A Risk and Cost-Benefit Assessment of Australian Aviation Security Measures

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The Australian government Office of Best Practice Regulation has recommended the use of cost-benefit assessment for all proposed federal regulations. An assessment of increased expenditure on the Air Security Officer (ASO), or air marshal, program since 2001 suggests that the annual cost per life saved is greatly in excess of the regulatory safety goal of $1-$10 million per life saved. As such, the ASO program would seem to fail a cost-benefit analysis. In contrast, hardening of cockpit doors has a significantly lower annual cost per life saved, suggesting that this strategy is a cost-effective security measure.

The Australian Government Office of Best Practice Regulation has recommended the use of cost-benefit assessment for all proposed federal regulations, and such assessments are routinely conducted by the Civil Aviation Safety Authority, Australian Radiation Protection and Nuclear Safety Agency, Roads and Traffic Authority of New South Wales (NSW), the Bureau of Transport and Regional Economics, and other agencies. However, while the 'Best Practice Regulation Handbook' states that "the Australian Government is committed to the use of cost-benefit analysis to assess regulatory proposals to encourage better decision making",[2] a close scrutiny of the assessment of risks and cost-effectiveness of proposed and implemented security measures appears not to have occurred.

Several risk-based approaches to cost-benefit analysis that consider economic and life-safety criteria for the protection of buildings, bridges and other built infrastructure have been developed. In these, cost-effectiveness is contingent on the likelihood, cost, and effectiveness of security/protective measures and consequence of terrorist attacks on such infrastructure.[3]

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[2] Office of Best Practice Regulation, *Best Practice Regulation Handbook* (Canberra: Australian Government, August 2007), p. 115.
[3] Mark G. Stewart, 'Life Safety Risks and Optimisation of Protective Measures for Terrorist Threats to Built Infrastructure', in Stewart Reid and Mark Stuart (eds.), *Optimal Strategies for Disaster and Hazard Mitigation: Proceedings of the International Forum on Engineering Decision Making, 12-15 December 2007, Third IFED Forum, Shoal Bay, NSW* (Sydney: Sydney University Press, 2007), pp. 19-30; Mark G. Stewart, 'Cost-Effectiveness of Risk Mitigation

Following this approach, Stewart and Mueller conducted an assessment of increased United States federal homeland security expenditure since the attacks of 11 September 2001 (9/11) and of expected lives saved as a result of such expenditure.[4] The cost-benefit analysis suggests that the annual cost per life saved ranges from US$64 million to US$600 million, greatly in excess of the regulatory safety goal (societal willingness to pay to save a life) of $1-$10 million per life saved. This means that the US$300 billion spent by the United States Government to protect the American homeland from terrorism since 2001 fails a cost-benefit analysis. These findings focus on the total homeland security budget. This is not to say, however, that every specific security measure fails to be cost-effective. There may be some that are. In all cases, a detailed analysis of each security measure is appropriate and potentially instructive, enabling as it does a meaningful assessment of the merits of each security measure in a rational, consistent, and transparent manner. There is an urgent need for such detailed analyses.

Since 9/11 government agencies in Australia, United States, Canada, Europe and elsewhere have devoted much effort and expenditure to attempt to ensure that a 9/11 type attack involving hijacked aircraft is not repeated. This effort has come at considerable cost, running in excess of US$6 billion per year for the United States Transportation Security Administration alone.[5] In particular, significant expenditure has been dedicated to two aviation security measures aimed at preventing terrorists from hijacking and crashing an aircraft into buildings and other infrastructure:

- Hardened cockpit doors

- Air Security Officer (ASO) program (air marshals)

These two security measures cost the Australian taxpayers and the airlines nearly $60 million per year. This paper seeks to discover whether these new aviation security measures are cost-effective. The preliminary cost-benefit analysis considers the effectiveness of aviation security measures, their cost and expected lives saved as a result of such expenditure. This will involve a quantitative estimate of risks and benefits since for policy decisions it is often preferable to communicate risks with numbers rather then words.[6] This

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Strategies for Protection of Buildings against Terrorist Attack,' *Journal of Performance of Constructed Facilities*, American Society of Civil Engineers, vol. 22, no. 2 (2008), pp. 115-120.
[4] Mark G. Stewart and John Mueller, *Assessing the Costs and Benefits of United States Homeland Security Spending*, Research Report No. 265.04.08 (Newcastle, NSW: Centre for Infrastructure Performance and Reliability, The University of Newcastle, April 2008).
[5] Congressional Research Service, *Homeland Security Department: FY2008 Appropriations*, CRS Report for Congress, 20 August 2007.
[6] David R. Mandel, 'Are Risk Assessments of a Terrorist Attack Coherent?', *Journal of Experimental Psychology: Applied*, vol. 11, no. 4 (2005), pp. 277-288.

paper provides a sound starting point for discussion about how to manage aviation security (and other counterterrorism measures) in an environment where funds are limited and the opportunity costs are high.

The adverse effects of terrorism are many, but the two dominant consequences are loss of life/injury and economic (monetary) losses. Experience suggests that property damage, loss of business, and other economic losses as a result of terrorism tend to be short-lived, particularly for developed nations which typically have resilient infrastructure, institutions, and economies. Of more concern to these societies, as with most other low probability/high consequence hazards such as nuclear power and chemical process plants, is the potential for terrorism to cause loss of life. This is what captures the imagination of citizens, contributing to the anxiety and dread they often experience. It follows that life-safety is likely to be the main criterion for assessing cost-effectiveness of aviation security expenditure.

It is recognised that many uncertainties exist in quantifying risks, particularly for threats such as terrorism where data are scarce or non-existent and where the threat is highly transient. Some sophisticated statistical approaches exist for terrorist threat prediction,[7] however, even though these models rely on expert judgments from security and other experts the inherent uncertainties can still be high. Hence, as the present paper will rely on judgement and scenario analysis in quantify key risk parameters the outcomes will be subject to a sensitivity analysis to assess if cost-benefit conclusions are influenced by the acknowledged uncertainty in risk reduction and other parameter estimates.

Regulatory Safety Goal: Costs Spent on Risk Reduction per Life Saved

While risks are seldom acceptable, they are often tolerable (or accepted reluctantly) if the benefits of mitigation measures are seen to outweigh the costs. There is much literature devoted to the problem of risks acceptability to society, as all activities bear some risk. Activities related to nuclear energy, chemical processes, aviation, etc. with large potential for loss of life or severe economic or social consequences have since the 1960s been subject to methodical and quantitative risk assessments.[8] Many risks can be

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[7] M. Elisabeth Paté-Cornell and Seth Guikema, 'Probabilistic Modeling of Terrorist Threats: A Systems Analysis Approach to Setting Priorities Among Counter-measures', *Military Operations Research*, vol. 7, no. 4 (2002), pp. 5-23; Richard John and Heather Rosoff, 'Estimating Likelihood of Terrorist Attacks by Modeling Terrorist Beliefs and Motivations', *First Annual DHS University Network Summit on Research and Education*, Department of Homeland Security, Washington D.C., 15-16 March 2007.
[8] Mark G. Stewart and Robert E. Melchers, *Probabilistic Risk Assessment of Engineering Systems* (London: Chapman & Hall, 1997).

reduced, though at increasing cost. A cost-benefit analysis provides a means to measure the cost associated with avoiding the risk.

The Office of Best Practice Regulation uses value of a statistical life for benefit assessment.[9] Elisabeth Paté-Cornell[10] suggests that a cost per life saved of $2 million or less is appropriate for current practice, Australian dam safety regulators adopt a figure of $5 million[11] and the Roads and Traffic Authority of NSW uses a value of $1.6 million.[12] For most activities a cost per life saved not exceeding $1-$10 million is typical as this provides a reasonably accurate reflection of societal considerations of risk acceptability and willingness to pay to save a life. This value is consistent with many studies as well as values currently used by most government agencies.[13] In other words, if the annual cost per life saved exceeds $1-$10 million then such risk reduction expenditure is deemed to have failed a cost-benefit analysis and so is not cost-effective. In such cases it is more rational to divert the expenditure to reduce the risks for other hazards where the benefits (lives saved) will be higher.

Cost per life saved is a very robust indicator of societal risk acceptability as it considers costs and benefits in a logical and transparent manner. However, a regulatory safety goal such as this should be interpreted with some flexibility as the regulatory safety goal is a 'goal' only and other non-quantifiable criteria may be important also in judging the overall acceptability of risks.[14] Past experience shows that it is likely that decisions may be made (or over-ruled) on political, psychological, social, cultural, economic, security or other non-quantifiable grounds. For example, some risks may be deemed unacceptable under any conditions based on morality[15] or based on their symbolic value to society. Nonetheless, the cost per life saved is a useful metric for assessing trade-offs, which can provide a starting point for further discussion and perhaps more detailed and complex analysis of how to

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[9] Regulation Taskforce, *Rethinking Regulation: Report of the Taskforce on Reducing Regulatory Burdens on Business*, Report to the Prime Minister and the Treasurer, Canberra, April 2006.
[10] M. Elisabeth Paté-Cornell, 'Quantitative Safety Goals for Risk Management of Industrial Facilities', *Structural Safety*, vol. 13 (1994), pp. 145-157.
[11] *Guidelines on Acceptable Flood Capacity for Dams*, Department of Natural Resources and Water, Queensland Government, February 2007.
[12] NSW Roads and Traffic Authority, *Economic Analysis Manual*, Sydney, 2005.
[13] W. Kip Viscusi, 'The Value of Life in Legal Contexts: Survey and Critique,' *American Law and Economic Review*, vol. 2, no. 1 (2000), pp. 195-222; Peter Ableson, 'Establishing a Monetary Value for Lives Saved: Issues and Controversies', *Cost-Benefit Conference*, Office of Best Practice Regulation, Canberra, November 2007.
[14] For a detailed review and discussion of risk acceptance criteria see Stewart and Melchers, *Probabilistic Risk Assessment of Engineering Systems*; Stuart R. Reid, 'Acceptable Risk Criteria', *Progress in Structural Engineering and Materials*, vol. 2 (2000), pp. 254-262; and Robert E. Melchers, 'On the ALARP Approach to Risk Management', *Reliability Engineering and System Safety*, vol. 71 (2001), pp. 201-208.
[15] Bruce Schneier, *Beyond Fear: Thinking Sensibly About Security in an Uncertain World* (New York: Copernicus, 2006).

manage the often conflicting societal preferences associated with assessments of risk, cost and benefits.

Aviation Security Risk Reduction Measures

Australia, like many countries, has a layered approach to aviation security that provides "strength in depth".[16] Many security layers comprise 'pre-boarding security' (i.e., deterrence and apprehension of terrorists prior to boarding aircraft) that includes intelligence, customs and border protection, passenger pre-screening, crew vetting, airport security officers, baggage screening, and so on. Then there are 'in-flight security' measures which can be grouped broadly as:

• Crew and Passenger Resistance

• Hardened Cockpit Door

• ASO Program

The risk that is the focus of this paper arises from the likelihood and consequences of an aircraft hijacking that could lead to 9/11 type attacks on buildings and other infrastructure. That is, we are concerned with the costs and benefits of measures that seek to prevent exact duplications of 9/11 in which commercial passenger airlines are commandeered, kept under control for some time, and then crashed into specific targets. We do not deal with efforts to prevent other air mishaps like the blowing up of an airliner without hijacking it or attempting to shoot it down with a missile. Such threats cannot be deterred or prevented by hardened cockpit doors or air marshals, and are outside the scope of this cost-benefit analysis.

If pre-boarding security fails, terrorists on board who seek to replicate the events of 9/11 may be foiled by one or more of three security measures. These are now discussed.

CREW AND PASSENGER RESISTANCE
One reason for the extent of the losses of 9/11 was the reluctance of crew and passengers to confront and resist the hijackers. This is perfectly understandable as most previous hijackings ended peacefully or with minimal loss of life as the main response to a hijacking was to "get the plane on the ground so negotiations can begin".[17] Indeed, only a few months before 9/11 three terrorists, in this case Chechens, had commandeered a

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[16] *Report 400: Review of Aviation Security in Australia*, Joint Committee of Public Accounts and Audit, The Parliament of the Commonwealth of Australia, June 2004, p. 34.
[17] Schneier, *Beyond Fear*, p. 4.

Russian airliner, demanding that it be flown to Saudi Arabia at which point they were overcome by local security forces with almost no loss of life.[18]

The 9/11 suicide attacks on the World Trade Centre and Pentagon changed this threat perception. Hence, on hearing of these attacks, the crew and passengers on the fourth aircraft United Airlines Flight 93 overpowered the hijackers before the aircraft could reach its intended target. Passengers will now fight back if there is any indication that the terrorists' intent is to enter the cockpit. For example, an attempted hijacking of a Qantas domestic flight in May 2003 was foiled by crew and passengers.

> Two flight attendants were stabbed and two passengers were injured as
> they struggled to restrain the armed man, who had attempted to enter the
> cockpit armed with two wooden stakes, an aerosol can and a lighter.[19]

This demonstrates the new paradigm that crew and passengers will in many cases no longer be passive in the event of a hijacking threat.

HARDENED COCKPIT DOORS

In the several years following 9/11 the Australian Department of Transport and Regional Services, United States Federal Aviation Administration and many other agencies required aircraft operators to install hardened cockpit doors in order to protects cockpits from intrusion and small-arms fire or fragmentation devices. The regulations mandated that

> the doors will be designed to resist intrusion by a person who attempts to
> enter using physical force. This includes the door, its means of attachment
> to the surrounding structure, and the attachment structure to the bulkhead.[20]

It also requires that the cockpit doors remain locked and cockpit access controlled. While the effectiveness of these doors in restricting cockpit access to a determined hijacker may be questioned,[21] there is little doubt that hardened cockpit doors will deter and delay a hijackers attempt to enter the cockpit.

The purchase and installation cost of each hardened cockpit door is typically US$30,000 to US$50,000. The total cost to 6 000 United States aircraft is estimated as US$300-US$500 million over a ten year period, including increased fuel consumption costs due to the heavier doors.[22] This cost will

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[18] Mark Kramer, 'The Perils of Counterinsurgency: Russia's War in Chechnya', *International Security*, vol. 29, no. 3 (2004/05), p. 58.

[19] Padraic Murphy and Phillip Hudson, 'Heroes Foil Qantas Hijack Attack', *The Age*, 30 May 2003.

[20] Federal Aviation Administration, 'FAA Sets New Standards for Cockpit Doors', FAA Office of Public Affairs Press Release, 11 January 2002.

[21] John R. Lott, 'Marshals Are Good, But Armed Pilots are Better', *Wall Street Journal Europe*, 2 January 2004.

[22] Federal Aviation Administration, 'Airlines Meet FAA's Hardened Cockpit Door Deadline', FAA Office of Public Affairs Press Release, April 2003.

decrease over time as door installation costs for new aircraft will be less than for existing aircraft. There are approximately 310 aircraft operated by Australian domestic and international airlines that required hardening of cockpit doors. If the annual cost of hardening 6000 cockpit doors in the United States is approximately US$40 million,[23] then a pro-rata best estimate annual cost of hardening cockpit doors for Australian airlines is $2.5 million (in Australian dollars). [24]

Hardened cockpit doors may be useful in preventing a direct replication of 9/11, but, unlike crew and passenger resistance, they contribute little to the prevention or mitigation of other kinds of terrorist acts on airplanes such as detonation of explosives.

AIR SECURITY OFFICER PROGRAM

One hundred and thirty ASOs, often called 'air marshals', are available to patrol Australian domestic and international flights. The ASO program has a budget of $135.5 million over the 2006 to 2010 period[25]—this is equivalent to $27.1 million per year. In addition, airlines are expected to provide free seats to air marshals, seats which are generally in first class to allow observation of the cockpit door. Qantas CEO Geoff Dixon estimates that providing the seats for air marshals will cost Qantas $25 million per year.[26] A large part of this expenditure would be for long haul international flights which may have up to six air marshals on a single flight. As Qantas aircraft make up nearly 100 percent of Australia's international fleet and approximately 65 percent of Australia's domestic airline fleet, the cost of free seats borne by other Australian airlines is approximately $5 million. The best estimate annual government and airline cost of the ASO program is approximately $55 million.

There is a 10 percent probability of air marshals being on a flight,[27] which is a similar percentage for the United States Federal Air Marshal Service.[28] They are more likely to be on 'high-risk' flights based on intelligence reports. However, experience from Australian air marshals is that "following increases in screening at airports and the installation of bullet-proof cockpit doors, there is little intelligence indicating which flights are at risk", and so now air marshals only "have random assignments or fly to protect VIPs".[29] While up to six air marshals may be on a single flight, changes to the ASO

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[23] Ibid.

[24] A$1=US$0.80 - US$0.90.

[25] Paul Maley, 'Overhaul Cuts Sky Marshals by a Third', *The Australian*, January 23, 2008.

[26] Mark Colvin, 'Geoff Dixon Defends Qantas Security Facilities', *PM: ABC Radio*, 30 May 2003.

[27] Mark Russell, 'Sky-high Cost of Our Flying Cops', *The Age,* 25 February 2007.

[28] Audrey Hudson, 'Flight Marshal Numbers Disputed, Agents Criticize Data "Padding"', *Washington Times*, 3 March 2005.

[28] Audrey Hudson, 'Air Marshals Cover Only a Few Flights', *Washington Times*, 16 August 2004.

[29] Simon Kearney, 'Air Marshal's Role Now VIP Security', *The Australia*n, 9 December 2005.

program from 2008 will reduce the number of air marshals on some 747 flights by a third, though with no changes in the ASO program budget.[30]

Publicity about the existence of the ASO program may have a deterrent effect, but this is ameliorated by the low percentage of flights that they can cover. It might even be argued that some crew and passengers may be reluctant to be the first to confront a hijacker if they believe an air marshal is on board, a hesitation that could conceivably give attempted hijackers the time they need to execute their plans. Hence, the anticipated presence of air marshals may be counter-productive in some cases. Apparently, however, Australian air marshals have had to act only once—when subduing a sixty-eight year-old man who produced a small knife on a flight from Sydney to Cairns in 2003.[31] United States air marshals have made fifty-nine arrests since 2001, but none of these incidents has been related to terrorism.[32]

The goal of the air marshals is primarily to prevent a replication of 9/11—a reason for putting them in the first class section upfront. Conceivably, they could be helpful in other terrorist situations—for example, if a passenger tried to blow up the airliner—but their added value over crew and passenger resistance is likely to be rather small.

Annual Cost Per Life Saved

Increased expenditure on security is expected to reduce fatality risks. The annual cost per life saved (C_{LS}) is

$$C_{LS} = \frac{C_R}{\text{lives saved due to enhanced security measures}} \qquad (1)$$

where C_R is the annual cost spent on enhanced security measures. The expected number of annual lives saved is the fatality rate before enhanced security measures multiplied by the percentage risk reduction due to enhanced security measures (R), then

$$C_{LS} = \frac{100 C_R}{R \times \text{annual fatality rate before enhanced security measures}} \qquad (2)$$

The following sections discuss the quantification of key parameters in Equation 2; namely,

- percentage risk reduction due to enhanced security measures (R)

- annual fatality rate before enhanced security measures

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[30] Maley, 'Overhaul Cuts Sky Marshals by a Third'
[31] Russell, 'Sky-high Cost of Our Flying Cops'.
[32] Laura Meckler and Susan Carey, 'Sky Patrol: U.S. Air Marshal Service Navigates Turbulent Times', *The Wall Street Journal*, 9 February 2007.

EFFECTIVENESS OF AVIATION SECURITY MEASURES
TO PREVENT A REPLICATION OF 9/11

The percentage risk reduction due to post-9/11 aviation security measures (R) needs quantification for the following aviation security measures:

- R(pre-boarding security)

- R(crew and passenger resistance)

- R(hardened cockpit door)

- R(ASO program)

For any security measure the percentage risk reduction R can vary from 0 to 100 percent. If a combination of security measures will foil every hijacking attempt then the sum of risk reductions from these security measures is 100 percent. However, if the security measures will not foil every hijacking then the sum of risk reductions from individual security measures will be less than 100 percent. Hence, the sum of risk reductions from all security measures cannot exceed 100 percent such that:

R(pre-boarding security) + R(hardened cockpit door) +
R(crew and passenger resistance) + R(ASO program) ≤ 100%   (3)

There are obviously many possible combinations of risk reductions dependent on the relative effectiveness of each security measure. It should be noted that the percentage risk reduction for a security measure is the additional risk reduction achieved by the presence of the security measure when compared to the overall risk reductions achieved by the presence, absence and/or effectiveness of all security measures.

For example, consider the case where it is predicted that (i) the probability of a hardened cockpit door in foiling a 9/11 type hijacking is 0.5, (ii) the probability of pre-boarding security in foiling a 9/11 type hijacking is 0.5, and (iii) the probability of crew and passenger resistance in foiling a 9/11 type hijacking is 0.5 and (iv) there is no ASO program. If this is viewed as a series system where each event probability is statistically independent then the probability of foiling the hijacking is 0.875.[33] The risk reduction is thus shared equally for R(hardened cockpit door) = R(pre-boarding security) = R(crew and passenger resistance) = 100% $\times$ 0.875/3 = 29.2% with the total percentage risk reduction equalling 87.5%.

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[33] Probability of foiling a hijacking = 1 – [1-Pr(success of hardened cockpit door)] $\times$[1-Pr(success of pre-boarding security)] $\times$ [1-Pr(success of crew and passenger resistance)] $\times$ [1-Pr(success of ASO program)] = 1-0.5 x 0.5 x 0.5 x 1.0 = 0.875 where Pr(success of hardened cockpit door) = Pr(success of pre-boarding security) = Pr(success of crew and passenger resistance) = 0.5 and Pr(success of ASO program) = 0.

This above example is one of the simplest case, as in reality, many probabilities will be conditional on the success or failure of other security measures,[34] the type of security measure adopted,[35] the extent of the threat,[36] timing and other dependencies, transient changes in threat levels, etc—this will complicate any reliability analysis considerably. Hence, the estimation of the probability of individual security measure performance and how they contribute to the overall probability of foiling a hijacking and the quantification of expected risk reductions is by no means straightforward. As is the case with any risk analysis of a complex system (such as aviation security), such information may be inferred from expert opinions, scenario analysis, statistical analysis of prior performance data, system modelling and probabilistic and reliability analysis.[37] The accurate modelling of aviation security reliability and risks is thus a complex task and so an area for further work. In the meantime, however, the paper will focus on the minimum risk reduction needed for security measures to be cost-effective. Whether such a risk reduction can be achieved can be based on expert judgement (or experience) and/or on detailed reliability analysis.

The extra and more vigilant policing, intelligence, immigration, passport control, airport screening and other pre-boarding security measures implemented since 9/11 should result in an increased likelihood of detection and apprehension of terrorists. Increased public awareness is also of significant benefit to aviation security. Added to this are the much enhanced preventative policing and investigatory efforts that have caught potential terrorists including, in the United Kingdom in 2006, some planning to blow up airliners. Combined, we suggest, these measures by themselves provide significant risk reduction. There has been no successful hijacking anywhere in the world since 9/11 and very few attempts at blowing up airliners—and none of these in Australia. In consequence, we suspect, R(pre-boarding security) is likely to be high.

If an air marshal is on an aircraft then the risk reduction due to the air marshal R(air marshal) may be significant. However, the probability of air marshals being on a flight is near 0.1 and so:

R(ASO program) =
R(air marshals) $\times$ Pr(air marshals on plane) = 0.1 $\times$ R(air marshals)   (4)

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[34] For example: the probability of successful crew and passenger resistance will most likely depend on whether there is an air marshal on board as the presence of an air marshal may actually deter some crew and passengers to confront a hijacker.

[35] For example: the probability of air marshals successfully foiling a hijacking will be dependent on the number of air marshals on the plane.

[36] For example: the probability of air marshals, crew and passengers, etc. in successfully foiling a hijacking will be dependent on the number of hijackers and the weapons available to them, which is in turn dependent on the effectiveness of pre-boarding security.

[37] Stewart and Melchers, *Probabilistic Risk Assessment of Engineering Systems*.

As discussed earlier, it could well be argued that the largest deterrent to an attempted hijacking is crew and passenger resistance. Experience shows that the actions of concerned citizens have foiled more attempted hijackings than hardened cockpit doors or air marshals. If this was the case, R(crew and passenger resistance) would be higher than R(ASO program) and R(hardened cockpit doors).

We recognise that there is significant uncertainty and complexity in quantifying the effectiveness of security measures. For this reason, results will be subject to sensitivity analyses that considers the minimum (lower bound) risk reduction needed for a security measure to be cost-effective.

ANNUAL FATALITY RATE DUE TO AIRCRAFT HIJACKING IN THE ABSENCE OF ENHANCED SECURITY MEASURES

Three Australians have died in the last three decades from terrorism within Australia (1978 bomb explosion outside Sydney Hilton Hotel). There have been no fatalities from hijacking of Australian aircraft. One possible estimate of fatalities due to a 9/11 type aircraft hijacking in the absence of enhanced airline security might thus be zero. However, since the events of 9/11 Australian aircraft operate in regions with a heightened threat environment. If we look to the United States, which might reasonably be construed as having one of the highest threats, no one was killed by aircraft hijacking in the years before 2001 and therefore before the escalation of expenditures. That is to say, history strongly suggests one should not normally expect there to be very many deaths from aircraft hijacking.

This, however, leaves out 9/11 itself. That terrorist event was massively off the charts both in direct financial costs and in the loss of life when it took place, and that continues to be true today: there has never been a terrorist attack of remotely that magnitude. As Todd Sandler and Walter Enders note,

> the casualties on 9/11 represent a clear outlier with deaths on this single day approximately equal to all transnational terrorist-related deaths recorded during the entire 1988-2000 period.[38]

With this in mind, one could potentially remove the 9/11 outlier from consideration on the grounds that it may well remain a (horrific) aberration with little relevance to the future. However, while it may be reasonable to leave 9/11 out of the statistics, it is not conservative, and, since hardened cockpit doors and air marshals are principally designed to prevent a replication of 9/11, this event needs to be included in the analysis. As the

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[38] Todd Sandler and Walter Enders, 'Transnational Terrorism: An Economic Analysis', in H. W. Richardson, P. Gordon, and J. E. Moore II (eds.), *The Economic Impact of Terrorist Attacks* (Cheltenham, UK: Edward Elgar, 2005), pp. 11-34.

threat to the US homeland is principally from Al-Qaeda,[39] it would be reasonable to consider the period of a heightened threat from Al-Qaeda to be a suitable time period for the estimation of fatality rate before enhanced security measures—this is a ten year period 1992-2001. Accordingly, we will assume that, in the absence of enhanced security measures, there would be a 9/11 replication every ten years in the United States. That is, the fatality rate before enhanced security measures would be 300 per year.

Conceivably, Australia could experience a 9/11 type attack every ten years just as devastating as 9/11 itself. However, this is only a possibility, as the likelihood and motivation for such an attack also needs to be considered. The probability of a 9/11 type attack in Australia is less likely than the United States as no such attack has occurred in Australia (whereas it has in the United States), and the threat to Australia and its interests is less than that faced by the United States—which is why the World Markets Research Centre Global Terrorism Index ranks Australia as 38th on a list of 186 countries at risk from terrorism.[40] The United States is ranked as the fourth highest risk of terrorism, following the higher risk countries of Colombia, Israel and Pakistan. Risk is typically referred to as a combination of probability (likelihood) and consequences. The motivation and political gains for an attack by Al-Qaeda or Jemaah Islamiyah on the Australian homeland is also lacking on a "rather low-profile target like Australia".[41] To be conservative, however, assume that the fatality risks due to aircraft hijacking for Australians is the same as for Americans. A United States annual fatality rate of 300 per year is equivalent to an annual fatality risk of 1×10^{-6} which is one in a million[42]—i.e., the annual probability of an American being killed in a 9/11 type attack is one in a million. If we assume that the annual probability of an Australian being killed in a 9/11 type attack is also one in a million (i.e. American and Australian annual fatality risks are identical) then this leads to an Australian annual fatality rate of twenty-one per year. This is an upper bound estimate as all evidence suggests that risks of terrorism in Australia are less than the United States, and history strongly suggests that the best estimate of an Australian fatality rate due to 9/11 type aircraft hijackings in the absence of enhanced airline security is near zero. Nonetheless, an annual fatality rate before enhanced security measures of 21 per year is used herein. Note that the annual fatality rate is an expected value, i.e., a fatality rate averaged over a reasonable length of time.

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[39] Fawaz A. Gerges, *The Far Enemy: Why Jihad went Global* (Cambridge: Cambridge University Press, 2005).
[40] Guy Dunn, *Forecasting Global Terrorism*, World Markets Research Centre, London, August 2003.
[41] Christopher Michaelsen, 'Antiterrorism Legislation in Australia: A Proportionate Response to the Terrorist Threat?', *Studies in Conflict and Terrorism*, vol. 28 (2005), pp. 321-329.
[42] Calculated as 300 fatalities divided by the US population of 300 million.

Results and Discussion

RISK REDUCTION

Equation (4) shows that air marshals need to be ten times as effective as any other security measure to have the same risk reduction as pre-boarding security, hardening cockpit doors or crew and passenger resistance. The latter two security measures are also considerably cheaper than the ASO program. The ASO program would only be more cost-effective if it is able to show extra benefit over the cheaper measure of hardening cockpit doors. However, the ASO program seems to have significantly less benefit which means that hardening cockpit doors is the more cost-effective measure.

COST-BENEFIT ANALYSIS OF HARDENED COCKPIT DOORS

The cost-benefit analysis parameters for hardening cockpit doors are:

- C_R=$2.5 million per year

- Annual fatality rate before enhanced security measures = 21 fatalities per year

Figure 1: Annual Cost Spent per Life Saved (C_{LS}) for Hardening Cockpit Doors, Showing Regulatory Goal of $10 Million Per Life Saved.
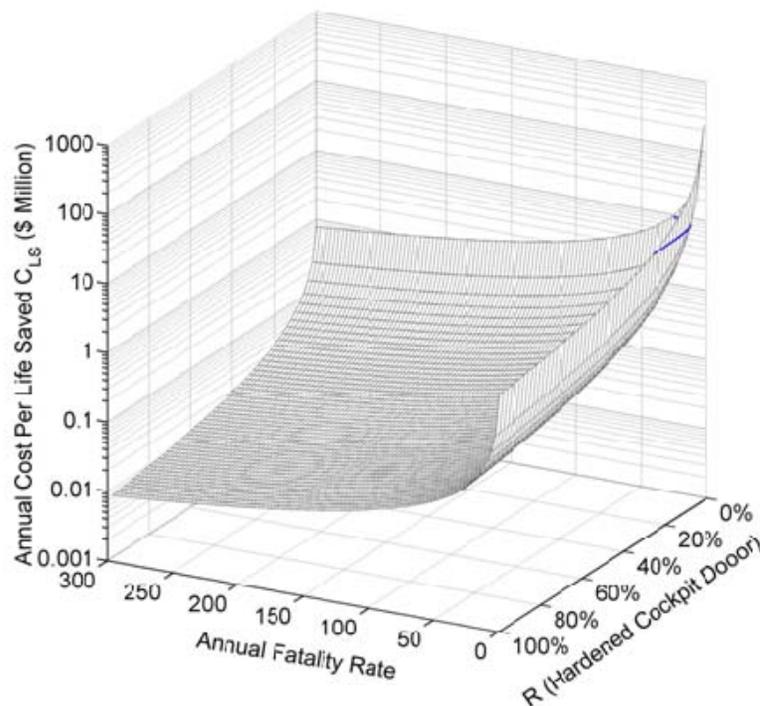
Using Equation (2), Figure 1 shows a plot of annual cost per life saved as a function of R(hardened cockpit door) and annual fatality rate before enhanced security measures. In nearly all cases the annual cost per life saved is below $10 million per life saved. When annual fatality rate before enhanced security measures is twenty-one fatalities per year and R(hardened cockpit door) is only 1.2 percent then annual cost per life saved is $10 million, and so would satisfy the upper limit of the regulatory goal of $1-$10 million per life saved. Hence, the lower bound of risk reduction for hardened cockpit doors to be viewed as cost-effective is only 1.2 percent. Since security experts believe that strengthening cockpit doors is one of the few security measures post 9/11 to be effective[43] then it is highly likely that the risk reduction achieved by the hardening of cockpit doors is well in excess of 1.2 percent.   So under this analysis hardening cockpit doors appears to be a cost-effective security measure.

COST-BENEFIT ANALYSIS OF AIR SECURITY OFFICER PROGRAM
The cost-benefit analysis parameters for the ASO program are:

- C_R = $55 million per year

- Annual fatality rate before enhanced security measures = 21 fatalities per year

Using Equation (2), Figure 2 shows a plot of annual cost per life saved as a function of R(ASO program) and annual fatality rate before enhanced security measures. When compared to hardening of cockpit doors (Figure 1), Figure 2 shows that there are more scenarios in which annual cost per life saved for the ASO program exceeds $10 million per life saved. At the extreme, it could be assumed that air marshals are the only effective security measure: R(air marshals)=100% and therefore R(ASO program)=100% $\times$ Pr(air marshals on plane)=10%. Even with this best case scenario, it follows from Equation (2) that the annual cost per life saved is high at $26.2 million. If Pr(air marshals on plane) is doubled to 0.2, annual costs per life saved are half of those calculated above, which would still be in excess of the regulatory goal of $1-$10 million per life saved. The lower bound of risk reduction caused by the ASO program to be viewed as cost-effective is thus 26.2 percent.   So the ASO program would only be cost-effective if we assume the best case of 1) the *only* effective security measure is the ASO program, and 2) air marshals ride on more than 26.2 percent of all passenger airplanes. This is not likely to be the case, particularly since there is no evidence to date of air marshals foiling a terrorist event. It would also have to be proven that the ASO program has a significant deterrent effect (i.e. deter terrorists from hijacking an aircraft) for it to be cost-effective, but

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[43] Schneier, *Beyond Fear*, pp. 247-248; Maley, 'Overhaul Cuts Sky Marshals by a Third', *The Australian*, January 23, 2008.

this would be ameliorated by the low percentage of flights that they can cover.

**Figure 2: Annual Cost Spent per Life Saved (C_{LS}) for ASO Program,
Showing Regulatory Goal of $10 Million Per Life Saved**
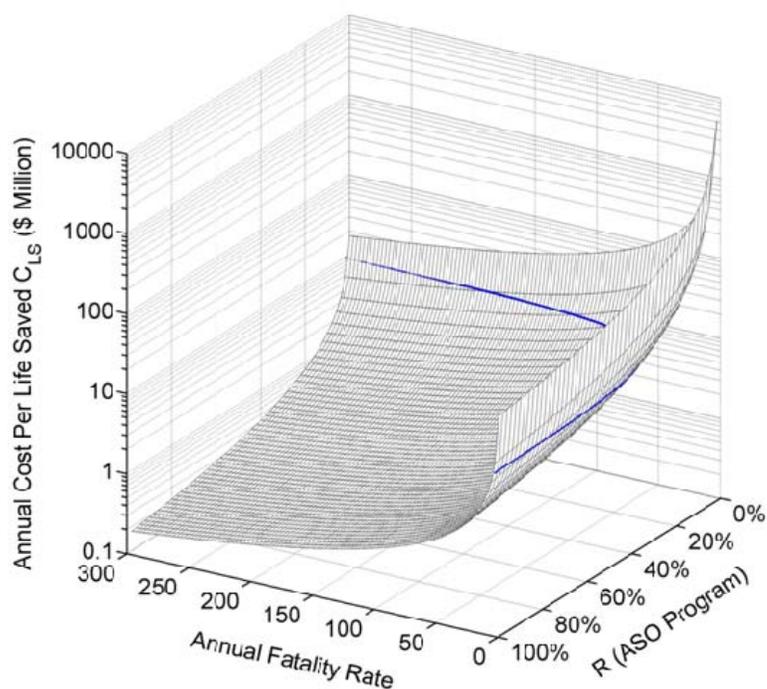
In reality, the risk reduction caused by air marshals may be closer to 25 percent (i.e., equally effective as the other three security measures and assuming that air marshals are on all flights and the combination of all security measures will foil every hijacking) leading to R(ASO program)=25%×0.1=2.5%. It follows from Equation (2) that the annual cost per life saved is $105 million—greatly in excess of the regulatory goal of $1-$10 million per life saved. Therefore, all reasonable combinations of security measure effectiveness lead to the conclusion that the ASO program fails a cost-benefit analysis.

DISCUSSION

Whereas analysis shows that hardening cockpit doors has been a cost-effective security measure, the ASO program fails a cost-benefit analysis. To be sure, the cost-benefit analysis is preliminary and the annual cost per life saved inferred herein are estimates only, but the magnitude of the costs

are large and even if some estimates are in error by 100 percent this will not change the cost-benefit conclusions. Nonetheless, the conclusions reported herein should not be viewed as fully conclusive as they are based in part on intuition and judgement about what levels of risk reductions are achievable. A detailed probabilistic and reliability analysis is clearly warranted to add more rigour to what the expected risk reductions would be for each security measures and to compare these with the minimum risk reductions described herein needed for a security measure to be cost-effective.

In addition to life-safety considerations, economic criteria such as reduced property damage and reduced GDP are other benefits of security measures. It has been estimated in a RAND report by Benjamin Zycher that these types of economic benefits are approximately equal to the value of lives saved.[44] Zycher also recommends that the total economic cost of security measures is at least twice the direct public expenditure due to the fact that

> government must obtain such resources, whether now or in the future, through the tax system (or through such explicit taxation as inflation), which imposes indirect costs upon the economy in the form of resource misallocation.[45]

Hence, in this case allowing for the marginal cost of government spending and the doubling of benefits due to inclusion of economic criteria results tend to cancel each other out, resulting in little change in annual costs per life saved calculated in the present analysis. Hence, it is expected that more comprehensive cost-benefit analyses that consider economic and financial matters will not change the conclusions of this paper.

Risk reduction measures that cost tens or hundreds of millions of dollars per life saved cannot be justified on rational life-safety grounds. If some of the additional federal government and private sector spending on aviation security were invested in other hazard or risk reduction programs many more lives would have been saved. For example, Tengs and Graham estimate that an investment of US$200,000 per year in smoke alarms will save one life.[46] Similar examples can be found for other risk reduction measures or regulations. While these numbers are approximate, they do illustrate the opportunity costs of the ASO program.

It might be argued that the $55 million spent on the ASO program is a prudent investment in a time of threat uncertainty. However, this is a spurious argument, as (i) there are likely to be other government expenditures that are not cost-effective and so the cumulative cost of such

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[44] Benjamin Zycher, *A Preliminary Benefit/Cost Framework for Counterterrorism Public Expenditures* (Santa Monica: RAND, 2003), p. 17.
[45] Ibid., p. 19.
[46] T. O. Tengs, and J. D. Graham, 'The Opportunity Costs of Haphazard Social Investments in Life-Saving,' in Robert W. Hahn (ed.), *Risks, Costs, and Lives Saved: Getting Better Results from Regulation* (Washington, DC: American Enterprise Institute, 1996), pp. 167-182.

expenditure can be considerable, and (ii) even a 'low cost' of $55 million could be used more productively to save lives—such as other security measures; flood protection; vaccination, screening and other health programs; vehicle and road safety; occupational health and safety, and so on.

Finally, this paper provides a starting point for further discussion. The assumptions and quantifications made here can be queried, and alternate hypotheses can be tested in a manner which over time will minimise subjectivity and parameter uncertainty inherent in an analysis for which there are little accurate quantitative data. This should lead to more widespread understanding and agreement about the relative cost-effectiveness of aviation and other counterterrorism security measures.

Conclusions

Bruce Schneier concludes that the only two effective antiterrorism countermeasures implemented after 9/11 were strengthening cockpit doors and passengers learning they need to fight back.[47] Athol Yates, Executive Director of the Australian Homeland Security Research Centre says that air marshals are of 'questionable' security value, and that

> hardening the cockpit doors and changing the protocols for hijacking has made it harder for terrorists to get weapons on board an aircraft and take control of it.[48]

The quantitative cost-benefit assessment in this paper supports these conclusions. A more detailed reliability and risk analysis of aviation security measures (or other counterterrorism measures) may well reveal other inefficiencies and suggest where resources may be better allocated to maximise public safety.

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[47] Schneier, *Beyond Fear*, pp. 247-248.
[48] Maley, 'Overhaul Cuts Sky Marshals by a Third'.