

The Center for Secure and Resilient Maritime Commerce

Sensor and Technology Applications in Port Security 2011 Summer Research Institute

Submitted to CSR Summer Research Institute

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ABSTRACT

The 2011 Summer Research Institute (SRI) at Stevens Institute of Technology studied how to improve Marine Domain Awareness (MDA) using sensor technology to detect, track, and classify vessels transiting waterways. The specific team studying this was the Sensors and Technology Applications in Port Security (STAPS) team. Near shore technologies were able to detect, track, and classify vessels using acoustic sensors, image processing, and electro-optics. Long range technologies such as high-frequency RADAR and satellites were able to detect and track large vessels. The limitations of each technology were also examined. Finally, an information system and user interface was created to aid in identifying vessel traffic abnormalities. The user interface overlays information to assess vessels all at once. The information system classifies targets using vessel behavior, AIS, and exclusion zones. After eight weeks, sensor and decision systems have been created that increase surveillance to improve port security.

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1.0 INTRODUCTION

Securing the nation's expansive Marine Transportation System (MTS) is a complex task. The MTS consists of over 25,000 miles of navigable waterways, including more than 238 locks in 192 locations, and over 2,700 marine terminals. Moreover, add in the 17 million registered recreational vessels and the United States (US) maritime domain becomes the epitome of a target-rich environment for those with malice intentions (Maritime Administration, 2011). The MTS also plays a vital role in the economic welfare of the US. The value of goods being carried by US vessels alone each year is more than one trillion dollars and creates over 13 million domestic jobs. The maritime domain facilitates approximately 25% of domestic and 90% of international trade. Securing the MTS ensures the continued function of the US economy, which affects every facet of society. With so much at stake, protecting this resource must be a high priority.

The US Department of Homeland Security (DHS) has a layered network of organizations overseeing port and maritime security. Among these organizations is the United States Coast Guard (USCG). One of the primary USCG functions is maritime law enforcement and waterway security. Their mission is to protect both the safety and security of all those who transit US waters. In order to effectively pursue this mission, the USCG and their partners need to be aware of what is happening on the waterways. Since September 11, 2001 and the bombing of the USS Cole in Yemen, Maritime Domain Awareness (MDA) is often defined as comprehensive knowledge of anything that could have an effect on maritime domain safety, security, economy, or environment. In order to effectively collect such information, sensor technology must be strategically implemented and managed. Sensor systems must include redundancy, and must be built on the principal of a layered defense system. The premise is that no single detection method or technology is ideal for all situations. Therefore, each individual system's strengths are maximized while the same system's weaknesses are covered by a complementing system. Such a system allows for the highest possible coverage across all conditions including high traffic areas such as New York Harbor, a significant component of the MTS.

New York Harbor offers a distinct challenge for optimizing MDA. Specifically, this region operates multiple container, vehicle, and petroleum terminals as well as refineries. Additionally, many of these terminals are near Newark Liberty International Airport, as well as substantial road and rail arteries. Due to this high concentration of critical infrastructure, the two miles between Port Newark and Newark Airport along the New Jersey Turnpike is often called the most dangerous two miles in the US. With that kind of reputation, the challenge of ensuring a secure maritime domain becomes far more difficult.



In response to the challenge of protecting such systems, DHS added another resource to oversee port and maritime security by utilizing academia. One of these resources is the Center for Secure and Resilient Maritime Commerce (CSR), a DHS Center of Excellence operated at the Stevens Institute of Technology's (SIT) campus located in Hoboken, New Jersey. CSR conducts research on technologies to improve MDA and infrastructure resilience by bringing together researchers from a wide array of backgrounds. The objective of such a program is to generate a unique product that is not limited by traditional stovepipes. They also run student programs that bring together additional resources and educate the next generation of Homeland security operatives. One of these programs is the Summer Research Institute (SRI).

Through its operation, the 2011 SRI brought 21 young professionals together from across the nation. Ten of these professionals, known as the 'Sensor and Technology Applications in Port Security Team,' were chosen to enhance MDA by pursuing technological developments in the areas of near shore technologies, long range technologies, image processing, and decision support. Over the eight week timeframe, the spectrum of technologies studied included cameras monitoring the visual and infrared bands of the electromagnetic spectrum, high-definition digital video recording devices, passive acoustic sensors, automatic identification systems, high-frequency radio detection and ranging (RADAR) systems, microwave RADAR systems, and satellite imagery. Subsequent sections detail the research that was conducted in support of technology development to enhance MDA throughout the maritime domain.

2.0 TEAM BACKGROUND

With the primary research objective laid out, a Summer Research Institute selection panel was convened to fill the ten positions available on the Sensor and Technology Applications in Port Security (STAPS) team. The team was composed of two student team leaders guiding three sub-teams: Near Shore Technologies, Long Range Technologies, and Decision Support. Chosen because of previous work experience and academic accomplishments, the team leaders selected were Ms. Danielle Holden and Mr. Brandon Gorton, both of whom were pursuing a Master of Science in Maritime Systems with a Graduate Certificate in Maritime Security at Stevens Institute of Technology (SIT). Ms. Holden also holds a Bachelor of Science in Marine Sciences from Rutgers University and Mr. Gorton possesses a Bachelor of Science in Engineering Management Technology from Western Michigan University.

Forming the Near Shore Technologies sub-team were two graduate students and one undergraduate student. The first was Kay Gemba, a Ph.D. candidate studying underwater acoustics at the University of Hawaii at



Manoa. Furthermore, Mr. Gemba completed a M.S. in Chemical Engineering, a B.S. in Aerospace Engineering, and a B.S. in Applied Math. Mr. Tyler Hee Wai, also from the University of Hawaii at Manoa, was the next member of the Near Shore Technologies sub-team. Mr. Hee Wai was working towards a M.S. in Mechanical Engineering with focus on acoustics and also holds a B.S. in Biomedical Engineering. The third and final member of the sub-team was Ms. Fatima Diop, an undergraduate student from Jackson State University who was completing a B.S. in Civil Engineering and a B.S. in Mathematics. The technologies most relevant to the Near Shore Technologies sub-team's specific research included acoustics, microwave Radio Navigations and Ranging (RADAR), and electro-optics.

The Long Range Technologies sub-team was equally impressive, consisting of three undergraduate students. Mr. Hasan Shahid was pursuing of B.Engr. in Electrical Engineering from SIT. The remaining two members were from the University of Puerto Rico at Mayaguez. Mr. Hector Pacheco was a student completing a B.S. in Electrical Engineering and Mr. Enrique Questell was working towards a B.S. in Civil Engineering. This team's primary technologies of interest included automatic identification systems, high-frequency RADAR, and satellite imagery.

Serving as a vital link between these two technologically based teams was the Decision Support sub-team. This duo consisted of two talented undergraduates from the University of Miami. Mr. Dan Reynolds, who was completing a Bachelor of Science in Industrial Engineering and Mr. Samuel Otu-Amoah, who was pursuing a Bachelor of Science in Aerospace Engineering. The Decision Support sub-team was responsible for aiding final users with vessel classification and threat assessment, as well as integration of sensor outputs into a single graphical user interface.

Though these individuals were assigned to specific sub-teams, all were involved in each of the three primary research areas. Consequently, all of the individual skill sets were able to be applied to each of STAPS sub-teams resulting in far greater analytical and problem solving capabilities. Benefits of this type of management style were numerous as communication between all members of STAPS was impeccable.

3.0 METHODOLOGY

This section of the report outlines the methods and processes used by each sub-team in conducting their research.



3.1 Near Shore Technologies Methodology

The Near Shore technologies consist of acoustics, electro-optics, Automatic Identification Systems (AIS) and the New York Harbor Observing and Prediction System (NYHOPS). These technologies are used jointly to detect, classify and track vessels. The data gathered from the combined technologies provides enough information to evaluate each technology's strengths and weaknesses. To clarify, there are three different AIS systems used by STAPS: United States Coast Guard (USCG) AIS, SIT's Transas AIS, and an AIS feed from Rutgers University. The Near Shore team used USCG and Transas AIS, while the Long Range team used Rutgers' AIS. As seen in Figure 1, the Near Shore Technology architecture consists of multiple sensors that were combined into a single interface.



Figure 1: Near Shore Technology Architecture

3.1.1 Passive Acoustics

Underwater tracking is achieved using Stevens Passive Acoustic Detection System (SPADES), which was deployed in the Hudson River off the Stevens Institute of Technology's (SIT) campus on June 10, 2011. SPADES allows for detection, tracking, and classification of surface and underwater vessels. It consists of four hydrophones that collect acoustic signals, which are then recorded and processed. The real-time data is then transmitted digitally to the land-based visualization center located in SIT's Maritime Security Laboratory (MSL). The acoustic signals are displayed through a proprietary graphical user interface (GUI) called New



Buoy, which serves as a tool for analysis. The SPADES system allows three types of analysis: spectral, cross-correlation and vessel signature.

Spectral: The signal waveform received from each hydrophone is processed and displayed in a spectrogram. Spectrograms relate time and frequency such that each signal over time has a characteristic in the frequency domain.

Cross Correlation: This display monitors acoustic signals and estimates multiple targets' bearings. The signal source and bearing are estimated by cross correlating the acoustic signal received from a pair of hydrophones.

Vessel Signature: Underwater noise generated by vessels can be used to determine vessel signature. In particular, the rotation of the propeller shaft and number of propellers has a large effect on the sound generated by vessels (Kudryavtsev et. al. 2003). This sound is characterized as amplitude modulated, high-frequency noise. The high frequency noise generated is very broadband and thus less useful for classification purposes than the low frequency amplitude modulation. To better understand amplitude modulation, Detection of Envelope Modulation on Noise, or DEMON, was utilized. To obtain the DEMON spectra of a signal, the raw acoustic data, recorded at 200 kHz, was sub-sampled to one kilo-Hertz by finding the root mean square average of 200 data points. The result was then plotted as a new data point. The fast Fourier transform of the resulting one kilo-Hertz signal is the DEMON spectra (Chung et. al. 2010).

3.1.2 Electro-Optics

High-resolution visible light and infrared (IR) cameras are used to monitor surface traffic and further confirm the presence of a target. The MSL operates a set of four visible light cameras are used to detect, locate, and establish the speed and bearing of any vessel. The IR camera is used in combination with optical cameras because of its ability to see in conditions where there is little visible light. IR cameras produce thermal images; the presence or absence of light does not change the appearance of the image (Richards 2001). Temperature, emissivity, and reflectivity are important factors that enable clear detection and tracking of a vessel when using an IR camera.

Google Earth and AIS allow us to see the vessels position and the AIS identification number in real time. External sources, such as MarineTraffic.com, provide information such as the name, size, type, or flag of the vessel of interest. Additionally, environmental parameters such as salinity, water temperature, and wind speed are recorded using NYHOPS in order to assess their effects on the technologies.



3.2 Long Range Technologies Methodology

The long-range system is comprised of three technologies: satellite, HF RADAR, and AIS. Figure 2 shows how these systems relate to each other. All data or imagery from these technologies was over-laid onto Google Earth, which became a crucial interface. By seeing all the data in one interface, individuals were able to demonstrate the efficiency of the long-range system.



Figure 2: Long Range Technology Architecture

The long-range team coordinated with Dr. Scott Glenn, Dr. Hugh Roarty, and Mike Smith from Rutgers University in New Brunswick, NJ to have access to their AIS system and their 13.45 MHz HF RADAR in Sea Bright, NJ (SEAB). Rutgers' SEAB system surveys the New York Harbor and Hudson River, as well as right outside of the harbor's entrance, with a three-kilometer resolution and 70-kilometer range. AIS also covers the mouth of the harbor, thus the systems overlap. Overlapping these systems is successful only when SEAB has detected a vessel, which depends on the power returning to the receiving antenna (Barrick et al. 1972):

$$P_r = \frac{P_t G_t A_r \sigma F^4}{\left(4\pi\right)^2 R_t^2 R_r^2}$$

where:

 $P_{\rm t}$ = transmitter power

 $G_{\rm t}$ = gain of the transmitting antenna

 $A_{\rm r}$ = effective aperture (area) of the receiving antenna

 σ = radar cross section, or scattering coefficient, of the target

F = pattern propagation factor

 $R_{\rm t}$ = distance from the transmitter to the target

 $R_{\rm r}$ = distance from the target to the receiver

The average amount of power retrieved by the receiving antenna was used to determine the optimal height for



which vessels can be detected. Given that SEAB has about a 13 MHz radio frequency, the theoretical optimal vessel height would be six meters (19 ft) from the surface of the water (Barrick et. al. 1972). Since HF RADAR can only detect large vessels with high freeboard, using both HF RADAR and AIS facilitates tracking vessels entering and exiting the harbor.

Students primarily focused on HF RADAR, then using AIS to validate their results. They accessed information from SEAB using four resources: Timbuktu, a SEAB website, a ship detection GUI and Google Earth. Timbuktu is a computer program that remotely controls other computers, and when given SEAB's IP address students were able to extract cross spectra (CSQ) and range cell (RC) information every four minutes, which would help in identifying the range, direction, radial velocity, and intensity of signals. CSQ and RC are displayed in Figure 10. However, students used the SEAB website more often, which was just as effective in retrieving CSQ, RC, and radial information. The vessel detection GUI, seen in Figure 11, incorporates CSQ and RC by mapping the range, radial velocity and bearing of signals over a set time interval (either one, two, or three hours). A summary of each resource's capabilities can be seen in Table 1 shown below. Google Earth was vital in integrating and overlaying both HF RADAR and AIS information; AIS was only seen using Google Earth. Once students had access to these tools, they were trained to read, analyze, and integrate HF RADAR and AIS data.

Table 1: HF RADAR	resource capabilities
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HF Radar	Bearing	Radial Velocity	Intensity	Range	Direction
SEAB website		Х	X	Х	Х
Timbuktu		Х	X	Х	
GUI	X	Х	X	Х	Х

Students applied their knowledge of HF RADAR and AIS by participating in a surprise simulation, executed on July 11, 2011, comprising of a dirty bomb releasing chemicals into the Hudson River. The team's mission was to continue monitoring the Hudson and surrounding areas in case there was more suspicious activity. AIS and HF RADAR data was received subsequent to the simulation. What the Long Range sub-team did not realize at the time was that there are two types of AIS signals. Class A AIS tracks only large commercial vessels. Class B AIS is available to any vessel that wants to buy and install the transmitter, and thus covers smaller commercial and recreational vessels. AIS was only identifying Class A vessels on the day of the event, and overlooking the Class B vessels, which is why the long range system was unable to pick up the "Suspicious Vessel." Additionally, the live feed of HF RADAR data was unavailable to students at the time of the exercise. Regardless, students still analyzed the effectiveness of HF RADAR in detecting smaller



vessels shortly thereafter.

A picture was taken over the range of HF RADAR to provide validation and AIS information via COSMO-SkyMed satellite on July 19, 2011 at 6:13 am. Satellite coverage and imagery was organized by the Center for Southeastern Tropical Advanced Remote Sensing at University of Miami. HF RADAR data, AIS data, and satellite imagery for 6:13 am was then compared and analyzed. COSMO-SkyMed is a Synthetic Aperture Radar (SAR) satellite operated by the Italian Space Agency. SAR satellites are used to provide higher resolution images than an optical satellite would generate. To produce an image of such high resolution, an optical satellite would require an antenna that could be up to several kilometers in length. However, SAR satellites use their own flight paths to simulate the length of antenna needed. The term synthetic aperture refers to the distance flown by the satellite taking the image. As the satellite passes its target, it sends a beam at multiple points along its flight path and integrates the received signals into a single image. Another advantage of SAR satellites over optical satellites is the ability to 'see' through clouds by using lower frequency signals. Because emitted signals are angled instead of parallel to the ground, SAR images of tall targets, such as mountains or buildings, tend to be slightly distorted. Effects include foreshortening, compression of horizontal distances; layover, the appearance of a structure leaning toward the satellite; and shadowing, caused by the emitted beam not reaching the target area (Graber 2011).

3.3 Image Processing Methodology

Digital image processing can be used to compare images in search for a vessel by utilizing the IR video feed, which is a sequence of JPEG images. An IR image measures the amount of thermal radiation that an object reflects. If an object has high reflectivity, it also has low emissivity and vice versa. Emissivity is the ability of an object to give off energy by radiation. Reflectivity is the measure of energy that is not absorbed by an object. In an image, light colors are normally presented for high emissivity objects, such as the paint on most metals. Dark colors are presented for high reflectivity objects, such as water and gold.

Applying this concept to MDA, a simple process can be done to detect vessels. The basic process is to subtract a picture from a normalized background image, and look for a difference in the area of interest. The background image is an average of different images without any vessels for a specific period of time. The motive for this background image is to reduce the error when the subtraction takes place.

To accomplish the image-processing tasks, a MATLAB program was used because of its simplicity for working with arrays and other techniques of interest. For example, a digital image is interpreted as an array of



two or three dimensions. In this case, the arrays are two dimensions and the elements represent the intensity of that pixel in the image.



Figure 3: Flowchart of Image Processing

In Figure 3, the method for processing the image is shown. The purpose of the image database is to obtain the background image by linearly averaging the images in the database. Then, an image of interest is taken and subtracted from the background image for comparison; this is a subtraction of the intensities of the images resulting in a new image with a lower range of intensities. A threshold had to be applied to generate a good comparison. This threshold varies depending on the emissivity of each vessel and the time of the day the IR image was taken.

3.4 Decision Support Methodology

The Decision Support Sub Team's objective was to take all the incoming data from the various sources, and make it into a usable system to fill user needs. Fundamentally, an operational system must provide the user with two things: a comprehensive operational picture, and the background information necessary to make sound decisions based on the data from the sensors. To address this, the sub team divided its focus across two separate fields: Data Fusion and User Resources. For data fusion, a GUI was developed to display data from all sensors using overlays onto a common operational display, thus giving the user a comprehensive overview of any situation. The team also created user resources to provide the end user with the information and decision support tools needed to readily interpret and act on the incoming data. This included information to assist in classification, tracking, and threat identification for any targets detected by the sensors.

3.4.1 Data Fusion

The GUI developed to combine the sensor data was named the Bay and Oceanographic Observation and Management System (BOOM) which can be seen in Appendix A. Coding for BOOM was done using



National Instruments' LabVIEW programming platform. This platform was chosen because it utilizes a flowchart approach to programming. That makes for a more intuitive conceptualization of the desired final result. It also reduces the time required to move from the point of initial conception to the stage of having a working prototype. This was very critical as only three weeks were given to complete the GUI.

In order to fuse the data from the various sensors into one system, the sensors had to be converted into a common format that was easy to implement and allowed for an intuitive and user-friendly display of the sensor information. To satisfy these requirements, Google Earth was chosen as the display tool. A Google Earth window was embedded into a LabVIEW panel and multiple functions were created so that the user could control what objects were displayed in the window. Data from the sensors were converted into the .kml file format utilized by Google Earth so that they could then be overlaid as layers onto a map. In addition to the Google Earth overlays, live optical camera feeds were also embedded into the LabVIEW panel.

3.4.2 User Resources

The first step to providing a system that fills the needs of an end user is to find out what those needs are. To do this, the Decision Support Team met with industry experts and members of the USCG to get input on the kind of resources that would provide them the maximum benefit. They expressed the need for a system that addressed the issue of vessels that do not transmit AIS. The USCG has operational procedures for evaluating vessels with AIS, but none that take into account the smaller commercial and recreational vessels that transit the New York Harbor on a daily basis. The first step in addressing that problem was to create a classification scheme. There are two options for the user in the case of a new target. First, they could get a positive identification on the vessel. A positive identification means defining the specific characteristics of that exact vessel by name, which is available via AIS. The second option is to classify the target, which means that the operator is able to gather enough information about the vessel to place it in a category, but not enough for a full identification. Here again, the Decision Support Team worked with the USCG to create a classification scheme that was compatible with their traditions and operational models; the classification scheme created became the core of a database called the Decision Support Database (DSD). The DSD was supplemented by decision support charts and procedure lists that were aimed to guide the user's decision-making. By using the SPADES and RADAR systems that were available to STAPS, they were able to track many vessels without AIS in real-time. The next step was to classify targets into general categories in the absence of an exact identification. To aid in that effort, the Tracking/Detection Parameters table, part of the DSD, was created. This table lists the classes of vessels, along with their defining characteristics in each sensor. When complete,



this table will allow the user to quickly check what they are seeing on the display against a database of possible likely vessel signatures.

Finally, the Decision Support Team began to address the issue of threat identification. The limited information available from sensor data makes it impossible to identify most threats, but there are certain patterns of operation which would be cause for concern. To help users identify this pattern, the DSD created the Areas of Operation table, which roughly outlines, through a series of yes or no questions, the expected operational area of each vessel class.

4.0 DISCUSSION AND ANALYSIS

This section of the report presents and examines the research that was conducted detailing near shore technologies, long range technologies, image processing, as well as decision support.

4.1 Near Shore Technologies Discussion

The acoustic signature of a vessel can be used to detect, track and identify it. To understand the capabilities of SPADES, the first step is to quantify the detection distances of the array, subject to weather conditions and high vessel traffic. About three weeks of detection work resulted in approximately135 vessels cataloged. The types of vessels detected and tracked range from jet skis and small pleasure crafts to full size tankers, though yachts and jet skies under full speed were never detected.

The array performed well for tracking small personal pleasure crafts under mechanical power, tankers, ferries, tug boats, cruise ships and fire boats, but detection and tracking of multiple vessels was difficult at times. For example, it was impossible to detect any vessel 'hiding' behind another vessel; vessels needed to be separate by several vessel lengths in order to have a distinct second harmonic. Furthermore, some of these vessels were simply overpowered by the noise of others.

4.1.1 Vessel Tracking Using a Cross Correlation Diagram

Data analysis revealed that detection distances were limited by ferry terminals; one to the north (2.5 km) and another to the south (770 m). During ferry dockings, these vessels put an enormous amount of acoustic energy in the water which sometimes overpowers the whole detection range. Also, the sheer quantity of ferries in operations, as many as six at a time, caused signal loss to any other vessel traveling by the array. The maximum observed detection distance was approximately 2.5 km. However, most vessels were detected or lost at a shorter distance, subject to interferences from other vessels and other noise sources. From the



north, a vessel was usually detected at about 1,200 meters and to the south at about 650 meters. Figure 4 shows one possible tracking scenario with incoming ferry noise.



Figure 4: SPADES tracking 3 vessels (1-3), Ferry noise from the north (4)

Generally speaking, it is impossible to make any prediction in terms of accuracy for these records since there is no complementary layer to compare the acoustic results to. Though AIS gives us distance and velocity information of a target, there is a certain unknown time and data processing lag associated with that information. Therefore, detection distances noted above should be considered as observations made by the Near Shore team.

Another component of classification is frequency identification. Each vessel has a distinct amplitude modulation from the engine and propellers, which can be detected through DEMON analysis. Therefore, similar types of vessels were expected to have similar acoustical peaks. This is shown in Table 2 where vessels were broadly categorized. Large vessels tended to have similar characteristics because larger vessels have larger engines that turn slowly, thus they have low frequency peaks. Conversely, small pleasure crafts were much more varied because smaller vessels have smaller and faster turning engines, causing higher frequency peaks. In Table 2, different types of vessels can be classified based on the value of the fundamental frequency and the presence of harmonics and non-harmonic peaks. With a well-populated database, this table could be a method of classifying a vessel solely through its acoustical characteristics.



	Fundamental				
	Frequency	1st	2nd	3rd	
Vessel type	range	Harmonic	Harmonic	Harmonic	Other frequency
Small cruise	5-6	10-12	15-18	n/a	n/a
Ferry	11-14	22-28	33-42	44-56	n/a
Tanker	4-6	8-12	n/a	n/a	n/a
Tugboat	14-20	28-40	n/a	n/a	n/a
RV Savitsky	47-54	95-109	143-163	n/a	n/a
Small pleasure					
vessel	88-97	n/a	n/a	n/a	154-172
34 foot Zurn	81	n/a	n/a	n/a	61, 141, 222
Jet Ski	26	53	79	105	n/a

Table 2: Classification of vessels by fundamental frequency

Note: Jet Ski and Zurn have the highest intensities in the highest frequencies present. Due to the high variance of the signatures of small pleasure craft, we present a variety of individual types.

Though this analysis is broadly useful, there is some overlap between the frequency characteristics of some vessels. Specifically, this database represents vessels at cruising speed. As previously discussed, the acoustical characteristics of a vessel depend on various factors, particularly engine speed. Therefore, these characteristics will not be stable as a vessel changes speed. Changes of greater than 10 percent in the position of the peak frequency generated by one vessel have been observed, which increases the difficulty inherent in using an acoustic signature to identify a vessel. Subsequently, the manner in which the peak frequencies changed relative to one another was investigated because the spectra of the vessel shifted due to a change in the engine speed. Three methods were then considered about classifying acoustic signatures in a more sophisticated manner such as examining the intensity in the prominent frequency peaks and time delays between intensity peaks in different frequency bands.

4.1.2 DEMON Analysis: Method One

In Figure 5, a representative DEMON spectrogram of a vessel, whose signature changes over time, is shown. Nine other tracks were found to show a comparable change in DEMON spectra. Next, the instantaneous DEMON spectra were examined as the peaks shifted according to vessel speed. In Appendix B, it was demonstrated that as the spectra changes, the position of the frequency peaks changes proportionally even when the peaks are not harmonics. From this data, the ratio between frequency peaks was calculated. The results were then compared to the frequency peaks of the DEMON spectra to account for the change in spectra from a change in engine speed.





Figure 5: DemodSpectrum of Vessel Varying Speed

The Stevens maritime asset, RV Savitsky, is a converted 40-foot Novi fishing vessel. Over the course of the Summer Research Institute, five clean signatures of the RV Savitsky were collected. A typical DEMON spectrogram for this vessel is shown in Figure 6. This representative DEMON spectrogram shows a strong fundamental frequency peak near 50 Hz as well as weaker harmonics at around 100 and 150 Hz.



Figure 6: DemodSpectrum of RV Savitsky

Also, the power in a one Hz bandwidth about the primary signal was considered to account for the fact that the fundamental frequency was not perfectly stable. Using the wider bandwidth and considering the ratio between the intensity in each of these frequency peaks, there was further characterization of the signature. The consistency between signals in the Savitsky over five runs is demonstrated in Table 3. The ratio of the 100 Hz signal and 50 Hz signals that was averaged over a one-minute period ranged between .34 and .43 over our five signatures. The third harmonic appearing at approximately 150 Hz had intensity between 15 and 20 percent of that in the fundamental frequency.



			~~ ••				
Savitsky 1	Peak	49.8 Hz		99.1 Hz		148.9 Hz	
	Relative Intensity		1		0.342		0.151
Savitsky 2	Peak	54.7 Hz		109.4 Hz		163.1 Hz	
	Relative Intensity		1		0.406		0.16
Savitsky 3	Peak	47.9 Hz		95.2 Hz		143.1 Hz	
	Relative Intensity		1		0.418		0.207
Savitsky 4	Peak	50.3 Hz		100.6 Hz		150.9 Hz	
	Relative Intensity		1		0.366		0.204
Savitsky 5	Peak	49.8 Hz		100.1 Hz		149.9 Hz	
	Relative Intensity		1		0.433		0.218

Table 3: Relative Intensity and Peak Intensity of the RV Savitsky Signal

4.1.3 DEMON Analysis: Method Two

The intensity changes in the different peaks over time were then calculated. Figure 7 shows the ratio between the intensities of the 50 and 100 Hz signals. This data was then analyzed using autocorrelation, cross-correlation, and Fourier analysis to look for consistent patterns and features in the way the signal changes over time. However, no repeated pattern has been found. A larger data set, particularly in the form of more records of the same ship, and further analysis is needed to see if this approach provides a more sophisticated and accurate method of identifying ships.



Figure 7: Ratio between Intensities 50Hz and 100Hz



4.1.4 DEMON Analysis: Method Three

Finally, the local maxima in the plot of the intensity in each frequency peak were examined. This was done to test the theory that there may be a time lag between intensity peaks in the fundamental and harmonic frequencies. In Figure 8, the time delay of the maxima in the 100 Hz signal from the corresponding maxima in the 50 Hz signal is shown. There are no consistent patterns in the delay between the signals. A larger data set would be needed to further investigate the usefulness of this as a method of classification.



Figure 8: Time Delay of Maxima

4.1.5 Applying Electro-Optics to Maritime Domain Awareness

Providing an additional layer of detection capabilities to the Near Shore sub-team, the field of electro-optics (E/O) consisted of cameras monitoring the visible and infrared (IR) bands of the electromagnetic spectrum. With data being collected during the day time as well as night time, it was important to maintain awareness of all traffic transiting the harbor in varying environmental conditions. For example, in times of low visible light, the IR camera was effective at detecting vessels characterized by high emissivity and low reflectivity. Conversely, the visible light camera was effective in detecting vessels of high reflectivity and low emissivity.



When paired together, the two types of E/O technology established a real-time, reliable method of near shore detection.

4.2 Long Range Technologies Discussion

The overarching objective of the Long Range Technologies sub-team was to utilize HF RADAR, AIS, and satellite imaging to detect, classify, and track vessels approaching the urban port environment and to determine the strengths and limitations of each technology. Data was collected using cross spectra (CSQ) and range cell created directly by the Coastal Ocean Dynamics Applications RADAR (CODAR) system and a Ship Detection Graphical User Interface (GUI) generated by MATLAB. Then, data analysis was performed by comparing the data collected from each resource. Specifically, AIS was used to track vessels off the coast of central New Jersey and near the entrance of the New York Harbor. Also, satellite images were interpreted to identify vessels by cross referencing with data from HF RADAR and AIS. This technique established a level of reliability for each technology; overlaying HF RADAR and AIS data as well as satellite images onto Google Earth was also highly beneficial.

4.2.1 Simulation Results

Detection and tracking of vessels was successful using HF RADAR. However, this method only detected large vessels and could not identify smaller vessels due to the large wavelength of the signal emitted by the antenna. In Figure 9, AIS data of the RV Savitsky from the simulation was used to plot a path on the Ship Detection GUI showing where 'peppers,' or signals would appear if HF RADAR detected the vessel. As shown, HF RADAR detected the Savitsky for a short time around 14:45 GMT but it could not track the research vessel elsewhere.





Figure 9: HF RADAR data on Ship Detection GUI (14:30:00 GMT to 17:30:00 GMT on 7/11/2011, with AIS data of the Savitsky overlay)

4.2.2 July 19th Exercise Results

As seen in Figure 10, the maximum detection range of Sea Bright (SEAB) is 287 kilometers bi-statically with two other HF RADAR sites; but about 70 kilometers by itself. The Ship Detection GUI only plotted signals within a detection range of 60 kilometers, shown in Figure 11. Most vessels detected by SEAB were relatively close to the antenna, usually within the range of the GUI, proving the GUI to be a more effective tool to track vessels than the CSQ. While SEAB was very effective in detection and tracking of vessels, classification of vessels was impossible with data provided by SEAB alone. In Figures 10 and 11, two vessels detected by SEAB around 10:13 GMT are circled in red. By cross-referencing data collected from SEAB with AIS data, as shown in Figure 12, the vessels were identified as tugboats named Joan Morgan (MMSI# 368669000) and Miss Gill (MMSI# 367122680).





Figure 10: Cross-spectra and Range Cell of CODAR data (10:10:59 GMT on 7/19/2011)

Detection of vessels in satellite images proved to be possible. Larger vessels were easily discernible, while smaller vessels were identified either by their wakes or by cross-referencing the images with data from other technologies. Images were taken of the lower Hudson River, the entrance of the New York Harbor, and the area just off the coast of Monmouth County, New Jersey. The two vessels detected in Figures 10 through 12, Joan Morgan and Miss Gill, were also identified on a satellite image of the area and are circled in red (see Appendix D and Appendix E).





Figure 11: CODAR data on Ship Detection GUI (10:20:00 GMT to 11:10:00 GMT on 7/19/2011)



Figure 12: AIS and CODAR data overlaid onto Google Earth (10:13:45 GMT on 7/19/2011)

Satellite imaging could prove to be an effective method of early detection if the images are received shortly after they are taken. Although these pictures can be accessed within minutes, the images used were received long afterwards, usually the next day. Additionally, since HF RADAR and AIS only detected large vessels, satellite imaging would only be useful to detect and track large vessels approaching an urban port environment.



4.3 Image Processing Discussion

This utility was applied to demonstrate usefulness of image-processing as a detection tool. In the first example, a sailboat is shown on the top right side of the river, shown in Figure 19.



Figure 13: Image of interest for example one target

A threshold was applied to the result of the subtraction of this picture from the background image to highlight the sailboat. The threshold, in this case, works as a logical expression. If the intensity of a pixel from the resulting picture surpasses the threshold, a one (1) as in true will appear in the resulted picture and paint that pixel white. Meanwhile, if the intensity of a pixel from the resulted image is below the threshold, a zero (0) as in false will appear in the resulted image and paint that pixel black. Since most of the pixels from the background image and the image of interest are similar, what will mostly stand out is the sailboat as shown in Figure 14.



Figure 14: Resulted image after subtraction and applying threshold



Since the area of interest is the Hudson River, the image may be cropped to only show this area and accomplish the identification of the vessel in a more efficient manner, as shown in Figure 15.



Figure 15: Cropped image, which only shows the Hudson River area

By doing this same process with several other images of interest at different times, it can be noticed that the threshold becomes less efficient because of the environmental changes throughout time. This causes greater changes in the intensities between the background image and the images of interest leaving a greater amount of noise in the resulting image. A solution to this problem could be to include more images from different times throughout the day in the database and take them into consideration for the background image.

4.4 Decision Support Discussion

The decision support team began the process of making a useful product out of the sensor inputs. This led to several interesting steps, including a working data fusion GUI and a raft of decision making tools, all based on the input of the potential users.

4.4.1 Data Fusion

The Bay and Ocean Observation Management (BOOM) System is a user-centered display that improves how sensors are operated and how data is displayed. This interface condenses all sensor information into one display and allows the user to see one or multiple sensor information at a time (see Appendix A). Appendix B lays out which technologies will be most useful given certain environmental conditions. Since all information is integrated into one interface, it is easier for a vessel of interest to be tracked using the various sensors such as AIS, RADAR, high-definition cameras, and SPADES. Therefore, without shifting attention from one screen to the next, one operator is able to monitor multiple sensors. In the event of an incident, the user is capable of getting a complete and comprehensive view of the situation. In addition to having the ability to track vessels, the user will be able to obtain information such as sea surface temperature, the direction of the currents, and the coverage zones of the various sensors which are overlaid onto a Google



Earth display. With the development of BOOM, the first steps have been taken towards the realistic goal of implementing such a system in a real-life setting.

4.4.2 User Resources

The main user resources developed by the Decision Support Team are contained in the Decision Support Database (DSD). The first tool, called the Identification/Tracking Parameters Table (Appendix G), lists the sensor characteristics of each vessel. Since there is limited information about the sensor characteristics of vessels, the most maritime sensing research is being completed in this sector. Consequently, it also poses the biggest problem to making a fully operational system out of the sensor network that STAPS was working with. For example, small tankers that were seen running up and down the Hudson had a consistent frequency spike between four and five hertz. With this database, the user can go to the detection table, look up four hertz, and know what class of vessel tends to emit sound around that frequency.

STAPS then applied their ability to detect and identify vessels to increasing security in a place like the Hudson River. Once an operator has identified a vessel, either specifically using AIS or using the the Identification/Tracking Parameters Table, the next step is to find out that vessel's information to see if it is operating as expected, and whether it should be tracked or ignored. For vessels with AIS, the Decision Support team provides a list of likely reference sites to look up the vessel's information; some sites used are Marine Traffic.com, Equasis.org, and websites of classification agencies like Lloyds Registry and the American Bureau of Shipping (ABS).¹ In the case where the operator has no identification (ID) and only a classification, the Classification Table in the DSD will provide basic information on each class of vessel, such as its overall length, beam, draft, and number of passengers.

Additionally, the Area of Operations Table (Appendix G) provides users with a quick set of checks to see if the vessel is generally operating as expected. For instance, say an approaching vessel is classified as a medium container ship. When looking at the Area of Operations Table, the user can select that classification, and then scan across to check what operating characteristics are expected from that vessel. In the case of a medium container ship, it is not required to stay out of exclusion zones, but its deep draft means that out of channel operation is *not* expected. The areas that medium container ships are likely to be found is around, or on the way to, container terminals. With this check list, the operator can determine that given the information he or she has, a container ship inbound under the Bayonne Bridge is normal and can mostly be ignored. By

¹ Lloyds Regestery: <u>http://www.lrshipsinclass.lrfairplay.com/</u> (note: Login Needed) American Bureau of Shipping: <u>www.eagle.org</u>



comparison, a container ship steaming up the Hudson in front of SIT would be quite suspicious and worthy of tracking. Generally, the user would follow a flow chart, in essence a guide to how to find a target on the console, apply the user-resources, and determine if the USCG should be contacted.

Such a system is not without weaknesses. In a situation presented by the simulation, all the hostiles would have to do is make sure they hijacked a vessel that would normally be passing close to their intended target. As more data is taken and synthesized to help define operational patterns, and as that data gets incorporated into later versions of the database, more of the basic threat ID can become automated. Likewise, as new and different sensor technologies develop, they may allow a more in-depth analysis of vessels', crews, and behaviors. This enhancement will improve the ability to identify threats earlier. However, tracking and threat detection are not the only valuable uses for a sensors technology system.

4.4.3 Simulation Exercise

For a full in depth report on the drill and its outcomes, reference the report contained in Appendix F. One thing this drill made very apparent was the need for accurate and timely data for the other team of Summer Research Institute students: the Consequence Assessment and Management (CAM) team. This is the other area where STAPS sensor network becomes invaluable. Without information about the physical environment, decision makers cannot run the dispersion and plume needed to determine evacuation plans and contact first responders. The Decision Support team began linking STAPS and CAM through pre-determined contact schemes and data packages. That way, in the event of an incident, STAPS would be able to provide CAM with as much information as possible so that CAM could provide information to decision makers. In addition, the resources already developed for assessing vessels become useful. For instance, CAM needed information on the capacity of the hostile vessel in order to estimate the size of a release plume. The other information that was useful to CAM is any optical data, both still frame and video. Optical data collected during any event helps them better estimate the size of the event. Finally, in the event of a true emergency, STAPS would be able to track the actual movements of a plume or liquid spill, providing CAM the ability to check the accuracy of their model and adjust the inputs to make more accurate predictions.

5.0 CONCLUSIONS

For the research areas of near shore technology, long range technology, image processing, and decision support, summarizations of the research are contained below.



5.1 Near Shore Technologies Conclusions

The near shore technologies have great potential for improving Maritime Domain Awareness (MDA) and subsequently port security. SPADES was successful at detecting vessels about 1,200 meters from the north and 650 meters from the south. The location of the system dictates its detection range; in this case detection distances were limited by the nearby ferry terminal. The cross correlation diagram is an excellent tool for vessel tracking and bearing estimation. The efficiency of the cross correlation analysis depends on the ratio of signal to noise. Furthermore, the electro-optic and microwave RADAR technologies complemented the acoustic system by providing a means to approximately confirm targets.

DEMON confirmed its ability to classify vessels based on their acoustical signatures. Based on the database developed over the course of the program, it became clear that similar classes of vessels have similar acoustical peaks. In an effort to categorize vessels and distinguish one vessel from another within the same class, three methods were implemented: (1) study of the intensity in the prominent frequency peaks and time delays in different frequency bands; (2) study the instantaneous DEMON spectra; and (3) study of the local maxima in the plot of the intensity of each frequency peak. However, these three methods were ineffective at providing defined characteristics, particularly in noisy environments.

5.2 Long Range Technology Conclusion

Each of the individual long-range technologies cannot detect, track, or identify vessels independently because of their limitations. For example, satellites can detect vessels with small enough resolution, but can only track vessels if pictures are taken continuously. They are also poorly suited for vessel identification. HF RADAR can detect and track a vessel in real time if the vessel is large enough, but it does not have resolution precise enough to detect small vessels, as was seen during the exercise conducted on July 19th. It also cannot identify vessels. On the contrary, AIS can detect, track, and identify any vessel with an AIS transponder. However, if the vessel's AIS is not activated the technology is ineffective. Also, while HF radar is real time, AIS data has a time delay of twenty minutes, thus not effective in an emergency situation like the July 11th crisis simulation.

Collectively, however, the long-range system works effectively to detect and track vessels because each technology validates the other. For instance, if HF RADAR detects a signal from a specific location, either a satellite image or AIS can validate if HF RADAR is seeing a vessel and what type of vessel it is. Also, as seen in the July 19th exercise, if HF RADAR and satellite imagery detect a vessel that AIS did not, then the AIS is off. As stated previously, the long-range system can identify vessels only if AIS is activated.



5.3 Image Processing Conclusions

The infrared camera is an outstanding detection system and security awareness technology because of its capability to detect thermal radiation. This utility is still under development, mainly to increase efficiency of detecting vessels at different times of the day, but it has shown promising results for the samples that were taken into consideration. Another feature for the utility that is still under development is automation, or to repeatedly analyze incoming images from the video feed and flag the user if any detection occurs.

5.4 Decision Support Conclusions

The Decision Support team began creating a working product out of a scattered group of sensor technologies. As a result, several tools have been created that should greatly increase the operational function of the system. The BOOM GUI covers the existing technologies, but is also written in a flexible format with plenty of room for expansion. Likewise, the DSD has ample room to grow and expand as well. Consistent vessel identification and tracking are well within the realm of possibility for this system in the future. Even the capability to identify threats has been somewhat improved by the Decision Support Framework. These improvements and additions to the MSL system, if implemented and pushed forward, will help SIT and the CSR labs to continue to use research to develop a functional operations system.

6.0 RECOMMENDATIONS FOR FUTURE WORK

When conducting further research to enhance MDA, recommendations have been compiled for each of the primary research areas including near shore technologies, long range technologies, image processing, and decision support.

6.1 Near Shore Technologies Recommendations

A major problem with acoustic vessel classification in the Hudson River is that the presence of multiple vessels contaminates the signature. This additional noise means that current identification capabilities are at best approximate and based on heuristics. This leads to identifications with low confidence rates and makes it nearly impossible to automate. To overcome this limitation, an existing algorithm should be utilized that finds the DEMON spectra generated in each direction using cross-correlation. Unfortunately, this algorithm is very processor intensive and cannot be used by SIT's current hardware. If this method were to be used in real time, it would allow the operator to identify the acoustic signatures of multiple vessels at the same time, greatly increasing the effectiveness of acoustic classification as a method of vessel identification.



The coverage area of the electro-optic system is limited. Human watches equipped with binoculars remained the best method to detect vessels at long range. Changing the location of the cameras, increasing the number of cameras, as well as increasing their resolution and zoom capabilities will increase operator awareness. A direct benefit of improving this hardware will be an increase in the distance at which detection and tracking can take place.

SPADES is currently located on the west bank of the Hudson River. It would be beneficial to conduct a comparative study in order to find the best location for the acoustic system according to the noise level and detection range for each location. In the research conducted above, environmental parameters such salinity, water temperature, and wind speed were recorded in conjunction with the data received from the acoustic system. The question: to what extent does a variation in any of these parameters alter the effectiveness of the system? It is important to take into account these parameters to establish under which conditions SPADES should be used.

6.2 Long Range Technologies Recommendations

A few improvements can be made to improve detecting, tracking, and identifying vessels with long-range technologies in the Hudson River area. Primarily, AIS, as it was tied to the HF RADAR system, should be tailored to include all classes of vessels rather than just Class A. By including Class B, surveyors will have a better idea of who is transiting the Hudson River. This will increase security and surveillance while optimizing all AIS resources. Surveillance of the Hudson River area could also be improved by adding higher frequency RADARs in New York harbor. Given how Sea Bright HF RADAR is a 13MHz system, with a three kilometer resolution, larger vessels are easier to detect because they cover more area than a small vessel over time and contain more conductive material. Therefore, having higher frequency RADARs will detect smaller vessels because the resolution and range will be smaller. Additionally, triangulating multiple higher frequency RADARs will tell the exact direction the vessels are traveling, which is especially useful if AIS is not being received.

Despite the effectiveness of both technologies, limitations were encountered. The HF RADAR system stationed in Sea Bright, New Jersey frequently crashed resulting in gaps of about 30 minutes to an hour in the data. In addition, it was inefficient to rely on Google Earth to overlay AIS and HF RADAR data because the data received from HF RADAR and AIS via Google Earth was 20 minutes delayed, therefore not real time. Also with Google Earth, AIS information was received every hour even though it updated every five minutes.



Therefore, it is essential to improve KML (overlay) files, so that overlaying information can be more efficient. Specifically, overlay files should be more automated and real-time.

6.3 Image Processing Recommendations

The use of image processing can be further developed by creating a database of background images sorted by every significant change in the environment. This can also be examined as a new technique to replace the database, such as creating a background image from calculating the mean and variance from two images and adjust the offset to be the same. Eventually, there could also be a learning capability written into an automated system, where the processor adjusts to normal variations in the background condition. Creating a fully functional GUI, or including this software in an integrated GUI such as BOOM, would facilitate its usefulness in a surveillance system.

6.4 Decision Support Recommendations

From the Decision support standpoint, there are several short-term steps that will help the CSR toward a more functional system. The next step, which the Decision Support team began to attempt but was unable to complete, was to define the operational boundaries of each type of vessel. For example, if a target, which was identified as a container ship, were heading up a channel that did not lead to a container terminal, it would provide another logic-check for the user. This would essentially be an extension of the existing Decision Support Areas of Operations table in the database. Furthermore, it could easily be factored into a learning algorithm in the future that would automatically check those variables. Good artificial intelligence is only possible when quality information is used as inputs. Therefore, it is also very important to continue to refine the capabilities of the individual technologies to detect, track, and identify targets. Without the ability to classify a target, all abilities to predict its threat status become null and void.

Finally, the SRI can learn from its experience with the exercise on July 11th, and begin to try to close the loopholes identified in that drill. One lesson learned was that the MSL has no means of communicating with operators in the MTS. The report on the drill (Appendix F) suggests that a marine VHF radio should be installed in the MSL. This would allow for more effective communication with SIT vessels during experimental work and drills. Also, it would offer a direct link to the USCG and their Emergency Marine Broadcast system in the case of a real emergency. This system would be an inexpensive addition to the MSL and would provide a vast array of benefits.



Another lesson learned from the drill was that the information available from STAPS's sensor network was not just useful for tracking and detecting threats before an attack. In fact, it is also extremely valuable in response to an incident. In the case of an emergency within the maritime domain, the sensor network becomes the eyes and ears of the response effort, particularly for the Modeling branch of CAM. To facilitate this function of STAPS, the report suggests investigating the viability of adding chemical, biological, radiological, and nuclear sensors to the network to help give CAM accurate information about concentrations and types of contaminates as quickly as possible. All of the research technologies that the CSR is concerned with, including those which detect acts of terrorism in the MTS, are rapidly changing systems. In order to keep up, the CSR must strive to produce useable systems that adapt to continuously changing threats and user needs.

The most important thing for future researchers to remember is that the systems they are developing and refining are going to be brought into operational use. To this end, the fulltime work at CSR and the next generation of SRI students should work with the idea of the end user in mind. The Decision Support team has begun the process of packaging the influx of data from STAPS' sensor systems and providing tools to aid the end user in vessel identification. However, that is just the beginning of bringing these technologies to an operational standard. As the sensor systems themselves get refined and more capable, the user interface and user information tools should also be improved. With better identification algorithms developed for SPADES, a large portion of the basic decision support checklist could be automated, requiring less energy from the user to quantify the anomalies.

A long-term goal would be to have a system that masks all normal traffic, only triggering the user to investigate targets that in some way do not conform to normal patterns. To achieve this, some definition of normal needs to be quantified and processes developed to measure it. This process may then be automated by developing algorithms that would make the comparisons and notify the operator in the event that a deviation from normal behavior is observed. If an interface like this were combined with a properly installed, layered sensor network, it could provide a whole new level of MDA.

Another long term goal from the standpoint of the user interface is to move from a sensor-centric system that shows information based on what sensors it came from, to a target-centric system where the user sees the target and identification information. However, the specific sensor data would be available if requested. Such a system, with a complete network of sensors and a standard operating interface, will be more scalable and transferable than the current systems in use. Moreover, it could be deployed across a broad spectrum of



situations, not just in New York harbor, but in any port in the US or overseas. Most importantly, it could be put in the hands of local operators with minimal training.

7.0 ACKNOWLEDGEMENTS

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Appendix





Appendix A: Printscreen of Bay and Oceanographic Observation Management System (BOOM)



	Clear		Fog		High v	wind	Light	rain	Heavy	rain	Light - High y	rain + vind	Heavy High	rain - wind
											mgn	wind	Ingn	wind
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
AIS														
HF RADAR														
IR														
Microwave RADAR														
SPADES														
HD														

Appendix B: Technology Comparison Given Environmental Conditions



Good

Moderate

Bad



		1st Frequency (Hz)	2nd Frequency (Hz)	3rd Frequency (Hz)
	Initial peak	25	100	175
1	Final peak	18	78	137
	Ratio (Final/Initial)	0.76	0.78	0.78
	Initial peak	66	200	400
2	Final peak	56.5	170	340
	Ratio (Final/Initial)	0.86	0.85	0.85
				
	Initial peak	65	87	152
3	Final peak	70	94	165
	Ratio (Final/Initial)	0.93	0.93	0.92
				
	Initial peak	97	169	
4	Final peak	70	123	
	Ratio (Final/Initial)	0.72	0.73	
	Initial most	92.5	1465	
5		83.5	146.5	
5	Final peak	89	156	
	Katio (Final/Initial)	0.94	0.94	
	Initial neak	78.5	138	
6	Final neak	97	171 5	
Ŭ	Ratio (Final/Initial)	0.81	0.8	
L		0.01	0.0	
	Initial peak	98	172	
7	Final peak	82.5	144.5	
	Ratio (Final/Initial)	0.84	0.84	
-				
	Initial peak	92	<u>1</u> 61	
8	Final peak	81.5	143	
	Ratio (Final/Initial)	0.89	0.89	
	Initial peak	79.5	139	
9	Final peak	88	154	
	Ratio (Final/Initial)	0.9	0.9	

Appendix C: Ratios of change in frequency peaks during speed change





Appendix D: Satellite image taken by COSMO-SkyMed on 7/19/2011 at 10:13:06 GMT





Appendix E: Cropped and zoomed views of Appendix B



Appendix F: Crisis Simulation Report



The Center for Secure and Resilient Maritime Commerce

Summer Research Institute Team

CRISIS SIMULATION REPORT July 11th, 2011

July 2011





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INTRODUCTION & EXERCISE DESCRIPTION

The 2011 Summer Research Institute (SRI) at Stevens Institute of Technology (SIT) is comprised of a 21member group of undergraduate and graduate students assigned with the task of tackling critical issues in maritime security and emergency response. The group is divided into two teams:

- 1. Sensors and Technology Applications in Port Security (STAPS)
- 2. Consequence Assessment and Management (CAM)

For the purposes of this report, it should be noted that CAM is further divided into two sub-teams:

- 1. Impact on Supply Chain (ISC)
- 2. Modeling and Response (MR)

At 1605 (GMT-4) on the afternoon of July 11, 2011, without warning, the entire SRI team received a bulletin for the purposes of running a hypothetical, real-time exercise. The bulletin contained the following information:

Notification issued 7/11/11 at 1605 (GMT-4): At 1600, a boat detonated a bomb in the Hudson River, exploding itself and releasing an oil spill into the river. Nearby radiation sensors are indicating this may have been a dirty bomb, releasing a radioactive contaminant into the air. The event occurred on the west side of the river, between Hoboken and Manhattan. The Coast Guard (USCG) and NYC Office of Emergency Management (OEM) and Hoboken police (HPD) have begun evacuating a 500 meter radius around the site and are telling people inside buildings to shelter in place for the time being.

The release occurred at position 40.74007N, 74.02331W

With this information, the SRI team was tasked with helping to manage the disaster by performing several different functions, including promoting situational awareness through remote sensing and computer modeling of the aftermath. The SRI team also performed a real-time assessment of the short and long term



effects on regional supply chains. Ultimately, it is the goal of the SRI team to facilitate efficient and wellinformed decision making in the event of a real-life, catastrophic event. The following sections of this report outline the individual team responses to the exercise, including successes and failures, as well as recommendations for improvement.

INDIVIDUAL TEAM RESPONSE Sensors and Technology Applications in Port Security (STAPS):

On the afternoon of the exercise, STAPS was operating out of the Maritime Security Laboratory (MSL) at SIT. The team was busy monitoring vessel traffic on the Hudson River and collecting data from multiple sensor systems to advance research on vessel identification and classification. Vessels seen throughout the morning included, but were not limited to, tugs, barges, ferries, tankers, cruise vessels, and pleasure craft such as sailboats and fishing vessels. The following is a list of sensor technologies that were being implemented during the afternoon of the exercise:

- Stevens Passive Acoustic Detection System (SPADES)—based in the MSL
- High-Frequency (HF) Radar—based at Rutgers University
- Bridgemaster TM Microwave Radar System
- Synthetic Aperture Radar (SAR) and optical satellite imagery downloaded to the University of Miami's Center for Southeastern Tropical Advanced Remote Sensing (CSTARS)
- Automatic Identification Systems (AIS), including data from Marinetraffic.com, the U.S. Coast Guard, Rutgers University, and TRANSAS [™] (a marine surveillance system at implemented at SIT)
- Optical Closed-Circuit Television (CCTV) cameras
- Intermittent human watch detail on the MSL building (the Babbio Center at SIT)
- Real-time environmental sensors that provide salinity, water temperature, and wind velocity information

At approximately 1535, the human watch detail spotted a suspicious vessel. The vessel was actually SIT's research vessel, the R/V Savitsky, posing as a suspicious craft. It approached along the western bank of the Hudson River, unusually close to the shoreline. The vessel's movements were documented on video by the watchman, who subsequently reported the position of the suspicious craft via shortwave radio to the rest of



the STAPS team. The vessel showed no signs of distress or mechanical failure, and was therefore deemed to be a legitimate threat. Soon after being notified, the STAPS team operating the monitoring console in the MSL was able to confirm the incoming target on CCTV. The track of the vessel was detected using SPADES. SPADES was also used in an unsuccessful attempt to categorize the vessel. Due to the small size of the target, attempts to acquire its position using radar were unsuccessful as well. AIS signals from the target were not picked up during the exercise because of a settings error in the AIS receiver system. Environmental conditions were documented and the target was given an active file number for documentation. Though the signal-to-noise ratio of the acoustic data was too small to conduct identification or categorization, STAPS was still able to confirm and track the target as it entered what was designated a hypothetical "restricted area," where the attack eventually took place.

Based on the assumption that the sensor systems in place would not have been destroyed in the attack, STAPS continued to monitor vessel traffic in the harbor with all its technologies in order to maximize marine domain awareness in the area, and to provide as much warning as possible in the event of a follow-up attack. A line of communication was established with CAM, and information regarding the primary characteristics of the perpetrating vessel was relayed.

INDIVIDUAL TEAM RESPONSE

Consequence Assessment and Management (CAM) – Modeling & Response (MR):

Upon receiving notification of the explosion, the Modeling and Response division of CAM immediately began using the known data to visually depict the scene of the event. The only useful data in hand at this point were the location and time of the blast and the fact that a 500-meter evacuation radius had been implemented. The first step for the MR team was to generate the map seen in Figure 1 below. It shows a Google Earth image of the incident site with overlays showing the precise location of the explosion as well as the approximate 500-meter radius. The evacuation radius was shaped to account for features of the urban environment. This map was then shared with the ISC team. It was of some interest that the Hoboken police station and the Hoboken train station, while not within the 500-meter radius, are located just outside this area and would probably have to be evacuated shortly after such an event.

MR then began the critical process of modeling the spill and atmospheric plume despite the fact that they had very little information about the size of the blast or the contents of the vessel. SCIPUFF and GNOME are the software programs that were used to generate the plume and spill models, respectively. Wind and current information at the blast location was available at the time, but the lack of information regarding the vessel



itself made generating spill and plume models difficult. A line of communication was opened with STAPS in order to receive any new information which might be useful in this respect.

At approximately 1715, STAPS was contacted and provided the MR team with primary dimensions and cargo/fuel capacities of the vessel. The estimates provided were as follows: the vessel used in the attack had a 40-foot length, a 15-foot beam, a cargo capacity of 6,000 pounds, and a 150-gallon diesel fuel tank. In order to gain an understanding of worst-case scenarios, models were generated for a 6,000-pound plume and for a 6,000-pound oil spill with 150 gallons of diesel included. There were some problems experienced with running the software, including a system crash. In all it took over two hours to gather information and develop models, and these were only as reliable as the information that was received. Finally, all information was shared with the ISC team.



Figure 1. Map of the site of the attack, including the exact location of the explosion and 500-meter evacuation radius



Figure 2. Image of GNOME modeling of the oil spill caused by the explosion



Figure 2 above shows GNOME modeling of the oil spill with 6,000 pounds of crude oil and 150 gallons of diesel. The model was run for a 24-hour period. The figure shows the time at which the spill was projected to make first landfall, 45 minutes after the explosion. A similar model was run which shows the shape, size, and direction of travel of the radioactive plume through the atmosphere, also over a 24-hour period. The resulting plume can be seen in Figure 3 below.



Figure 3. Image of SCIPUFF modeling of the atmospheric plume at two different points in time after the attack

INDIVIDUAL TEAM RESPONSE

Consequence Assessment and Management (CAM) – Impact on Supply Chain (ISC):

The ISC sub-team began their response process by developing a diagram to visualize the immediate effects caused by the explosion. The analysis period corresponds to the first four hours after the incident. It considers the plume and spill forecasts developed by the MR sub-team and the effects of that outcome on regional supply chains. The focus of the report was on four related categories: Evacuation, mass transport, impact on communication networks, and impact on ports and airports.

Evacuating Hoboken would be a challenging process given the small number of routes out of the city. Ferry services would likely be suspended, while Port Authority Trans-Hudson (PATH) trains would become quickly overwhelmed with people. Depending on the direction of the resulting radiological plume, roads may be closed, leading to traffic jams for cars and buses. Communications failures may result as cellular networks



become inundated with traffic. Information released to the general public would have to be carefully controlled to prevent widespread panic.

POSSIBLE IMPROVEMENTS Sensors and Technology Applications in Port Security (STAPS):

Most improvements to the STAPS team need to be in the area of logistics. The network of technologies should be expanded to get as much information as possible about any and all maritime incidents on the Hudson River. The reliability of the system also needs to be improved. Usually, SRI would have access to HF radar, located in Sea Bright, NJ, to track vessels entering New York harbor. However, the HF radar was undergoing maintenance the day of the simulation. SRI students can also access images from optical and SAR satellites, though satellite passes must be scheduled in advanced through CSTARS in Miami. Not having reliable data from HF radar and satellites hindered the team's ability to detect and identify suspicious vessels. In order to fill gaps in capability, the STAPS team should look into adding a marine VHF radio base station to the MSL. This would allow for more effective communication during a drill and provide access to USCG emergency broadcasts. The addition of chemical, biological and radiation (CBR) sensors to the network would provide critical information to the CAM team.

Redundancy in the sensor network could improve data availability. Sensors could have been damaged if a real detonation occurred. Therefore, creating and implementing back-up sensor systems would improve resiliency and enhance local marine domain awareness. At Rutgers University, faculty and staff are able to access HF radar computers from various locations using a computer program that accesses and remotely controls other computers. In the event that one HF radar in Rutgers University's network fails, other radars compensate by expanding their ranges to ensure uninterrupted coverage. This level of redundancy and accessibility would greatly improve the functionality of the sensor network.

The simulation was conducted on a system of sensors that is still under development. Moreover, the system architecture is focused on research, not operational surveillance, limiting its performance in a drill capacity. For example, an operational MDA system would have multiple radars and hydrophone arrays installed, allowing it to triangulate exact positions of targets and provide uniform coverage. SPADES uses only one hydrophone array, limiting its effective range and accuracy. While SPADES can pick up the presence of vessels, it has an effective range of less than three kilometers and can only determine the target's bearing but not its range. It is also unable to differentiate the unique acoustic signatures of multiple targets



simultaneously. While HF radar is useful for tracking vessels that are entering the Hudson River, its large range (about 290 km) makes distinguishing smaller targets from noise quite problematic. Ideally, multiple sensors would be covering each area of interest, and the range of HF radar would be adjustable to suit any given situation.

STAPS needs to improve the information flow both internally and in its interaction with other organizations and teams. STAPS also needs to document an official procedure for response._ Immediately following the attack, all STAPS could do was wait for orders from OEM. STAPS was not provided with a pre-determined point of contact to the CAM team or the U.S. Coast Guard in case of an emergency. There was also no record of the information required by the CAM team in order to complete its modeling output. Contact between the two teams was not made until about 45 minutes into the simulation, implying that the CAM team either did not know who to contact or could not get a hold of anybody from the STAPS team. A proper operational plan for STAPS should include contact procedures for both the CAM team and the USCG. STAPS also needs to establish a standard data set to provide the CAM team with vital information. Finally STAPS' plan needs an established hierarchy of control, including a clear chain of command. These improvements will help the combined teams of the SRI to provide a more effective warning and response infrastructure in the event of an attack.

POSSIBLE IMPROVEMENTS

Consequence Assessment and Management (CAM) – Modeling & Response (MR):

Generally, the MR team was able to efficiently assess, gather, and analyze information. As mentioned previously, a map of the surrounding area and the 500-meter evacuation zone was generated within just a few minutes. Generating models of the spill and the plume, however, was a longer process, which could be streamlined with better information sharing and preparedness. Real-time oceanic and atmospheric data is readily available for the purposes of model-building. However, it was during this process that the MR team discovered some limitations. There was a lack of information about the exact nature of the vessel and its contents, which made generating an accurate model very difficult. Better communication between the two teams (CAM and STAPS) may have facilitated faster, more accurate modeling results. Information on the size of the vessel did not reach the CAM team until an hour and fifteen minutes after the explosion. Even then, the information provided about the vessel's characteristics was only enough to make very loose assumptions about the size of the bomb, the amount of oil spilled, and the type and quantity of radiological



material dispersed into the atmosphere. Due to the lack of sufficient information concerning the nature of the device, many generalized assumptions had to be made before even an initial model could be generated.

Information regarding radiation levels in the area of the attack would be very useful to facilitate the evacuation and clean-up process. During the exercise, the MR team had no way to access this type of data. This information would have to come from the STAPS team, which would attain it from radiation sensing systems in the region.

In future exercises, several sets of models should be generated rather than just one. MR outlined two worst case scenarios – plume and spill. In reality, the chances that these models would accurately represent what is actually unfolding in the field are very small. In a real scenario, several models should be sequentially generated and studied. Constant communication between MR and the STAPS team should be used to gain up-to-date information and determine which model most accurately represents the real event as it unfolds.

POSSIBLE IMPROVEMENTS

Consequence Assessment and Management (CAM) - Impact on Supply Chain (ISC):

In the immediate wake of the hypothetical event, there was a lack of information detailing any specifics of the attack. The Impact on Supply Chain division of CAM found it difficult to make assumptions based on the minimal data provided. Among these assumptions are: type of radioactive material released, size of blast radius, and actions taken by first responders. In addition, it was unclear what role the ISC team should play in the overall response effort. Such information is essential to assess both immediate and long term impacts. CAM should develop a protocol for responding to such a situation. In addition, analyzing the behavior of individuals in an emergency situation would help to predict the psychological effects of an event on the populace. The implementation of these improvements will help the combined teams of the SRI to provide a more accurate assessment of the short and long-term effects of an attack in the NY Harbor region.

RECOMBINING EFFORTS

It is clear in the wake of the exercise that there are several areas of the SRI methodology in which there are room for improvement. The two SRI teams (STAPS and CAM) must make a concerted effort to streamline intergroup communication, thereby hastening the sharing of information in the critical moments following an attack or natural disaster. While the individual research of each team has moved forward in a largely



independent manner thus far, this exercise has exposed that in order to effectively respond to a crisis, efficiency in the area of information channeling is vital to responding appropriately to an event such as the hypothetical dirty bomb attack of July 11th.

Atmospheric plume and ocean contaminant models are chaotic by nature; that is, they depend on assumptions regarding initial conditions that can greatly affect a highly sensitive output. Just one faulty assumption can easily render the output useless. If the MR team fails to generate a reliable model, then the ISC team's ability to make reliable predictions and decisions is greatly hindered. This, however, highlights a role easily filled by the STAPS team. Although the STAPS team's primary function is to detect threats and prevent an attack, the information it gathers during and after an attack can be equally valuable. By comparing models and simulations to what is really happening in the field, the STAPS/CAM team relationship would prove to be invaluable during an actual catastrophic event. The necessity for this unhampered exchange of information makes clear the fact that that the two teams, STAPS and CAM, should not be considered as two separate entities working independently. Rather, they should be treated as two critical pieces of an overall human resource structure which must be integrated effectively if it is to perform its desired function.

APPENDIX - EMERGENCY PROTOCOL INSTRUCTION SHEET

In the wake of the July 11th exercise, the biggest lessons learned were that critical breakdowns in communication occurred and that specific, step-by-step instructions should be outlined for both teams which provide guidance during a catastrophic event in the maritime domain. The following pages show an outline of this emergency response protocol, including a contact sheet with all pertinent.



SRI 2011 Protocol for Maritime-Based Port Threat Last revised: July 13, 2011

Sensor Technology and Applications in Port Security (STAPS) Team:

- A) Personnel on duty determine the situation is a threat scenario
- B) Contact Coast Guard and Consequence Assessment Team below and relay known information:

-US Coast Guard Sector NY Address: 212 COAST GUARD DR STATEN ISLAND, NY 10305 Phone: Primary Phone: 718-354-4037 Emergency Phone: 718-354-4353 Fax Number: 718-354-4009 VHF Radio: Channel 16 Rescue 21 VHF DSC MMSI Number: 003669929 Web/email: http://homeport.uscg.mil/newyork

-Consequence Assessment Team Leaders Chris (Kip) Francis---(201)- 213 4649 Lizbeth Concho------(201) 238 4940 - Sensor Team Leaders Danielle Holden-----(908)-319-6704 Brandon Gorton-----(269)-277-4005

- Fill out the Modeling response worksheet and send to the Consequence Assessment team as soon as possible
 Maintain Contact with Consequence Assessment team
- D) Assign following jobs to personnel:
 - Watchman- observes with binoculars and keep lookout over river and city
 - <u>Communicator</u>- works with exchanging data with USCG and Consequence Assessment team
 - Documenter- record all data with a computer
 - Acoustics Operator- responsible for detecting vessel signature and location
 - Radar Operator- responsible for AIS and HF radar vessel tracking
 - Camera Operator- responsible for documenting vessel/attack description
- E) Maintain awareness and readiness for the possibility of following attacks



Consequence Assessment and Management (CAM) Team

Modeling and Response and Impact on Supply Chain

A) Establish Communication with STAPS Team Establish Communication with Impact on Supply Chain Sub-Team

Consequence Assessment Team Leaders Chris (Kip) Francis---(201)- 213 4649 Lizbeth Concho------(201) 238 4940 Sensor Team Leaders Danielle Holden-----(908)-319-6704 Brandon Gorton-----(269)-277-4005

- B) Gather all know data from the most current report and the other teams
- C) Establish team leader and distribute jobs to teammates

Jobs:

Documenter- record all data with a computer Ocean Modeling- use GNOME to plot oil spill in water Atmospheric Modeling- use SCIPUFF to track atmospheric plume Explosion/Plume Modeling- use Hotspot to track explosion radius Communication - relay data back to the sensor team such as model data to see if it is reasonable Google Earth -find and plot terrorist attack location and evacuation radius - plot any incoming data (currents, tide, wind, etc)

- D) Run the models with data received from the sensor team from the Make sure all data is in units the model can use
 Make sure the data being placed in the model is consistent with live data from other locations
- E) Send model data out to sensor team for conformation of accuracy
- F) Contact decision makers and explain situation (see contact sheet below)



Contact Sheet

<u>New York Police Department (NYPD)</u>

Phone:

Emergency: 911 Terrorism Hot-Line: 1-888-NYC-SAFE

Manhattan

Police Precinct	Phone #	Address
1st Precinct	(212) 334-0611	16 Ericsson Place
5th Precinct	(212) 334-0711	19 Elizabeth Street
6th Precinct	(212) 741-4811	233 West 10 Street
7th Precinct	(212) 477-7311	19 1/2 Pitt Street
9th Precinct	(212) 477-7811	130 Avenue C
10th Precinct	(212) 741-8211	230 West 20th Street
13th Precinct	(212) 477-7411	230 East 21st Street
Midtown So. Pct.	(212) 239-9811	357 West 35th Street
17th Precinct	(212) 826-3211	167 East 51st Street
Midtown No. Pct.	(212) 767-8400	306 West 54th Street
19th Precinct	(212) 452-0600	153 East 67th Street
20th Precinct	(212) 580-6411	120 West 82nd Street
Central Park Pct.	(212) 570-4820	86th St & Transverse Road
23rd Precinct	(212) 860-6411	162 East 102nd Street
24th Precinct	(212) 678-1811	151 West 100th Street
25th Precinct	(212) 860-6511	120 East 119th Street
26th Precinct	(212) 678-1311	520 West 126th Street
28th Precinct	(212) 678-1611	2271-89 8th Avenue
30th Precinct	(212) 690-8811	451 West 151st Street
32nd Precinct	(212) 690-6311	250 West 135th Street
33rd Precinct	(212) 927-3200	2207 Amsterdam Avenue
34th Precinct	(212) 927-9711	4295 Broadway

U.S. Coast Guard (USCG) – Sector New York (01-37040)

Address:

212 COAST GUARD DR STATEN ISLAND, NY 10305 Phone: Primary Phone: 718-354-4037 Emergency Phone: 718-354-4353 Fax Number: 718-354-4009 VHF Radio: Channel 16 Rescue 21 VHF DSC MMSI Number:003669929 \ Web/email:



http://homeport.uscg.mil/newyork

U.S. Coast Guard (USCG) - Auxiliary

Address:

Flotilla 22 - Sandy Hook, NJ c/o US Coast Guard Station Sandy Hook 20 Crispin Rd Highlands, NJ 07732 Phone: (732) 872-3429 VHF Radio: Channel 16 Web/email: info@a0140202.uscgaux.info

New York Fire Department (FDNY)

Phone: Main: (718) 999-2000 Emergency Medical Service Command (718) 999-2770/1753

Office of Emergency Management (OEM)

Address: 165 Cadman Plaza East Brooklyn, NY 11201 Phone: Public Inquiries in NYC: 311 Public Inquiries outside NYC: 212-639-9675 Press Inquiries: 718-422-4888 Web/email: General correspondence (Contact the Commissioner): http://www.nyc.gov/html/mail/html/mailoem.html

Ready New York inquiries (Contact the OEM Ready NY Coordinator) http://www.nyc.gov/html/oem/html/contact/readyny_inquiries.shtml

CERT inquiries (Contact the OEM CERT Coordinator http://www.nyc.gov/html/oem/html/contact/cert_inquiries.shtml



Appendix G: Decision Support Database

Tracking & Detection Table

	Tracking/Detection Parameters								
4	Classification 👻	Wake Description 🕞	Fundimental Freq(I -	First Harmor 👻	Secondary H 🗸	IR signature 👻	Silohouette 👻	Picture 👻	
	Eruise Ship		5-6	10-12	15-18				
	🗉 Large Cargo (Suezma								
	Large F/V								
	Large P/V								
	▪ Large Sail								
	🗉 Large Tanker (afram								
	Medium Cargo (pana								
	 Medium F/V 								
	 Medium P/V 								
	 Medium Rec 								
	Pilot								
	PWC								
	Small Cargo (handyr								
	 Small F/V 		47-54	95-109	143-163				
	 Small P/V 		10-12						
	 Small Rec 		88-97						
	 Small Sail 								
	🗉 Small Tanker (handy		4-6	8-12					
	Super Cruise								
	- A -								

Areas of Operations

III Tracking/Detection Parameters III Areas of Operations III CAM Info III Classification							
🕗 Classification 👻	Areas of exclusion 👻	Out of channel operations? 👻	Erradic Operations Expected? 👻	Expected areas of Operations 👻			
Container Large							
Container Medium				Upper Bay, Red Hook or Port E.			
Container Small							
🗉 Cruise Ship							
Earge F/V							
targe P/V							
🗉 Large Rec							
🗉 Large Sail							
Medium F/V							
Medium P/V							
 Medium Rec 							
Pilot							
+ PWC							
Small F/V							
Small P/V							
🗄 Small Rec							
🗉 Small Sail	\checkmark						
🗉 Super Cruise							
Tanker Large							
Tanker Small							
Tug& Tow							
 Tug(unhitched) 							

