CENTRE FOR INFRASTRUCTURE
PERFORMANCE AND RELIABILITY

RESEARCH REPORT

Assessing the Risks, Costs and Benefits of Australian Aviation Security Measures

M.G. Stewart and J. Mueller

Research Report No. 266.04.08

ISBN No. 9781 9207 01 97 0

THE UNIVERSITY OF
NEWCASTLE
AUSTRALIA

ASSESSING THE RISKS, COSTS AND BENEFITS OF AUSTRALIAN AVIATION SECURITY MEASURES

Mark G. Stewart
Professor and Director, Centre for Infrastructure Performance and Reliability
The University of Newcastle
New South Wales, 2308, Australia
phone: +61 2 49216027 email: mark.stewart@newcastle.edu.au

John Mueller
Professor and Woody Hayes Chair of National Security Studies
Mershon Center for International Security Studies and Department of Political Science
Ohio State University
Columbus, Ohio 43201, United States
phone: +1 614 2476007 email: bbbb@osu.edu

ABSTRACT
The Australian government Office of Best Practice Regulation has recommended the use of cost-benefit assessment for all proposed federal regulations. 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 (TSA) alone. 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; (i) Hardened cockpit doors and (ii) 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 analyses considers the effectiveness of security measures, their cost and expected lives saved as a result of such expenditure. An assessment of increased expenditure on the Air Security Officer (air marshals) program since 2001 suggests that the annual cost is $157.2 million per life saved. This is greatly in excess of the regulatory safety goal of $1-$10 million per life saved. As such, the ASO program seems to fail a cost-benefit analysis. In contrast, hardening of cockpit doors has an estimated annual cost of only $700,00 per life saved, suggesting that this strategy is a much more cost-effective security measure.

1. INTRODUCTION

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 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"[1], 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.[2] Following this approach, Stewart and Mueller conducted an assessment of increased United States federal homeland security expenditure since the 9/11 attacks and of expected lives saved as a result of such expenditure[3]. 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 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

---

[1] *Best Practice Regulation Handbook*, Office of Best Practice Regulation, Australian Government, Canberra, August 2007, p. 115.

[2] Mark G. Stewart, 'Life Safety Risks and Optimisation of Protective Measures for Terrorist Threats to Built Infrastructure,' *International Forum on Engineering Decision Making: Optimal Strategies for Disaster and Hazard Mitigation* (Sydney University Press, 2007), pp. 19-30. Mark G. Stewart, 'Cost-Effectiveness of Risk Mitigation 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.

[3] Mark G. Stewart and John Mueller, *Assessing the Costs and Benefits of United States Homeland Security Spending*, Research Report No. 265.04.08, Centre for Infrastructure Performance and Reliability, The University of Newcastle, NSW, Australia, April 2008.

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 (TSA) alone[4]. 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:

1. Hardened cockpit doors
2. 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 analyses considers the effectiveness of 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[5]. This paper provides a sound starting point for discussion about how to manage homeland security and counter terrorism 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

[4] *Homeland Security Department: FY2008 Appropriations*, CRS Report for Congress, Congressional Research Service, 20 August 2007.

[5] David R. Mandel, ‘Are Risk Assessments of a Terrorist Attack Coherent?’, *Journal of Experimental Psychology: Applied*, Vol. 11, No. 4 (2005), pp. 277-288.

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[6], 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.

2. 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 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 1960's been subject to methodical and quantitative risk assessments[7]. Many risks can be 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[8]. The cost per life saved varies considerably with the activity or regulation, for example, a

---

6 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.

7 Mark G. Stewart and Robert E. Melchers, *Probabilistic Risk Assessment of Engineering Systems*, (London: Chapman & Hall, 1997).

8 Regulation Taskforce 2006, *Rethinking Regulation: Report of the Taskforce on Reducing Regulatory Burdens on Business*, Report to the Prime Minister and the Treasurer, Canberra, January.

median of $42,000 to a maximum of over $10 billion[9]. Table 1 shows the expenditure per life estimated to be saved for specific United States government regulations for risk reduction[10]. As can be seen, society (as represented by the United States government) spends far more money per life saved for efforts to prevent death from 'dread' type risks such as exposure to asbestos and arsenic than for some efforts to prevent death from more mundane activities such as driving a motor vehicle. This is often a function of psychological and political aspects of risk perception. While it is recognized that many individuals may be risk averse, decision-making bodies (such as government) need to act rationally in the distribution of risk reduction funds in order to achieve the best outcomes (risk reduction) for society as a whole. Clearly, however, electoral and lobbyist pressure may well circumvent such rationality as evidenced by the high number of government regulations that require expenditure of tens of millions of dollars and more to save one statistical life. Further, the lack of coordination and consistency in risk management between federal, state and local agencies also contributes to haphazard or inconsistent regulation. Tengs and Graham cite the following example: "To regulate the flammability of children's clothing we spend $1.5 million per year of life saved, while some 30% of those children live in homes without smoke alarms, an investment that costs about $200,000 per year of life saved." [11]

Elisabeth Paté-Cornell[12] 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[13] and the Roads and Traffic Authority of NSW uses a value of $1.6 million[14]. For most activities a cost per life saved not exceeding $1-$10 million is typical. This value is consistent with many studies as well as values currently used by most government agencies[15,16]. In other words, if

---

[9] T.O. Tengs, M.E. Adams, J.S. Pliskin, et al, 'Five-Hundred Life-Saving Interventions and Their Cost-Effectiveness', *Risk Analysis*, Vol. 15, No. 3 (1995), pp. 369-390.

[10] Table 1 is adapted from W. Kip Viscusi, 'The Value'.

[11] T.O. Tengs, and J.D. Graham, 'The Opportunity Costs of Haphazard Social Investments in Life-Saving', *Risks, Costs, and Lives Saved: Getting Better Results from Regulation*, R.W. Hahn (ed.), American Enterprise Institute, 1996, pp. 167-182.

[12] M. Elisabeth Paté-Cornell, 'Quantitative Safety Goals for Risk Management of Industrial Facilities', *Structural Safety*, Vol. 13 (1994), pp. 145-157.

[13] *Guidelines for Acceptable Flood Capacity for Dams*, Department of Natural Resources and Water, Queensland Government, February 2007.

[14] *Economic Analysis Manual*, NSW Roads and Traffic Authority, Sydney, 2005.

[15] 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.

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.

Regulation	Year	Agency	Cost per Life Saved (millions of 1995 dollars)
Unvented space heater ban	1980	CPSC	0.1
Seatbelt/air bag	1984	NHTSA	0.1
Aircraft cabin fire protection standard	1985	FAA	0.1
Steering column protection standards	1967	NHTSA	0.1
Underground construction standards	1989	OSHA	0.1
Aircraft seat cushion flammability	1984	FAA	0.6
Trihalomethane in drink water	1979	EPA	0.5
Auto fuel system integrity	1975	NHTSA	0.5
Aircraft floor emergency lighting	1984	FAA	0.7
Concrete and masonry construction	1988	OSHA	0.7
Passive restraints for trucks and buses	1989	NHTSA	0.8
Auto side impact standards	1990	NHTSA	1.0
Children’s sleepwear flammability ban	1973	CPSC	1.0
Auto side-impact standards	1990	NHTSA	1.0
Metal mine electrical equipment standards	1970	MSHA	1.7
Trenching and evacuation standards	1989	OSHA	1.8
Hazard communication standard	1983	OSHA	1.9
Trucks, buses and MPV side-impact	1989	NHTSA	2.6
Grain dust explosion prevention	1987	OSHA	3.3
Rear lap/shoulder belts for autos	1989	NHTSA	3.8
Standards for radionuclides in uranium mines	1984	EPA	4.1
Ethylene dibromide in drinking water	1991	EPA	6.8
Asbestos occupational exposure limit	1972	OSHA	9.9
Electrical equipment in coal mines	1970	MSHA	11.1
Arsenic emission standards for glass plants	1986	EPA	16.1
Cover/move uranium mill tailings	1983	EPA	53.6
Coke ovens occupational exposure limit	1976	OSHA	75.6
Arsenic occupational exposure limit	1978	OSHA	127.3
Asbestos ban	1989	EPA	131.8
1,2-Dechloropropane in drinking water	1991	EPA	777.4
Hazardous waste land disposal ban	1988	EPA	4,988.7
Municipal solid waste landfills	1988	EPA	22,746.8
Formaldehyde occupational exposure limit	1987	OSHA	102,622.8
Atrazine/alachlor in drinking water	1991	EPA	109,608.5
Hazardous waste listing for wood-preserving chemicals	1990	EPA	6,785,822.0

Table 1. Regulatory Expenditure Per Life Saved.

[16] Peter Ableson, ‘Establishing a Monetary Value for Lives Saved: Issues and Controversies’, *Cost-Benefit Conference*, Office of Best Practice Regulation, Canberra, November 2007.

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[17]. 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[18] 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 manage the often conflicting societal preferences associated with assessments of risk, cost and benefits.

3. AVIATION SECURITY RISK REDUCTION MEASURES

The United States TSA has arrayed '20 Layers of Security' to 'strengthen security through a layered approach' – see Figure 1.[19] Australia, like the TSA, has a layered approach to aviation security that provides "strength in depth"[20]. 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, etc.. Then there are 'in-flight security' measures which can be grouped broadly as:

1. Crew and Passenger Resistance
2. Hardened Cockpit Door
3. Air Security Officer Program

---

[17] For a detailed review and discussion of risk acceptance criteria see Stewart and Melchers, *op. cit.*; 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.

[18] Bruce Schneier, *Beyond Fear: Thinking Sensibly About Security in an Uncertain World* (New York: Copernicus, 2006).

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

[20] *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.

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.

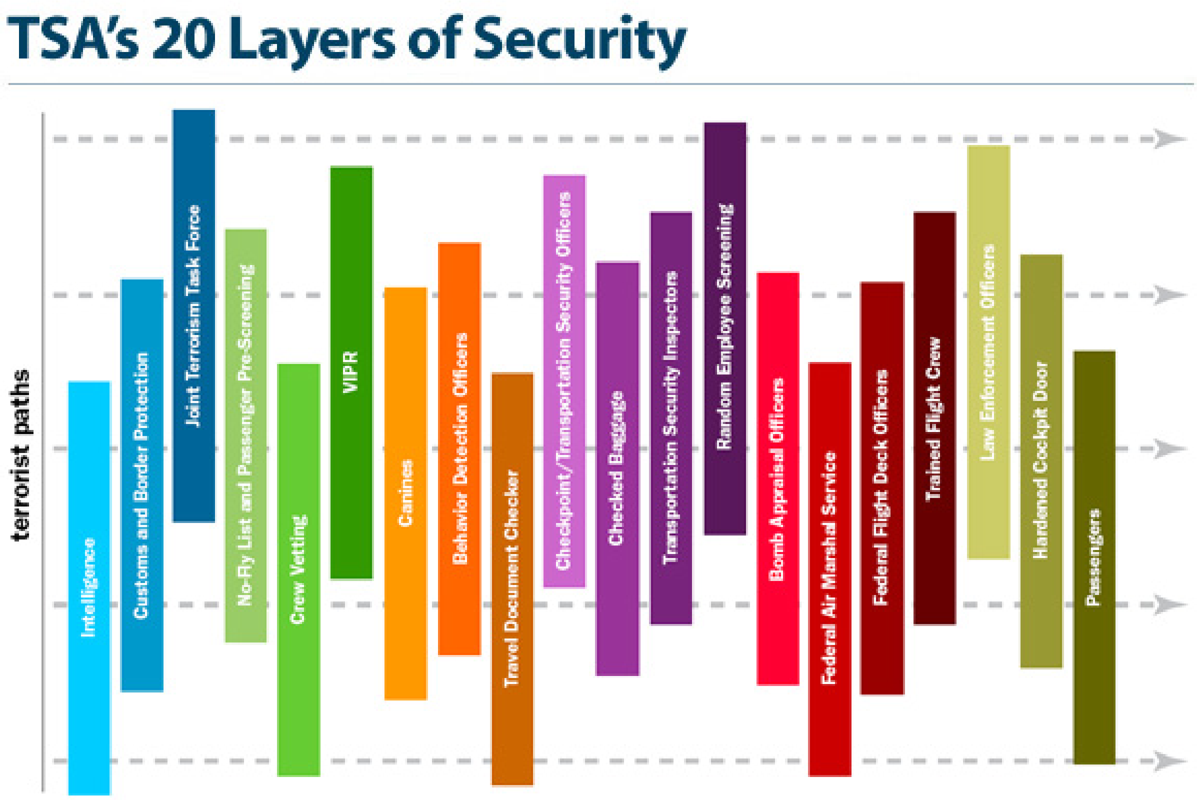

Figure 1. The United States Transportation Security Administration (TSA) 20 Layers of Security.

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.

3.1 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".[21] Indeed, only a few months before 9/11 three terrorists, in this case Chechens, had commandeered a 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.[22]

The 9/11 suicide attacks on the World Trade Center 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"[23]. This demonstrates the new paradigm that crew and passengers will in many cases no longer be passive in the event of a hijacking threat.

3.2 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

---

[21] Schneier, *op. cit.*, p. 4.

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

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

structure to the bulkhead"[24]. 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[25], 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 10-year period, including increased fuel consumption costs due to the heavier doors.[26] This cost will 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 6,000 cockpit doors in the United States is approximately US$40 million[27], then a pro-rata best estimate annual cost of hardening cockpit doors for Australian airlines is $2.5 million (in Australian dollars[28]).

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.

3.3 Air Security Officer Program

One hundred and thirty Air Security Officers (ASOs), often called 'air marshals', are available to patrol Australian domestic and international flights. The Air Security Officer program has a budget of $135.5 million over the 2006 to 2010 period[29] - 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

---

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

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

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

[27] *ibid.*

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

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

per year[30]. 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% of Australia's international fleet and approximately 65% 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% probability of air marshals being on a flight,[31] which is a similar percentage for the United States Federal Air Marshal Service[32]. 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"[33]. While up to six air marshals may be on a single flight, changes to the ASO 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[34].

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 68-year-old man who produced a small knife on a flight from Sydney to Cairns in 2003[35]. United States air marshals have made 59 arrests since 2001, but none of these incidents has been related to terrorism.[36]

---

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

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

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

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

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

[34] Maley, *op. cit.*

[35] Russell, *op. cit.*

[36] Meckler,Carey, *op. cit.*

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.

4. ANNUAL COST PER LIFE SAVED

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

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

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

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

The following sections discuss the quantification of key parameters in Eqn. (2); namely,

- risk reduction due to enhanced security measures (R)
- annual fatality rate before enhanced security measures

4.1 Effectiveness of Aviation Security Measures to Prevent a Replication of 9/11

The percentage reduction in the risk of a replication of 9/11 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(Air Security Officer program)

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 U.K. in 2006, some planning to blow up airliners. Combined, we suggest, these measures by themselves reduce the risk of a replication of 9/11 by at least 50%, and this is likely to be a lower bound value. 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 much greater than 50%. Nonetheless, for the present analysis assume R(pre-boarding security)=50%.

If there is an attempt to hijack an aircraft, it is assumed all three in-flight security measures have an equal share of risk reduction; namely,

R(hardened cockpit door)= R(crew and passenger resistance)= R(air marshals)

This is conditional on air marshals being on the aircraft. However, the probability of air marshals being on a flight is near 10%. So we assume that the probability of air marshals being on a hijacked plane is Pr(air marshals on plane)=0.1. Hence:

- R(pre-boarding security) 50.0%
- R(crew and passenger resistance) 16.67%
- R(hardened cockpit door) 16.67%
- R(Air Security Officer program)
  = R(air marshals) x Pr(air marshals on plane)=16.67×0.1 1.67%

The risk reduction due to the Air Security Officer program is appropriate for hijacking of a single aircraft, or for hijacking of multiple aircraft. If there are air marshals on every flight (and therefore Pr(air marshals on plane)=1.0), if all cockpit doors are hardened, and if crew and passengers will resist a hijacking, the risk reduction is 100%. In other words, every attempted hijacking will be foiled. This is a best case scenario, but there but there may be scenarios under which hijackings can still occur. Bruce Schneier suggests several: “a plane that’s empty enough that the hijackers outnumber the passengers, a hijacker who succeeds in convincing the passengers that he’s not suicidal or a terrorist (carrying a baby would go a long way towards calming the passengers), a hijacker who succeeds in taking over a bullet proof cockpit (turning a security countermeasure into a vulnerability), or a hijacker that convinces everyone that she's a sky marshal".[37] The effectiveness of the security measures is likely to be over-estimated at 100%.

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 much greater than 16.67%.

While the above risk reductions are our best estimate, we recognise that there is significant uncertainty in quantifying the effectiveness of security measures. Hence, results will be subject to sensitivity analyses that considers the minimum (lower bound) risk reduction needed for a security measure to be cost-effective.

4.2 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

[37] Schneier, *op.cit.,* p. 274.

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 threat to the U.S. 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 10 year period 1992 – 2001. Accordingly, we will assume that, in the absence of enhanced security measures, there would be a 9/11 replication every 10 years in the United States. That is, the fatality rate before enhanced security measures would be 300 per year.

However, the threat environment in Australia is not the same as 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. The threat to Australia and its interests is clearly less than that faced by the United States. 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[41]. As the population of Australia is only 21 million, to match the United States annual fatality risk of 1×10^{-6} requires an Australian annual fatality rate of 21 per year. This is an upper bound estimate as risks of terrorism in Australia should be less than the United States. Nonetheless, an annual fatality rate before enhanced security measures of 21 per year is used herein.

---

[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* (Elgar, 2005), pp. 11-34.

[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] Calculated as 300 fatalities divided by the U.S. population of 300 million.

5. RESULTS AND DISCUSSION

5.1 Risk Reduction

Hardening cockpit doors has the highest risk reduction (16.67%) at lowest additional cost of $2.5 million. On the other hand, the ASO program costs $55 million pa but reduces risk by only 1.67%. The ASO program may 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.

5.2 Cost-Benefit Analysis

5.2.1 Hardened Cockpit Doors

If there is no Air Security Officer Program, then hardening cockpit doors reduces risk by R(hardened cockpit doors) =16.67% at an additional cost of $2.5 million; hence:

- C_R=$2.5 million per year
- R=R(hardened cockpit door)=16.67%
- Annual fatality rate before enhanced security measures = 21 fatalities per year

It follows from Eqn. (2) that the annual cost per life saved (C_{LS}) is $714,000.

An annual cost per life saved of $714,000 is less than the regulatory goal of $1-$10 million per life saved. If the effectiveness of pre-boarding security is increased from 50% to 80% the effectiveness of hardened cockpit doors is reduced to R=6.67%, and the annual cost per life saved is increased to $1.8 million. If (i) effectiveness of hardened cockpit doors is double that of crew and passenger resistance or air marshals or (ii) crew and passengers do not resist a hijacking - R(crew and passenger resistance)=0%, then in both scenarios R=25% and the annual cost per life saved is reduced to $476,000. If it is assumed that the increased expenditures on pre-boarding security has only been "minimally effective"[42] - R(pre-boarding)=0% and in that case R doubles to 33.34% and the annual cost per life saved is

[42] Schneier, *op. cit.*, p. 248.

reduced to only $357,000. If the existing fatality rate is reduced to a near zero level (as past statistics suggest) to say 2 fatalities per year then the annual cost per life saved is increased to $7.5 million. In all these cases the annual cost per life saved is less than $10 million.

If R(hardened cockpit door) is only 1.2% then annual cost per life saved is $10 million. Hence, the lower bound of risk reduction for hardened cockpit doors to be viewed as cost-effective is only 1.2%. Since security experts believe that strengthening cockpit doors is one of the few security measures post 9/11 to be effective[43] [44] then it is highly likely that the risk reduction achieved by the hardening of cockpit doors is well in excess of 1.2%. So under this analysis hardening cockpit doors appears to be a cost-effective security measure, a finding that is not overly sensitive to the relative weightings of risk reduction between security measures.

5.2.2 Air Security Officer Program

The ASO program reduces risk by 1.67% at an additional cost of $55 million, hence:

- C_R=$55 million per year
- R=R(Air Security Officer program)=1.67%
- Annual fatality rate before enhanced security measures = 21 fatalities per year

It follows from Eqn. (2) that the annual cost per life saved is $157.2 million.

An annual cost per life saved of $157.2 million is greatly in excess of the regulatory goal of $1-$10 million per life saved. If the effectiveness of pre-boarding security is increased from 50% to 80% (R=0.67%), the annual cost per life saved is increased to $392.9 million. If (i) effectiveness of air marshals is double that of crew and passenger resistance or hardened cockpit doors or (ii) crew and passengers do not resist a hijacking - R(crew and passenger resistance)=0%, then in both scenarios R=2.5% and the annual cost per life saved becomes $104.8 million. If it is assumed that the increased expenditures on pre-boarding security are ineffective [R(pre-boarding)=0%] then R(Air Security Officer program) doubles to 3.33% and the annual cost per life saved becomes $78.6 million. If the existing fatality rate is reduced to

[43] Schneier, *op. cit.* , pp. 247-248.

[44] Maley, *op. cit.*

a near zero level (as past statistics suggest) to say 2 fatalities per year then the annual cost per life saved is increased to $1.65 billion.

At the extreme, it could be assumed that air marshals are the only effective security measure: R(air marshals)=100% and therefore R(Air Security Officer program)=100% x Pr(air marshals on plane)=10%. Even with this best case scenario, the annual cost per life saved remains 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 Air Security Officer program to be viewed as cost-effective is thus 26.2%. So the Air Security Officer program would only be cost-effective if we assume the best case of 1) the only effective safety measure is the Air Security Officer 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 this would be ameliorated by the low percentage of flights that they can cover. Therefore, all reasonable combinations of security measure effectiveness suggest that the Air Security Officer program fails a cost-benefit analysis.

5.3 Discussion

As discussed in Section 4.1, the effectiveness of security measures is likely to be over-estimated because we assume that loss of life due to aircraft hijacking is completely eliminated (R=100%) and because we ignore the possibility of scenarios in which hijackers can still succeed despite the presence of new security measures on aircraft. There may also be other aviation security measures, such as a double cockpit door, that could further enhance security. If the loss of life due to aircraft hijacking is not completely eliminated or other security measures are implemented the percentage risk reductions for hardened cockpit doors and the Air Security Officer program will be lowered, leading to higher annual costs per life saved. Accordingly, the Air Security Officer program would be deemed even less cost-effective. However, even an order of magnitude reduction in the effectiveness of hardened cockpit doors (resulting in a ten-fold increase in cost per life saved of $7.1 million) would not change the conclusion that hardened cockpit doors appears to be a cost-effective aviation security measure under our assumptions.

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[45]. 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".[46] 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.

Whereas analysis shows that hardening cockpit doors has been a cost-effective security measure, the Air Security Officer 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% this will not change the cost-benefit conclusions.

Note that the costs per life saved and findings described herein are very similar also for United States aviation security measures[47]. The Federal Air Marshal Service and strengthening cockpit doors cost the United States government and the airlines nearly $1 billion per year. The report by Stewart and Mueller assessing the risks, costs and benefits of United States aviation security measures showed that strengthening cockpit doors is cost-effective whereas the Federal Air Marshal Service is not.

---

[45] Benjamin Zycher, 'A Preliminary Benefit/Cost Framework for Counterterrorism Public Expenditures', RAND, Santa Monica, 2003, p.17.

[46] *op. cit.*, p. 19.

[47] Mark G. Stewart and John Mueller, *Assessing the Risks, Costs and Benefits of United States Aviation Security Measures*, Research Report No. 267.04.08, Centre for Infrastructure Performance and Reliability, The University of Newcastle, NSW, Australia, April 2008.

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[48]. 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 Air Security Officer 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 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 data. This should lead to more widespread understanding and agreement about the relative cost-effectiveness of aviation and other counter terrorism security measures.

6. 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.[49] Athol Yates, Executive Director of the Australian Homeland Security Research Centre says that air marshals are of ‘questionable’ security value, and that

---

[48] 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.

[49] Schneier, *op. cit.* , pp. 247-248.

"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".[50] The quantitative cost-benefit assessment in this paper supports these conclusions. While defence-in-depth and layered approaches to security have merit, in this instance the Air Security Officer program (and other air marshal programs) carries with it a great opportunity cost and may be one layer too many.

ACKNOWLEDGEMENTS

Part of this work was undertaken while the first author was a visiting scholar at the Mershon Center for International Security Studies at Ohio State University. He greatly appreciates the assistance and financial support of the Mershon Center. The first author also appreciates the financial support of the Australian Research Council.

[50] Maley, *op. cit.*

THE UNIVERSITY OF NEWCASTLE

SCHOOL OF ENGINEERING

CIVIL, SURVEYING AND ENVIRONMENTAL ENGINEERING

RESEARCH REPORTS

This report is one of a continuing series of Research Reports published by Civil, Surveying and Environmental Engineering at the University of Newcastle. An abridged list of recently published titles in this series is provided below. Requests for a more detailed list and/or copies of other reports should be addressed to:

The Secretary
Civil, Surveying and Environmental Engineering
The University of Newcastle
University Drive
CALLAGHAN NSW 2308

Telephone: (02) 4921 6058
Facsimile : (02) 4921 6991

REPORT NO.	ISBN NO.	TITLE AND AUTHOR
262.03.2007	1 9207 0178 8	Computation Of Effective Cement Paste Diffusivities From Microtomographic Images M. Hain, K. Krabbenhoft and P. Wriggers
263.03.2007	1 9207 0179 6	Variational Plasticity Models For Geomaterials K. Krabbenhoft, A.V. Lyamin, S.W. Sloan and J.D. Zhao
264.02.2008	9781 9207 01 94 9	A Variational Theory Of Plasticity For Frictional Materials K. Krabbenhoft
265.04.2008	9781 9207 01 96 3	Assessing The Costs And Benefits Of United States Homeland Security Spending M.G. Stewart and J. Mueller
266.04.2008	9781 9207 01 97 0	Assessing The Risks, Costs And Benefits Of Australian Aviation Security Measures M.G. Stewart and J. Mueller
267.04.2008	9781 9207 01 98 7	Assessing The Risks, Costs And Benefits Of United States Aviation Security Measures M.G. Stewart and J. Mueller