A Relative Cost-Benefit Approach for Evaluating Alternative Airport Security Policies

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***Abstract*—While careful and prudent settings for airport security policies and strategies are more important than ever, most of them have been implemented as a direct result of terrorist activities rather than motivated by a proper assessment. Furthermore, even if many scholars have proposed ways to assess and evaluate alternative airport security policies particularly by using cost-benefit analysis, they have overlooked two important facets: parameter measurability and social aspects of security policies. In this study, we develop a variant of cost-benefit analysis which we term "Relative Cost-Benefit Analysis" and illustrate how we can resolve these problems.**

***Keywords*-airport security; cost-benefit analysis; security policy evaluation**

I. Introduction

It has widely argued that the goal of airport security investment is to balance the cost of providing increased security with the reduction of risks from a terrorist attack [1]–[4]. For example, passenger baggage reconciliation and baggage scanning are regarded as an essential step in ensuring security of an airport since these procedures may reduce the risk of a terrorist's non-suicidal attack on an aircraft. Yet, these might cause costs for purchasing and maintaining necessary equipment and employing additional staff, and costs due to delay. Balancing costs and benefits in using a particular security policy is, therefore, one of the most important tasks for policy and decision makers.

A security policy is costly in many ways, since it requires money and effort for compliance and restrains the freedom of regulated parties [5]. As a result, administrators, legislators and government agencies who are engaged in implementing security policies might not be able to justify the decision to adopt a certain security policy without doing some substantial analysis. Many of the previous studies on airport security have investigated this based primarily on a cost-benefit analysis, but they have faced significant problems in the concrete measurability of model parameters. For example, various studies used the cost from a successful attack as a part of the total cost, ranging from $1.4 billion [6], to $30 billion [1], to $70.7 billion or more [7]. Furthermore it is often difficult to monetize many costs, for example, in terms of societal implications or loss of life.

The key observation behind our research contribution is that pure-cost benefit analysis may solve the wrong problem: in most of the cases, policy-makers may face a choice among various policy alternatives. Loosely speaking they are asked to do something with respect to security policies (either to cut the costs or improve security) and have various security policy proposals from various stakeholders. According to the report published by the SECONOMICS project [8],[1] however, most of the policies and strategies in aviation security have been implemented as a direct result of terrorist activities rather than motivated by a proper assessment, and have been proposed reactively. The report further argues that many governments may make security decisions against new threats without proper evaluation of the threats: for example, governments may invest in security not because they are really dangerous but because media and the pubic directly request for it.

Therefore, it is important to provide policy-makers with a framework to compare alternative security policy proposals and to determine which one to employ even when they are faced with unquantifiable and unmeasurable parameters. Given a series of recent debates on security policies, it is also important to incorporate additional facets such as social aspects of security policies into the framework.

In this study, we therefore focus on developing a method that can incorporate both monetary and sociological values in determining the best alternative strategy for security instrument allocations. In particular, we propose a model to be used to assess airport security policies directed at preventing terrorist attacks.

The rest of this article is organized as follows. In the next section, we provide research questions and an approach to be used for this study. In Section III, we present an overview of a cost-benefit approach for assessing airport security policies and explore the impact of alternative security policies. In detail, this section focuses mainly on providing the background of a cost-benefit approach and describing how the issue of non-quantifiable and non-monetizable parameters can be addressed. While many economics scholars and others who wrote about

[1]SECONOMICS is an three-year EU project funded by the FP7 in SECURITY, whose main objective is to develop innovative risk assessment techniques and tools that will support policy-makers in security-related decisions. The practical relevance of SECONOMICS research will be validated against various challenging domains, including airport security.

airport security policies have largely ignored sociological and psychological aspects of alternative security policies, this section provides a hint for including these aspects in the analysis. Section IV develops possible airport security scenarios with more detailed and explicit parameters and provides an illustrative example and a computational analysis. Finally, Section V concludes the article.

II. Research Questions and Approach

This study aims at developing a model for evaluating the impact of various policies for airport security. We provide a model for performing an analysis on current and newly proposed security policies with respect to technological costs and performance, and the impact on social welfare. In this study, we particularly want to answer the following questions:

1) How does the change in the current security policy alter the cost and benefit of airport security? Is employing a new security policy cost-effective?
2) Can a new security policy be aligned with societal needs and values?
3) What are the tradeoffs between alternative security policies?

Let us consider an example. Airport security procedures mainly include processes for inspecting an object including people, package and suitcase to limit entry of unauthorized personnel and objects, or to prevent the introduction of weapons or explosives into an airport or onto an airplane [9]–[11]. The main purpose of the procedures is therefore to avoid possibility that a threat reaches an airplane. Passengers and their belongings need to pass through the screening system which is formed by various check points. All of them are inspected by complex screening devices and security staff for threats. Most of the airports employ different strategies for the allocation of check points to prepare for different types of threats.

There are three commonly known ways that a passenger can carry a threat onto an airplane: in their checked-in bags, in carry-on bags, or on themselves. The primary security instruments for inspecting checked-in baggage are explosive detection systems (EDSs), explosive trace detection (ETD), and hand search with additional X-ray inspection. Carry-on baggage are commonly examined by an X-ray machine. If an operator finds a suspicious item, additional inspections including hand search and open bag trace are conducted. Passenger inspection generally has two stages: in the first stage, some or all of the passengers are profiled or prescreened. In the second stage, physical screening using a metal detector is performed. Additional search using a hand wand metal detector or pat-down can also be implemented.

Following public reports on slack security at an airport, a policy-maker may decide to improve security training for X-ray inspectors, or to increase the ratio of passengers to be manually screened. Furthermore, cost reduction pressure might make a policy-maker decide to move some of screening procedures from a local check point to a centralized facility. In these situations, traditional cost–benefit analysis would force him to identify the cost of a terrorist attack (for which they have no clue) and to use this variability ranging in the billions to weight security measures which are lower by three orders of magnitude (which makes numerical estimates hardly significant).

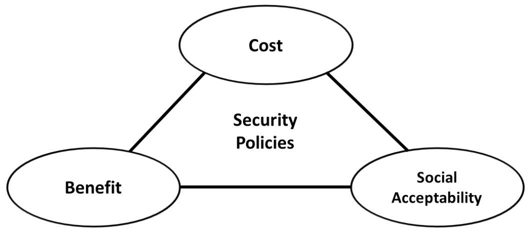

Figure 1. Three dimensions in evaluating security policy implementation

To find the answers to these questions, we develop a ***relative cost-benefit approach*** which can assess the impact and the cost of the decision to use a specific security policy.

III. Overview of Approaches for Alternative Security Policies

The goal of an airport security policy is to reduce the risks from terrorist attacks while being cost effective and being perceived as acceptable by the society. As a result, when various alternative security policies are proposed, decision makers need to compare these policies with each other and with a current security policy regarding three dimensions as shown in Figure 1: the expected benefits of a new security policy measured by reduced security risks; the total cost of the implementation; and the public acceptability of the new policy.

While there have been a variety of approaches that make it possible to compare alternative policies, the suitability of the analysis depends highly on the availability of data and information. In the field of airport security and safety, cost-benefit analysis (CBA), which is conducted by subtracting the expected benefits of the policy from the total cost of the implementation, is one of the most dominating approaches widely used by practitioners and researchers. For example, Jacobson and his colleagues conducted extensive studies on airport security systems and policies using CBA (e.g., [1], [6], [12]–[14]). In these studies, the authors compared various alternative security technologies, procedures and policies including screening for only selectees vs. both selectees and non-selectees, employing single device vs. multiple devices, and allocation of screening devices in multiple check-points. In addition, other scholars including Martonosi [15] and Martonosi Barnett [3] have studied effectiveness of airline passenger profiling using CBA. Even in other fields such as port and maritime security, CBA has been increasingly used (e.g., [16], [17]).

As many researchers (e.g., [18]–[20]) have argued that, however, while CBA can provide insight and information to decision-makers for determining appropriate security policies to be implemented, it has been known to have several limitations. First, most of the studies using CBA added up all the costs and benefits of a policy and compared the totals. In many cases, they implicitly assumed that all things can be either monetized or quantified: both benefits and costs are quantified simply as dollar totals. However, these studies used measures that are very difficult, if not impossible, to quantify and monetize. For example, as explained in the introduction, the estimated costs from a successful attack in various studies showed a wide variability. This variability is because of the fact that the costs incurred by a successful attack can include not only damage on an airport and an airplane but also loss of life, damage on infrastructure and huge undesirable impacts on the society and economy. This highlights that while various estimates might give decision- and policy-makers impression of how security is important, the estimates that allow such a huge range of different evaluation might inevitably involve countless judgment calls and studies using these estimates might be unreliable.

Second, these studies also did not consider the public costs of a proposed policy. For example, various security policies including passenger profiling, pat-down and 3D body scanner have caused public debate about the value of these strategies and the public acceptability. A key issue in the debate was the question of whether it is acceptable to use special scrutiny at an airport to prevent a terrorist threat. Since the translation of public opinion and valuation on a security policy into dollars is very difficult, however, increased inconvenience due to the proposed security policy has not been analysed in the previous literature.

In the following subsections, we explore how to overcome these issues. The first subsection is dedicated to an overview of CBA and description to overcome the first limitation. The second subsection explains how we can take public valuation on a proposed security policy into account in the analysis.

A. Overview of a Cost-Benefit Approach

In the field of security, CBA has taught us a great deal over the years about how policy- and decision-makers can most efficiently and economically achieve a given security goal. CBA makes it possible to compare and access current and alternative security policies particularly in the passenger/item screening procedures. This subchapter provides the foundations for CBA and extends CBA to include our revisionary account for overcoming the first limitation explained in the beginning of the section (i.e., the problem of using non-quantifiable values).

To conduct CBA for aviation security, we first need to identify costs and benefits of current and alternative possible policies. The major benefits of the policies are linked with avoiding the damage of a terrorist attack, both to the airport and the society in general. These benefits come from deterrent effect of screening policies and the potential to identify and remove a dangerous item before it is used. On the other hand, the major costs commonly include the equipment and personnel related costs associated with the policy. We define parameters for calculating costs and benefits of security policies as shown in Table I.

Table I
DESCRIPTION OF PARAMETERS

Parameter	Description
C_B	The total annual costs of a current (base) security policy
P_B	The effectiveness of a current (base) security policy (i.e., the probability that this security policy can detect an attempted attack)
C_{Pi}	The total annual costs of a proposed (alternative) security policy i
P_{Pi}	The effectiveness of a proposed (alternative) security policy i (i.e., the probability that this security policy can prevent an attempted attack)

From these parameters, we calculate the ratio of the cost difference to the outcome (i.e., effectiveness) difference between the base and proposed policies (hereinafter, referred to as "C-O ratio") as shown below:

$$\frac{\mathrm{C}_{Pi} - \mathrm{C}_B}{P_{Pi} - P_B}.^2 \tag{2.1}$$

There are several benefits of using the ratio rather than using the expected value of a proposed security policy employed in the previous literature for CBA. First, while the expected value needs to use an assumption regarding the underlying risk preference and utility function of a stakeholder, the ratio does not need to make such an assumption. Second, the ratio does not require parameters which are difficult to estimate such as the cost of a successful attack and the probability of a terrorist attack. While CBA is based on an expert-driven process for accuracy of measurement, it still involves high uncertainty in measuring the values of parameters. For example, the cost of a successful attack cannot be easily monetizable if monetizable at all: the cost estimate should be determined by the value of lives lost in a successful attack as well as the likelihood of damage to the economy, the society and the environment. By measuring the ratio directly, we are able to circumvent these issues.

(2.1) can be regarded as a value which shows a condition for which implementation of proposed policy i is more cost-effective and beneficial than the base policy [15], [17]. The interpretation of this ratio is similar to Martonosi [17]. First, if $C_{Pi} < C_B$ and $P_B < P_{Pi}$ (i.e., (a) in Figure 2), it is always beneficial to switch to the proposed policy i since the proposed policy i improves detection capability and decreases costs. The shaded area of (a) in Figure 2 therefore shows the area for dominant security policies. Second, if $C_B < C_{Pi}$ and $P_{Pi} < P_B$ (i.e., (b) in Figure 2), it is never advantageous to switch to the proposed policy since the detection capability with the proposed policy i decreases and the costs rise. The shaded area of (b) in Figure 2 therefore displays a dominated

[2] The ratio implies that a policy-maker weights the importance of the reduction in costs and the increase in effectiveness equally. This assumption can be relaxed by introducing a weight, $k \in [0, \infty]$, to outcome difference which gives $(C_{Pi} - C_B)/k(P_{Pi} - P_B)$. For example, if a terrorist's threat is high (low), then a policy-maker would have $k > 1$ ($k < 1$).

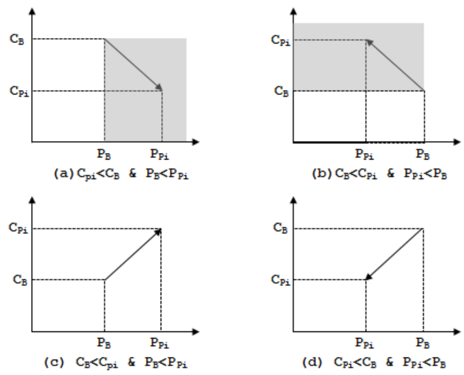

Figure 2. Effect of current and alternative security policies on costs and outcomes

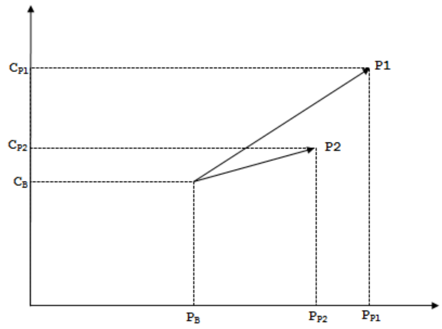

Figure 3. Comparison of alternative security policies when $C_B < C_{Pi}$ and $P_B < P_{Pi}$.

policy by the current security policy. Third, if $C_B < C_{Pi}$ and $P_B < P_{Pi}$ as shown in (c) in Figure 2, it is unclear whether switching to the proposed policy i is beneficial. For example, substituting a pat-down procedure with 3D body scanning would increase the costs as well as the detection effectiveness. In this case, we might not be able to determine which policy option is better. Fourth, there can be a situation where $C_{Pi} < C_B$ and $P_{Pi} < P_B$ as illustrated in (d) in Figure 2. For example, one can think of the case where a policy-maker considers removing a current security procedure such as passenger baggage reconciliation. Similarly with (c), it is also uncertain whether switching to the proposed policy i is beneficial. Finally, it is possible to think of two cases where $C_{Pi} = C_B$ or $P_{Pi} = P_B$. If the base and proposed policies have the same costs, the policy with the higher detection rate is better. Similarly, if the detection rates of the two policies are same, the cheaper policy is always better.

An issue in using this approach is that comparing cost-benefit between the current and proposed policies is limited by our inability to justify the cost-effectiveness of the proposed policy as in the cases of (c) and (d) in Figure 2: while these cases are the ones that most commonly occur, the current approach cannot provide a clear insight into these cases. In reality, however, a policy-makers have various policy alternatives: they are usually asked to do something for security and have various security policy proposals (e.g., proposals focusing on cost cutting or security improvement). Furthermore, rather than do nothing, policy-makers are forced to compare alternative security policy proposals and to choose one of them. Consequently, it is important for policy-makers to have a way to compare and evaluate various different security policy proposals rather than one proposed security policy.

With this in mind, we illustrate how we can further the current approach and how alternative security policy proposals can be compared. For illustrative purpose, we assume a situation where a decision maker faces a choice between two alternative security policies, $P1$ and $P2$. These alternative policies might include such options as adopting competitive security technologies and altering combinations of passenger groups to be inspected.

Since a policy which has C-O ratio in (b) is never beneficial, we only take into account policies with C-O ratios in (a), (c) and (d). We first consider a case where C-O ratios of $P1$ and $P2$ belong to (a) and/or (d). In this case, for $P2$ to be preferred to $P1$, we must have:

$$\frac{\mathrm{C}_{P2} - \mathrm{C}_B}{(P_{P2} - P_B)} \leq \frac{\mathrm{C}_{P1} - \mathrm{C}_B}{(P_{P1} - P_B)}. \tag{2.2}$$

For example, if we consider that $P1$ and $P2$ change the costs and the detection rates as shown in Figure 3, we can identify that while $P1$ and $P2$ do not strictly dominate the current policy as in (c) in Figure 2, $P2$ strictly dominates $P1$. As a result, it is more beneficial for a policy-maker to select $P2$ than $P1$.

On the other hand, when C-O ratios for the proposed security policies, $P1$ and $P2$, are both in (d), $P2$ is preferred to $P1$ if:

$$\frac{\mathrm{C}_{P2} - \mathrm{C}_B}{(P_{P2} - P_B)} \geq \frac{\mathrm{C}_{P1} - \mathrm{C}_B}{(P_{P1} - P_B)}. \tag{2.3}$$

This is because of the fact that the higher ratio of $P2$ than the ratio of $P1$ in (d) implies higher cost reduction and/or lower decrease in effective of $P2$ than $P1$.

The decision to select one of alternative security policies gets more interesting, if we consider a case where C-O ratios of $P2$ and $P1$ belong to (d) and (c), respectively. To make the analysis possible, however, we need to make a assumption that the costs, C_B and C_{Pi}, have the same unit with the effectiveness of the policies, P_{Pi} and P_B. Particularly, we normalize the unit of the costs to be [0, 1]. Therefore, we have $-1 \leq (C_{Pi} - C_B) \leq 1$ and $-1 \leq (P_{Pi} - P_B) \leq 1$.

In order for $P2$ in (d) to be preferred to $P1$ in (c), we must have:

$$\frac{1}{\frac{C_{P2} - C_B}{P_{P2} - P_B}} < \frac{C_{P1} - C_B}{P_{P1} - P_B}. \tag{2.4}$$

In contrast, $P1$ in (c) is preferred to $P2$ in (d) if

$$\frac{1}{\frac{C_{P2} - C_B}{P_{P2} - P_B}} > \frac{C_{P1} - C_B}{P_{P1} - P_B}. \tag{2.5}$$

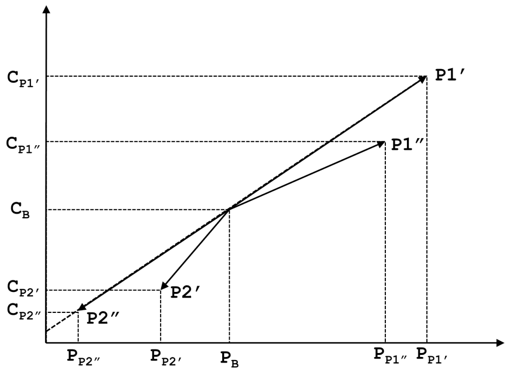

Figure 4. Comparison of alternative security policies when C-O ratios for $P1$ and $P2$ are in (c) and (d), respectively.

For illustration, we generate Figure 4. From (2.4) and (2.5), it can be identified that, while $P2'$ is preferred to $P1'$, $P1''$ is preferred to $P2''$.

B. Adding Psychological and Sociological Aspects

The previous literature on airport security has focused mainly on monetary costs and benefits of proposed policies. These studies conducted a quantitative "risk assessment" to estimate costs and benefits of proposed policies under consideration. If CBA can be conducted only by microeconomic calculations or is applied to economic regulations rather than social regulations, then the approach used by the previous airport security literature would be sound and desirable [21]. Cost effectiveness, however, is not the only objective of airport security policies, and is not the only lens for studying airport security policies. While a tighter security policy would be desirable from the viewpoint of government agencies and airport operators, the benefits flowing to passengers and the general public might not justify the added costs caused by distress from tightened security. Whether a security policy is worth to be implemented should also be based on whether the policy is socially compliant – whether it harms the public well-being – since the policy might cause the general public to inflict the risk of welfare loss.

A related practical problem commonly observable in the previous airport security literature is that practitioners and researchers do not usually engage in the assessment of passengers' and citizens' welfare change due to a proposed security policy. As pointed out in the beginning of the section, they do not evaluate the tranquil mental states including relief and the distressing mental states such as anxiety and worry that might be caused by policy change. This trend has caused a series of problems since many security policies also entail issues in citizens' money, time, freedom, health and privacy. Indeed, for many studies of airport security, the only parameter considered with respect to passengers and the public is a delay cost. However, it is also important to take into account the public's psychological reactions to proposed policies since these security policies might also incur other costs and benefits to the public. If the public's costs for proposed security policies are described solely as a means of a delay cost, the costs would not be very high. But if other psychological and sociological impacts of proposed policies on the public are included, the policies would be very expensive. In this subchapter, we discuss how best to measure psychological and sociological impacts of policies on passengers and citizens and develop a model that can include this factor in the analysis.

Similarly with technologies such as RFID and biometric recognition, various aviation security policies are known to alter mental states to passengers and citizens. For example, passenger profiling would be advocated by passengers and the public since it will not only save time standing in line but also reduce the anxiety by increasing the security system's ability to identify potential terrorists and the effectiveness of screening. It might however increase concerns on fairness and anti-discrimination. In a similar vein, while the implementation of 3D body scanner would increase the aviation security level, it might limit the right to privacy, freedom and equal treatment. Although various researchers have considered sophisticated assessment techniques including queuing theory to evaluate passengers' incurred monetary costs from alternative security policies, their mental states affected by the security policies have been widely ignored.

In order to exemplify how the pubic side can be included in the analysis, we consider a policy-maker who is asked to implement one of alternative security policies. Here, we define additional parameters: L_B and L_{Pi} are welfare losses of passengers or the general public measured from the current and proposed security policies (See Table II). For example, these values can be measured by the fraction of passengers who feel their travel experience disrupted or who feel their privacy threatened due to a corresponding security policy.

Table II
DESCRIPTION OF ADDITIONAL PARAMETERS

Parameter	Description
L_B	Welfare losses of the public/passengers due to a current (base) security policy
L_{Pi}	Welfare losses of the public/passengers due to a proposed (alternative) security policy i

In the fields including environmental and health economics, many calibrated scales for evaluating public's welfare have been developed. The idea of these scales is to allocate scores to the states of the public opinion with respect to specific policies or regulations [19]. For example, the quality-adjusted life years (QALY) scale was developed to measure the public's affected states from a specific policy on a cardinal scale, with the highest score (i.e., one) representing maximum welfare loss and the lowest number (i.e., zero) minimum welfare loss. We therefore argue that, using a similar method with QALY, we can evaluate the overall welfare losses (or social unacceptability) of passengers/citizens.

As an illustrative purpose, assume that a policy-maker conducts a survey on current and proposed airport security

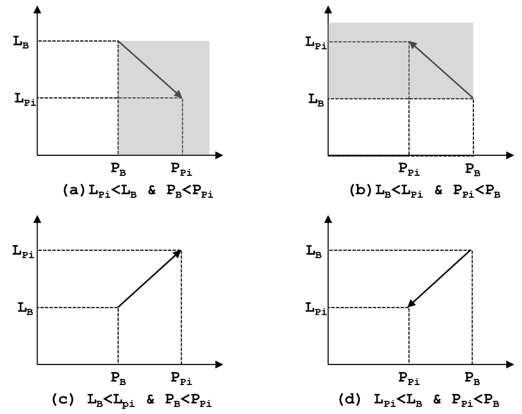

Figure 5. Effect of current and alternative security policies on welfare and outcomes

policies to the general public (e.g., current pat-down searches vs. proposed 3D body scanning). The survey participants are asked to score on a scale with respect to how they feel about the policies, ranging from zero (e.g., strongly acceptable) to one (e.g., strongly unacceptable). After identifying the overall score, we can calculate the ratio of the welfare difference to the outcome difference between the base and proposed policies (hereinafter, referred to as "W-O ratio") as shown below:

$$\frac{\mathrm{L}_{Pi} - \mathrm{L}_B}{P_{Pi} - P_B}. \tag{2.6}$$

Figure 5 shows the effect of security policies on welfare and outcomes, and the interpretation of the figure coincides with Figure 2. Similarly with the previous section, we now consider that a policy-maker confronts a choice between two alternative security policies $P1$ and $P2$. If $(P_{Pi} - P_B) > 0$ (i.e., W-O ratio in (a) or (c) of Figure 5), for $P2$ to be socially preferable to $P1$, we must have:

$$\frac{\mathrm{L}_{P2} - \mathrm{L}_B}{(P_{P2} - P_B)} < \frac{\mathrm{L}_{P1} - \mathrm{L}_B}{(P_{P1} - P_B)}. \tag{2.7}$$

For instance, consider a situation where a policy-maker is considering two alternative aviation security policies which might increase the security level at the cost of the decreased freedom of passengers: e.g., the strict security policy with 3D body scanning for all passengers ($P1$); and the moderate security policy with 3D body scanning for passengers with high risk ($P2$). If (2.7) holds, then it implies that the moderate policy, $P2$, is more preferred to the strict policy, $P1$.

In contrast, there can be alternative policies with $(P_{Pi} - P_B) < 0$ and $(L_{Pi} - L_B) < 0$ (i.e., W-O ratio in (d) of Figure 5). In this case, $P2$ is socially preferable to $P1$ if

$$\frac{\mathrm{L}_{P2} - \mathrm{L}_B}{(P_{P2} - P_B)} > \frac{\mathrm{L}_{P1} - \mathrm{L}_B}{(P_{P1} - P_B)}. \tag{2.8}$$

The comparison of $P1$ with W-O ratio in (c) and $P2$ with W-O ratio in (d) can also be made similarly with the previous section. That is, for $P2$ in (d) to be socially preferred to $P1$ in (c), the relationship should be:

$$\frac{1}{\frac{L_{P2} - L_B}{P_{P2} - P_B}} < \frac{L_{P1} - L_B}{P_{P1} - P_B}. \tag{2.9}$$

In contrast, we must have

$$\frac{1}{\frac{L_{P2} - L_B}{P_{P2} - P_B}} > \frac{L_{P1} - L_B}{P_{P1} - P_B} \tag{2.10}$$

for $P1$ in (c) to be preferred to $P2$ in (d).

IV. Example of Airport Security Policies and Procedures

In this section, we exemplify possible security policies in use and provide a numerical illustration of a policy comparison.

A. Examples of Security Policies

Generally speaking, in an airport, all passengers/items are subject to several security checks. They need to pass through various check-points where they are inspected by security personnel and devices (e.g., X-ray, metal detectors and hand search). For passengers' bags, for example, inspection occurs by passing them through a fixed X-ray scanner. Inspectors examine the scanned image for finding any signs of risk. After the inspection, security personnel may perform additional screening for some passengers/items. For instance, security personnel conduct a manual hand-search for suspicious passengers/items. However, for an illustrative purpose, here, we consider a simplified base security policy.

- Base security policy (B): The current policy mandates the scanning of 100 per cent of passengers/baggage via deployed screening machines. The costs for this security policy include amortized fixed equipment costs, annual operations and maintenance costs for the scanning equipment and salaries for the operators and inspectors.

Any (even very small) changes in a security policy are likely to alter the current state. For example, new security devices might need to be purchased, operated and maintained; more teams of inspectors and operators might need to be hired; and additional infrastructure would need to be installed. These factors consist of the basis for alternative airport security policies to be presented below. In detail, the viability of the following alternative policies is considered.

- Alternative security policy (P1) – 100 per cent inspection of passengers/baggage using current screening machines and γ per cent inspection with a new security measure (e.g., 3D body scanner): This policy requires the scanning of 100 per cent of passenger/baggage with current technology. γ per cent need to have additional inspection by a device with new security technology. New devices and a team of operators and inspectors for these devices are required. In addition to the costs incurred in the base policy, therefore, additional costs for purchase, operations, maintenance and inspection are needed.

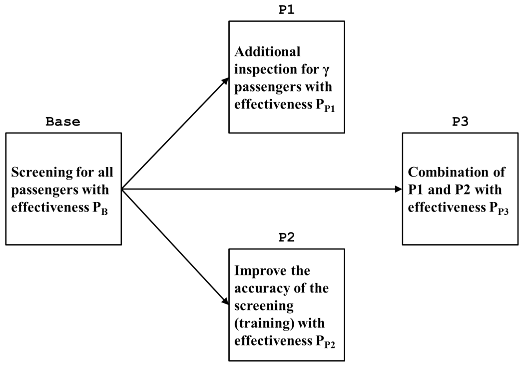

Figure 6. Visualization of alternative security policies

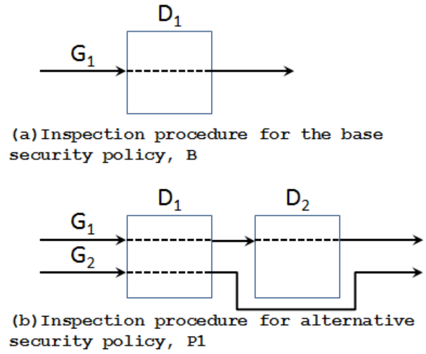

Figure 7. Example of base and alternative security policies

- Alternative security policy (P2) – 100 per cent inspection of passenger/baggage using current scanning machines with an additional training program: due to improved training for inspectors, we assume that greater accuracy is possible. While this case improves on current security policy by reducing the false alarm rate, it incurs the costs for the training program.
- Alternative security policy (P3) – the combination of P1 and P2: 100 per cent inspection of passengers/baggage using current screening machines and an additional inspection with a new security measure and an additional training program.

Figure 6 visualizes the current and alternative security policies.

B. Detailed Parameters

We now present detailed parameters for comparing the security policies. The parameters include the items related to a screening technology, performance, maintenance and operation. Here, we also take into account incurred costs of a training program. The benefits of any policy are assumed to be measured by a detection rate of the policy. It should be noted that here we only explore the procedure for calculating C-O ratio in III.A since W-O ratio presented in III.B. follows the same calculation procedure.

We first consider the costs related to devices and man hours. The costs for screening devices are comprised of equipment purchase, maintenance and operation costs. Therefore, if we define C_S as the purchase price of each screening device with a particular technology and Y_S as the period over which the cost of the device will be amortized, then the purchase price per year is C_S/Y_S assuming constant depreciation. Furthermore each device will require maintenance and repairs, R_S, per year. Lastly, each device will require N_S operators and inspectors at any time, and we assume that these operators and inspectors earn a salary, S_S, per year and work in three shifts per day. We also assume that an airport has M_S scanning devices. Thus the annual costs for screening per airport are $M_S(C_S/Y_S + R_S + 3N_SS_S)$.

As for the training costs, we assume that all operators and inspectors are required to participate in a training program. If we define T_S as the training cost for each worker, the annual total costs incurred by a training program are $3T_SN_S$.

We now consider the benefits of a security policy which are measured by a detection rate (i.e., effectiveness). If P_{Policy} is defined as a detection rate and γ as a fraction of passengers scanned, then the rate that a dangerous passenger is prevented from an attack is the product of the probability of scanning and the detection rate, γP_{Policy}. For example, since the base security policy scans all of the passengers, γ equals to 1.

C. Numerical Illustration

Here, we present a numerical calculation. Particularly, we focus our attention mainly on the base policy, B, and two policy alternatives, $P1$ and $P2$: a policy-maker faces to choose one of the two proposed policy options over the current security policy. As for the current security policy, we assume that all of the passengers/items need to pass through a security check point with an X-ray machine for baggage and a metal detector for a passenger (see Figure 7 (a)). The fictitious values for the calculation are displayed in Table III. Further, the detection rates of a metal detector and an X-ray device for an attempted attack are assumed to be 0.90 and 0.95, respectively. Therefore, the combined detection rate of these two devices becomes

$$P_B = 0.90 \times 0.95 = 0.855.$$

Table III
THE ELEMENTS OF A BASE POLICY AND ITS VALUES

Measure	Number of units	Annual cost/unit	Detection rate
Metal detectors	1	6,500	90%
X-ray devices	1	90,000	95%
Operators /inspectors	5 (3 shifts)	19,200	–

The total annual costs can be calculated as shown below:

$$C_B = (1 \times 6,500) + (1 \times 90,000) + (5 \times 3 \times 19,200) = €384,500$$

We now extend our calculation on the base security policy to $P1$ which employs an additional screening procedure. As explained, this policy requires all the passengers/items to pass through a compulsory security check-point and some of them to be inspected at an additional check-point. Here, we assume that, after the inspection of passengers using a metal detector, a thorough inspection using a full-body scanner is carried out for γ per cent of randomly chosen passengers. As shown in (b) of Figure 7, therefore, while passengers in G_1 need to pass through only a metal detector, those who are in G_2 need to pass through both a metal detector and an optional full-body scanner. We assume here that 20% of passengers are additionally screened by a full-body scanner. A full-body scanner costs € $110,000$ per year and requires 3 additional operators/inspectors with the detection rate 99%.

As a result, the total annual cost for P1 is given by

$$\begin{aligned} C_{P1} &= (1 \times 6,500) + (1 \times 90,000) \\ &\quad + (1 \times 110,000) + (8 \times 3 \times 19,200) \\ &= €667,300 \end{aligned}$$

and the aggregated detection rate becomes

$$\begin{aligned} P_{P1} &= [0.8 \times 0.90 + 0.2 \times (1 - 0.1 \times 0.01)] \times 0.95 \\ &= 0.874. \end{aligned}$$

Therefore, the ratio becomes

$$\frac{\mathrm{C}_{P1} - \mathrm{C}_B}{P_{P1} - P_B} = \frac{667,300 - 384,500}{0.874 - 0.855}$$

We now consider a case where a policy-maker can implement an additional security training program ($P2$). Assume that the annual cost for a training program per worker is €700 and the program improves the detection rate for X-ray machine by 2%.[3] The total annual costs for $P2$ are given by

$$\begin{aligned} C_{P2} &= (1 \times 6,500) + (1 \times 90,000) \\ &\quad + (5 \times 3 \times 19,200) + (5 \times 3 \times 700) = €395,000 \end{aligned}$$

and the detection rate becomes

$$P_{P2} = 0.90 \times 0.97 = 0.873.$$

As a result, the ratio of the cost difference to the outcome difference between B and $P2$ is given by

$$\frac{\mathrm{C}_{P2} - \mathrm{C}_B}{P_{P2} - P_B} = \frac{395,000 - 384,500}{0.873 - 0.855}$$

From these ratios, it can be identified that C-O ratio for $P1$ is bigger than C-O ratio for $P2$. This result implies that $P2$ is clearly better than $P1$.

[3] In the SECONOMICS workshop held in Falconara, Italy, on September, 2013, one of the airport security experts mentioned that detection rates of some security devices cannot be improved by training. He said that only a few devices including X-ray machines need interaction with inspectors. On the contrary, he mentioned that detection rates of measures such as a liquid detector and a 3D body scanner cannot be increased by inspectors. Another participants also confirmed that some airports measure the effectiveness of a training program, particularly, on the detection rate of X-ray machines.

V. Conclusions

This article develops a model for determining the best alternative policy for airport security. The model proposed here is simple but flexible, so it can compare and evaluate alternative security policies. In the model development, we incorporate the perspectives of cost, benefit and social acceptability associated with various security configurations involving technological security measures and a training program.

In the literature review, we have identified that, while cost models to measure the cost and benefit of airport security policies have been well recognized, the actual application procedures are difficult to perform and seldom applied in real decision-making situations.

Unlike the cost models presented in the previous literature, the model proposed here has two distinguishing advantages. First, the model is not based on the parameters that are not quantifiable or measurable. We only employ parameters that might be identified relatively easily by airport security experts. Furthermore, the model does not depend on policy-makers underlying risk preferences or utility function. Due to this aspect, this model can be easily applied to compare any proposed security policies. This model can be used by a high-level policy-maker who decides nation-wide security policies as well as by an airport security manager who want to compare two training programs with different costs and benefits. Second, by incorporating a social aspect in the model, this study tries to shed light on some of the issues neglected in the airport security research. In particular, while various airport security policies have generated a huge debate on whether the values of these policies are socially acceptable, consideration of this issue has received relatively little, and only very recent, academic attention. The model developed here tackles this important topic and as such begins to fill the gap.

In the presentation of an example, this article provides a case study for comparing various alternative security scenarios using the model developed. More specifically, we provide readers with detailed steps for calculating the ratio of the cost difference to the outcome difference using fictitious values, and perform an in-depth presentation of applications of the model.

Its convenience notwithstanding, the model proposed here has some certain limitations, some of which are inherent in the data required and some are related to peculiarities of the model. In terms of data limitations, although the model requires the minimum volume of the data, the validity of the data might not be assessed easily. Validation process is therefore very important to this study. The results of the model depend highly on the values of the parameters provided by various stakeholders. These values are expert-driven and considerable uncertainty still remains. We argue that many problems with and questions related to the data can be resolved using proper validation. For example, we can assess the validity of the data by comparing the data from airports with similar size and environment as well as by getting opinions from an expert group of airport stakeholders. Other limitations stem from the structure of the model. Most importantly, while our emphasis on the model has been put on the ease of applications, this might be a double-edged sword. Inclusion of other factors such as the characteristics of an airport (e.g., size and traffic volume) might make the model more realistic and robust.

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