	2015	APR 13		7	16
	2015	AUG 16			12
	2016	MAR 12		25	4
Total	2016	JUL 24		10	7
Duncan Island			**11**	**110**	**110**
	2012	JAN 28		31	8
	2014	APR 02		10	7
	2014	SEP 04		7	6
	2015	MAR 02		46	15
	2015	AUG 04		10	12
Total	2015	OCT 19		10	21
Woody Island			**6**	**114**	**69**
	2012	DEC 14		52	15
	2014	SEP 09		16	15
	2014	FEB 07		10	8
	2015	JAN 05		13	13
	2015	APR 05		13	10
	2015	DEC 15		13	19
	2016	APR 25		26	18
	2015	JUL 29		19	18
Total			**8**	**162**	**116**
GRAND TOTAL (SCS)			80	965	1003

Imagery Catalogue					
Location – Shipyards/Ports	Year	Month/ Day	Total Images	Tile Count	SPOTR Detects
Longpo (18 12 N 109 41 E)	2013	OCT		7	163
	2014	APR		27	116
	2014	MAY		7	29
	2014	NOV		7	131
	2015	JUN 28		12	53
	2015	NOV 25		24	60
	2016	APR 7		27	494
Total			**7**	**111**	**1046**
YangPu	2012	MAY		46	411
	2014	APR		10	503
	2014	NOV		10	686
	2015	OCT 7		10	527
	2016	JUL 23		46	358
Total			**5**	**122**	**2485**
Behai (21˚29'N 109˚06'E)	2013	DEC 9		4	504
Total			**1**	**4**	**504**
Haikou (20˚02'N 110˚06'E)	2014	JUN 16		7	30
Total			**1**	**7**	**30**
Hong Kong	2015	NOV 15		7	857
Total			**1**	**7**	**857**
NgongShuenChau	2013	AUG 28		13	1372
	2015	OCT 29		19	631
	2016	AUG 9		7	881
Total			**3**	**39**	**2884**
Sanya Naval Yard	2016	JUN 14		16	328
Total			**1**	**16**	**328**
Yulin (18 20 26 N 109 69 43 I	2014	MAY		19	353
	2014	AUG		19	596
	2015	MAY		16	490
	2015	OCT		10	532
	2016	FEB		7	468
	2016	JUN 6		19	294
Total			**6**	**90**	**2733**
TOTAL SHIPYARDS/PORTS			25	396	10867
TOTAL SCS			80	965	1003
GRAND TOTAL			105	1361	11870

APPENDIX B. DIGITALGLOBE NEXTVIEW LICENSE

This appendix text has been directly quoted in its entirely from DigitalGlobe (2005).

NEXTVIEW IMAGERY END USER LICENSE AGREEMENT

1. Introduction

This End User License Agreement ("EULA") is between DigitalGlobe, Inc., a Delaware Corporation ("DigitalGlobe" or "Seller") and National Geospatial-Intelligence Agency ("NGA"), the purchaser of this EULA, which governs the use of the data products or documentation ("Products") accompanying this EULA in accordance with Contract NMA 301–03-3-0001 (the "Contract").

2. Applicability

This license applies to imagery and products licensed under the Contract, including data downlinked to domestic and foreign ground stations.

3. License Granted and Permitted Uses

a. General Terms

(1) This clause applies to all unprocessed sensor data and requirements-compliant processed imagery, imagery services, imagery-derived products and imagery support data licensed under this Contract. No other clauses related to intellectual property or data rights of any sort shall have any effect related to the unprocessed sensor data and requirements-compliant processed imagery, imagery services, imagery-derived products and imagery support data delivered under this Contract.

(2) All license rights for use of the unprocessed sensor data and requirements-compliant processed imagery, imagery services, imagery-derived products and imagery support data provided to the U.S. Government purchased under this NGA contract are in perpetuity.

(3) Licensed users may generate an unlimited number of hardcopies and softcopies of the unprocessed sensor data and requirements-compliant processed imagery, imagery services, imagery-derived products and imagery support data for their use.

(4) (i) Licensed users may generate any derived product from the licensed unprocessed sensor data; and requirements-compliant processed imagery, imagery services, imagery-derived products and imagery support data.

(ii) Unprocessed sensor data and requirements-compliant processed imagery, imagery services, imagery-derived products and imagery support data licensed under this NGA contract have no restrictions on use and distribution, but shall contain the copyright markings.

b. Licensed Users

(1) The imagery may be used by the U.S. Government (including, all branches, departments, agencies, and offices).

(2) The U.S. Government may provide the imagery to the following organizations:

- State Governments
- Local Governments
- Foreign Governments and inter-governmental organizations
- NGO's and other non-profit organizations

(3) In consideration for the flexibility afforded to the U.S. Government by allowing unprocessed sensor data and requirements-compliant processed imagery, imagery services, imagery-derived products and imagery support data to be shared, the United States Government shall use its reasonable best efforts to minimize the effects on commercial sales. Acquisition and dissemination of imagery and imagery products collected within the United States shall be restricted in accordance with law and regulation.

DigitalGlobe, Inc.

NextView EULA_5749 Rev 1.0

08/10/05

LIST OF REFERENCES

Arciszewski, H. F. & De Greef, T. E. (2011). A smarter common operational picture: The application of abstraction hierarchies to naval command and control. Presented at the 16th International Command and Control Research and Technology Symposium, Quebec City, 2011. The Hague, The Netherlands: TNO Defense. Retrieved from https://www.researchgate.net/publication/235039633

Balduzzi, M., Pasta, A., & Wilhoit, K. (2014, December). A security evaluation of AIS automated identification system. In *Proceedings of the 30th Annual Computer Security Applications Conference*, 436–445.

Bannister, N. P., & Neyland, D. L. (2015). Maritime domain awareness with commercially accessible electro-optical sensors in space. *International Journal of Remote Sensing*, *36*(1), 211–243. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/01431161.2014.990647#.V00Dw5ErLIU

Baylis, P., Kroll, G., & Madon, T. (2016). Micro-satellite data: Measuring impact from space. Retrieved from https://www.poverty-action.org/sites/default/files/publications/Goldilocks-Deep-Dive-Micro-satellite-Data-Measuring-Impact-from-Space_4.pdf

Board, N. S. (2006). Command and control systems. In *C4ISR for future naval strike groups* (chapter 4). Washington, DC: National Academies Press. Retrieved from https://www.nap.edu/read/11605/chapter/6

Board, N. S. (2008). Information sharing, a key enabler. In *Maritime security partnerships* (chapter 3). Washington, DC: National Academies Press. Retrieved From https://www.nap.edu/read/12029/chapter/5

Boraz, S. C. (2009). Maritime domain awareness: Myths and realities. *Naval War College Review*, *62*(3), 137.

Bush, G. W. (2005). National strategy for maritime security: National plan to achieve maritime domain awareness. Retrieved from https://www.ise.gov/sites/default/files/0509%20National%20Strategy%20for%20Maritime%20Security.pdf

Chen, Y. (2013). Will satellite-based AIS supersede LRIT? Marine navigation and safety of sea transportation: Advances in marine navigation. *TransNav*, *8*(2), 91–94. Retrieved from http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-a59b74fb-50a0-4e95-9044-ac4bd505d2d9

Chinese naval bases. (n.d.). Retrieved February 21, 2017, from http://www.globalsecurity.org/military/world/china/ports.htm

Cronin, C. (2016). Southeast Asia from Scott Circle: The overlooked gap in the Southeast Asia Maritime Initiative. *Center for Strategic & International Studies Newsletter*, *VII*(9). Retrieved from https://www.csis.org/analysis/southeast-asia-scott-circle-overlooked-gap-southeast-asia-maritime-security-initiative#TheWeekAhead

Department of Defense. (2015). Asia-pacific maritime security strategy. Retrieved from https://www.defense.gov/Portals/1/Documents/pubs/NDAA%20A-P_Maritime_SecuritY_Strategy-08142015-1300-FINALFORMAT.PDF

Department of the Navy. (2007). Foreign disclosure manual. Retrieved from https://doni.daps.dla.mil/SECNAV%20Manuals1/Foreign%20Disclosure%20Manual%20CH%201.pdf

DigitalGlobe (2005). Nextview imagery end user license agreement. Retrieved from https://evwhs.digitalglobe.com/myDigitalGlobe/Console.html#3/0.09/-0.09

DigitalGlobe. (2014, June 11). U.S. department of commerce relaxes resolution restrictions digitalglobe extends lead in image quality [Press Release]. Retrieved from http://investor.digitalglobe.com/phoenix.zhtml?c=70788&p=irol-newsArticle&ID=1939027

DigitalGlobe. (n.d.a.). EV-WHS Desktop user manual. Retrieved on March 15, 2017 from https://evwhs.digitalglobe.com

DigitalGlobe. (n.d.b.). DigtialGlobe Frequently asked questions. Retrieved on January 19, 2017 on from https://evwhs.digitalglobe.com

Faltemier, T., Steinhaeuser, K., Miller, D., & Paradis, L. (2016, June 20). Computer vision for maritime domain awareness [PowerPoint]. Manassas, VA: Progeny Systems Corporation.

Grimes, J. (2009). *Department of defense information sharing implementation plan*. Washington, DC: Office of the Assistant Secretary of Defense for Networks and Information integration. Retrieved from dodcio.defense.gove/Portals/0/Documents/ISE/dod%20ISIP%20-%20APR%202009_approved.pdf

Hong, N. (2012). *UNCLOS and ocean dispute settlement: Law and politics in the South China Sea.* New York, NY: Routledge.

Hutchins, S. G., Gallup, S. P., MacKinnon, D., Schacher, G., Miller, S., Freeman, J., & Poeltler, B. (2008). *Enhancing maritime domain awareness*. Monterey, CA: Naval Postgraduate School. Retrieved from http://calhoun.nps.edu/bitstream/handle/10945/37457/123.pdf?sequence=1&isAllowed=y

International Maritime Organization (IMO). (n.d.). AIS transponders. Retrieved September 28, 2016, from http://www.imo.org/en/OurWork/Safety/Navigation/Pages/AIS.aspx

Jackson, V., Rapp-Hooper, M., Scharre, P., Krejsa, H., & Chism, J. (2016, March 22). Networked transparency: Constructing a common operational picture of the South China Sea. Center for a New American Study. Retrieved from https://www.cnas.org/publications/reports/networked-transparency-constructing-a-common-operational-picture-of-the-south-china-sea

Jones, C. (2007). Intelligence reform: The logic of information sharing. *Intelligence and National Security*, *22*(3), 384–401. Retrieved from https://gvpt.umd.edu/sites/gvpt.umd.edu/files/pubs/Jones_IntellReform.pdf

Kaplan, R. D. (2014). *Asia's cauldron: The South China Sea and the end of a stable pacific.* New York, NY: Random House.

Klein, N. (2011). *Maritime security and the law of the sea*. Oxford: Oxford University Press.

Krizhevsky, A., Sutskever, I, & Hinton, G. (2012). ImageNet classification with deep convolutional neural networks. Retrieved from https://www.nvidia.cn/content/tesla/pdf/machine-learning/imagenet-classification-with- deep-convolutional-nn.pdf

Leavitt, H. J., Dill, W. R., & Eyring, H. B. (1973). *The organizational world*. New York, NY: Harcourt Brace Jovanovich.

Mahan, A. T. 1. (1918). *The influence of sea power upon history, 1660–1783* (13th ed.). Boston, MA: Little, Brown, and Company.

Maresca, T. (2015). Obama boosts Philippine Navy, sends China a message not to expand presence. *USA Today*. Retrieved from http://www.usatoday.com/story/news/world/2015/11/17/obama-boosts-philippine-navy-sends-china-message-not-expand-presence/75935378/

Marina, S. (2013). CSII: The eyes and ears of the Caribbean. Retrieved from https://dialogo-americas.com/en/articles/csii-eyes-and-ears-caribbean

McLean, K. (2013). Capacity building for maritime domain awareness in east Africa [PowerPoint]. Retrieved from https://ec.europa.eu/jrc/sites/jrcsh/files/US_Naval_Forces_presentation.pdf

Morgan, J. & Wimmer, B. (2005). Enhancing awareness in the maritime domain. *CHIPS Magazine* April-June 2005. Retrieved from http://www.doncio.navy.mil/CHIPS/ArticleDetails.aspx?ID=3218

MR Popovich and Company. (2010). Operational and tactical command and control systems. [PowerPoint]. Retrieved from http://www.slideserve.com/xylia/topic-11-operational-and-tactical-command-and-control-systems-enabling-objectives

Mugridge, D. (2012). Securing oceans from space. *Geospatial World*. Retrieved from http://www.geospatialworld.net/article/technology-securing-oceans-from-space/

National Oceanic and Atmospheric Administration. (n.d.). Vessel monitoring system. Retrieved on November 6, 2016 from http://www.nmfs.noaa.gov/ole/about/our_programs/vessel_monitoring.html

Naval Postgraduate School. (2013). Common operating picture (COP) products [Power Point]. Retrieved from http://faculty.nps.edu/scrunyon/DHS/Monterey_Earthquake_Project_Playbooks/NPS-DHS_Playbook_RSC-09_Common_Operating_Picture(COP)_Products.pdf

Obama, B. (2012). *National strategy for information sharing and safeguarding*. Washington, DC, The White House. Retrieved from https://nsi.ncirc.gov/documents/NSISS_2012_White_House.pdf

Ochs, A. (2015). *Use of commercial imagery capabilities in support of maritime domain awareness.* Monterey, CA: Naval Postgraduate School. Retrieved from http://calhoun.nps.edu/bitstream/handle/10945/45917/15Jun_Ochs_Adam.pdf?sequence= 1

The Office of the Director, Operational Test & Evaluation, (2011). *DOT&E FY2011 annual report*. Washington, DC: Office of the Secretary of Defense. Retrieved from http://www.dote.osd.mil/pub/reports/fy2011/pdf/navy/2011gccs-m.pdf

Parameswaran, P. (2016). America's new maritime security initiative for Southeast Asia. *The diplomat*. Retrieved from http://thediplomat.com/2016/04/americas-new-maritime-security-initiative-for-southeast-asia/

Parker, W. (2012). Discover the basics of radar imaging. *Earth Imaging Journal*. Retrieved from http://eijournal.com/print/articles/discover-the-benefits-of-radar-imaging

Pearlson, K. E. and Saunders, C. S. (2013). *Managing and using information systems: A strategic approach*. New York, NY: Wiley.

Roach, J. A. (2015). China's shifting sands in the Spratlys. *American Society of International Law 19*(15). Retrieved from https://www.asil.org/insights/volume/19/issue/15/chinas-shifting-sands-spratlys

Seavision. (n.d.a). FAQ webpage. Retrieved January 17, 2017, from http://seavision.mda.gov/faq

SeaVision (n.d.b). What is seavision. Retrieved September 10th, 2016, from http://seavision.mda.gov/about-seavision

Signalis. (2015, February). STYRIS CSS [Brochure]. Bezons Cedex, France. Retrieved from http://www.signalis.com/fileadmin/STYRIS/CSS/STYRIS_CSS_ Brochure_V1.3_Preview_Spreads.pdf

Steinhaeuser, K. (2016). SPOTR operational view [Power Point Slides]. Manassas, VA: Progeny Systems Corporation.

Sutin, A., Bunin, B., Sedunov, A., Sedunov, N., Fillinger, L., Tsionskiy, M., & Bruno, M. (2010, November). Stevens passive acoustic system for underwater surveillance. IEEE. Retrieved from http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber= 5730286

Tauri Group. (2016). State of the satellite industry report. Satellite Industry Association. https://space.taurigroup.com/reports/SIA_SSIR_2016.pdf

Thomas, G. (2013). Space-based AIS: The game changer. *Canadian Naval Review, 9*(1). Retrieved from http://www.navalreview.ca/wp-content/uploads/public/ vol9num1/vol9num1art6.pdf

Till, G. (2016). *The changing dynamics of seapower and concepts of battle*. In International Order at Sea (chapter 8). London: Palgrave Macmillan. Retrieved from http://link.springer.com/chapter/10.1057/978-1-137-58663-6_8#page-1

Tweed-Kent, S. (2014, September 02). Improving maritime security through common standards [Web Log Post] Retrieved from https://www.ise.gov/blog/sean-tweed-kent/improving-maritime-security-through-common-standards

U.S. Department of Transportation. (n.d.). Seavision information sheet, version 5.0. Retrieved on 17 February 2017 from http://ec2-107-22-98-244.compute-1.amazonaws.com/sites/default/files/2016-03/SeaVision_v5.06%20(glossy)_0.pdf

U.S. Joint Chiefs of Staff. (2010). *Department of defense dictionary of military and associated terms*. Joint Publication (1–02). Washington, DC: U.S. Joint Chiefs of Staff.

U.S. Joint Chiefs of Staff. (2015). *Unclassified shared situational awareness (USSA) concept of operations (CONOPS)*. Washington, DC: U.S. Joint Chiefs of Staff. Retrieved from https://community.apan.org/support/m/info/152432/download

Volpe Center. (n.d.) Maritime safety and security information system (MSSIS). Retrieved on 17 February 2017 from https://www.volpe.dot.gov/infrastructure-systems-and-technology/situational-awareness-and-logistics/maritime-safety-and

Walker, T., (2013). Maritime security in West Africa. *African Security Review. 22*(2): 85–91. Retrieved from https://issafrica.s3.amazonaws.com/ site/uploads/PolBrief79.pdf

White House. (2012). *National strategy for global supply chain security (NSGSCS)*. Executive Summary. Washington, DC: The White House. Retrieved from https://obamawhitehouse.archives.gov/sites/default/files/national_strategy_for_global_supply_chain_security.pdf

White House. (2013, December). *National maritime domain awareness plan for the national strategy for maritime security*. Washington, DC: The White House. Retrieved from https://obamawhitehouse.archives.gov/sites/default/files/docs/national_maritime_domain_awareness_plan.pdf

White House, Office of the Press Secretary. (2015). *Fact sheet: U.S. building maritime capacity in Southeast Asia* [Press release]. Washington, DC: The White House. Retrieved from https://obamawhitehouse.archives.gov/the-press-office/2015/11/17/fact-sheet-us-building-maritime-capacity-southeast-asia

Wilson, B., Porche, I. R., Eisman, M., Nixon, M., Tierney, S. Yurchak, J. M. … Critelli, S. (2016). *Maritime tactical command and control analysis of alternatives*. Retrieved from http://www.rand.org/pubs/research_reports/RR1383.html

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