A Decision Analysis to Evaluate the Cost-Effectiveness of MANPADS Countermeasures

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Abstract

This report describes a decision analysis to assess the cost-effectiveness of MANPADS (Man-Portable Air Defense Systems) countermeasures. These countermeasures are electronic devices that can be installed on commercial airplanes to detect and deflect surface-to-air missiles (SAMS) fired by terrorists. The model considers a terrorist attempt to shoot down a commercial liner with a heat seeking surface-to-air missile (SAM). The analysis occurred in two stages: First, a decision tree model was built using the *Treeplan* software and all inputs were parameterized to cover a wide range of reasonable possibilities. A Visual Basic interface was established to create a user friendly and interactive tool to explore alternative sets of parameters. Use of this tool suggested that the probability of an attack, the total economic costs due to the attack, and the cost of the countermeasures were the key drivers of the decision of whether or not to equip commercial planes with MANPADS countermeasures. Subsequently another model was built in *Treeage Pro*, a tool that is especially valuable that for sensitivity analysis. The *Treeage Pro* model is also completely parameterized to account for the type of weapon, the type of aircraft, the location of delivery of the weapon, distance from the airplane, and possible countermeasures. While the model focuses on one attack, it can easily be adopted to multiple and possibly sequential attacks. The analysis suggests that countermeasures installed on planes to deflect heat seeking SAMs can be cost-effective, if the probability of such an attack is large (>0.5 in ten years), the losses are large (>$100 billion), and the countermeasures are relatively inexpensive (<$15 billion).

1. Introduction

The threat of attacks on U.S. and other Western commercial aircraft using man-portable air defense systems (MANPADS) – heat-seeking or laser-guided surface to air missiles (SAMs) - has been recognized widely since 2001 (see for instance Bolcomm and Feikert, 2004; Shanker, 2002; Phelps 2003; and Hunter, 2003).[1] In recent years, there have been publicized MANPADS attacks on large civilian aircraft, in Baghdad, Iraq (*Space Daily,* 2003) and Mombasa, Kenya (*Jane's Intelligence Review,* 2003)[2] which heightened fears of such attacks in the U.S. soil or overseas. It is estimated that at least 4,000 to 5,000 of these missiles may be accessible to anti-Western terrorist organizations (*Associated Press,* 2003).

In addition to MANPADS, other threats to the aviation system must be addressed, including concerns that terrorists might turn to alternative weapons systems and tactics, using, for example, large caliber sniper rifles, mortars or rocket-propelled grenades (RPGs) (see Grau, 1998; Violence Policy Center, 2002; Bennett, 2003; O'Sullivan, 2004; Chow et al., 2005) to attack airborne planes and/or grounded aircraft and airport facilities. Not only are passengers, personnel and airline infrastructure threatened, but also the health of the entire airline industry, which has suffered long-term economic damage in the aftermath of the September 11, 2001 al Qaeda attacks, and is only now recovering from this event. In particular, there have been significant concerns at the policy level that missile attacks on airplanes, possible at multiple locations and repeated over time, would

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[1] There were earlier warnings as well. See for instance Marvin B. Schaffer, "Concerns About Terrorists With Manportable SAMS," *RAND Corporation Reports,* October 1993

[2] The 2003 Baghdad attack on a DHL A300 cargo jet was attacked with a Russian-made SA-14 MANPADS missile, and resulted in a wing fuel tank fire, loss of all three hydraulic systems and a crash landing with no injuries at the Baghdad International Airport; the Mombasa attack was directed at an Israeli Arkia charter jet, but the missile(s) did not hit the target.

be a devastating blow to the industry and could cause massive related economic consequences to tourism, travel and related industries.

There are effective electronic countermeasures against most infrared-guided missiles. These countermeasures have up to now have been used primarily on military aircraft, and consist of a missile detection and tracking device coupled with either "smart" flares ejected from the plane to confuse the missile, or infrared jammers that actively interfere with the missile homing seeker.[3] The U.S. Department of Homeland Security (DHS) currently has initiated a multi-million dollar program to develop direct infrared countermeasures (DIRCMs) that jam the heat seeking device of a MANPAD and deflect its course away from the airplane. This program is in support of a pending decision by Congress on whether or not to request some or all U.S. commercial airliners to install them. At present, there are no effective countermeasures against *non*-infrared MANPADS, such as laser beam-riders (LBR)[4], command line-of-sight (CLOS) missiles, or against other weapons that might damage or destroy an aircraft in the air or on the ground.

In addition to countermeasures intended to prevent attack, there are also measure that increase the likelihood that an airliner survives a "successful" hit. These survival countermeasures include hardening the engines, fuselage, and/or the cockpit; improving redundancies in key systems; installing fuel tank fire-suppression systems; and/or better training pilots how to safely land attack-damaged planes. At this writing, current DHS

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[3] Generally referred to as directed infrared counter-measures (DIRCM).

[4] Pakistan, for instance, produces an effective laser beam-rider MANPADS, which was modeled after the Swedish RBS-70 missile, against which infrared countermeasures are ineffective. There are concerns that radical Islamic members of the Pakistani Army are sympathetic to al Qaeda and similar terrorist groups, and might be a source for non-IR, LBR MANPADS weapons, training or recruitment.

initiatives are concentrating primarily on preventing infrared-guided MANPADS missile hits, via aircraft-based DIRCM systems, and not on survivability countermeasures.

The purpose of the analysis presented in this paper is to contribute to the discussion about the cost effectiveness of DIRCMs. Some analysts and some airline officials have already concluded that they are not cost-effective (see, for example, RAND, 2005), because of the substantial capital and operations and maintenance costs relative to the potential losses of lives and the losses to the economy. Some believe that whatever conclusions are drawn about threats to airlines or countermeasure benefit-cost, policy analysis should assume terrorists would attempt to adapt to or circumvent any countermeasures by using other weapons or tactics to try to bring down airplanes, if the they desire to do so (Chow et al., 2005; O'Sullivan, 2004). Regardless of costs and effectiveness, many argue that the country should do anything it can to protect human lives against and imminent threat and to protect the economy against another major disaster involving the airline industry.

To explore some of these issues and tradeoffs, this analysis focuses on a scenario of a single attack using a heat seeking SAM to attempt to shoot down a large plane in the U.S. Using a standard decision tree analysis, it examines the effects of implementing countermeasures to reduce the likelihood of this attack being successful. The idea of this analysis was not to focus on the specific numerical probabilities or consequences, but to provide a very flexible tool for decision makers to explore the impact of alternative assumptions on the cost-effectiveness of installing MANPADS countermeasures.

In the next section of this paper, we show the basic decision tree used throughout this analysis. This tree was built using an Excel Add In called "Treeplan," an Excel add-in (Decision Support Services, 2005). All probabilities and consequences in this tree are parameterized (kept as variables) and they are controlled through a Visual Basics interface that is very user friendly and shows immediately how the changes in the inputs (probabilities, consequences, and tradeoffs) affect the outputs (equivalent expected costs of the MANPADS threat with or without countermeasures) both in numerical and graphical form. Additional sensitivity analyses were performed using the software “Treeage Pro,” by Treeage Software, Inc. (2005). This software allows users to explore one-, two-, and even three-way sensitivity analyses to determine the impacts of input changes on the analysis outputs.

2. Decision Tree and Preliminary Sensitivity Analysis

Figure 2.1 shows the decision tree used throughout this report. The key decision is whether to install countermeasures or not. At this point, it is not important to consider exactly what type of countermeasures to install, since the effects of the countermeasure are parameterized in terms on the deterrence probability and of the effectiveness in avoiding a hit or fatal crash. This decision has costs and these costs are parameterized as well, using information form various sources, including the recent RAND report (Chow et al., 2005).

Considering the decision not to install countermeasures (lower part of Figure 2.1), the first event node concerns whether terrorists will attempt an attack on airplanes on US soil. This probability (p) is not very well known and subject to revisions using intelligence information. In this analysis, we consider a ten-year time horizon and vary the probability of an attack through the full range from 0 to 1. Here we focus on a single attack and we will discuss generalizations to multiple and repeated attacks in the conclusion section.

Next is the probability that an attempt will be interdicted (q), for example, by citizens alerting the police about suspicious activity near the perimeter of the airport. Countermeasures focusing on perimeter control would affect this probability, but in this analysis we only evaluate countermeasures installed on the planes and we assume that the interdiction probability is zero. Future applications of this model can use this parameterized probability to explore the cost-effectiveness of perimeter control countermeasures – particularly for shorter range, non-MANPADS weapons. If the attack is not interdicted, and the missile is successfully fired, there is a chance (h) that the missile hits the plane. Finally, depending on how and where the plane is hit, there is a chance that the pilots manage to land the plane safely or not (r).

The event nodes are identical for the decision to install countermeasures, but the countermeasures will have an effect of several probabilities. First, installing countermeasures may deter terrorists from launching this type of attack. This deterrence effect is parameterized by a factor d. If d is large (100%), the terrorists are completely deterred, if d is zero, they are not deterred at all. In this analysis we varied the deterrence probability from 0 to 100%. Next is the effectiveness of perimeter control countermeasures, parameterized as f, the effectiveness of increasing the probability of interdiction of a missile attack on an airplane. This parameter f is currently only a placeholder and set to 0% throughout the analysis. Any electronic countermeasures on the aircraft are designed to deflect the missile from hitting the plane and the effectiveness of achieving this is expressed in the parameter e. The analysis uses a range of 50% to

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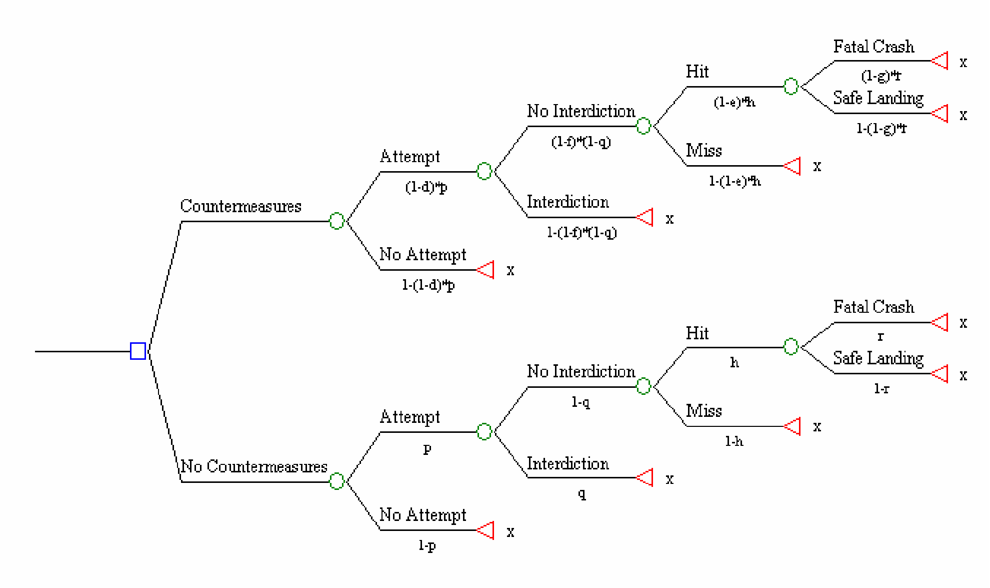
100% for this parameter. Another parameter is g, the effectiveness of avoiding a fatal crash, given a hit. This parameter depends on measures to harden the airplane or to improve pilot training. It is set at zero for this analysis. Thus, the only non-zero effectiveness parameters are d (deterrence effectiveness) and e (deflection effectiveness).

Figure 2.1: MANPADS Decision Tree



This tree summarizes the major decisions and events; we also have to describe the consequences of the attack at each of the end nodes of the tree. We consider five consequences:

1. Losses of lives due to a crash (LL)
2. Cost of the aircraft (CP)
3. Economic losses to the airline industry and the overall economy (EL)
4. Costs of the countermeasures (CC)
5. Number of false alarms (FA)

As with the probabilities, we used a highly parameterized approach and constructed the model to cover a very wide range of losses and costs. We used a range of losses of life between zero and 500 deaths and a cost of the loss of the airplane at $100 million to $500 million. We consider losses to the airline industry and the overall economy between zero and $500 billion. The high-end of this range was motivated by several recent analyses that estimated the economic costs of a 9/11-like attack on the airline industry. For example, Gordon et al. (2005) estimate that these economic costs were somewhere between $250 billion and $400 billion for the two years following the 9/11 attack, which included the cost of an initial shutdown, followed by a drop in passenger volume of about 20% in the first year and 10% in the second year. Santos and Haimes (2004) estimated that a drop of 10% in airline passenger volume cost the economy up to $40 billion/year. Hits with safe landings and misses also have economic costs, since they may create reduced passenger traffic. For hits with safe landings, we used a range from 0% of the economic costs of a hit and fatal crash to 50%. For misses, we used a range from 0% of the economic costs of a hit and fatal crash to 25%.

The costs of countermeasures are controversial. The RAND Corporation estimated a capital cost of $10 billion and $2.5 billion annual operations and maintenance costs, assuming that all large commercial airlines are equipped with countermeasures. This would lead to an (undiscounted) $35 billion life-cycle cost over a ten year time frame. Other sources quote higher or lower costs. We parameterized the ten year costs of the system at between $5 billion and $50 billion. Another possible cost is associated with possible false alarms, especially those that lead to notification of the surveillance system and possible grounding of airplanes. There is no hard data on false alarms, but false alarms will occur and their consequences will be largely dependent on the policy taken for responding to alarms – false or otherwise. We varied false alarms between 0 and 20 per year.

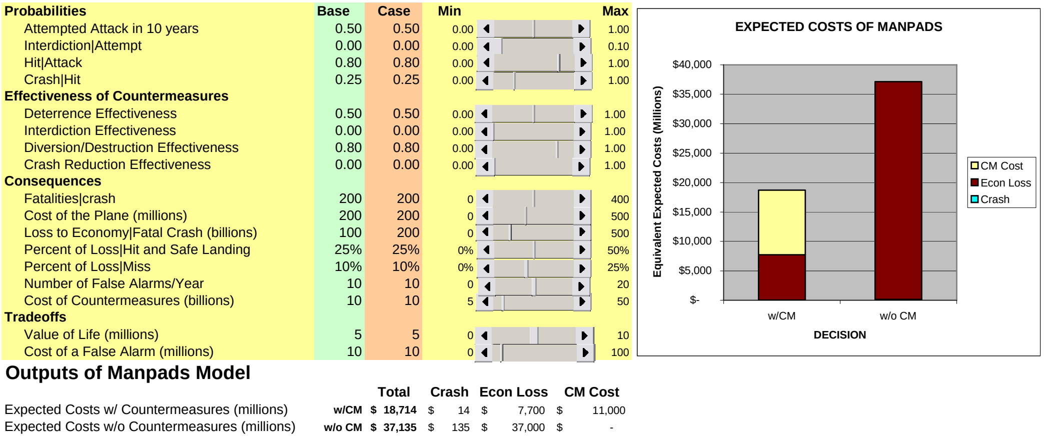
All consequences are in dollars, calculated for ten years, with the exception of lives lost and false alarms. For lives lost, we used a range from $5 million to $10 million per life lost, which is consistent with the economic literature on the value of life. For false alarms, we used a wide range from zero per incident to $100 million per incident, reflecting the uncertain consequences of a false alarm, depending on the policies in place to react to them.

With this information, we can calculate an overall equivalent cost (EC) at the end of each branch of the decision tree as the sum of the five component costs. With this decision tree and parameterizations in hand, we can proceed with exploring the effects of input parameters (probabilities and consequences) and output values (expected equivalent cost), where the expected equivalent cost is calculated in the usual way by multiplying each cost at the end of the decision tree with its probability and adding this up across branches – separately for the two decisions. Figures 2.2 and 2.3 show some preliminary results – one favoring countermeasures (lower equivalent costs of countermeasures) and one favoring no countermeasures (higher equivalent costs of countermeasure).

Most notably, the case that favors countermeasures includes a 50% chance of a successful MANPADS attack in the next the years in the U.S., $200 billon economic cost of an attack, and $10 billion cost of countermeasures. The case that favors no countermeasures has a 25% chance of an attack, $100 billion economic costs of an attack and $20 billion cost of countermeasures. Otherwise these two cases are identical. As we will discuss later, these three parameters are crucial in determining whether countermeasures are cost-effective or not.

These figures also illustrate how the initial sensitivity analysis is performed. Without being too concerned about specific numbers, the decision tree probabilities and consequences are controlled by so called “sliders,” which can vary the parameters over wide range. By physically moving these sliders, the decision maker can get hands-on experience with the effects of the changes of inputs on the outputs by observing in real time, how the graphically displayed results change as he or she slides the imput parameters from low to high values.

Figure 2.2: Inputs that Favor MANPADS Countermeasures

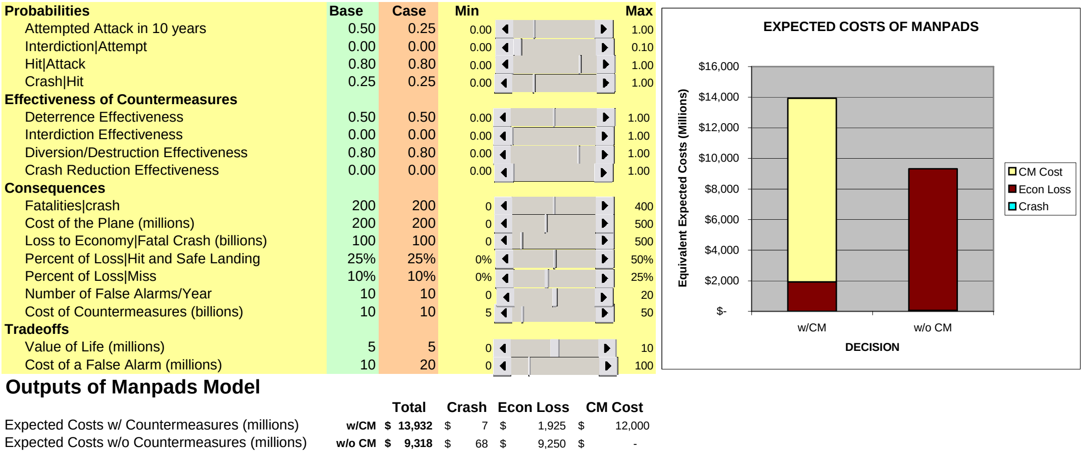


Probabilities	Base	Case	Min	Max
Attempted Attack in 10 years	0.50	0.50	0.00	1.00
Interdiction|Attempt	0.00	0.00	0.00	0.10
Hit|Attack	0.80	0.80	0.00	1.00
Crash|Hit	0.25	0.25	0.00	1.00
Effectiveness of Countermeasures				
Deterrence Effectiveness	0.50	0.50	0.00	1.00
Interdiction Effectiveness	0.00	0.00	0.00	1.00
Diversion/Destruction Effectiveness	0.80	0.80	0.00	1.00
Crash Reduction Effectiveness	0.00	0.00	0.00	1.00
Consequences				
Fatalities|crash	200	200	0	400
Cost of the Plane (millions)	200	200	0	500
Loss to Economy|Fatal Crash (billions)	100	200	0	500
Percent of Loss|Hit and Safe Landing	25%	25%	0%	50%
Percent of Loss|Miss	10%	10%	0%	25%
Number of False Alarms/Year	10	10	0	20
Cost of Countermeasures (billions)	10	10	5	50
Tradeoffs				
Value of Life (millions)	5	5	0	10
Cost of a False Alarm (millions)	10	10	0	100

Outputs of Manpads Model

		Total	Crash	Econ Loss	CM Cost
Expected Costs w/ Countermeasures (millions)	**w/CM**	**$ 18,714**	$ 14	$ 7,700	$ 11,000
Expected Costs w/o Countermeasures (millions)	**w/o CM**	**$ 37,135**	$ 135	$ 37,000	$ -

Figure 2.2: Inputs that Favor No Countermeasures



Probabilities	**Base**	**Case**	**Min**	**Max**
Attempted Attack in 10 years	0.50	0.25	0.00	1.00
Interdiction|Attempt	0.00	0.00	0.00	0.10
Hit|Attack	0.80	0.80	0.00	1.00
Crash|Hit	0.25	0.25	0.00	1.00
Effectiveness of Countermeasures				
Deterrence Effectiveness	0.50	0.50	0.00	1.00
Interdiction Effectiveness	0.00	0.00	0.00	1.00
Diversion/Destruction Effectiveness	0.80	0.80	0.00	1.00
Crash Reduction Effectiveness	0.00	0.00	0.00	1.00
Consequences				
Fatalities|crash	200	200	0	400
Cost of the Plane (millions)	200	200	0	500
Loss to Economy|Fatal Crash (billions)	100	100	0	500
Percent of Loss|Hit and Safe Landing	25%	25%	0%	50%
Percent of Loss|Miss	10%	10%	0%	25%
Number of False Alarms/Year	10	10	0	20
Cost of Countermeasures (billions)	10	10	5	50
Tradeoffs				
Value of Life (millions)	5	5	0	10
Cost of a False Alarm (millions)	10	20	0	100

Outputs of Manpads Model

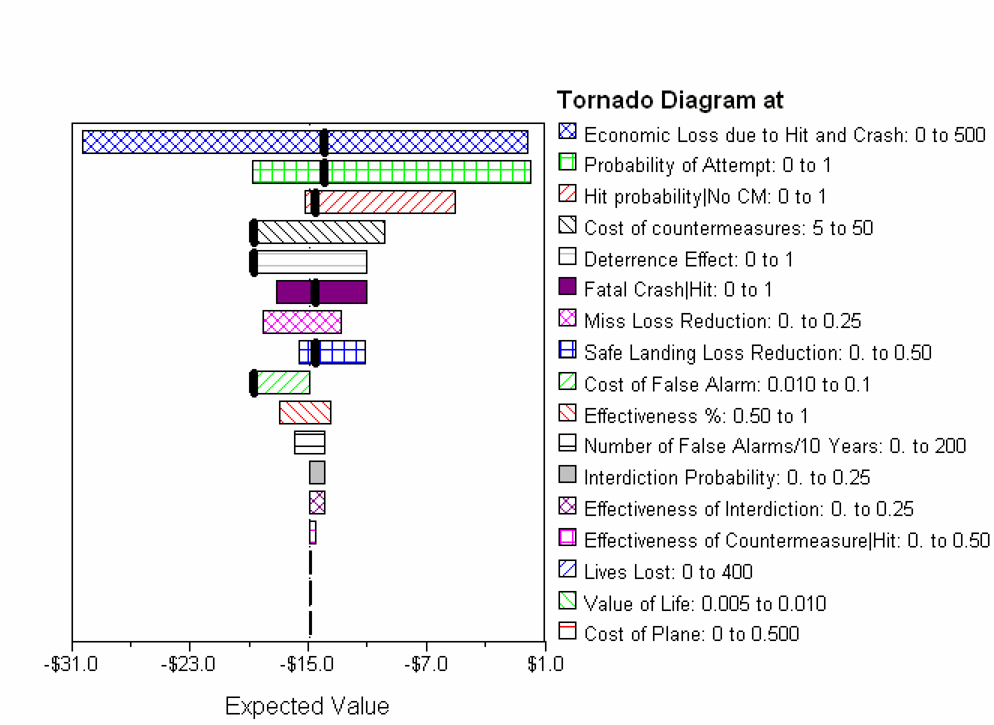
		Total	**Crash**	**Econ Loss**	**CM Cost**
Expected Costs w/ Countermeasures (millions)	**w/CM**	**$ 13,932**	$ 7	$ 1,925	$ 12,000
Expected Costs w/o Countermeasures (millions)	**w/o CM**	**$ 9,318**	$ 68	$ 9,250	$ -

3. Sensitivity Analyses

While the analysis with sliders and dynamic updating is very user friendly, it does not cover all sensitivity analyses that one may want to explore. In the following, we used the same decision tree model, but a different software tool (Treeage Pro) to run numerous sensitivity analyses.

First, we ran a tornado analysis, which shows the change in expected equivalent cost of the optimal decision (countermeasures vs. not) as a function of changing each input variable through the range of numbers shown in Figures 2.1 and 2.2. The larger the horizontal bar in a tornado diagram is, the more impact the input variable has on the output. It is clear from Figure 3.1 that the probability of an attempt and the economic losses due to a hit and fatal crash are the most important input variables.

Figure 3.1 Tornado Diagram



Figures 3.2-3.4 show one-way sensitivity analyses, in which one of the parameters (loss due to a hit and crash; probability of an attempt; effectiveness of diverting the missile) are varied.

The lines in figures 3.2-3.4 show the expected equivalent costs of using countermeasures vs. not using countermeasures. The cross-over points indicate where one should move from no countermeasures to countermeasures. For the purpose of these sensitivity analyses, all variables except for the ones shown in Figure 3.2-3.4 are kept constant at the base-case values shown in Figures 2.1 and 2.2.

Figure 3.2

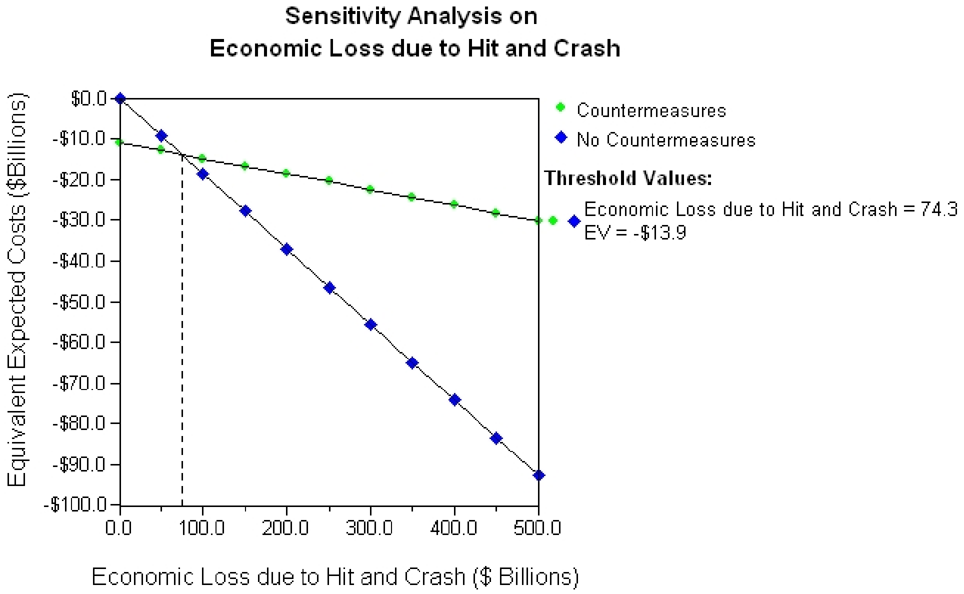

Sensitivity Analysis on
Economic Loss due to Hit and Crash
Equivalent Expected Costs ($Billions)
$0.0
-$10.0
-$20.0
-$30.0
-$40.0
-$50.0
-$60.0
-$70.0
-$80.0
-$90.0
-$100.0
0.0
100.0
200.0
300.0
400.0
500.0
Economic Loss due to Hit and Crash ($ Billions)
Countermeasures
No Countermeasures
Threshold Values:
Economic Loss due to Hit and Crash = 74.3
EV = -$13.9

Figure 3.3

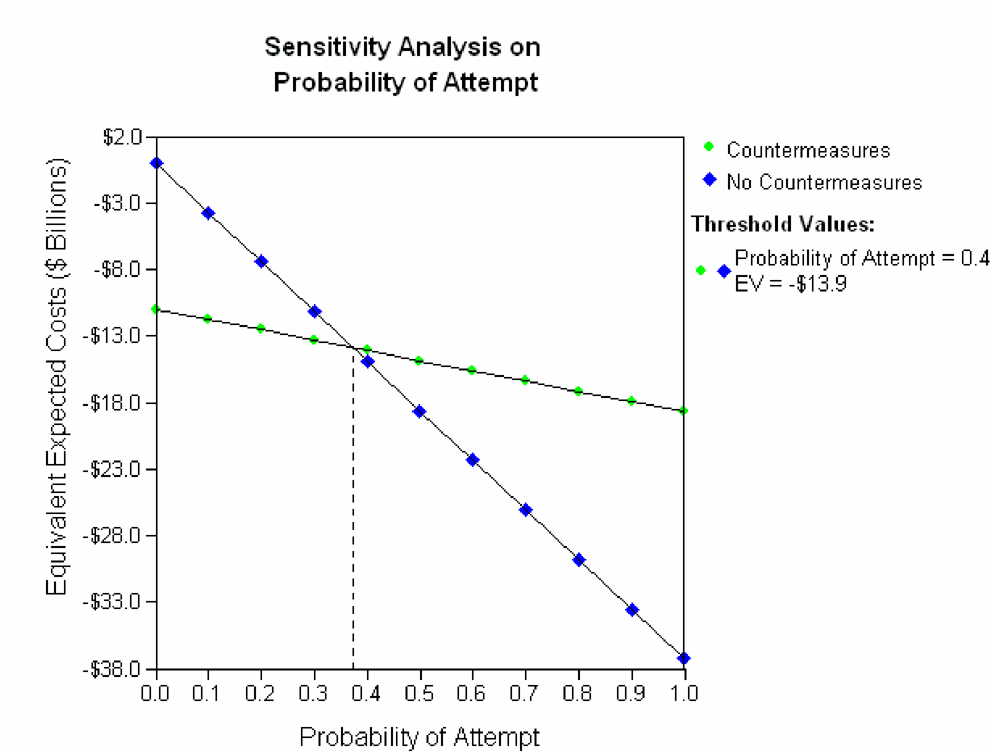
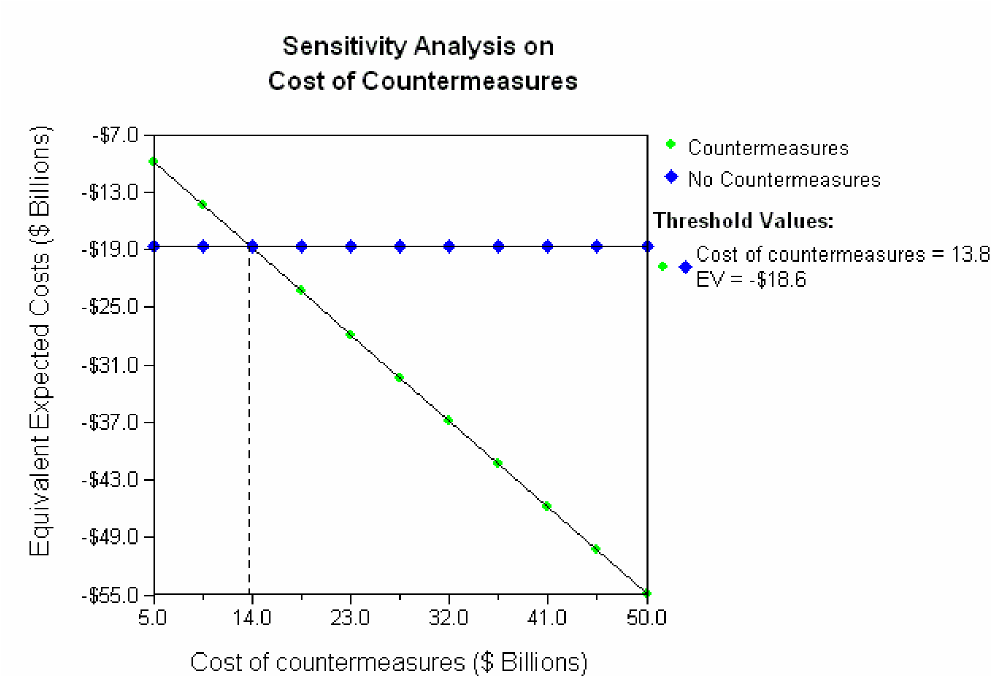

Sensitivity Analysis on
Probability of Attempt
Equivalent Expected Costs ($ Billions)
$2.0
-$3.0
-$8.0
-$13.0
-$18.0
-$23.0
-$28.0
-$33.0
-$38.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Probability of Attempt
Countermeasures
No Countermeasures
Threshold Values:
Probability of Attempt = 0.4
EV = -$13.9

Figure 3.4



In short, these three analyses show that countermeasures are preferred, if economic losses are large (above $75 billion), if the probability of attack is larger than 40% in five years, and if the cost of countermeasures is less than $14 billion.

To explore the joint effects of the three most important variables, we conducted several sensitivity analyses varying two parameters at the same time. Figure 3.5 shows how the decision to deploy or not to deploy countermeasures changes as a function of the probability of an attempted attack and the economic losses of a hit and crash. The line that separates the lower left area (no countermeasures) and the upper right area (countermeasures) is defined by the combination of the probability of an attempt and the economic losses at which the two decisions have identical equivalent expected costs. For example, if the probability of an attack is 0.35 in the next the years and the economic losses are $100 billion, then the two expected costs are about equal. Combinations of probabilities and economic losses in the lower left suggest not to deploy countermeasures, combinations in the upper right area suggest to employ countermeasures.

Figure 3.5

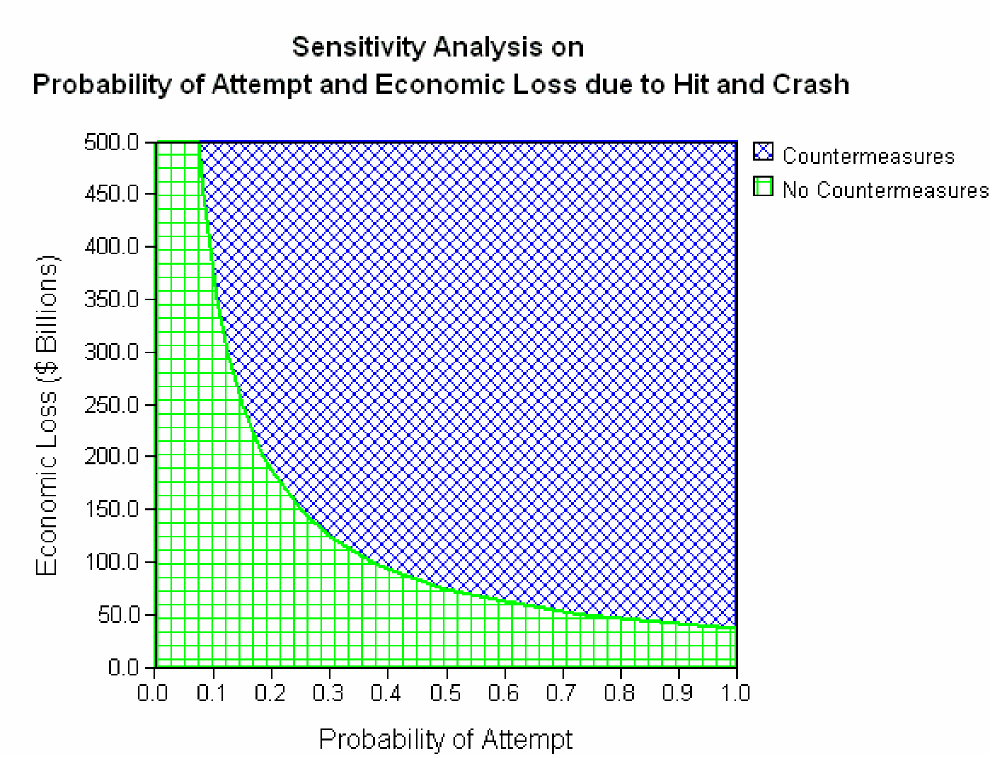


Figure 3.5 shows the same relationship, but for a higher cost of countermeasures of $30 billion instead of $10 billion. As expected, the area for which countermeasures are preferred (upper right) is now much smaller. In other words, to justify expensive countermeasures, much higher probabilities of an attempt and much higher economic losses are required.

Figure 3.6

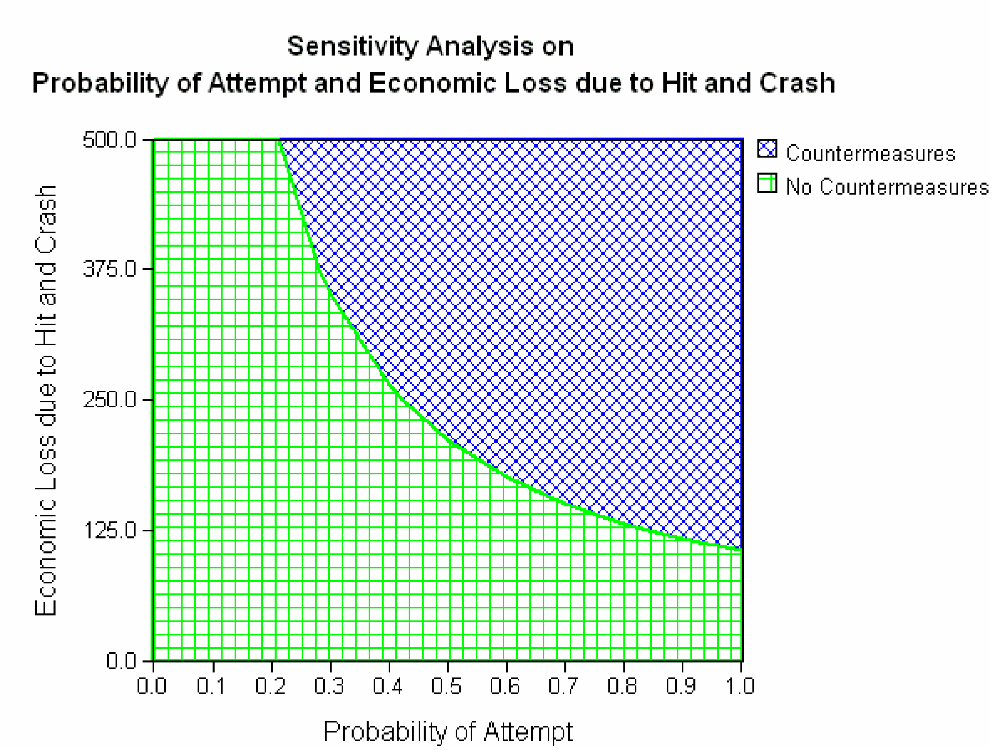
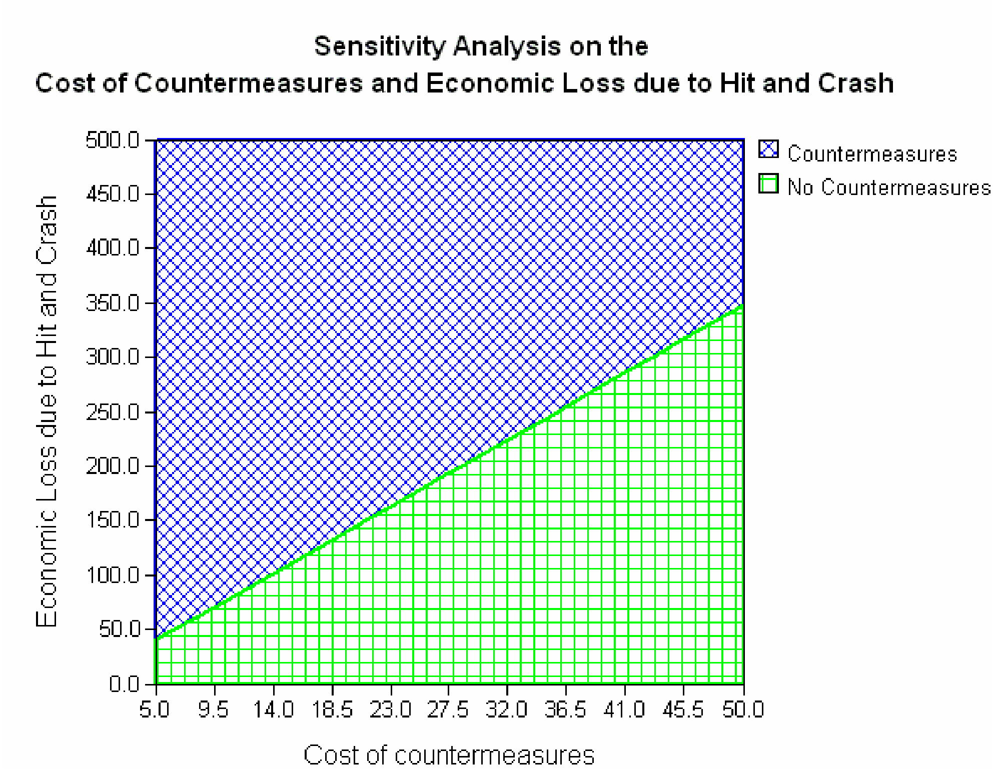


Figure 3.7 shows how the decision to deploy or not to deploy countermeasures depends on the anticipated economic losses and the cost of countermeasures. For

example, if the cost of countermeasures is $20 billion and the losses to the economy due to a MANPADS attack are $100 billion, the preferred option is not to employ countermeasures.

Figure 3.7



Conclusion

In this paper we have applied a decision tree analysis combined with many sensitivity analyses to the current public debate of about the cost-effectiveness of proposed directed infrared countermeasures (DIRCM) countermeasures intended to protect large commercial airliners from MANPADS attacks. The analysis indicates that of the many variables that affect the decision of whether or not to deploy these countermeasures, three are especially important:

1. The economic losses due to a MANPADS attack
2. The probability of a MANPADS attack
3. The cost of countermeasures

While this may not be surprising, it is surprising that many of the other variables are less or not important, at least in a range that many experts consider plausible. As a result, we believe that countermeasures can be cost-effective if the probability of such an attack is large (>0.50 in ten years), the economic losses are very large (>100 billion), and the cost of countermeasures is moderate (<$15 billion).

Perhaps the two main contested variables are the cost of a MANPADS attack to the economy and the cost of countermeasures. Several recent studies indicate that the cost of an attack to the economy can be quite large. If the economic impacts approach those of 9/11 they can be in the hundreds of billions of dollars. However, it is unlikely that a single MANPADS attack would produce such impacts. Multiple and repeated attacks that show the intent and the capability of terrorists to destroy commercial airplanes can, however, have a substantial economic effect.

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Figure 3.7 shows the tradeoff between the costs of countermeasures and the economic losses in case of a successful attack. At low costs of countermeasures (e.g., less than $10 billion) and high economic losses (e.g., more than 200 billion), countermeasures are preferred. At high costs of countermeasures (e.g., more than $30 billion) and lower economic losses (e.g., less than $100 billion) no countermeasures are preferred.

This model focused on DIRCM countermeasures against heat seeking missiles. However, the model can easily be adapted for use to assess countermeasures for other surface-to-air attacks, using, for example, laser-guided missiles, rocket-propelled grenades (RPGs), mortars, or large caliber rifles. Each weapon will have its own parameters (e.g., hit and crash probabilities) and consequences.

The model also can be used to investigate alternative countermeasures, for example hardening the airplanes or pilot training (reduces the probability of a crash, given a hit), perimeter control (increases the probability of interdiction), or improved methods for detecting MANPADS (reduces the probability of an attempt).

This model focuses on one attack, but it can be adapted to multiple simultaneous attacks. This involves assessing probabilities over the number of attempted attacks, the number of successes and the consequences of multiple simultaneous attacks.

Another important model extension is to examine how MANPADS countermeasures affect the probabilities of using other types of weapons (rocket propelled grenades, mortars, laser guided missiles, or high-caliber assault weapons). If terrorists are planning a large scale attack on airplanes in the US, their tactics and weapon choice is likely to change, especially if DIRCM countermeasures are installed. In this case, the risks of attacks on airplanes may simply shift from one attack mode to another.

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