EXECUTIVE SUMMARY

Mitigating Container Security Risk Using Real-Time Monitoring with Active Radio Frequency Identification and Sensors

by

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**Container Security: A Growing Concern**

Goods are at the core of global trade and approximately 90% of worldwide cargo is transported by container. In fact, more than 16 million containers annually arrive in the United States (U.S.), the majority arriving via ocean cargo ships. Consider that a majority of these containers are large enough to hold multiple nuclear warheads, many tons of Anthrax, and other mass-destruction devices.\(^1\) “Clearly, a terrorist attack on a major U.S. port could bring this trade to a grinding halt”\(^1\) Just the threat of weapons of mass destruction or other chemical and/or biological weapons making their way to the U.S. poses phenomenal challenges for global supply chains.

In the wake of intensified security concerns since the September 11, 2001 attacks on the United States, tracking containers and their contents presents a concern for those institutions and personnel charged with ensuring their security. In response, the U.S. Department of Homeland Security (DHS) has created the Container Security Initiative (CSI) that consists of four central components\(^2\):

1. Establishing security criteria to identify high-risk containers
2. Pre-screening containers before they arrive at U.S. ports
3. Using technology to pre-screen high-risk containers
4. Developing and using smart and secure containers

The main goal of the CSI is to secure the U.S. and global economy from a container security perspective. The research in this paper is in line with the four CSI components.

The thesis analyzes the risks associated with global container transportation. The concept of an e-container is set forth as a risk mitigation technology that uses real-time monitoring of a container’s physical status acquired from an array of embedded RFID-enabled sensors. A framework is suggested that relates sensor-identified signatures and phenomena to behaviors that represent breaches in container security. A theoretical model suggests which sensors are required to identify individual breaches in order to mitigate container security risk.

**The Risks of Container Shipping**

As a prelude to presenting the risks of container transportion, the thesis discusses the different types of container structures, how a container is transported, and touches on the present technology used to secure them. Systems used to aid in efficiently loading and inspecting containers are presented, as well as the problems associated with removing and replacing seals at multiple border crossings.

The U.S. Customs and Border Patrol can “rule out 94% of the cargo as potential threats prior to arrival” in a U.S. port of entry\(^3\). This also means that only 6% of the cargo entering the country is actually inspected. Containers that were secure at their port of origin may have been tampered with or had any number of events affect their integrity or security at any point during their journey.

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to their final destination. Some of the major risks associated with shipping a container, whether it is by truck, rail or ship are as follows:

- Stowaways & Human Smuggling
- Weapons Smuggling
- Nuclear Materials Smuggling
- Drug Smuggling
- Injection of Chemical and Biological Agents into the container
- Theft of Containers and their Contents (Piracy)
- Explosion or Leakage of Dangerous Materials
- Risk of Damage to Goods During Inspection
- Size of Maritime Vessels

Each risk is discussed in detail (in the thesis) with statistics and relevant examples from the last decade are used. An example is below:

**Stowaways and Human Smuggling**
In 2001, the U.S. border patrol apprehended 1.2 million people that tried to enter the country illegally. Since 1994, the Border Patrol has made 11.4 million apprehensions nation-wide. Figure 5 demonstrates the living conditions within a container used to transport people from China to the United States.


"According to the Congressional Research Service and the U.S. State Department, 700,000 to 2 million people, the majority of them women and children, are trafficked each year across international borders. Thirty-five percent are under the age of 18 ... According to CRS, trafficking in people represents the third-largest source of profits for organized crime after drugs and guns, generating billions of dollars each year."

“In June 2000, in Dover, Great Britain, customs officials found 58 Chinese migrants dead. The 54 men and 4 women were asphyxiated in the airtight refrigerated trailer of a truck passing into England.”

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Sensors and RFID Technology

In 2002, the U.S. government enacted the United States Container Security Initiative. One of the goals of this initiative is to use information technology to identify, track, and target high-risk shipments for inspection. The existing port infrastructure cannot meet CSI requirements and hence there is a need for new and innovative ways of leveraging cutting-edge technology to cost-effectively meet the requirements. Government and industry are partnering to introduce “smart” containers that employ RFID tags to monitor containers. This collaboration is an extension of the Customs-Trade Partnership Against Terrorism (C-TPAT); referred to as the C-TPAT Plus.

Radio Frequency Identification (RFID) is the next generation barcode. It is a technology that allows businesses to automate the collection of supply chain information, thereby creating error-free fulfillment, delivery and visibility. The thesis gives an overview of Active and Passive RFID.

Telemetry sensory can be connected to active RFID tags and used to monitor and detect different metrics that are useful to the supply chain stakeholders in order to mitigate risk. The sensors are actually used to measure changes in their respective metric such as temperature increase or humidity decrease. The currently available sensors can measure numerous parameters within the containers and will be discussed below:

1. Ambient Temperature
2. Light
3. Humidity
4. Pressure
5. Vibration
6. Sound
7. Acceleration
8. Existence
9. Current Draw
10. Motion
11. Air Exchange
12. Explosives
13. Location
14. Radioactivity
15. Weapons Existence
16. Chemical

Findings: Threat and Phenomena

Signatures observed by sensors can be interpreted as representing certain threats. Threats will be observed from different perspectives depending on the sensor. For example, human cargo will be detected in a motion sensor as a moving object. In a humidity sensor, a human presence will be represented by an increase in humidity due to breathing and in a CO₂ sensor by a steady increase in CO₂ levels in the surrounding atmosphere. See Appendix 1 for a deeper look into sensors.

This model demonstrates how phenomena exhibited by sensors may be interpreted as behavior within the container. Figure 1 maps sensor data to behaviors.

A key assumption used in the creation of the following models is that the sensors will be functioning in a sealed, air-tight container, and will perform their function flawlessly. The sensors can function similarly in a non-air-tight container; however the results must be interpreted differently. Also, it assumes that sensing begins when the container is originally sealed. For instance, weapons smuggling can be exhibited in sensors as a container breach if inserted after the first sealing. This model assumes that the weapons were inserted at the start. If inserted later, the e-container will show signs of a container breach, and show the existence of weapons as well once inserted.

The second model in Figure 2, demonstrates the correlations made between phenomena and sensor identified risks.

The core findings of the modeling done in this thesis are illustrated when the sensor identified phenomena is interpreted as a manifestation of the above identified risks. Figure 3 demonstrates the correlations between sensor activities and the risks of container transport.
**Analysis of Findings: Determining the effective sensor combination**

Figure 1 demonstrates the combinations of sensors that are required in order to identify the phenomena exhibited by sensors. There is sensor overlap. When some risks are mitigated using a set of sensors, others will be covered as well. Ports, shippers, governments and the CBP must decide which risks are more likely to occur, and must determine areas of investment.

It is obvious from the findings that the e-container is most effective at discovering an incident of tampering with a sealed container. It is more difficult to determine the safety of container contents. This means that it is relatively easier to detect if someone has broken into a container to insert something than it is to monitor the original items that were placed into a container before it was sealed. The reason for this is that it is fairly simple to detect a container breach.

Explosions, Stowaways and Human Smuggling, and Container Theft are the three risks that are easier to monitor since they can be observed using a multitude of different sensors. There are many behaviors and phenomena that can be used to interpret a container break-in, theft, or movement in the container. If items are tagged with RFID passive tags, maintaining an inventory of the items inside the container will inform shippers of items that have been removed and not replaced (during a customs inspection, items are removed and replaced however loss and pilferage occurs).

Weapons smuggling is difficult to monitor. There are sensors in development that can scan for weapons, however there are no perfect scanning methods as of yet. It appears from the model that if we consider the situation where a container is sealed and later opened (breached) for weapon insertion, the e-container can treat weapons smuggling as a container breach, and once a breach has occurred, the container will be inspected.

There are some risks that can be discovered only using sensors designed specifically for identifying a specific phenomena. For example, nuclear materials can only be discovered using sensors designed to detect radioactivity and drug smuggling can only be detected with chemical sensors calibrated for that purpose.

Monitoring the theft of items from a container equipped with an RFID reader will become increasingly easier as an increasing number of objects are tagged with passive RFID tags. Monitoring the goods manifest of a container while it is being inspected will save time and loss and pilferage from the inspection process. In addition, monitoring theft of the entire container is best done using a GPS and noting movement where it is unexpected.

Ambient Temperature, Humidity, Light, Air Pressure, Sound and Motion are the types of sensors that cover the greatest number of instances of sensor identified phenomena while Humidity, Air Pressure, and Air Exchange are the three most versatile sensors, as they span 4 different risk areas. Acceleration, Current Draw, GPS, Radioactivity and Weapons Existence on the other hand, are only useful for observing a single characteristic per sensor.

Finally, the most effective combination of sensors to use in order to monitor the complete list of identified risks is: RFID Existence, Air Exchange, Radioactivity, Chemicals, and Weapons Existence. Current draw can be used to detect tampering with the tag.
**Recommendation: The e-Container**

When the data from sensors is combined with active RFID, the ability to track the security and vital sign of a container emerges.

What the thesis proposes is a system that combines active RFID with a set of sensors located inside the container with the RFID antenna being the only part of the system on the exterior of the container. On the exterior, the antenna would be protected, and have its own specific sensor that would detect tampering.

The system (Figure 4) gives an end-to-end visibility of the container shipment in real-time. A container can be tracked by satellite when sailing on the sea, by Wi-Fi / Wi-Max network when in the port proximity, or by cellular network when traveling on land. The container has a seamless transition from various readers with no interruption of service.

![Figure 4. Proposed Overall System Architecture](image)

**Conclusion**

The thesis analyzes the risks associated with global container transportation. The phenomena exhibited by each of the identified risks involved in global container shipping can be detected, identified, and monitored using an *e-container*. The e-container concept is set forth as a risk mitigation technology that uses real-time monitoring of a container’s physical status acquired from an array of embedded RFID-enabled sensors. This integrated solution is used to capture metrics, and communicate this information to a centralized data center.

By modeling the correlations between sensor-identified phenomena and the risks, the thesis establishes the optimal selection of sensors to use in order to detect and monitor each risk. As long as one can identify risk occurrence, one can act upon it.

U.S. Customs and Border Protection Commissioner Robert C. Bonner called containers “the potential Trojan horse of the 21st century”. With the correct systems and sensors in place to identify and detect phenomena associated with risk, the 6 steel walls of a container become slightly more transparent.

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Phenomena vs. Sensor Model

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**Figure 1.** The phenomena sensors may detect is matched with each sensor or set of sensors.
### Phenomena Correlated to Identified Risks

**Figure 2.** The phenomena sensors can detect is correlated to the Identified Risks from Section 2. It should be noted that in most cases, redundancy using combinations of sensors will obtain the desired result.
## Sensors vs. Identified Risks

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**Figure 3.** Model of Sensors vs. Identified Risks
Appendix 1

A Note Regarding Sensors

Sensor telemetry provides information in analog format. In order for a computer to provide an analysis on the data, it must be converted into a digital format using an Analog-to-Digital Converter (ADC). “However, the way in which we capture environmental data digitally entails practical issues related conversion, resolution, error, delay, and power consumption” (Emery, 2005). The bits are then sampled at predefined intervals to detect changes and patterns since the general idea is to transmit only deviations from a pre-existing state.

1. Ambient Temperature
   The ambient temperature in a container will be measured in Fahrenheit, Celsius or Kelvin.
   
   Temperature sensors can give fast and accurate readings with water resistance and physical robustness. Source: http://www.thermometrics.com/htmldocs/jdrel.htm

2. Light
   Light sensors exist that are sensitive enough to detect existence and intensity as well as a broad wavelength light sources
   
   Light sensors can detect existence and intensity of light. Source: http://www.globalspec.com/FeaturedProducts/Detail?ExhibitID=8690&deframe=1

3. Humidity
   Humidity sensors detect moisture levels in the atmosphere
   

4. Air Pressure
   Air pressure sensors can detect present and changes in air pressure (measured in Pascals) to help control ventilation.

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8 For information on practical issues related to conversion, please refer to (Emery, 2005)
5. **Vibration**
Vibration sensors can detect small-scale linear velocity, spatial displacement and acceleration. This detects movement of the object being monitored.

6. **Sound**
Sensors can measure sound in frequency and decibels. They can detect changes in sound levels that range from sonic to ultrasonic.

7. **Acceleration**
Sensors are able to detect movement of the container in any direction as well as the acceleration.

8. **RFID tag Existence**
A small RFID reader can be used to take an inventory of the RFID Passive tagged objects within the container.

   ![RFID Reader](http://www.rfidjournal.com/article/articleview/393/1/1/)

   This RFID reader is small enough to plug into any standard CF slot or PCMCIA slot with an adapter. Source: [http://www.rfidjournal.com/article/articleview/393/1/1/](http://www.rfidjournal.com/article/articleview/393/1/1/)

9. **Current Draw: on the Tag**
The Active RFID tag in the container will require monitoring. A current sensor can be placed on the tag to monitor current draw.

10. **Motion**
A motion sensor can be used to record movement inside the container.

   ![Motion Sensor](http://www.xsens.com/index.php?mainmenu=applications&submenu=human_motion&subsubmenu=biomechanics)

   This Motion Sensor can monitor human movements to measure body segment orientations (3D angles) and kinematic data (such as 3D accelerations) wirelessly with low-weight/low-power requirements. Source: [http://www.xsens.com/index.php?mainmenu=applications&submenu=human_motion&subsubmenu=biomechanics](http://www.xsens.com/index.php?mainmenu=applications&submenu=human_motion&subsubmenu=biomechanics)

11. **Air Exchange**
Air exchange sensors can be used to determine air quality - carbon monoxide, carbon dioxide, formaldehyde, volatile organic compounds, etc.

12. **Explosives**
An explosives sensor can be used to detect any form of explosives the may enter the container.
13. **Global Position**  
A Global Positioning System (GPS) can be used to monitor the container’s physical location at all times.

14. **Radioactivity**  
A radioactivity sensor can be used to determine existence and levels or radioactive materials inside the container.

15. **Weapons Existence**  
Ultrasound sensors in early stages of development can scan an object or human and create an ultrasound image of the concealed object.

![](https://example.com/ultrasound.png)  

16. **Chemicals**  
“Researchers at the Georgia Institute of Technology have developed a chip-based machine that can detect illegal drugs similar to how a police dog does. The Dog on a Chip can recognize as little as one-trillionth of a gram of cocaine from as far away as a drug-sniffing dog could detect it. The research team is enhancing its device to detect additional drugs, chemical agents, bombs, and other harmful substances such as anthrax” (Paulsen, 2004).

![](https://example.com/chip.png)  
Chips can detect cocaine vapor and potentially other illicit drugs and Anthrax. Source: [http://www.computer.org/computer/homepage/0504/briefs](http://www.computer.org/computer/homepage/0504/briefs)