Evaluating the Use of Electronic Door Seals (E-Seals) on Shipping Containers

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Key Words: E-Seal, electronic container seal, container security, container tracking, container shipping, RFID technology.

Abstract

Electronic door seals (E-seals) were tested on shipping containers that traveled through ports, over borders, and on roadways. The findings showed that using these RFID devices could increase supply chain efficiency and improve the security of containerized cargo movements, particularly when E-seals replace common mechanical seals. Before the benefits of E-seals can be realized, several barriers must be addressed. A major problem has been a lack of frequency standards for E-seals, hindering their acceptability for global trade. Routine use of E-seals would also require new processes that might slow their acceptance by the shipping industry. Disposable E-seals, which decrease industry concerns about costs and enforcement agency concerns about security by eliminating the need to recycle E-seals, are not common because they need to be manufactured in large quantities to be cost effective. Compatibility with existing highway systems could also promote E-seal acceptance, as containers could be tracked on roadways.

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Introduction

Around the world, millions of standardized intermodal shipping containers are used to transport freight. Because of the sheer volume of containers, securing them from threats such as terrorist attacks while also efficiently processing the containers through the freight supply chain is a major challenge. One technology application that potentially addresses both security and processing concerns is the use of RFID (radio frequency identification device) electronic seals (E-seals) to secure the doors of the containers. (Zhang & Zhang, 2007; Mueller, 2005; Tsilingiris, Psaraftis & Lyridis, 2007a; Tsilingiris, Psaraftis & Lyridis, 2007b, Moskal, 2009)

Since the late 1990s, the United States Department of Transportation (USDOT) and the Washington State Department of Transportation (WSDOT) have been testing E-seal technology. E-seals replace the mechanical, one-time use seals commonly used by the shipping industry. E-seals, which are functionally transponders, have the capability to record and transmit information about the integrity of the sealed container at pre-defined intervals. Information can also be recorded when the container passes by a stationary reader, or when it is read by a handheld reader.

The USDOT and WSDOT funded three tests of E-seals along trade flows that occurred primarily in Washington state. The goal of the tests was to evaluate whether it was possible to use this technology to minimize the processing delays associated with container inspections at port terminal gates and border crossings and to improve cargo security. WSDOT, in particular, explored whether E-seals could expedite the truck transport of containers over the State of Washington–Province of British Columbia, Canada, international border.

The tests involved a series of international container movements, mainly from the Puget Sound ports of Seattle and Tacoma but also through the land border at Laredo, Texas. Participants in the project included ports, marine shipping lines, trucking companies, and U.S. federal border enforcement agencies. Several different types of E-seals were tested between 2001 and 2008.

E-seal Overview

E-seals are transponders that can be used by shippers and enforcement agencies desiring to track shipments and that can also help determine shipment status and shipment integrity. E-seals can report their positions and are able to record the time that they were activated, compromised, or removed (Zhang, Liu, Yu, & Zhang, 2007; Kim et al., 2007). E-seals are electronic replacements for common mechanical container door seals (Figure 1) and use the locking bar on the container's back door. The European Conference of Ministers of Transport, in a review of container security, noted that E-seals were an "appealing solution" for both security and processing concerns but also called for more technical standards and operational experience before the technology is mandated and concluded that a complicated hardware and software infrastructure must be developed for E-seals to be effective (2005, p. 54).

Different E-seal designs have been developed over the last decade and include devices that communicate by using RFID, infrared, direct contact, long-range cellular, or satellite transmissions. While each seal has its own characteristics, RFID E-seals were selected for the State of Washington test because they were a relatively mature product that showed promise for both increasing container security and reducing processing delays for cargo inspections. The RFID E-seal design involved relatively simple technology that potentially could be mass-produced at a reasonable cost. The RFID E-seal is the most common type in use today because of its reliability and ease of integration with current infrastructure (Wolfe, 2002; Le-Pong & Wu, 2004).

RFID E-seals are typically either active or passive. A passive seal relies on a signal from the reader to activate the E-seal from a period of inactivity and electronically prompts the unit to transmit its information. This information can include the E-seal identification number; time and date when the seal was affixed; whether the seal has been tampered with; and the time of any event that occurred since the seal was activated. These E-seals tend to be short-range and directional because they rely on the power from readers.

Because a passive E-seal does not require a constant power source, it can usually be operated for an extended period of time with batteries. The batteries power the signal transmission when the seal is interrogated by a reader. They also keep an internal clock running, run internal checks, and log any events. E-seals powered by batteries can have a signal range of up to 30 meters.

Active E-seals have the same capabilities as passive seals, but they can also initiate transmissions. The advantages of using this kind of seal include a much greater range of up to 100 meters and a much stronger signal, which allows the signal to be transmitted around and beyond minor obstructions. Active E-seals cost more because of their enhanced capabilities and the number of batteries needed to power them. These seals also have greater maintenance costs because of the requirement to more frequently replace the batteries (Englert, Parmar & Byambajav, 2007). The State of Washington project tested active seals because they were better at seal-reader communication in a more challenging roadway environment, with higher vehicle speeds and longer distances between the seals and the readers.

Other E-seal Tests

Several other tests of transponders on containers have occurred and have indicated both the promise and problems with this technology. In 1999, China initiated a test to determine whether the use of Electronic Product Code/RFID tags, together with other technologies such as GPS tracking, could result in a more secure and efficient border crossing process between Hong Kong and Mainland China. The project continued until 2004 and tracked over 9,900 trucks. Data were collected regarding the average travel time for both legs of the trip (dispatch and return) to provide a better understanding of traffic conditions.

One idea that was tested during this project was the use of a special “Green Lane,” which allowed trucks equipped with Electronic Product Code/RFID tags to pass through Customs without stopping. On the basis of historical information, as well as data collected from this project, it was estimated that a 2-minute reduction in the time necessary to process documentation at the border resulted in a 50 percent reduction in time to cross the border. The Green Lane concept was re-implemented in 2006. In spite of the benefits of these lanes, enrollment by commercial vehicle operators was low. One report speculated that this was due to a lack of awareness by truck drivers, as well as concerns about lower incomes due to reduced travel (EPCglobal, 2006; Tradelink eBiz, 2007).

Operation Safe Commerce (OSC) was part of a U.S. government-sponsored effort to determine what security devices actually work and where freight security should be heading. One of OSC’s objectives was to create a basis for possible future international standards in securing containerized shipments. The OSC test involved the three major load centers in the United States: Seattle/Tacoma, Los Angeles/Long Beach, and New York/New Jersey. One of the several trade lane tests in OSC involved tracking a major food company’s containerized foodstuffs through the supply chain. E-seals were applied to the containers before they left the company’s mill in South America and were tracked along their route until the containers reached a distribution center south of Seattle, Washington.

The trade lane test was conducted from 2003 to 2004 and tracked approximately 100 containers. One overall lesson learned was that E-seal technology is only a part of the freight security solution, and the creation of a secure supply chain requires the development of international standards for security measures at terminals, at access control points, and through information interchange. The project determined that an international agreement of security standards must ultimately be developed, agreed upon, and revised on a regular basis (Science Applications International Corporation, 2007; Moskal, 2009).

In 2003, E-seal deployments were analyzed under the USDOT's Cargo Handling Cooperative Program (CHCP). This 6-month effort tested several different E-seal technologies in a laboratory, on a container passing through a container yard, on a container on an open road, and on a container on a double stack rail car. This program identified several design attributes that distinguished the different E-seals, including the frequency used (MHz), the method of transmitting information, the reader infrastructure, and the distance of the seals from an antenna for data transmission. The CHCP report concluded that E-seal technology, as a whole, may not be mature enough to be deployed on a wide-scale basis. A majority of the E-seals tested under controlled circumstances worked as expected. The results started to vary when the E-seals were tested in practical applications, but they worked perfectly after E-seal providers, who had experience with deploying their product in the commercial environment, helped resolve problems involving reader setups (Science Applications International Corporation, 2003).

In 2006, the European Community funded CHINOS (Container Handling in Intermodal Nodes—Optimal and Secure!). This 3-year, multiple agency project is exploring container handling with an emphasis on integrating new technology used to optimize container movement and processing. Part of this effort involves exploring the ability to identify and secure containers using E-seals. CHINOS tests in cargo terminals have validated the ability of E-seal information to be read in a real world freight operating environment. The ultimate result of these tests will be to develop a prototype system for automatic container identification (CHINOS, 2009).

History of the Washington State Tests

The first Washington state E-seal test, conducted between 2001 and 2002, resulted from a convergence of the freight mobility needs of a number of different organizations, as well as timely funding. WSDOT was interested in reducing border queues for trucks by facilitating commercial vehicle movements over the international border with British Columbia at Blaine, Washington. The U.S. Customs Service (USCS), now known as Customs and Border Protection (CBP), wanted to track all containers crossing the border to and from Canada. American Presidential Lines (APL) showed an interest in using E-seals because the USCS required that containers arriving in Seattle, Washington, destined for Canada have in-bond status when they crossed the border. APL had been incurring fines as a result of misplaced or missing paperwork associated with in-bond confirmation at the time of border crossing, and APL viewed E-seals as a way to automatically verify when its containers crossed into Canada.

The initial test was designed to explore the feasibility of using E-seals to electronically clear in-bond shipping traveling from the Puget Sound ports across the Washington–British Columbia border. The E-seals used were disposable, active, battery-powered seals manufactured by eLogicity (Figure 2) that communicated at 315 MHz. This seal was attached to the container’s door locking bar by inserting a locking pin into the transponder (seal body) that could only be removed by cutting the pin. The pin could not be removed without the E-seal recording that it had been tampered with, unless it was first deactivated. This E-seal could be read by using a fixed roadside reader or handheld reader.

Several E-seal readers were installed at the ports of Seattle and Tacoma, as well on an approach road to the Washington–British Columbia international border and at the border itself. At the same time, the project's system integrator developed software to provide an Internet-based system to link the roadside and port readers, Customs software, and data systems from the involved port and shipping lines. This software and reader network was designed to provide Customs officers advance notice of the arrival of an E-sealed in-bond container and also to automatically clear the bond when the E-seal passed under a reader and the reader’s antenna at the border (Figure 3).

The first test scenario involved the E-seals attached to containers of agricultural products trucked 160 kilometers north from the Port of Tacoma along Interstate-5 to Canada. The E-seals passed through the CBP facility at the international border crossing at Blaine, Washington. This test used 47 E-seals that were attached to containers by Maersk Line personnel at the Port of Tacoma.

The second scenario involved E-seals attached to containers of auto parts shipped from Japan to the Port of Seattle, then following the same route as the first scenario into Canada. The second scenario used 30 E-seals that were attached to containers of auto parts in Japan by Westwood Shipping lines personnel.

Initially, some of the E-seals were not read as they transited the I-5 corridor. The problem was that the E-seals were not able to transmit their information while passing through a transponder field at normal traffic speeds. The project staff worked with the vendor to update the seal transmission system to better capture reads as the E-seals passed under the reader’s antenna at normal traffic speeds. Following this re-engineering, the E-seals' data were captured by all of the readers for the remainder of the scenario testing.

The next WSDOT E-seal test was a USDOT Intelligent Transportation System (ITS) operational deployment initiative project, which was conducted between 2003 and 2008. Four commercially available RFID E-seals were evaluated and one was selected based on usability, operational characteristics and availability. The second test's E-seal worked in a fashion similar to that of the first seal, except that after deactivation and removal it could be reused on another container, and it was more sensitive to tampering activities. The metal alloy U-bolt was inserted into the transponder and used a fiber optic cable to record whether the seal had been tampered with. If the fiber optic cable was broken, the seal would record this as a tamper event. After the seal had been used, the U-bolt could be cut off and another one installed for further seal use. This E-seal, as with the previous seal, could be read with a fixed reader or handheld reader (Figure 4). This E-seal, manufactured by Telematics Wireless, was an active, battery powered seal that was compatible with the 915 MHz Commercial Vehicle Information Systems Network (CVISN) readers used on North American highways for tolling and freeway speed weigh-in-motion (WIM) systems.

The purpose of this second test was to determine whether E-seals would be valuable in facilitating supply chain processes, providing useful data to public transportation agencies and private sector participants, and expediting the inspection and release of commercial vehicles by enforcement agencies. The test worked closely with the U.S. Department of Agriculture (USDA) to track containers of restricted agricultural products both from the Port of Tacoma to British Columbia, where 60 seals were tracked, as well as from Laredo, Texas, to Canada through Detroit, where 120 seals were used. These E-seals were re-engineered several times to work more effectively in a highway environment. Again, readers were installed at the ports and the Washington–British Columbia border. Since these seals were CVISN compatible, they could also be read by 20 statewide roadway readers installed by WSDOT for WIM and data collection.

An overview of the project's different E-seal trade flow tests is found in Table 1. The tests indicated that the E-seals offered reasonable proof to USDA and CBP officers that a container had crossed a border or exited a terminal. They also showed that E-seals could be used as a reliable form of proof of a container exiting a particular port or crossing a border at a particular time, and in an un-tampered condition. In addition, the seals provided near real-time monitoring and tracking of container movement throughout the supply chain that could be used to improve asset visibility, throughput, and administrative efficiency. Authorized users were able to access this record online at any time to verify seal location, status (tampered or un-tampered), date, and time.

Process Improvements

A computer simulation of border clearance systems by Khoshons, Lim & Sayed evaluated E-seals used on truck flows across the same land border crossing studied in several of the Washington state project tests (2006). The study concluded that the use of any transponder system at the border reduced total inspection time and total delay per truck.

The Washington state project attempted to quantify similar process improvements when E-seals were used to replace traditional mechanical seals. The analysis was applied to the regulatory and inspection steps required of containers leaving Mexico with restricted food products (such as avocadoes, which present an insect pest risk to U.S. growers) and transiting the United States to reach Canada. This container movement required both entry and exit processing by CBP and its agricultural specialists, as well a bond posted by the shipper to guarantee that the cargo would not stay within the United States. The resulting regulatory requirement and associated documentation were determined on the basis of interviews with CBP and USDA staff. The processing times for the existing mechanical seals were based on these interviews, as well as direct observation. The E-seals processing times were also based on interviews and on the findings from the Washington state E-seal trade lanes tests.

Container flows out of Mexico start with shippers obtaining a permit from the USDA at the port of entry. The USDA sends the associated documentation (known as a green sheet) to the port of exit, where a bond number is issued by CBP and assigned to the cargo container. At the same time, the truck driver is given a designated shipment route and is told from which land border port the container must exit the United States.

With a mechanical seal, the perimeter of the container is inspected for integrity at the port of entry from Mexico and is sealed by a CBP Agricultural Assurance (AS) officer. The truck is then released and allowed to pass through the United States to the designated port of exit. At the port of exit, an appointment is made with the CBP AS officer, who receives the relevant documentation and visually inspects the mechanical seal. The documentation is then faxed to the port of entry to close out the bond, and the container can leave the United States. If this occurs after hours, the shipment status information is entered the following day. As a result, seals may or may not be inspected by an AS officer. Figure 5 shows the flow of the mechanical seal transiting process.

The use of a mechanical seal requires approximately 140 minutes of processing time (Table 2). A large portion of the time for manually processing mechanical seals is consumed during inspection at the port of exit and by manual paperwork.

This process is similar for an E-sealed container except that the CBP AS officer at the port of entry affixes an E-seal and also has to enter the container and in-bond information into both CBP and container tracking databases. When the truck reaches the port of exit, a fixed gate reader reads the E-seal, and the appropriate documentation, associated with the E-seal ID, is called up and provided electronically to the CBP officer. The E-seal can also be inspected by using handheld readers to determine whether the seal has been tampered with. The CBP then officially closes the in-bond file, and the container is allowed to exit the United States. E-seal readers at the border can also automatically verify that the container has left the country. Figure 6 provides the flow diagram for the E-seal transiting process.

In the tests, the E-seal personnel time requirement was approximately 31 minutes, including 3 minutes per day for four days to track the container's position as it transited the United States (Table 2). The ability to track the container's position and seal security status with the E-seal technology could offer a significant increase in in-bond container security over that provided by mechanical seals.

Industry and government resistance to technology-based container security systems is often related to perceived additional costs (Moskal, 2009). Although not inclusive of all potential costs, such as those for installing reading equipment, a process-based cost comparison was calculated by applying the hourly wage ($25.51 in 2006) of a mid-grade CBP officer to each seal procedure (Table 2). Even assuming a four-day transit trip from Canada to Mexico with three daily position checks, the CBP labor costs associated with the use of E-seals were estimated to be far less ($14) than those associated with mechanical seals ($60).

The analysis found that E-seal-based procedures were less labor intensive and required less paperwork and fewer personnel checks than mechanical seals. Thus, the use of E-seals could reduce the total delay and inspection costs for containers crossing the border.

Operational Barriers

While it is likely that E-seals could offer processing improvements in trade flow, the acceptance of this technology will also depend on successfully addressing a number of operational barriers. Given the problems found in the Washington tests for all the trade flows, the installation and programming of the E-seals need to be as straightforward as possible. Both private sector shipping company employees and federal enforcement personnel had some difficulties installing and programming the E-seals and entering the appropriate information onto the Internet. Many of the personnel who would install the E-seals on containers have multiple duties, so the simpler the E-seal is to install and program, the more effectively E-seals could be integrated into trade flows. Training manuals, some hands-on instruction, and laminated instruction cards designed to be used on-site all helped reduce errors. It is also possible that more automated E-seal data entry processes, such as using a PDA with wireless data transfer protocol, could help.

As with the Cargo Handling Cooperative Program test (Science Application International Corporation 2003), a number of technology problems occurred during the real world trade lane applications in this project that were not found during the preliminary engineering tests completed in a controlled environment. The E-seals used for the Washington state test worked well at slower vehicle speeds, reflecting their original intent to be used in a port or Customs facility. However, actual applications of the E-seals on freight flow movements determined that they needed to be re-engineered for use on roads because infrequent transmissions between the

E-seals and the fixed readers caused reads to be missed. This project found that the vendors/manufacturers played an important role in re-engineering the E-seals to work whenever problems were found. After re-engineering, the USDA successfully used the E-seals and associated project software to transit and clear agricultural products traveling from Mexico and the Port of Tacoma into Canada.

An example of an operational trade lane problem that might have been found only when the E-seals were tested in actual freight flows involved confusion due to multiple E-seal reads when containers traveling through the CBP facility in Detroit were cleared. The problem was that multiple seals were being stored in the Custom booths at the border crossing, and the fixed border readers were repeatedly reading these seals. This finding suggested that a procedure to isolate multiple seals or the use of a technology such as faraday shields would be necessary in some situations.

Another finding highlighted by the tests in Washington state was a need to account for fixed E-seal readers that became inoperable because of expected construction projects, unexpected events such as vehicle collisions with the roadside readers, or equipment failure. These events caused problems during the USDA test, indicating that E-seal systems need to have some operational redundancy in terms of multiple readers in the network or need to include paper-based back-up procedures.

E-seal Infrastructure

While the European Conference of Ministers container security report specifically identified the lack of readers and other supporting infrastructure as a limitation for a viable E-seal system (2005), the Washington state effort determined that that the fixed roadside E-seal readers' infrastructure was relatively easy to install. WSDOT personnel assisted in the installation of the readers and the associated overhead antennas and found them similar in complexity to other roadside ITS equipment requiring power and communications linkages. The reader technology improved considerably over the course of the tests, resulting in further reductions in installation complexity and cost. The first readers used were the size of a traffic signal cabinet and cost around $18,000. Current readers cost less than $3,000, are the size of a book, and are notably easier to install.

One important factor that makes the use of E-seals feasible is the Internet. It provides a low or no-cost network to link the fixed readers' network together, and integrates the different government enforcement agencies' and private-sector software systems. The website developed for this project can also be used by these organizations to monitor and track the sealed containers.

Institutional Issues

A variety of institutional issues can slow the widespread adoption of the E-seal. Moskal, for example, noted concerns about "cultural" differences among supply chain participants impeding the implementation of container security systems (2009). For the Washington State project, these difference were apparent in the need to link a wide range of different institutions' gate and terminal software (shipping lines and ports), enforcement systems (USDA and CBP), and possibly highway readers (departments of transportation). While the Internet could be used as a framework to integrate these systems, providing functional connections could hinder the development of the software needed to effectively track the E-seals beyond just a port environment. In a number of cases, these connections require dealing with bureaucratic inertia that can slow the adoption of technology. Border enforcement agencies, because of security and privacy concerns in particular, were protective of their software and linkages into their software, restricting the ability to develop effective, automatic E-seal-based clearance programs. This issue might be reduced if standards were adopted.

A related complication is that the operational procedures of the private sector and U.S. federal enforcement agencies must be adjusted to accommodate the functional application of E-seal technology. For example, enforcement agency officers may already have a procedure for installing mechanical security seals on containers of interest, but the use of E-seals may notably change this procedure, requiring additional steps related to the programming of the E-seal and entering the data onto the Internet. Such additional steps may complicate users' acceptance of E-seals.

Another institutional concern is related to the contractual relationship between the marine shipping lines and the labor unions that operate in the ports. These contracts have some limitations on the installation of new technology. The Washington state E-seal tests required some discussion with the ports' unions before several readers were installed at port gates. The issue would be of less concern if E-seals were mandated by enforcement agencies for security reasons, as opposed to being used to improve processes in ports or by shipping lines.

Standards

Chao and Lin, while developing a technology acceptance model for container security, surveyed marine terminal users (2009). They concluded that a company's acceptance of a specific technology, such as RFID tags, is often dependent on its competitors also adopting the same technology. Their report recommended that shippers wait for global standards before adopting security systems. Similarly, Mueller noted that potential users of E-seals are hesitant to support or adopt any particular E-seal technology because they do not want to invest in a technology or standard that might change in the future (2005).

A similar reluctance to commit to any particular E-seal technology was also expressed by the shipping lines participating in the Washington state test. This concern would be reduced if a particular E-seal technology was mandated by border enforcement organizations or another government agency.

The two types of E-seals tested in the State of Washington used different frequencies and communication protocols. The eLogicity E-seal used a frequency controlled by the U.S. Department of Defense. This limited the possibility of any long-term application for this seal. The Telematics Wireless E-seal used the same frequency and communication protocol as that used by the North American roadway CVISN systems. In addition to requiring different reader technologies, neither E-seal was compatible with international E-seal frequencies. While this was not a major issue for the Washington state tests, because the widespread use of E-seals on containers will almost certainly involve global trade flows, the lack of a commonly accepted international standard could hinder the adoption of E-seals. Under existing frequencies, for instance, an E-seal installed in Japan to comply with that country's broadcast frequency on a container en route from Japan to the United States will not work in the United States. The importance of frequency standards was cited in the European Conference of Ministers of Transport report (2005), as well as highlighted in findings from the Operation Safe Commence tests (Science Applications International Corporation, 2007).

There have been some efforts to create an international standard for E-seal frequencies. However, some countries are reluctant to absorb the cost of changing their infrastructure to accommodate an international frequency. Currently, the International Standards Organization (ISO) has two standards (ISO 18185) that use either the 433 MHz or 2450 MHz frequencies (International Standards Organization, 2007). The standards include minimal mechanical characteristics for the seal. There are two issues with these current standards: 1) very few countries allow both frequencies to be operated within their jurisdiction and neither ISO frequency is accepted globally, and 2) the ISO standards themselves currently have no security structure or protection protocols.

The adoption of an international E-seal standard would have many benefits. It would focus the efforts and harmonize the design of E-seals by manufacturers and protect any investment in E-seal infrastructure by the freight community, which should result in lower cost seals. Perhaps even more critical, since most container movement is international, is that it would make the use of E-seals in overseas trade more acceptable. However, finding an acceptable frequency might be a challenge because of ongoing institutional, political, and technical concerns (European Conference of Ministers of Transport, 2005; Mueller, 2005; Laird, 2007; Zhang, Liu, Yu, & Zhang, 2007; Moskal, 2009)).

Disposable E-seals

Daschkovska and Scholz-Reiter completed a cost benefit analysis of disposable and reusable E-seals by estimating the return on investment under several scenarios involving container movement through a Customs process (2008). While both types showed a positive return on investment, the savings with the disposable E-seals were double those of reusable seals, mainly because of lower initial costs. This hypothetical test did not directly consider the accountability processes and costs that would be required to recycle reusable E-seals.

The re-cycling needs associated with the reusable portion of the Telematics E-seal concerned different stakeholders during the tests in Washington state. The recycling process would need to include procedures for the removal, maintenance, storage, and re-use of the seal body. In addition, re-useable E-seals would need to be isolated when not in use to prevent them from receiving signals, which would lead to erroneous data transmissions and reduced shelf life and reliability.

In contrast, the e-Logicity disposable seal eliminated the cost and process associated with having to set up and maintain a recycling mechanism. With disposable seals, there was also no security concerns related to safe storage and a chain of custody for recycled E-seals. However, a big challenge to using disposable E-seals is the manufacturer's ability to produce an affordable seal. Laird suggested that $10 or less would be a reasonable price point for a single use E-seal (2007). This price would make widespread application of E-seals more attractive to the container industry. However, production of small batches (less than 1,000) of E-seals generally makes them too expensive. Only with large batches of E-seals and the resulting economies of scale, including the ability to use manufacturing shortcuts such as integrated circuit boards, is it likely that E-seals will be inexpensive enough to be considered disposable.

Cargo Types

E-seals, as tested in Washington state, may not be appropriate for all cargoes. These E-seals are perhaps best for more routine cargo movements that need to be secured against tampering, electrically cleared, or tracked at fixed points but that do not need a high level of security. While these E-seals do increase security, they can also be defeated. Englert, Parmar and Byambajav, for example, list a number of security problems, such as spoofing or cloning, associated with an E-seal's RFID capabilities (2007). E-seals can also be physically bypassed by removing the doors or accessing the cargo through other parts of the container such as the walls (Chao and Lin 2009).

High threat or expensive goods, such as hazardous materials, precious metals, or munitions, may justify more costly and sophisticated E-seals linked to container intrusion detection sensors, GPS/cellular trackers, and other sensors. The European Conference of Ministers of Transport report suggested that E-seals would be most appropriately used as part of a tiered smart container system, with E-seals being linked to RFID devices in the cargo and permanently affixed to the container (2005).

Conversely, a container with a low value cargo such as a bulk good may not warrant any type of electronic device or seals unless perhaps it needs to be cleared through an international border.

Highway-Compatible E-seals

The Washington state tests indicated that E-seal technology can be successfully integrated with the current roadway ITS infrastructure. The CVISN-compatible Telematics Wireless E-seal was able to be tracked with WSDOT's roadside WIM transponders system. The CVISN system is in use throughout the U.S. and Canada and represents a fairly comprehensive roadway network. The use of highway-compatible E-seals potentially would allow containers to be tracked on the highway system. Currently, the ability to track cargo on North American highway systems is poor. Overlapping with the highway transponder systems could also increase the number of E-seals in use because it would increase the value of E-seals to commercial vehicle operators who stop at weigh stations and border crossings.

Conclusions

A series of field operational tests completed over a 10-year period has indicated that electronic container door seals (E-seals) technology can increase efficiency and improve security and asset visibility. Almost certainly, universal use of E-seals along with associated infrastructure could provide notable improvements in security, container tracking, and reduced processing time and transactions costs. The E-seal technology was found to reduce paper work and inspection times. The seals also provided near real-time monitoring and tracking of container movement throughout the supply chain, which could be used to improve asset visibility, throughput, and administrative efficiency. However, a number of barriers could delay or even forestall the adoption of E-seals. A major issue is the adoption of standards, as E-seals available today use a range of different technologies, hindering their adoption for the international trade flows in which container use is almost universal. The use of E-seals would also require changes in operational procedures and new software linkages for both the private sector and public Customs enforcement agencies. Such changes often require dealing with intuitional inertia, which can hinder the adoption of new technology.

Another barrier to widespread E-seal technology use is acceptability of the E-seal to the container industry. Recycling a multiple-use E-seal requires a process to remove, transfer, store, and secure the seal, whereas a disposable E-seal avoids these complications and is seen as much more usable. However, a big challenge to the use of disposable seals is the manufacturers' ability to produce E-seals at a low enough cost.

The tests also determined that a viable E-seal must be tested in a real world environment to identify problems that do not show up in controlled environments. Difficulties with installing and programming the E-seal by enforcement and dock staff during the tests was an ongoing problem, indicating that E-seal acceptance would be enhanced with a simple and intuitive E-seal design paired with training aides.

Use of E-seals that are technologically compatible with the widespread highway transponder network could help increase their value to the container industry, as a compatible seal would allow containers to be tracked on the highway network.

References

Chao,S. & Lin, P., (2009) Critical factors affecting the adoption of container security service: The shippers' perspective. *International Journal of Production Economics*, doi:10.1016/j.ijpe.2008.12.021.

CHINOS project website (2009). Retrieved June 4, 2009 from http://www.chinos-rfid.eu/ipublic.htm

Daschkovska, K., & Scholz-Reiter, B. (2008). Electronic seal for efficient container logistics, In Haasis, H., Kreowski, H., & Scholz-Reither, B. (Ed.), *Dynamics in logistics* (pp 305-312*)* Berlin: Springer -Verlag.

Englert, B., Parmar A., & Byambajav, D. (2007). *Evaluating and improving the security of RFID tags in shipping containers.* (Final Report METRANS, Project AR 06-01). California State University, Department of Computer Engineering and Computer Science.

EPCglobal (2006). *Hong Kong unveils RFID cross border feasibility study findings*. Release dated September 27.

European Conference of Ministers of Transport (2005). *Container security across modes.* OCED Publications, ISBN 92-821-033, Paris.

International Standards Organization (2007). *ISO 18185-1:2007***,** *Freight containers -- Electronic seals -- Part 1: Communication protocol* (2007-04-26).

Kim, D., Lee, M., Kang, Y., Chung, S., Yoon, W., Min, J., & Kim, H. (2007). Design and Performance Analysis of Electronic Seal Protection Systems Based on AES, *ETRI Journal*, 29 (6), 755-768.

Khoshons, M Kevan; Lim, Clark C; & Sayed, Tarek (2006). A simulation and evaluation of international border crossing clearance systems: A Canadian case study. *Transportation Research Record: Journal of the Transportation Research Board*, 1966, 1-9.

Le-Pong, C. & Wu, C. (2004). The role of electronic container seal (E-seal) with RFID technology in the container security initiatives. In *Proceedings of the 2004 International Conference on MEMS, NANO and Smart Systems*, 116-120.

Laird, M. (2007). The pending ratification of ISO 18185 what it means for the electronic container seal ('E-seal') market, *ABI Insights*, ABI Research, 2Q.

Moskal M**.**, (2009) *Case Study: The Reality of DF Technology Transition for Maritime Domain Awareness with a Focus on Container Security* In Shahbazian et al. (eds.), *Harbour Protection Through Data Fusion Technologies***,** Springer Netherlands, 61-68.

Mueller J. (2005). *Emerging technology in German port security: electronic container seals*, U.S. Commercial Service, Germany, June 27. Retrieved from June 4th 2009 from http://www.ic.gc.ca/scdt/bizmap/interface2.nsf/vDownload/ISA_1962/$file/X_9445346.PDF

Science Applications International Corporation. (2003). *Cargo handling cooperative program, Program Sector: Agile port and terminal systems technologies, Program Element: Cargo, equipment tracking and identification technology, Demonstrations, container seal technologies and processes*, (Phase 1. Final Report, Contract Number: N66001-02-D-0039-0001) Center for Commercial Deployment of Transportation Technologies, July 11.

Science Application International Corporation (2007). *Deploying and Testing Electronic Container Seals Twelve Questions and Answers, Experience from the Washington State DOT*, U.S. Department of Transportation, Washington, D.C.

Tsilingiris, P., Psaraftis, H. & Lyridis, D. (2007a). *RFID in the ocean container transport* Paper presented at the Annual conference of the International Association of Maritime Economists (IAME 2007), Athens, Greece.

Tsilingiris, P., Psaraftis, H., & Lyridis, D. (2007b). *RFID-enabled innovative solutions promote container security*, Paper presented at the Annual International Symposium on Maritime Safety, Security and Environmental Protection (SSE07), Athens, Greece.

Tradelink eBiz. (2007). Red lights on green lane, April. Retrieved May 13, 2009 from http://www.tradelink-ebiz.com/english/331n08or3m9a51l/newscast/tp_0701b.html

Wolfe, M. (2002). *Electronic cargo seals: context, technologies, and marketplace*. North River Consulting Group, Prepared for the Intelligent Transportation Systems Joint Program Office, Federal Highway Administration, D.C., July.

Zhang, J, Liu, Y., Yu C., & Zhang, C. (2007). Smart container security – the E-seal with RFID technology, *Proceedings - 7th International Navigational Symposium on Marine Navigation and Safety of Sea Transportation*, Gdynia, Poland, June, 545-547.

Zhang J. & Zhang C., (2007). Smart Container Security: the E-seal with RFID Technology, *Modern Applied Science* 1(3), 16-18.

Table 1: Overview of the E-seal trade flow tests

Trade Flow	**Origin**	**US Port of Entry**	**US Port of Exit**	**Destination**	**E-seal**	**E-sealed containers tested**	**E-seal Readers Installed**
In-bond containers of agricultural products	Various countries	Port of Tacoma	Blaine, WA	British Columbia	E- Logicity: active, disposable seal, 317 MHz	47	Port of Seattle, Port of Tacoma, Blaine border approach roads, Blaine customs facility
In-bond containers of automobile parts	Japan	Port of Seattle	Blaine, WA	Vancouver, British Columbia		30	
In-bond containers of restricted agricultural products	Mexico	Larerdo, Texas	Detroit	Canada	Telematics Wireless: active, recyclable body and disposable hasp, 915 MHz	120	Port of Seattle, Port of Tacoma, Blaine customs facility, Detroit border crossing, other existing WSDOT highway readers used
In-bond containers of restricted agricultural products	Various countries	Port of Tacoma	Blaine, WA	Canada		60	

Table 2: Procedural steps by minutes and cost for mechanical seals and E-seals

Procedural Steps	**Mechanical Seal (Minutes)**	**Direct labor cost by CBP officer**	**E-seal (Minutes)**	**Direct labor cost by CBP officer**
Installation.	0.3	$0.12	5	$2.15
Documentation (mechanical seal includes faxing information.)	3	$1.29	5	$2.15
Record events in database.	-		3	$1.29
Checking seal status.	10	$4.30	3 per day for 4 days while in transit (12 total)	$5.16 total for 4 days
Port of Exit FAX exit information to Port of Entry.	10	$4.30		
Provide paper work at Port of Exit.	13	$5.59	3	$1.29
Make appointment to inspect seal at Port of Exit.	45	$19.35	-	
Inspect seal and container.	60	$25.51	-	
Monitor E-seal data screen at border.	-		3	$1.29
Approximate Total Time/Cost	**140**	**$60.46**	**31**	**$13.33**

Figure 1. Common mechanical container door seal.

Figure 2. Disposable E-seal used in the first test.

Figure 3. E-seal reader antennas on gantry at Washington-British Columbia border.

Figure 4. E-seal and handheld reader used in the second test.

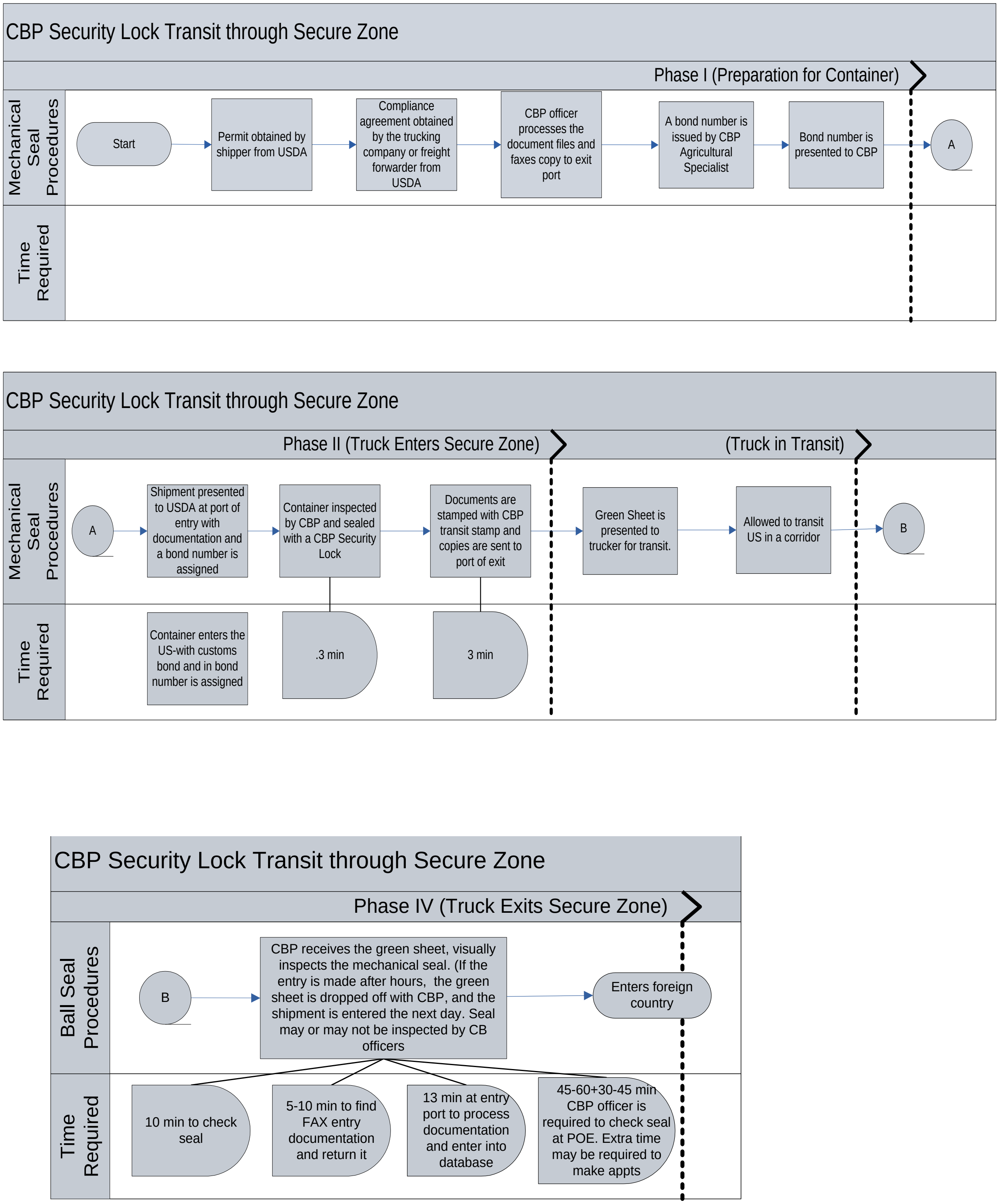

Figure 5. Mechanical seal transiting procedure

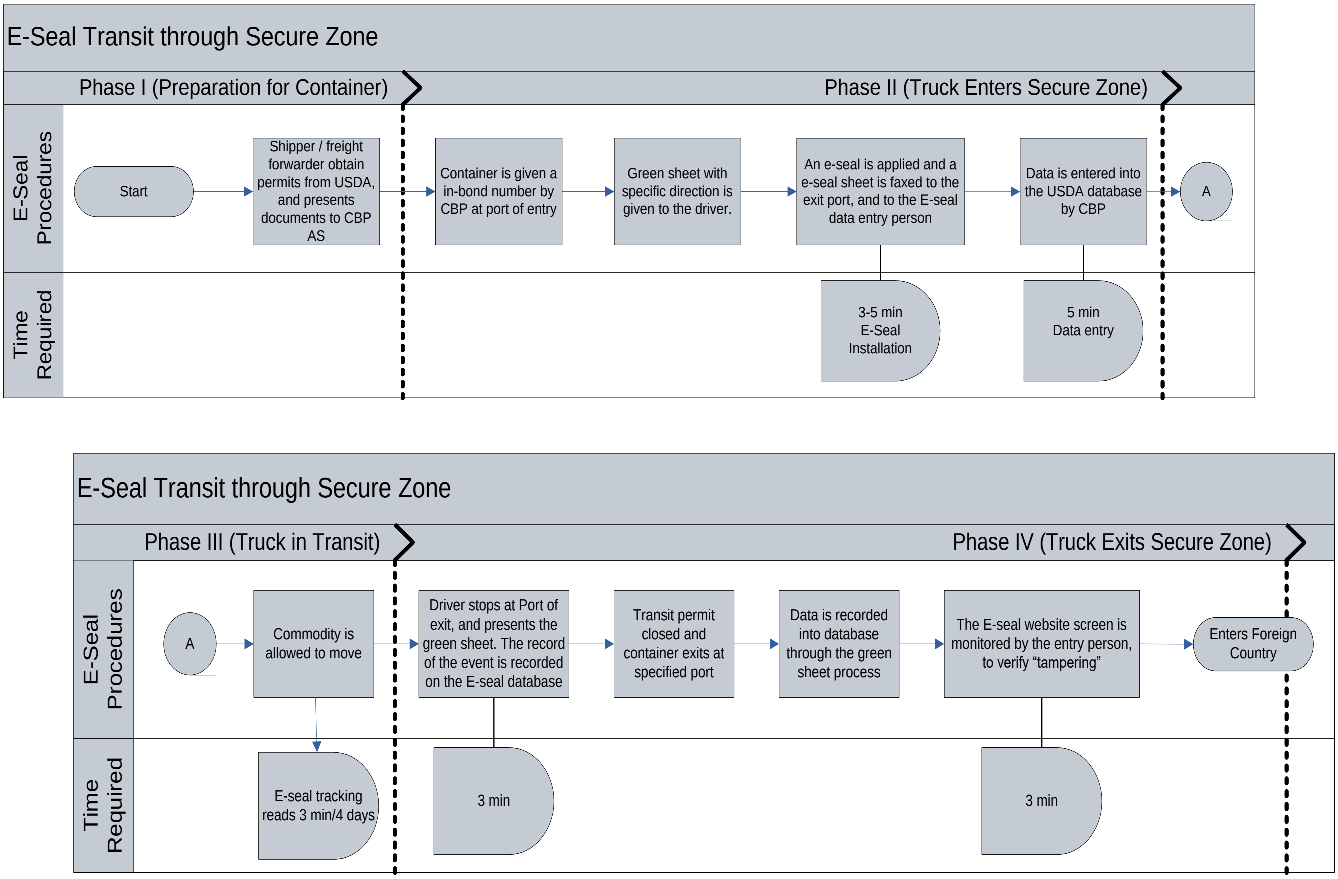

Figure 6. E-seal transiting procedure.