A COST-BENEFIT ANALYSIS OF ALTERNATIVE DEVICE CONFIGURATIONS FOR AVIATION CHECKED BAGGAGE SECURITY SCREENING

by

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TABLE OF CONTENTS

ABSTRACT

In the two years since the terrorist attacks of September 11, 2001, the security of our nation's civil aviation system has assumed renewed urgency, and efforts to strengthen aviation security have received a great deal of congressional attention (GAO-03-1150T). As of early 2003, an estimated 1,100 explosive detection systems (EDS) and 6,000 explosive trace detection machines (ETD) had been deployed to ensure 100% checked baggage screening (GAO-04-440T). These two explosive detection technologies are an integral part of the security strategies currently being used in US airports. However, the prohibitive costs associated with deploying and operating such devices and machines has led the TSA to evaluate the cost, effectiveness, maturity, and efficiency of these devices to ensure that they achieve the maximum pay-off in improved security for funds spent (Jacobson et al. 2003b).

In addition to the evaluation of cost effectiveness of current explosive detection devices, research into advanced screening equipment and associated technologies has also become a priority. The main objective of this thesis is to evaluate the cost effectiveness of the explosive detection technologies currently in US airports supplemented with evaluations of the newest technologies which could possibly be used to screen checked baggage in the future. The research analyzes both single device systems in addition to several cascading sequences of devices. In particular, the expected annual direct cost of using these devices for 100% screening under various checked baggage screening scenarios is obtained. The tradeoffs between using single device strategies and sequenced combinations of the devices are also studied. Lastly, the expected number of successful threats under the different checked baggage screening scenarios with 100% checked baggage screening is studied.

The results indicate that for the current security setup, with current device cost and probability parameters, single device systems are less costly and give optimal successful threat values. The cost model introduced provides an effective tool for the execution of cost-benefit analyses of alternative device configurations for aviation checked baggage security screening. Butler and Poole (2002) and Poole and Passantino (2003) feel that a risk-based system is a superior approach to aviation security. If the US implements this type of security system, this cost model will be a valuable tool in developing the optimal device configuration.

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION AND BACKGROUND

In the two years since the terrorist attacks of September 11, 2001, the security of our nation's civil aviation system has assumed renewed urgency, and efforts to strengthen aviation security have received a great deal of congressional attention (GAO-03-1150T). As a result, the Aviation and Transportation Security Act (ATSA) required the Transportation Security Administration (TSA) to acquire and deploy certified explosive detection systems into US airports. These systems were required to screen all checked baggage no later than December 31st, 2002. As of early 2003, an estimated 1,100 explosive detection systems (EDS) and 6,000 explosive trace detection machines (ETD) had been deployed to ensure 100% checked baggage screening (GAO-04-440T). These two explosive detection technologies are an integral part of the security strategies currently being used in US airports. However, the prohibitive costs associated with deploying and operating such devices and machines has led the TSA to evaluate the cost, effectiveness, maturity, and efficiency of these devices to ensure that they achieve the maximum pay-off in improved security for funds spent (Jacobson et al. 2003b).

In addition to the evaluation of cost effectiveness of current explosive detection devices, research into advanced screening equipment and associated technologies has also become a priority. Detecting explosives in checked and carry-on baggage is the top concern (Singh and Singh 2003). Many problems have been found regarding security screener proficiency which puts even more importance on machine threat detection. The main objective of this thesis is to evaluate the cost effectiveness of the explosive detection technologies currently in US airports and new technologies which could possibly be used to screen checked baggage in the future. The research analyzes both single-device systems in addition to several cascading sequences of devices. In particular, the expected annual direct cost of 100% screening under various checked baggage screening scenarios is obtained. The tradeoffs between using single-device strategies and sequenced combinations of the devices are also studied. Lastly, the expected number of successful threats under the different checked baggage screening scenarios with 100% checked baggage screening is studied.

This thesis is organized as follows. Chapter 2 defines and compares current and developing security technologies. Chapter 3 identifies alternate areas of improvement for the current airport security configuration and reviews previous areas of research. Chapter 4 presents the detailed cost model, including values and ranges for the cost model parameters. Chapter 5 reports results for different scenarios. Chapter 6 offers concluding remarks and recommendations.

CHAPTER 2

AVIATION SECURITY TECHNOLOGY

Many different explosive detection technologies exist today. All technologies and procedures used in US airports must be federally certified, however only two methods, explosive detection systems (EDS) and explosive trace detection (ETD), are currently certified. Other explosive detection technologies exist and are in use at airports in Europe and also by US customs. Below is a review of security system technologies with brief descriptions of how each works.

2.1 Technology Defined

2.1.1 Explosive Detection Systems (EDS)

Explosive detection systems (EDS) are used to screen baggage for explosives. EDS machines use technology derived from medical Computed Tomography (CT) to quickly locate and identify explosive devices concealed in checked baggage. As the conveyor moves each bag through the machine, the system produces a scan projection X-ray image. From this image, the powerful onboard computer determines which areas need "slice" images, taken by the rotating X-ray source. Using sophisticated computer algorithms, the system analyzes these slice images and compares their properties with those of known explosives. If a match is found, the system alarms and displays the object on the screen (CTX 2004).

2.1.2 Explosive Trace Detection (ETD)

Explosive trace detection (ETD) systems are used to screen baggage for explosives, and work by detecting vapors and residues of explosives. Note that there are three ETD device strategies used to sample checked baggage for explosive residues. The first strategy is *trace closed* (TC), where only the outside of a checked bag is sampled. The second strategy is *trace open* (TO), where both the outside and the inside lining of a bag are sampled. The third strategy is *trace aggressive* (TA), which samples the outside and the inside lining, as well as any item larger than a soft-drink can (Butler and Poole 2002). The 40/40/20 method simply refers to a screening strategy that screens 40% of the bags using trace closed, 40% using trace open and 20% using aggressive open.

2.1.3 High-speed x-ray

High speed x-ray is the most common means of inspection for carry-on luggage. This type of x-ray technology can help provide information about object density. This conventional x-ray screening system provides superior image resolution for high confidence detection applications (L3 2004).

2.1.4 Dual-energy x-ray

This technology, also referred to as automated x-ray, subjects baggage to two different dual-energy x-ray sources to calculate the atomic composition, density and other characteristics of objects in the bag. A computer processes these images and displays any threat detected on a workstation computer screen. A scatter detection enhancement feature enables the machine to automatically detect thin sheet explosives by detecting when x-rays are scattered by the thin materials. One particular system, Z-Scan7, uses an arithmetic reconstruction technique that calculates the probability that the explosive materials could be present given the composition of the materials in the bag (Rao and Binzoni 2001).

2.1.5 Multi-energy x-ray

This technology is also a dual-view x-ray device. The system uses multi-energy technology and a special material-separation method to improve detection. It uses two x-ray sources with different energies to distinguish between organic materials and explosives. Automatic image evaluation is conducted by a high-performance computer (Rao and Binzoni 2001).

2.1.6 Backscatter x-ray

This technology is a variation of the x-ray methods above. In addition to transmitting an x-ray beam through the bag, it places a receiver on the same side of the bag. The x-rays, which are scattered back, are then analyzed by a computer program. A series of algorithms make computations based on density readings and other factors to determine whether a material is suspect (Ellenbogen 1996).

2.1.7 Quadruple resonance (QR) analysis

This analysis device detects explosives using a variant of magnetic resonance technology. The explosive detection device contains an internal coil, which generates radio-frequency pulses that sense the unique structure of explosives. If an explosive is present, the system will emit a unique unalterable signal which is sent to the system's internal computer for analysis. This device requires no interaction or interpretation. The results are presented in a pass or fail mode (Rao and Binzoni 2001).

2.1.8 Coherent X-Ray Scatter (CXRS)

This system harnesses the unexploited technique of dispersive coherent x-ray scatter to identify materials based on their molecular make-up. The accuracy that this technique offers is much greater than all other techniques (Yxlon 2003).

2.2 Technology Compared

2.2.1 Current technologies

High-speed x-ray detection methods are currently the most common means of inspection for carry-on luggage in US airports. X-ray technology relies on state-of-the-art, patented technology to screen for explosives, firearms and contraband and is ideal for use in airports. Researchers point out that it is not clear why this type of screening is sufficient for carry-on baggage yet is not acceptable for screening checked baggage (Butler and Poole 2002). This type of technology is safer to humans and also to the contents of baggage which is screened. This type of technology needs continued research because terrorists are constantly searching to finds way to hide or modify explosives to throw off the screening.

Since its creation in November 2001, the TSA has deployed over 1,100 explosive detection systems (EDS) and 6,000 explosive trace detection machines (ETD) to over 440 airports nationwide to ensure 100% checked baggage screening (GAO-04-440T). With this 100% mandate, the various certified technologies, in addition to the technologies in development, must be compared to ensure the best screening system is in place. Current technologies need to be compared with new and upcoming technologies to ensure that US airports have the highest quality security systems.

The majority of newly deployed security devices are explosive trace detection (ETD) systems. These ETD systems have low throughput and large staffing requirements due to the hand labor required for each searched bag. The trace closed method has unacceptable false-negative rates. However, switching to the trace open technique can more that triple the inspection time therefore slowing throughput. Finally, sometimes even in trace open searches, ETD fails to detect items (Butler and Poole 2002).

Explosive detection system (EDS) machines are the other currently deployed devices. These devices require enormous space, about the size of a small SUV Not only are these devices exceptionally large, they weigh six to eight tons, have a slow 150-200 bags/hour throughput and are very costly at about a million dollars apiece. The low throughput and high costs make these machines a poor choice for mass screening of bags (Butler and Poole 2002). In-line EDS systems, those which have been installed into the baggage handling areas, have a throughput that is two to three times higher, but they are especially expensive due to extremely large up-front installation costs. Future plans to integrate these systems into baggage handling areas also cause concern because of the inadequate space to handle installation of the massive machines.

There are two main categories where new technologies are striving to achieve improvements: throughput and accuracy. The throughput of a machine is of significant importance to manufacturers of these devices because a faster machine yields quicker service and shorter lines for airport passengers. More efficient service keeps both the screeners and passengers content.

The Transportation Security Laboratory (TSL) is currently a part of TSA. TSL certifies only machines which pass their strict guidelines for acceptable false positive and false negative rates. There are two types of errors these systems can make. They represent the accuracy of the devices. A false positive, also known as false alarm, occurs when the system identifies a substance as an explosive material when it is not. This error is problematic because it leads to further security steps, which can cause the system to slow, leading to unhappy passengers and additional costs. Explosive detection devices can produce false alarms that must be resolved by human intervention or technical means (Singh and Singh 2003). Even modest false alarm rates can lead to thousands of items requiring additional security given the millions of bags processed every day. The second type of error, a false negative, occurs when the system fails to identify explosive material. This type of error is catastrophic because a threat has passed through the security system.

Although the downfalls of current security devices have been pointed out, the EDS and ETD machines are superior to all other devices at this time because they are the only security systems federally certified. The following section will highlight the increasing capabilities and also the drawbacks of new and upcoming technologies.

2.2.2 Upcoming technologies

The Transportation Security Administration (TSA) continuously researches the types of detection technologies available for use in airports. The main factors involved in the choosing of machinery are the speed, false alarm rate, distinguishability of explosives from other materials, the cost and the role of human operators. The most emphasized hindrance of the current US airport security system is the lack of concentration on research of new technologies. For example, Congress mandated 100% checked baggage screening by means of ETD or EDS systems. The system will be saturated with these two excessively expensive screening systems. Instead of throwing millions of dollars into these mediocre technologies, it has been suggested that the US invest money into researching the newest technologies in order to maintain the optimal screening strategy (Butler and Poole 2002). Many of the new technologies mentioned above have the potential to improve the entire screening environment in terms of screening accuracy, cost and passenger convenience.

All of the x-ray security technologies: high speed, dual-energy, multi-energy, backscatter and coherent scatter have a much higher throughput than the current EDSs. Throughput is one of the characteristics of security systems that the US strives to improve. Although the automated x-ray systems, also known as dual-energy, are currently used in Europe to fulfill their 100% baggage screening requirement, they are not accurate enough to be certified for use in the US because the false clear probabilities of these devices are highly variable depending on the nature of the threat. A proposed security strategy uses these systems as the first tier of a two- or three-level screening system (Poole and Passantino 2003). The bags signaling alarms are then routed to an EDS machine on the next tier which offers higher accuracy. Alarms on the second tier will either continue to a third tier EDS machine or be re-routed through the second tier. The use of the automated x-ray high-throughput device has the potential to speed up the screening process resulting in a more cost effective screening strategy.

The backscatter x-ray has twice the throughput of currently certified EDSs as well as significantly lower cost. This technology is currently in use at European airports and also by the US Air Force to screen baggage and parcels before flight. The screening time could presumably be cut dramatically if these systems were to replace the EDSs.

Quadruple resonance (QR) devices have very small staffing requirements, which can result in lower costs. If an explosive is present, the system will emit a signal to the system's internal computer for analysis. The device requires no interaction or interpretation. The coherent X-Ray scatter device provides a specificity of the molecular make-up unmatched in all other technologies. This specificity should produce relatively low false positive rates. Each of these technologies has characteristics that could benefit aviation security in the US. The major downfall is they are not currently certified for use in the United States.

CHAPTER 3
SECURITY OPERATIONS

The TSA made significant progress in their attempt to fulfill the requirement that 100% of checked baggage undergo explosive detection equipment screening. However, significant work and costs still lie ahead. Not all airports have installed the explosive detection equipment required; airports remain that are currently using alternative screening methods (Mead 2003).

3.1 Current TSA Environment

Current airport security screening procedures have resulted in long security lines and personal intrusion. These unpleasant experiences have been termed the 'hassle factor.' This hassle factor is hurting the airline industry. A survey by Delta airlines of its frequent flyers found that nearly 25% cited the hassle factor as a reason for not flying (Poole and Passantino 2003). Issues similar to this along with the immediate need for heightened security have led the TSA to reevaluate the current security environment.

The TSA is using a two-phase deployment strategy for EDS and ETD systems. To begin with, some airports use EDS as the primary security system with the trace machines used to resolve alarms. Other airports use the trace machines exclusively and some use a mix of EDS and trace machines to screen checked baggage (Mead 2002). The TSA now faces the second phase of deployment which consists of integrating the EDSs into baggage handling systems at the largest airports. EDS machine deployment continues to cause problems because the cost of integrating these machines into the baggage handling systems could be significantly more than the amount allotted by the TSA for machine installation. The integration will entail extensive work and also high costs. It has not yet been determined who will be responsible for these costs.

Butler and Poole (2002) believe more attention should be focused on developing new advanced security technology and increasing the use and deployment of current equipment compared to the concentration of efforts on current EDSs. Mead (2001) states that TSA short-term goals include improvement of screener proficiency and the utilization and efficient deployment of the security equipment currently on hand. Long-term goals include the development and deployment of advanced security equipment that is capable of screening all baggage, passengers, crews and all others with access to aircraft for all threat objects.

Dillingham, Director of Civil Aviation Issues, testified in 2001 that the TSA has worked to improve screener proficiency. Many problems related to sub-par performance were due to low wages and minimal benefits, which resulted in extremely high turnover rates (GAO-01-1171T). Since legislation transferred the responsibility of improving security from the airlines to the TSA, TSA has hired, trained and deployed approximately 40,000 individuals for the screening workforce (GAO-03-1150T). One aid to improve screener performance is Threat Image Projection (TIP), a device which projects the image of a threat onto the screener's monitor to keep screeners alert, provide real-world conditions and to measure screener performance in identifying threat items. Most EDS machines are now equipped with TIP and all x-ray machines used to screen passenger carry-on articles were TIP ready as of January 1, 2004.

Security costs are much greater than the government anticipated. In August 2001, the Air Transport Association estimated that the annual security cost for the airline industry totaled approximately $1 billion. However, TSA expenditures exceeded $5.8 billion for the fiscal year (FY) 2002 (Mead 2003). Because of the increasing trend in annual security costs, cost controls must be a priority for the TSA. Mead states that the overriding goal for TSA must be to provide tight and effective security in a manner that avoids waste and ensures cost-effective use of taxpayer dollars (2003). The improvements in aviation security were noteworthy and carried a large price tag.

In 1998, the Federal Aviation Administration (FAA) introduced a Computer Assisted Passenger Prescreening System (CAPPS) to determine those passengers (and their corresponding checked bags) that could not be cleared from posing a potential security risk to the airspace system (Mead 2002a,b). In particular, *selectees* are those passengers that are not cleared by CAPPS, while *non-selectees* are those passengers who are cleared by CAPPS (Jacobson et al. 2003c). Another step towards improving airport security technology will be the development and implementation of CAPPS II in conjunction with other security components including: on-site passenger and baggage screening, federal air marshals and hardened cockpit doors. Another possibility is the implementation of a registered traveler program.

Airport security as a whole has many areas that need additional advancements. One of these is airport access controls. Access controls include current requirements intended to prevent unauthorized individuals from using forged, stolen or outdated identification or their familiarity with airport procedures to gain access to secured passenger areas or to ramps and doorways leading to the aircraft (GAO-01-1171T). Information and technology are beginning to play a larger role in the security industry. TSA is currently working on the establishment of a Transportation Workers Identification Card (TWIC). Once in full operation, the program will use the TWIC card as the standard credential for airport workers and will be accepted by all modes of transportation. These cards will be necessary to grant persons access to secure, nonpublic areas (GAO-03-1150T).

3.2 Proposed Procedure

Currently with the 100% checked-baggage mandate, equal resources are dedicated to each and every bag. Butler and Poole (2002) believe the focus of baggage inspection should be shifted from detecting objects to identifying high-risk passengers and matching inspection technologies to those risk groups. Passengers should be sorted by risk levels with increased technological resources used on higher-risk passengers. This risk-based screening approach divides airline passengers into three groups:

- Those about whom a great deal is known, all of it consistent with that person not being a threat. (Low Risk)
- Those about whom very little is known, all of it consistent with that person not being a threat. (Medium Risk)
- Everyone else. (High Risk)

It seems reasonable to allocate more resources to those passengers in the third group than those in the second and more on the second group that those in the first rather than spending the same amount on each passenger regardless of their group placement (Poole and Passantino 2003).

This approach is similar to the other risk-based programs such as the "known shipper" program used by commercial US cargo operators and also US customs programs such as INSPASS and NEXUS. Air and surface cargo operations rely on federally accepted known shipper programs, which reduce the level of inspection required for a shipper who is known to be low risk. INSPASS is similar to a trusted traveler program for US citizens returning from overseas. This program was developed in order to comply with the 1990 law which mandated that immigration waiting periods be less than 45 minutes. NEXUS is a program at the US-Canadian border, which similar to the INSPASS, permits travelers to volunteer for pre-clearance enabling them to bypass long lines when passing through border facilities (Poole and Passantino 2003). There are two main characteristics that risked-based security must posses: a system for pre-clearing the subset of low-risk passengers and a system for selecting out high-risk passengers.

TSA is developing proposals to efficiently use passenger screening resources (GAO-03-1150T). These proposals include the development of a registered traveler program which will pre-clear a subset of low-risk passengers. These low-risk passengers will also receive expedited processing at airports. This program will be available to voluntary participants who successfully pass background checks. The registered traveler program plans to issue either unique identifiers or cards which enable these chosen passengers to undergo an efficient, time-reduced screening experience. This program will allow airports to allocate fewer security resources to those individuals who are low risk. If, for example, persons cleared by the registered traveler program were not required to have their bags screened by the expensive EDS machines, a large airport might need 20 EDS machines rather than 40 or 50. This simple example illustrates the potential increase in cost effectiveness and airport security.

The group of low risk passengers will include airline flight crews, cockpit crews and those individuals who have gone through extensive background checks needed to receive government security clearances. The individuals who complete the subset of low risk passengers are those who have volunteered to undergo a civilian version of a security clearance. All of the passengers mentioned above will be invited to participate in the registered traveler program. The program has three key components necessary for success. The first component is the set of cleared passengers. Once registered, the passengers must verify their identify upon entering the airport. This verification is done by means of a card encoding biometric information unique to that person. The biometric information could be a variety of things such as: finger prints, face or hand geometry, or an iris scan. The final element of the registered traveler program is that it must be kept secure. Security of the passenger list and information is essential because any type of breach could lead to unauthorized persons entering the airport.

Poole and Passantino (2003) define the fundamental characteristic of risk-based decision-making as the ranking of risks along a quantifiable scale, typically expressed numerically like a credit report score. Following the risk level assessment, the airport security resources are applied in measures proportional to the risk level. Those labeled high-risk receive the most extensive security scrutiny available. Mid-level risks receive examination and inquiry; however it is not as substantial as the inspection received by members of the high-risk group. Substantial change in the security system will occur for the low-risk group which will receive the least inspection, intentionally so.

The US currently uses the Computer Aided Passenger Prescreening System (CAPPS), a scoring system to rate risk levels for passengers passing through airport security. Following the events of September 11, 2001 Congress determined that the existing CAPPS system was not effective as a counter-terrorist measure.

In a Congressional briefing Bell (2003) states that in order to establish a new layered security approach, CAPPS II is being developed to enhance airline security while simultaneously improving the convenience of airline passengers. The CAPPS II system is an automated passenger screening system that uses personal information, currently available from the reservation and ticketing process, to confirm the passenger's identity and issues a risk level that determines whether any further screening is necessary. There is no storage of passenger information. However, a database is maintained with information about identified terrorists. However, before implementation, many privacy concerns must be addressed.

Barnett (2003) researches the CAPPS II system and poses the following questions:

- Will the system work?
- How will we know whether it is working?
- How will it be used?
- What might be the net effect of the system on aviation security?

These questions will likely be answered as time passes. Barnett suggests that the public should be better informed about the CAPPS II system. He raises several cautionary points: it is unclear how far CAPPS II can raise the likelihood that an actual terrorist will be channeled to high-level airport security screening. It will also be difficult to test the validation of CAPPS II. Presumably, scarce data about past terrorists would be used to develop the model. If so, testing the model based on past terrorist events would come close to circular reasoning. Another testing method, feeding various terrorist plots into the computer, would not succeed because it is implausible to assume that experts can predict how future terrorists will behave. In addition, reduced screening for low-risk passengers could raise the probability that a terrorist mistakenly classified low-risk would succeed in destroying an aircraft. Finally, even the smallest increase in the chance of a false-negative error could cause CAPPS II to fail a cost-benefit test. The use of the CAPPS II system has the potential to increase the cost effectiveness of airport security, however the issue is what measures should be undertaken to improve CAPPS. Although some may question the effectiveness of CAPPS II, in a Congressional briefing Bell (2003) states that CAPPS II is critical to the protection of United States citizens, our airline industry, and our economy.

Even though CAPPS is currently used, the security system is not risk-based because the screening procedures do not effectively differentiate between high and low risk passengers. With the 100% baggage screening mandate, all bags receive the same scrutiny. The research in this thesis presents a cost model which will illustrate the possible benefits of a risk-based approach to airport security. Dillingham testifies that CAPPS II and the registered traveler program have the potential to make screening more efficient (GAO-03-1150T). The General Accounting Office in review of the concept asserts that the registered traveler program could potentially improve aviation security and more effectively target resources. The program would improve both the passenger and baggage screening processes. The passenger screening process changes would vary with each risk category.

A proposed approach (Poole and Passantino 2003) will use average screening for ordinary travelers, thorough screening for high risk travelers and less detailed screening for those in the registered traveler program. Participants in the registered traveler program will have their own security lanes. Their identity is confirmed at either the check-in counter or at the registered traveler kiosks. The registered travelers will no longer have to remove their laptops or pre-9/11 toiletries. These passengers will pass through standard metal detectors and the carry-on bags will be processed by high-speed x-ray machines. All other passengers will pass through standard checkpoint lanes. The passenger boarding passes will electronically indicate their assessed risk level; high or medium risk. Selectees, those identified as high risk, will have their carry-on baggage screened via explosive trace detection (ETD) as a standard procedure. For additional scrutiny, passengers may be subjected to backscatter machines to screen for threat objects on their person. Non-selectee passengers will continue through regular lanes whose technology and procedures would be essentially the same as today's TSA screening methods.

Given the new reality of global terrorism, it makes sense to continue two policies that were adopted following 9/11: positive passenger-bag matching and 100% screening of checked bags for explosives; however a risk-based approach would permit the latter to be done in a more effective manner (Poole and Passantino 2003). A new multi-tiered baggage processing procedure would be located in the baggage handling area. Figure 3.1 shows a typical 3 layer baggage processing system. The facility layout of US airports may need to be modified to accommodate the newly revised flow of bags. These multi-tiered systems will resemble those currently in use in Europe. Figure 3.2 depicts the logic of system operations.

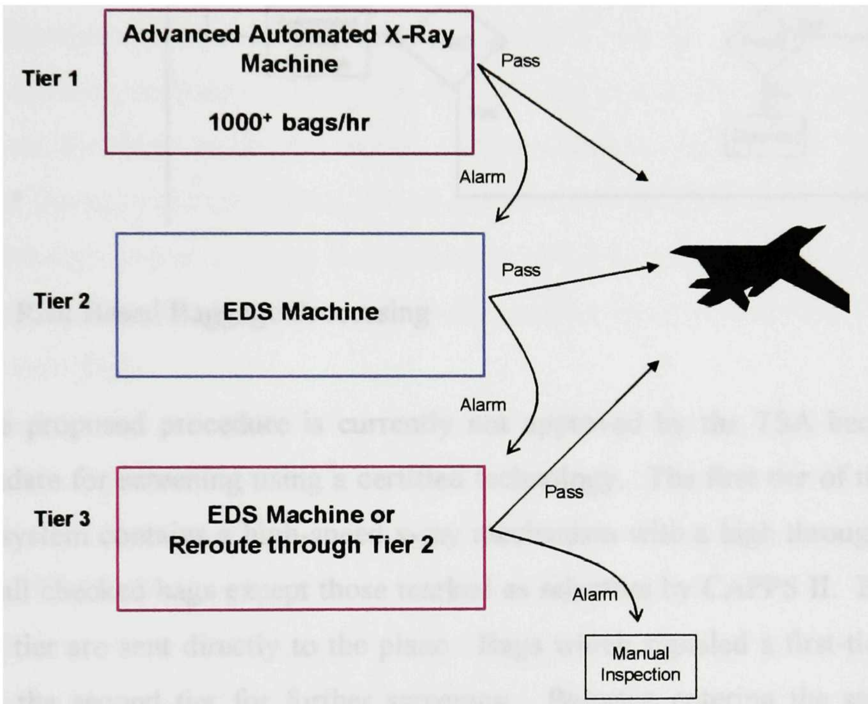

Figure 3.1: Three-Tiered Baggage Processing Procedure

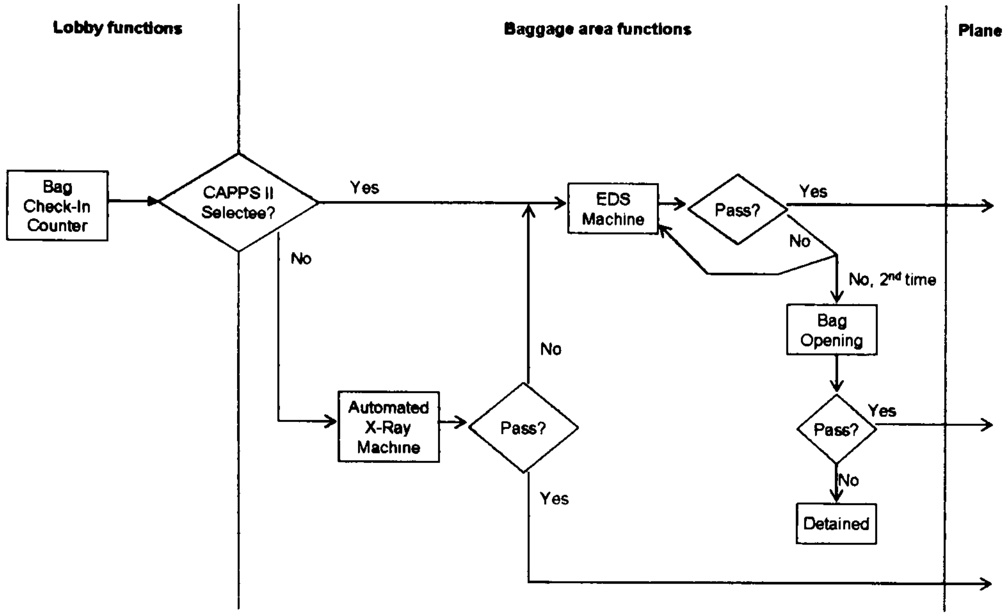

Figure 3.2: Risk Based Baggage Processing

The proposed procedure is currently not approved by the TSA because of the 100% mandate for screening using a certified technology. The first tier of the proposed screening system contains a high-speed x-ray mechanism with a high throughput, which processes all checked bags except those marked as selectees by CAPPS II. Bags cleared at the first tier are sent directly to the plane. Bags which signaled a first-tier alarm are sent on to the second tier for further screening. Baggage entering the second tier is screened by an EDS machine or by a replacement technology. The third tier of the baggage screening system is either an additional EDS machine or simply a second pass through the second tier. The third tier processes any bags signaling an alarm on the second level. Any alarms on this tier are manually inspected in a secure location.

3.3 Previous Research

Airport security systems have been analyzed in many different fashions. Some research focuses on cost while others are based on other performance measures.

Jacobson et al. (2001) measure the effectiveness of baggage screening devices with baggage value performance measures. The first measures used were the Uncovered Flight Segments (UFS) and Uncovered Passenger Segments (UPS). These two performance measures provide a useful framework for measuring the effectiveness of a baggage screening security device deployment to a given station. Stations refer to the airport or terminal being examined. Flight Segment Baggage Value (FSBV) and the Passenger Segment Baggage Value (PSBV) have also been used (Jacobson et al. 2003d). The FSBV assigns a value to each selectee bag based upon the proportion of the baggage on that flight segment that the bag represents. The PSBV assigns a value to each selectee bag based on the proportion of baggage that the bag represents times the number of passengers on the flight segment. Integer programming is used to solve for screening assignments that optimize the values of each performance measure. Using these baggage value performance measures gives the system the ability to treat each selectee bag as an individual rather than as part of a group and the model solutions include partial screening of baggage on a flight.

Previous work has addressed cost-benefit tradeoff questions concerning the use of EDS machines. Using pre-September 11th, 2001 data, Jacobson et al. (2003c) develop and analyze a cost model that quantifies the expected annual cost associated with screening different combinations of selectee and non-selectee checked bags. They conclude that as excess EDS baggage screening capacity is used to screen non-selectee checked bags, the expected annual cost increases. They also report that the marginal increase in security per security dollar spent is significantly lower when non-selectee checked bags are screened than when only selectee checked bags are screened.

Jacobson et al. (2003b) extend the cost model introduced in Jacobson et al. (2003a) to analyze the use of EDSs within the guidelines set forth in the ATSA. They also incorporate the impact of deterrence. Deterrence in this context is defined as the effect that screening a greater proportion of checked bags has on the level of threat in the system. Therefore, deterrence can translate into a reduction in the level of threat within the system. Using post-September 11th, 2001 data, Jacobson et al. (2003b) analyze and compare scenarios for screening different combinations of selectee and non-selectee checked bags using various cost measures. Their key conclusion is that 100% checked baggage screening may provide effective deterrence against terrorist activities, depending on the perceived cost of a terrorist incident and the deterrence effect achieved by screening only selectee checked bags.

3.4 Problem Statement

As previous work has only focused on the EDS and ETD security systems, this thesis introduces a cost model to measure the costs and benefits associated with various security configurations involving single and two-device scenarios. In addition to EDS and ETD systems, the cost model also introduces two alternative screening systems: dual-energy x-ray and backscatter devices. These machines are not currently certified by Transportation Security Laboratory (TSL) to screen checked bags, but research in security technology suggests that these types of screening devices may be deployed in US airports in the future. In particular, the expected annual direct cost of using these four devices for 100% screening of selectee and non-selectee checked baggage under various screening scenarios is obtained. The tradeoffs between using single-device strategies or a sequenced combination of devices are also studied. Lastly, the expected number of successful threats under the different checked baggage screening scenarios with 100% checked baggage screening is studied.

The previously described risk-based system proposed by Poole and Passantino uses the multi-level security screening procedure. The multi-device system must be analyzed for the optimal device configuration. This thesis will study the two-device system. The outcome of this analysis will be useful to decision makers evaluating the proposed risk-based security system. If implemented, results from this study will be beneficial in the analysis of optimal device configurations for the two-tiered baggage screening system.

CHAPTER 4
METHODOLOGY

The main objective of this thesis is to evaluate the cost effectiveness of the checked baggage screening systems currently in US airports supplemented with evaluations of the newest technologies which could possibly be used to screen checked baggage in the future. The research analyzes single-device systems and several two-device systems.

4.1 Previous Cost Model

The cost model in this thesis includes device and system probability concepts introduced by Kobza and Jacobson (1997). The develop probability models based on Type I (false positive) and Type II (false negative) errors. The concept of controlled sampling is introduced, a concept in which objects may take different paths through the system. Their results indicate that, for specific threat levels, multiple-device systems can be identified which outperform single-device systems for certain error probability measures. They present the concepts of device and system probabilities which will be applied in the cost model of this research. Previous cost models failed to incorporate the system probabilities since they considered only single devices. The cost model was first introduced by Jacobson et al. (2003a). This thesis modifies their model.

4.2 Data Needs

Data is needed to support the cost model used in this analysis. The data is represented as parameters that can be classified into four groups: 1) probability parameters, 2) cost parameters, 3) time parameters and 4) volume parameters.

4.2.1 Probability Parameters

The first four probability parameters are random variables obtained based on the testing and evaluation of a baggage screening security device. Such testing is required before a device can gain federal certification. The probability that a checked bag contains a threat is assessed by personnel within the TSA based on the perceived threat level. This value is considered highly sensitive and may change based on changes in national and/or international situations or intelligence information.

$P_{FA} = P_{A|NT}$ = probability that a device falsely indicates a threat (false alarm)

$P_{TC} = P_{NA|NT} = 1 - P_{FA}$ = probability of a true clear for a checked bag

$P_{TA} = P_{A|T}$ = probability that a device correctly detects a threat (true alarm)

$P_{FC} = P_{NA|T} = 1 - P_{TA}$ = probability of a false clear for a checked bag

P_T = probability that a checked bag contains a threat

With multiple-device systems, a system alarm must be distinguished from a device alarm. Two possibilities for defining a system alarm in a multiple-device system are:

- Case 1: An object triggers an alarm at any device in the system.
- Case 2: An object triggers an alarm at all the devices along its path through the system.

System alarms in this research will be defined by Case 2. The motivation for choosing this definition is that the multiple devices check each other and the system only gives an alarm if all the devices on the path agree. In addition, Case 2 is the rule currently in use in most airport security operations in the United States. The formulations for Type I and Type II system error probabilities and an illustration of a two-device system are shown below.

$$P_{FA} = P_{A|NT} = P^{D1}_{A|NT} - P^{D1}_{A|NT}(1 - P(AD2|AD1 \cap NT)) \quad 4.1$$

$$P_{FC} = P_{NA|T} = P^{D1}_{NA|T} + (1 - P^{D1}_{NA|T})P(NAD2|AD1 \cap T) \quad 4.2$$

where D1 = Device 1
D2 = Device 2
A = Alarm
NA = No Alarm
T = Threat
NT = No Threat

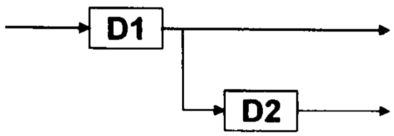

Figure 4.1: Two-Device System

See Kobza and Jacobson (1997) for a detailed description of system probability models with the comprehensive mathematics supporting the theory.

4.2.2 Cost Parameters

Expected values for the first four cost parameters are obtained based on information collected and analyzed by the TSA. The expected value for the next cost parameter is available from the baggage screening security device manufacturer.

C_{FA} = cost of a false alarm = cost of falsely indicating a threat in a checked bag

C_{FC} = cost of a false clear = cost of not detecting a threat in a checked bag

C_{TA} = cost of a true alarm = cost of correctly detecting a threat in a checked bag

C_{TC} = cost of a true clear = cost of correctly not indicating a threat in a checked bag

C_O = annual maintenance costs (operational) for a baggage screening device, including annual lease expenses. This is independent of the volume of checked bags.

C_I = cost of operating a baggage screening security device, per checked bag inspected

C_F = cost of purchasing the baggage screening device

Note that in most airports, baggage screening security devices are not operated twenty-four hours per day. Therefore, ample non-operational time is available for maintenance; hence breakdowns rarely occur while the devices are in operation. The expected value for the last cost parameter was obtained from the TSA based on salaries paid to the federal employees hired to operate the baggage screening security devices and information from the manufacturer. Note that the maintenance and operational cost per year for a baggage screening security device, C_O, is assumed to be a fixed cost, independent of the volume of checked bags screened, while C_I is the variable cost of screening each checked bag.

4.2.3 Time Parameters

These two time parameters are assumed to be deterministic, obtained based on information available from the baggage screening security device manufacturer as well as insights from TSA personnel.

N_1 = number of years of useful life for a baggage screening security device before technical obsolescence

N_2 = number of years of useful life for a baggage screening security device before it wears out due to being in operation

4.2.4 Volume Parameters

The first two volume parameters are deterministic, available from the baggage screening security device manufacturer. The last two volume parameters are random variables. Their expected values were obtained based on discussions with the TSA, and are a function of the airport under study. Different values can be entered into the model for the last two parameters and the results can be examined.

S_C = number of checked bags a baggage screening security device can screen before wearing out due to being used

S_{CAP} = number of checked bags a baggage screening security device can process per year (i.e., the baggage screening capacity)

S_1 = number of selectee checked bags received per year at the airport

S_2 = number of non-selectee checked bags received per year at the airport

4.3 Cost Model

This section describes the cost models used to analyze the cost and benefit of 100% checked baggage screening. The CAPPS multiplier β is defined as the ratio of the proportion of threats in selectee versus non-selectee checked baggage. This value can be modified once CAPPS II is fully developed and the new value for β is found. Given values for the CAPPS multiplier and the probability that a checked bag contains a threat, P_T, as determined by the TSA, the probability that a selectee checked bag contains a threat ($P_{T|S}$) and the probability that a non-selectee checked bag contains a threat ($P_{T|NS}$) can be computed using

$$P_{T|S} = P_T [1 + ((\beta-1)S_2) / (\beta S_1 + S_2)], \quad 4.3$$

$$P_{T|NS} = P_T [1 - ((\beta-1)S_1) / (\beta S_1 + S_2)]. \quad 4.4$$

Note that it is reasonable to assume that $\beta > 1$, since CAPPS is designed to screen out passengers who are less likely to be threats to the system (i.e., non-selectee passengers).

To determine the effective lifetime of a baggage screening security device, three factors must be considered. First, regardless of usage, a baggage screening security device will become technologically obsolete and require replacement in N_1 years. Second, regardless of the volume of checked bags processed, a baggage screening security device will wear out in N_2 years due to bearing erosion and other factors resulting from it being turned on for any length of time (i.e., a baggage screening security device wears out from being operational). Third, regardless of the length of time that a baggage screening security device is in use, it can only process S_C checked bags before total replacement of the unit is required (i.e., a baggage screening security device wears out from being used to screen checked bags).

To determine the effective lifetime of a device, for example an EDS, consider the number of checked bags an EDS can process before wearing out is estimated to be S_C = 10,000,000 bags. Note that since the number of checked bags an EDS can screen in a year is estimated to be S_{CAP} = 270,000 checked bags, which is obtained (approximately) by multiplying six peak hours per day of operation by 125 checked bags per peak hour by 360 days, then the number of EDSs needed to handle the volume of all checked bags at an airport is $M = \lceil (S_1 + S_2) / S_{CAP} \rceil$ or to handle only selectee checked bags at an airport is $M = \lceil S_1 / S_{CAP} \rceil$. Using this information, the effective lifetime of an EDS is

$$N_{eff} = \min \{N_1, N_2, (M)(S_C) / (S_1+S_2)\}. \qquad 4.5$$

The cost model captures the annual cost (both direct and indirect) of operating a baggage screening security device. Direct costs include the annual purchasing, maintaining, and operating costs of the baggage screening security device, as well as costs associated with processing the volume of true clears, addressing true alarms (including the possible closing of an airport terminal), and resolving false alarms (including the possible need to call in law enforcement officers and bomb squads). Indirect costs are costs associated with false clears or not screening checked bags that result in a threat incident. Since such incidents are typically rare events and the time between them may be long, the associated costs may only need to be paid once every ten or twenty years. The cost model accounts for this by amortizing the cost (using the straight line method) and representing it as an annual cost. The cost model is as follows:

$$\begin{aligned} Cost = {} & M(C_F / N_{eff}) + MC_O + C_I(S_1+S_2)+C_{FA}P_{FA}[(1- P_{T|S})S_1+(1-P_{T|NS})S_2]+ \\ & C_{FC}P_{FC}[P_{T|S}S_1 + P_{T|NS}S_2]+C_{TA}(1-P_{FC})[P_{T|S}S_1+P_{T|NS}S_2]+ \\ & C_{TC}(1-P_{FA})[(1-P_{T|S})S_1+(1-P_{T|NS})S_2] \qquad 4.6 \end{aligned}$$

where the

- first component represents the annual (direct) cost of purchasing the baggage screening security device,

- second component represents the annual (direct) cost of operating / maintaining the baggage screening security device,
- third component represents the annual (direct) inspection cost for checked bags screened by the baggage screening security device,
- fourth component represents the annual (direct) cost of false alarms,
- fifth component represents the annual (indirect) cost of false clears,
- sixth component represents the annual (direct) cost of true alarms,
- seventh component represents the annual (direct) cost of true clears.

The cost model in equation 4.6 measures the annual cost of using a baggage screening security device to screen S_1 selectee checked bags and S_2 non-selectee checked bags. Note that if S_2 is set to zero, then equation 4.6 reduces to the case of screening only selectee checked bags. The expected annual cost is computed using the expected value for the parameters in the cost model since the cost parameters and the probability parameters that are multiplied in equation 4.6 are all independent. All the values, distributions, and expected values of the parameters for the devices (EDS, ETD, Automated X-Ray and Backscatter) are given in Table 4.1; note that TSA personnel provided data and information that were used to obtain these values and distributions. The values in Table 4.1 shown below represent device specific parameters and those listed in Table 4.2 are system parameters independent of the devices.

Table 4.1: Device Parameter Values, Ranges, and Distributions

Parameter	Expected Value (EDS)	Expected Value (ETD - TC)	Expected Value (ETD - TO)	Expected Value (ETD - AG)	Expected Value (XRAY)	Expected Value (BACK)
P_{FA}	0.125	0.1	0.05	0.02	0.2	0.05
P_{FC}	0.05	0.2	0.15	0.1	0.05	0.05
C_F	$1,000,000	$45,000	$45,000	$45,000	$500,000	$333,333
C_O	$125,000	$14,000	$14,000	$14,000	$62,500	$41,667
C_I	$0.19	$0.30	$0.83	$1.29	$0.03	$0.09
N_1	10 years	5 years	5 years	5 years	10 years	10 years
N_2	10 years	5 years	5 years	5 years	10 years	10 years
S_C	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000	10,000,000
S_{CAP}	270,000	164,160	60,480	38,880	1,728,000	540,000
Bags/Hour	125	60	28	12	800	250

Table 4.2: System Values

Parameter	System Value
S_1	125000
S_2	2500000
P_S	0.05
P_T	1.0E-09
C_{FA}	$9.16
C_{FC}	$30,000,000,000
C_{TA}	$1,000,000
C_{TC}	$0
β	114

The cost of a false clear, C_{FC}, is both large and difficult to estimate. Therefore, a second cost model is formulated that only considers direct costs (i.e., all but the fifth term in equation 4.6 is used). The resulting direct cost model represents the annual direct cost of operating a baggage screening security device.

$$\text{Cost}_D = M\,(C_F / N_{eff}) + M\,C_O + C_I\,(S_1 + S_2) + C_{FA}P_{FA}\,[(1 - P_{T|S})\,S_1 + (1 - P_{T|NS})\,S_2] + C_{TA}\,(1-P_{FC})\,[P_{T|S}\,S_1 + P_{T|NS}\,S_2] + C_{TC}\,(1-P_{FA})\,[(1-P_{T|S})\,S_1 + (1-P_{T|NS})\,S_2] \qquad 4.7$$

A third measure used to quantify the effectiveness of 100% checked baggage screening is the expected number of successful threats, which is just the fifth term in equation 4.6 divided by C_{FC}.

$$E[ST] = P_{FC} [P_{T|S}S_1 + P_{T|NS}S_2] \qquad 4.8$$

Table 4.1 contains the expected values for the parameters that are random variables in equations 4.6, 4.7, and 4.8 for all the devices studied. Note that there are three ETD machine strategies used to sample checked baggage for explosive residues. The first strategy is *trace closed* (TC), where only the outside of a checked bag is sampled. The second strategy is *trace open* (TO), where both the outside and the inside lining of a bag are sampled. The third strategy is *trace aggressive* (TA), which samples the outside and the inside lining, as well as any item larger than a soft-drink can (Butler and Poole 2002). Note that since they are security sensitive information, real values are not used for some of this data and cannot be disseminated in the public domain.

CHAPTER 5

MODEL ANALYSIS AND RESULTS

The cost model presented in Chapter 4 will give researchers a tool for evaluating a variety of scenarios which can be useful. The model was implemented in Excel. There are input sheets for the system parameters and one for each of the device scenarios. There are also output sheets for each scenario evaluated in the cost model. Currently, the model is able to evaluate various single or dual-device scenarios. The results for each scenario tested are shown below.

The model was constructed as one simple Excel file with separate sheets for each of the following: system parameters, single-device parameters, dual-device parameters, outputs for each scenario and graphed results. The newly modified cost model uses consistent inputs, all from one source only. If an input is changed, there is no need to change it in any additional places because the model automatically uses the most recent value. The model is easily adaptable to a changing security environment. In addition to the ease of adaptability, the cost model is user-friendly. A novice can understand how to use and run the model and therefore does not need a detailed user-guide. The next sections explain the cost model in detail.

5.1 Single Device Scenarios

The expected annual direct cost and the expected number of successful threats measures introduced and discussed in Section 4.3 provide tools for comparing the relative effectiveness of different baggage screening strategies using EDSs, ETDs, dual-energy x-ray and backscatter technologies. Seven single-device and twelve dual-device baggage screening scenarios are studied with the ability to distinguish between selectee and non-selectee checked bags.

For the single-device scenarios, one device was used to screen all checked bags (selectees and non-selectee). The following scenarios were examined.

Scenario 1: EDS

Scenario 2: ETD – TC (trace closed)

Scenario 3: ETD – TO (trace open)

Scenario 4: ETD – TA (trace aggressive)

Scenario 5: ETD - 40-40-20 (40% TC, 40% TO, 20% TA)

Scenario 6: Dual-energy X-Ray

Scenario 7: Backscatter

These single-device scenarios were studied and results for expected annual cost per bag and expected number of successful threats for each scenario are presented below.

Figure 5.1 reports the expected annual direct cost per checked bag for the various scenarios. First comparing the results of the scenarios which use ETD, the expected direct cost per screened bag of using an ETD with trace closed is always less expensive than using an ETD with trace open, which is always less expensive than using an ETD with trace aggressive. However, the expected number of successful threats per one billion checked bags is always smallest using an ETD with trace aggressive. This is reasonable, since trace aggressive results in fewer errors that can lead to a successful threat, though the lower throughput makes it more expensive to implement. Backscatter x-ray performs the best resulting in the lowest annual cost per bag. EDS and dual-energy x-ray systems have the highest costs. It is important to note that both the expected cost and expected number of successful threats are necessary in deciding which single-device scenario is best.

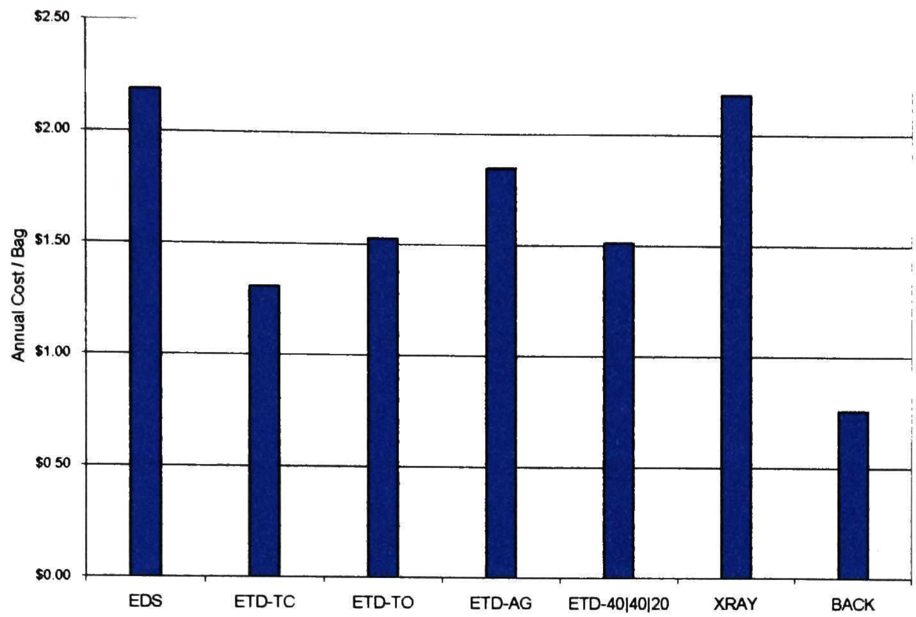

Figure 5.1: Single-Device Expected Annual Direct Cost / Bag

Figure 5.2 represents the expected number of successful threats per one billion checked bags for the single-device scenarios. Comparing the first two non-cascading scenarios, ETD is more cost effective than EDS, however EDS results in fewer successful threats than ETD. Automated x-ray machines have the highest cost and the expected number of successful threats is also high. This is due to the high level of variability in the false clear probability. The expected number of successful threats is the lowest with the EDS and backscatter systems. The results show that backscatter is currently the best option because it produces the lowest cost and the best value for expected number of successful threats. The ETD scenario fails to compete with the other three single-device scenarios because of the high value of the expected number of successful threats.

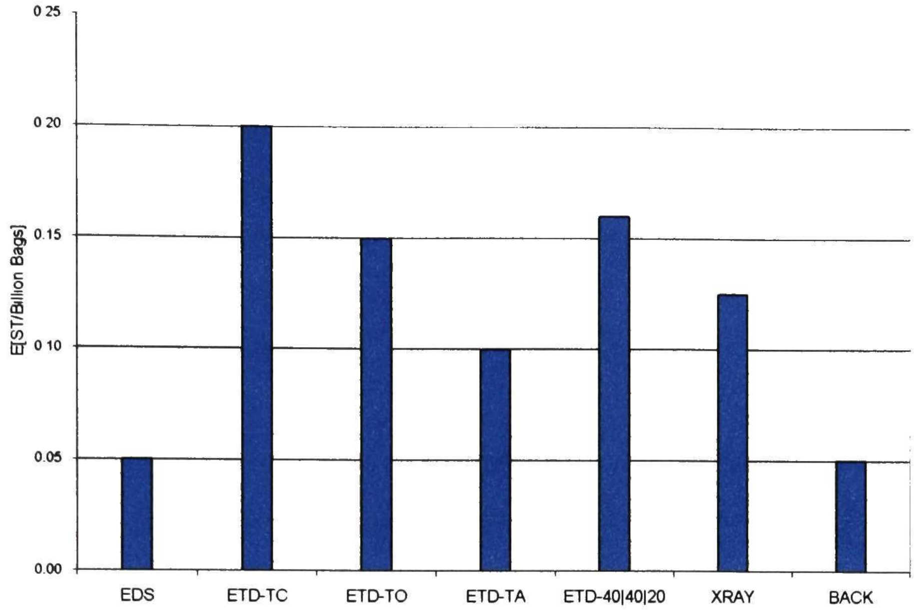

Figure 5.2: Single-Device Expected Number of Successful Threats/Billion Bags Checked

5.2 Two-Device Scenarios

Single-device scenarios have been evaluated, but if our airport security systems implement a system similar to the multi-tiered, risk-based scheme previously mentioned in Chapter 3, a model capable of comparing different device configurations will be useful. Currently, the Excel model is able to evaluate various two-device scenarios. These two-device scenarios are studied in this section and the results for expected annual direct cost and expected number of successful threats are presented.

Proposed security procedures include multiple devices when screening checked bags as shown previously in Figure 3.1. The following scenarios all use a cascading sequence of screening devices. All checked bags (selectee and non-selectee) first pass through one device and all bags signaling alarms are then screened by an additional device. The devices studied include: explosive detection systems (EDS), explosive trace detection-trace open (ETD-TO), dual-energy x-ray (XRAY) and backscatter x-ray

(BACK). Trace open is used as the chosen ETD method in this section because it is representative of typical ETD device operations.

Scenario A: All checked bags are first passed through an EDS. Bags signaling alarms are then screened by the following devices.

Case 1: ETD-TO

Case 2: XRAY

Case 3: BACK

Scenario B: All checked bags are first passed through a trace open ETD. Bags signaling alarms are then screened by the following devices.

Case 1: EDS

Case 2: XRAY

Case 3: BACK

Scenario C: All checked bags are first passed through a dual-energy x-ray machine. Bags signaling alarms are then screened by the following devices.

Case 1: EDS

Case 2: ETD-TO

Case 3: BACK

Scenario D: All checked bags are first passed through a backscatter machine. Bags signaling alarms are then screened by the following devices.

Case 1: EDS

Case 2: ETD-TO

Case 3: XRAY

These two-device screening scenarios were studied and results for expected annual cost per bag and expected number of successful threats for each scenario were obtained and are presented below.

Figure 5.3 illustrates the expected annual direct cost per checked bag for the various two-device scenarios. First we will evaluate the results of each scenario as a group. For Scenario A, where baggage is first screened by EDS followed by an alternate device, all three cases perform similarly in terms of expected direct cost. These scenarios result in annual costs at approximately $2 per bag inspected. For Scenario B, where baggage begins with ETD-trace open screening, all three cases give cost values in the $1.50-$2.00 ranges. This is slightly better than Scenario A. Scenario C first routes baggage through dual-energy x-ray screening with alarms being screened by three alternate devices. Scenario C results in the highest expected annual cost values. All three cases resulted in costs between $2.00-$2.50. For Scenario D, the baggage is first screened by the backscatter x-ray. This set of device configurations performs the best in terms of cost effectiveness with cost values ranging between $0.80-$1.20. When all the device setups are compared individually, the three cases from Scenario D achieve superior results in terms of expected direct annual cost.

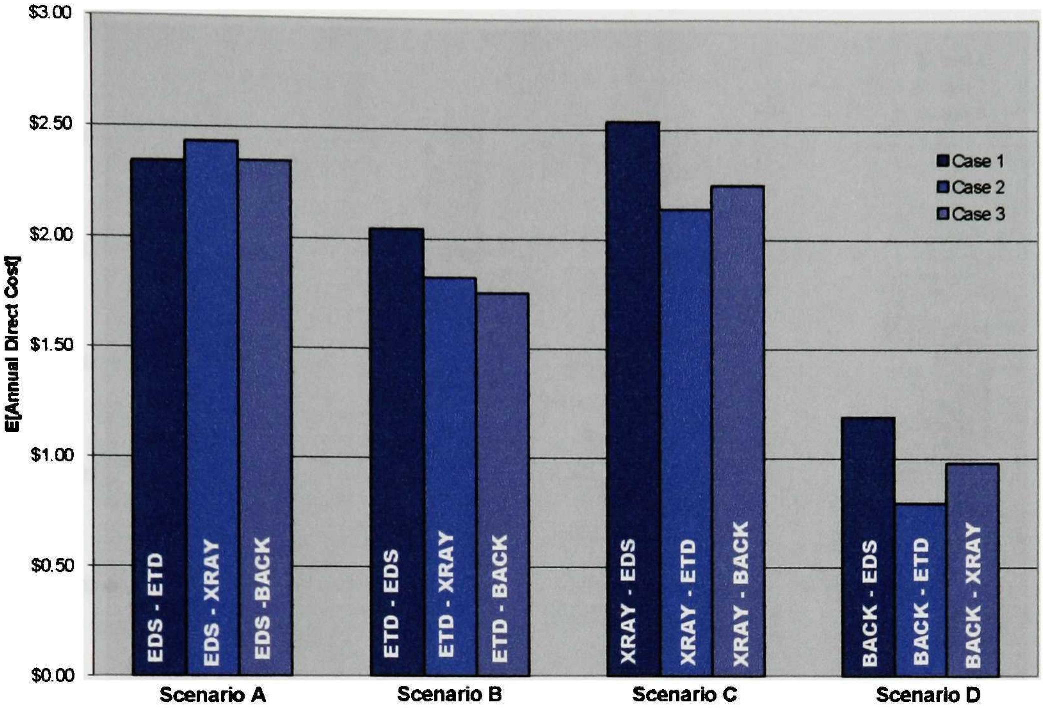

Figure 5.3: Two-Device Expected Annual Direct Cost / Bag

Figure 5.4 shows the expected number of successful threats per one billion checked bags for the two-device systems. The results clearly show that scenarios involving ETD trace open perform poorly. This is a result of the high false clear probability. Scenarios involving the dual-energy x-ray device also have inferior values for the expected number of successful threats. These automated x-ray machines have a high level of variability in their false clear rates. This is the reason these devices have not yet been certified. If device manufacturers can improve the false clear probabilities of their devices, the results of the device will improve. It seems from these results that the scenarios involving EDS and backscatter x-ray devices will deliver superior results. When considering both the expected annual direct cost and the number of successful threats, the scenarios involving both the EDS and backscatter systems perform the best in the cost model.

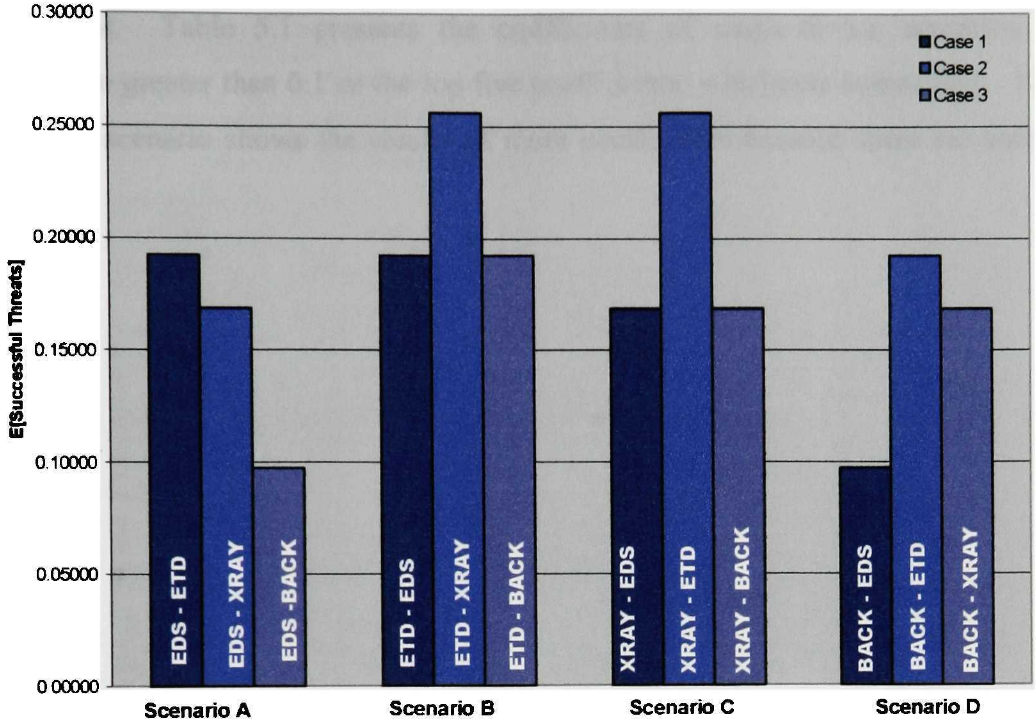

Figure 5.4: Two-Device Expected Number of Successful Threats / Billion Bags Checked

5.3 Sensitivity Analysis

The cost model was implemented in an Excel spreadsheet. Sensitivity analysis was performed using the software package *@Risk*. The parameters in Table 4.1 and 4.2 were varied uniformly over a range of +/- 10% of the value, with the exception of the P_{FC} for dual-energy x-ray. This parameter was varied uniformly from 0.1 to 0.15. A smaller range was chosen because the false clear probabilities for the automated x-ray are highly variable depending on the nature of the threat. This is the principle reason these devices have remained uncertified. For future certification, the error probability variability must be minimized. The values in Table 4.2 were used as inputs in each and every scenario. The values in Table 4.1 were used as inputs in the event the device was utilized in the scenario. The expected number of successful attacks and the expected direct cost for all single and two-device scenarios were monitored as outputs. The model was executed

10,000 times and the correlation coefficient between each input and output was computed by *@Risk*. Table 5.1 presents the coefficients of single-device scenarios with a magnitude greater than 0.1 or the top five coefficients, whichever comes first. The ETD 40/40/20 scenario shows the results of more coefficients because there are many more inputs.

Table 5.1: Correlation Coefficients for Single-Device Scenarios

	E[Annual Direct Cost]		E[Successful Threats]	
Device	Parameter	Correlation Coefficient	Parameter	Correlation Coefficient
EDS	P_{FA}	0.463	P_T	0.694
	C_{FA}	0.462	P_{FC}	0.693
	Operational Hrs.	-0.381		
	Operational Days	-0.373		
	Bags/Hr	-0.373		
ETD-TC	C_{FA}	0.607	P_T	0.702
	P_{FA}	0.596	P_{FC}	0.701
	Operational Days	-0.276		
	Bags/Hr.	-0.275		
	Operational Hrs.	-0.264		
ETD-TO	Bags/Hr	-0.497	P_T	0.699
	Operational Days	-0.490	P_{FC}	0.699
	Operational Hrs.	-0.488		
	$/Screener/Yr	0.372		
	C_{FA}	0.208		
ETD-TA	Operational Days	-0.537	P_T	0.701
	Bags/Hr	-0.516	P_{FC}	0.700
	Operational Hrs.	-0.506		
	$/Screener/Yr	0.366		
ETD 40/40/20	C_{FA}	0.442	P_T	0.851
	Operational Hrs. TO	-0.333	P_{FC} TC	0.403
	Bags/Hr TO	-0.329	P_{FC} TO	0.297
	Operational Days TO	-0.326		
	Operational Hrs. TA	-0.269		
	P_{FA} TC	0.263		
	Bags/Hr TA	-0.256		
	Operational Days TA	-0.248		
	$/Screener/Yr TO	0.229		
	$/Screener/Yr TA	0.192		
	P_{FA} TO	0.148		
XRAY	C_{FA}	0.704	P_{FC}	0.899
	P_{FA}	0.700	P_T	0.423
BACK	C_{FA}	0.601	P_T	0.700
	P_{FA}	0.598	P_{FC}	0.700
	Bags/Hr	-0.231		
	Operational Days	-0.224		
	Operational Hrs.	-0.213		

Several observations can be made from this analysis. First, the expected direct cost responds similarly for the following scenarios: EDS, ETD trace closed, dual-energy x-ray and backscatter. Moreover, the expected direct cost is most sensitive to the cost of a false alarm and the probability of a false alarm. Recall that direct costs exclude those associated with detected or undetected threats. Therefore, the direct costs reflect the operational costs associated with screening baggage and resolving false alarms. The ETD trace open, trace aggressive and 40/40/20 scenarios had results different from those described above. In these scenarios, the highest correlation coefficients resulted from the device inputs pertaining to bags/hour, operational days and operational hours. The reason these results differ from the other four scenarios is that the throughputs of the other devices are much higher. The low throughput of the trace open, trace aggressive and 40/40/20 devices severely increases the cost of inspection which in turn increases the expected annual cost.

The impact of threats on the system is reflected in the expected number of successful threats. For all of the single-device scenarios, this measure is highly correlated with the threat probability and the false clear probability. The threat probability's high correlation coefficient is of obvious importance. All of the scenarios are sensitive to the probability of a false clear, since every bag (and thus, every threat) mistakenly cleared results in a successful attack.

The two-device scenarios had somewhat similar results which are shown in the lengthy correlation tables in the appendix. First, the expected direct annual cost was studied as an output. All four groups of scenarios resulted in high correlation coefficients for the following inputs: the false alarm probability, the cost of a false alarm, the device throughput, operational hours and operational days. The correlation coefficients order varied slightly on a case by case basis. The results are similar to the single-device scenarios. The expected number of successful threats was also studied and the @RISK simulation gave results similar to the single-device scenarios. Each of the three scenarios, including all 12 cases gave equivalent outcomes. The results illustrated that the expected number of successful threats is highly correlated with the probability of a threat and the false clear probabilities of both devices in the scenario.

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

The model presented will give researchers a tool for evaluating a variety of scenarios which can be useful. The model was implemented in Excel. There are input sheets for the system parameters and one for each of the device scenarios. There are also output sheets for each scenario evaluated in the cost model. Currently, the model is able to evaluate various single or two-device scenarios. The results for each scenario include the expected annual direct cost and the expected number of successful threats per one billion bags screened.

The results indicate that for the current security setup, with current device cost and probability parameters, single-device systems are less costly and have lower expected number of successful threats. The ETD scenarios had a higher expected number of successful threats. This suggests that the use of ETD systems should be re-evaluated. The backscatter x-ray systems achieve superior results compared to all other single-device scenarios in terms of expected cost and number of successful threats. For this reason, US aviation security systems need to continue ongoing research into this type of screening. If a two-tiered system is used, backscatter x-ray and EDS systems performed the best in the cost model in terms of both cost and expected number of successful threats. The dual-energy x-ray system also performed well in terms of cost, but the high variability in the false clear probability resulted in higher number of successful threats for every scenario involving the x-ray device. Scenarios involving ETD gave poor results indicating these systems are neither cost effective nor effective in terms of identifying threats.

This thesis made a research contribution with the development of an easily implemented cost model with consistent input parameters which incorporated two new technologies. The cost model also introduced the concept of system probabilities to ensure accuracy of the cost model formulas. The cost model allows the user to test both single and two-device scenarios. The model is user friendly and easily adaptable to the ever-changing security environment.

The cost model introduced provides an effective tool for the execution of cost-benefit analyses of alternative device configurations for aviation checked baggage security screening. Future enhancements of the model would be to incorporate multiple layers in order to allow users to test three or more tiered security systems, acquire more accurate real-world data, incorporate the large installation costs into the model and continually modify the model to adapt to the ever-changing airport security environment. Butler and Poole (2002) and Poole and Passantino (2003) feel that a risk-based system is a superior approach to aviation security. If the US implements this type of security system, this cost model will be a valuable tool in developing the optimal device configuration. The cost model can easily be adapted for new technologies. Although only 12 two-device scenarios were studied, any combination of technologies may be evaluated using this cost model.

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APPENDIX

A.1: Scenario A Correlation Coefficients

	E[Annual Direct Cost]		E[Successful Threats]	
Device	Parameter	Correlation Coefficient	Parameter	Correlation Coefficient
EDS-TO	P_{FA} EDS	0.497	P_T	0.796
	C_{FA}	0.443	P_{FC} TO	0.562
	Bags/Hr EDS	-0.368	P_{FC} EDS	0.171
	Operational Hrs. EDS	-0.358		
	Operational Days EDS	-0.355		
	C_O EDS	0.190		
	C_F EDS	0.164		
EDS-XRAY	P_{FA} EDS	0.464	P_{FC} XRAY	0.893
	C_{FA}	0.461	P_T	0.420
	Bags/Hr EDS	-0.371	P_{FC} EDS	0.098
	Operational Hrs. EDS	-0.352		
	Operational Days EDS	-0.342		
	C_O EDS	0.189		
	C_F EDS	0.160		
EDS-BACK	C_{FA}	0.46	P_T	0.832
	P_{FA} EDS	0.456	P_{FC} BACK	0.381
	Operational Days EDS	-0.377	P_{FC} EDS	0.380
	Operational Hrs. EDS	-0.371		
	Bags/Hr EDS	-0.369		
	C_O EDS	0.194		
	C_F EDS	0.169		

Table A.2: Scenario B Correlation Coefficients

	E[Annual Direct Cost]		E[Successful Threats]	
Device	Parameter	Correlation Coefficient	Parameter	Correlation Coefficient
TO-EDS	Operational Days TO	-0.495	P_T	0.795
	Bags/Hr. TO	-0.487	P_{FC} TO	0.572
	Operational Hrs. TO	-0.473	P_{FC} EDS	0.168
	$/Screener/Yr. TO	0.354		
	C_{FA}	0.204		
	P_{FA} TO	0.187		
	S2	-0.179		
	C_F EDS	0.149		
TO-XRAY	Bags/Hr. TO	-0.500	P_T	0.709
	Operational Days TO	-0.499	P_{FC} XRAY	0.577
	Operational Hrs. TO	-0.491	P_{FC} TO	0.357
	$/Screener/Yr. TO	0.361		
	P_{FA} TO	0.196		
	C_{FA}	0.196		
TO-BACK	Bags/Hr. TO	-0.495	P_T	0.792
	Operational Hrs. TO	-0.494	P_{FC} TO	0.558
	Operational Days TO	-0.494	P_{FC} BACK	0.159
	$/Screener/Yr. TO	0.362		
	C_{FA}	0.200		
	P_{FA} TO	0.199		

Table A.3: Scenario C Correlation Coefficients

	E[Annual Direct Cost]		E[Successful Threats]	
Device	Parameter	Correlation Coefficient	Parameter	Correlation Coefficient
XRAY-EDS	P_{FA} XRAY	0.714	P_{FC} XRAY	0.812
	C_{FA}	0.621	P_T	0.559
	S2	-0.178	P_{FC} EDS	0.122
	C_F EDS	0.125		
XRAY-TO	C_{FA}	0.699	P_T	0.714
	P_{FA} XRAY	0.694	P_{FC} XRAY	0.582
			P_{FC} TO	0.359
XRAY-BACK	P_{FA} XRAY	0.705	P_{FC} XRAY	0.811
	C_{FA}	0.668	P_T	0.550
			P_{FC} BACK	0.156

Table A.4: Scenario D Correlation Coefficients

	E[Annual Direct Cost]		E[Successful Threats]	
Device	Parameter	Correlation Coefficient	Parameter	Correlation Coefficient
BACK-EDS	S2	-0.547	P_T	0.830
	P_{FA} BACK	0.456	P_{FC} EDS	0.387
	C_{FA}	0.455	P_{FC} BACK	0.368
	C_F EDS	0.357		
	Operational Hrs. BACK	-0.166		
	Bags/Hr BACK	-0.164		
	Operational Days BACK	-0.160		
	C_F BACK	0.110		
BACK-TO	P_{FA} BACK	0.632		0.795
	C_{FA}	0.562	P_{FC} TO	0.569
	Operational Days BACK	-0.217	P_{FC} BACK	0.153
	Bags/Hr BACK	-0.206		
	Operational Hrs. BACK	-0.204		
	S2	-0.191		
	C_F BACK	0.151		
	C_O BACK	0.113		
	$/Screener/Yr. BACK	0.111		
BACK-XRAY	P_{FA} BACK	0.547	P_{FC} XRAY	0.806
	C_{FA}	0.537	P_T	0.544
	S2	-0.383	P_{FC} BACK	0.143
	C_F XRAY	0.217		
	Operational Days BACK	-0.205		
	Operational Hrs. BACK	-0.199		
	Bags/Hr BACK	-0.193		
	C_F BACK	0.147		
	$/Screener/Yr. BACK	0.120		

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