Multidisciplinary background for modeling processes and phenomena related to terrorism

Authors[*]*:*

Gabriela PRELIPCEAN,
Irina CAUNIC, Mircea BOSCOIANU

Abstract. *The study aims to create an integrated framework of analysis allowing the optimization of government decisions to intervene in case of a major terrorist attack for limiting the consequences and restoring order and functionality, based on a set of specific models.*

This initiative is due to the lack of knowledge in this area of research and it is justified by the existence of new risks, as the risk of terrorism. Internationally there is a growing trend in conducting researches on the extreme risk events, which should lead to an intensification of scientific knowledge at national level.

Key words: terrorist organizations, mathematical models, interdependent security model

JEL Classification: G1

Introduction

Since September 2001, a radically change in the nature of risk associated with the international terrorism has led the target countries to reassess the threats and means of protection.

* Gabriela Prelipcean - "Stefan cel Mare" University of Suceava gprelipcean@yahoo.com; Irina Cauniuc – "Alexandru Ioan Cuza", University of Iasi irina_caunic@yahoo.com; Mircea Boscoianu - "Henri Coanda" Air Force Academy Brasov mircea_boscoianu@ yahoo.co.uk

The risk of terrorism was considered until 2011 a manageable exposure, but the new modes of attack (characterized by: lack of target predictability, attack severity, nature attack frequency) as well as increasing the CBRN threat (chemical-biological-radiological-nuclear threat) radically change strategies and the protection plans. In addition to risk association and increasing potential size, the increasing risk unpredictability fundamentally changes the nature of terrorism risk insurance.

The financial resources for preventing and counteracting the new modern terrorism involve development of new solutions and risk management strategies to protect the critical infrastructure and the personnel.

1. Mathematical formulation of an interdependent security model

We consider a period model 1 and a number n of agents with neutral risk aversion, namely Ai, i = 1,.... n. They are key players who must choose whether to invest or not in their own security. This choice is made discreetly: to invest or not to invest.

Every agent faces the risk of a large loss L. There are two ways that can cause a loss: it can be initiated either on the property of that agent or on another property. The probability for a loss to occur on the agent` property of an agent who has not invested in security is p, so that the expected loss for this event is pL. If the agent has invested in preventing measures then the risk is supposed to be 0. The situation is completely symmetric and all the agents are identical. Regarding the airlines, even they receive scan luggage, preventing possible losses, could be a risk coming from luggage transferred from other airlines. Therefore, there is an additional risk of loss from other agents that haven`t invested in security precaution measures, denoted by q.

These probabilities are analyzed as follows: for any transport there is a probability p, as an airline without a security system to load a bomb to explode on board. Concerning the chances of contamination, q is the probability/risk that there is a dangerous luggage loaded on each flight, which is subsequently transferred to other airlines where it could explode. Suppose that there isn`t enough time for an airline to check luggage to other airlines before being loaded on the aircraft. If there is a number n>2 airlines, the probability per flight that this luggage be transferred from airline I to airline j is q/(n-1). Note that the probability of a luggage coming from an airline without a security system to explode per flight is p + q.

Suppose that damages resulting from the security system multiple errors are more severe than those resulting from a single error. In other words, there are not additional damages. In the case of airlines luggage, they consider that a terrorist act is as serious as several terrorist acts. The key issue is whether there is or not an error and not how many errors exist. Indeed, since the probabilities are so low, the unique events are all that can be considered. A disaster can be defined as an event so serious that it is very hard to imagine another event with such extreme negative consequences. We will focus on a case of two airlines, each being considered as an agent. This example shows the basic intuition in a simple framework.

1.1. The 2-Agent problem

We assume that each agent is fully informed on the risk and cost of protection and need to decide / to make a choice between investing in security S and not investing N. We consider S, the decision to invest in a luggage scanning system, and N decision not to invest. Table 1 shows the advantages of agents in the case of four possible outcomes:

Table 1. Expected results associated with the decision to invest or not to invest in security

		Agent 2 (A2)			
		S		N	
Agent 1 (A1)	S	Y-c	Y-c	Y-c-qL	Y-pL
	N	Y-Pl	Y-c-qL	Y-[pL+(1-pL)qL]	Y-[pL+(1-pL)qL]

In this case, Y represents the income of each agent before occuring any expenses or losses due to security risks. The cost of investment in security per flight is c. The reasoning of these outcomes is direct. If both agents invest in security, each bears a cost c and do not face any loss, thus, the net income is Y-c. If A1 invests and A2 does not invest, then A1 may incur a cost c and the imminent loss from A2. The probability that A2 contaminates A1 is q, so the expected / predicted loss of A1 due to a bomb originated elsewhere is qL. This cost represents the side effects/negative externalities imposed by A2 on A1. A2 does not support security costs for luggage or the risk of contamination from A1, but bears the risk of own loss from home pL. If any agent does not invest in security, then both have an expected result $Y-[pL+(1-pL)qL]$.

Now, since the results are specified, there is an obvious question: What are the conditions under which the agent will invest? Table 1 shows that for security investment to be a dominant strategy, we need:

$Y-c>Y-pL$ and $Y-c-qL> Y-[pL+(1-pL)qL]$

The first inequality says only that $c <pL$: security investment cost should be lower than the expected loss, a normal condition for an isolated agent. The second inequality is more interesting: $c<pL<pL(1-q)$. This is clearly a stricter inequality which reflects the possibility of contagion from the secondary agents. This possibility reduces incentives to invest in security because, in isolation, investment in security offers the agent a complete detachment of risks but that does not mean a contagion effect. Even after investment there is a risk of loss due to the inaction of other agents. When there is a possibility of positive contagion, the investment in security provides a lower risk. If you simplify the problem of two agents with identical costs, considering the case they decide simultaneously, without communication, one of the agents can influence the attitude of the other agent. In this non-cooperative environment, if $c< pL(1-q)$, then both agents want to invest in protective measures (S,S); if $c>pL$ then no agent wants to invest in protection (N, N); if $pL<c< pL(1-q)$ then there are two Nash equilibria (S, S) and (N, N) and the solution of this game is not established.

If the agents have different investment costs for security measures, then there could be a Nash equilibrium when an agent invests in security and the other does not. In this case, c1 and c2 are the costs of the two agents, and (N, S) is Nash equilibrium if $c1>pL$ and $c1<pL(1-q)$. This equilibrium requires that the two costs differ by at least pqL.

The solution concept for the two agents with identical costs and risks is illustrated below in a numerical example. Suppose that $p=2$, $q=1$, $L=1000$ and $c=185$. The matrix in Table 1 is now represented in Table 2.

Table 2. Expected costs associated with the decision to invest or not to invest. Illustrative Example

	Agent 2 (A2)				
	S			N	
Agent 1 (A1)	S	Y-185	Y-185	Y-285	Y-200
	N	Y-200	Y-285	Y-280	Y-280

If A2 invests in security (S), then it is worth that A1 also invests, since without protection A1`s expected losses will be pL= 200 and he will have to spend 185 to eliminate the risk. If A2 is not investing in security (N), then there is a chance that A1 have a loss even if he invested in protection. A1`s expected benefits from the investment in security will be only pL(1-q)=180, representing less than the cost of safety measures. Then A1 will not want to invest in protection. In other words, either both agents invest in protection or both will not invest. These are the two Nash equilibria.

2. Highlighting the mathematical model for understanding the terrorist organizations' operating mechanisms

2.1. Solving a dynamic model of terrorism

There are many ways to describe a terrorist organization, such as by ideology or the political platform, by the operating patterns and even by methods of recruitment. In this case we analyze it in terms of human resources. In particular, we are interested if there are changes over time in the number of leaders and the followers. The followers include categories such as experienced managers, weapons experts, financiers, politicians and religious leaders who support the organization. Leaders of these organizations include those with a certain rank as well as those dealing with files and folders. The number of these two groups gives us important information about the power of an organization. Precise characteristics of these two groups and their relative size depend on each organization. However, the distinction remains relevant even in the case of decentralized organizations such as al-Qaeda group in Afghanistan, because we can identify leaders among the experienced terrorists (see discussion in Hoffman, 2003, Sageman, 2004). The distinction between these two groups is very important in practice because, in general, those who make decisions often have to decide on the new target group (Wolf, 1989, Ganor, 2005). Leaders are more valuable targets but harder to find .

We also analyze a terrorist organization in terms of political alternatives. Therefore, we consider a terrorist organization as two varying amounts, L and F, corresponding to the number of leaders and the number of followers. Also, L and F determine the overall strength (Strength S) of the organization. Because the leaders have skills and experience, they contribute more to the total strength of the organization than the equivalent followers. So, the strength S is the sum of two variables, considering the greater importance of the leaders (m>1).

$S = mL+F$

We now identify a set of fundamental processes to change the proportion of leaders and followers. These processes represent the mathematical model. While some processes are self-evident, others benefit from quantitative comparisons of data. The second method is not relevant due to the lack of data relating to members of the terrorist organizations.

History of al-Qaeda and other terrorist organizations (Laqueur, 2001, Harmon, 2000; Hoffman, 2006) suggests that the number of leaders and terrorist experts are grouped mainly when the followers gain experience or receive training (internal or international, in states that support terrorist groups, Jongman and Schmid, 2005). Therefore, the group of leaders (L) increases with the new leaders proportionally to the increasing number of followers (F). We call this process Promotion / Advancement and the proportionality parameter is p. This increase was opposed to a personal loss, especially due to situations such as fatigue or desertion (Horgan, 2005). This phenomenon is modeled as a loss of a fraction (d) of the group leaders per unit of time. An additional important influence on the organization is exerted by the anti-terrorist measures targeting the leaders of these organizations through arrests, assassinations and communications interrupting effort in order to force them to become passive for a long time. Such measures determine the elimination of a number of leaders in a certain period of time. Combating Terrorism (CT) is a constant rate of elimination rather than a quantity which depends on the size of the organization, because the goal is to see what impact the resources allocated to CT will have on the organization. It is assumed that the human resources and the available funds to combat terrorist organizations lead to capture or remove a certain number of operators. We suppose that, on average, in a certain interval, the group of leaders is fueled through promotion, and reduced due to internal losses and counter-terrorism measures.

The dynamics of followers group (F) is somewhat similar to the dynamic of leaders group. As for leaders, some internal losses are expected. This can be modeled as an elimination of fraction (d) from the group of operators per unit of time, and for simplicity, rate d is the same as the rate for leaders. Very similar to the leaders case analyzed above, the measures to combat terrorism are supposed to remove a certain number (k) of followers in a certain period of time. Most importantly, we must consider how and why new recruits join a terrorist organization. Undoubtedly, in many organizations promotion / advancement is for many reasons proportional to the strength of the organization: the strength determines the ability to perform successfully, thus leading to an increased interest in the organization. Moreover, the strength of the organization provides the labor force to publicize the attacks and to find new recruitment methodes.

Assuming that the recruitment is proportional to the strength of the organization, we can observe the widely seen cycle where the successful attacks lead to a higher recruitment process, further leading to more power and implicitly more attacks. Overall, the group of followers is fueled through recruitment and reduced due to internal losses and counter-terrorism measures.

The numerical values of the above parameters (p, d, m, k,) depend on each organization and vary in time. Fortunately, it is possible to draw more general conclusions without knowing the parameter values. Finally, it should be noted that measures to combat terrorism should not be restricted to the parameters b, k (elimination of leaders and followers), and measures such as public defenders, attacks on terrorist bases, communications disruption can weaken these organizations, reducing capabilities through the other parameters.

In the description above, we assumed that measures to combat terrorism are parameters that can be modified without affecting the recruitment process. This is an important simplification because in practice it may be difficult to respond to terrorist attacks without generating a reaction of promoting the recruitment process. (Ganor, 2008, Hanson and Schmidt, 2007). However, this simplification advantages exceed the disadvantages. First, it is clear that any model that would consider such an effect would be more complicated than the current model and therefore more difficult to analyze or use. Second, the current model can be easily generalized to incorporate such an effect. Thirdly, the power of this effect is usually hard to describe as it depends on factors such as the specific measures used to combat terrorism, terrorist activities and the political environment. Indeed, Udwadia et al. (2006), who incorporated these effects, realized their model based on observations of the specific context concerning the ongoing conflict in Iraq.

The model included the additional implicit assumptions. First, it requires a state characterized by stable and progressive changes so that the effect of a terrorist or counter-terrorist activity is weak. This would be acceptable in all cases when terrorist organizations are not very small and thus changes are not very stochastic. Second, the model assumes that an increase in organization is constrained only by the available labor force, and factors such as money or weapons do not require an independent constraint. Third, it is assumed that an increase in the number of followers is not restricted by the number of potential recruits available (Manningham-Buller, 2006).

Despite its simplicity, the model leads to many plausible forecasts and many useful policy recommendations. Indeed, the simplicity of the model is very important to make it particularly useful in practical analysis concerning the dynamics of terrorism.

3. Presentation of the analytical model for understanding the processes of terrorism based on the game theory

3.1. Resource allocation model for protection against terrorism

Combating Terrorism focuses on two basic philosophies: defensive policies and pro-active measures. Defensive policies protect potential targets by inclucing terrorists to think that attacks are costly. The efficiency of defensive actions also largely limit the losses of the society. Airlines are an example regarding the protective measures by installing metal detectors in airports and equipment to scan passengers.

Combating terrorism through proactive and offensive actions that directly affect terrorists implies government operations to safely limit the terrorist resources and their sponsors. For instance, terrorist resources can be reduced by capturing the members of these extreme organizations or by destroying their non-human resources such as weapons, ammunition and training camps.

In this part of the study we have focused on the defense decisions. Thus, a government should allocate a critical fixed amount at the defense resources level, D, for the protection of N potential targets. Theoretical and empirical analysis identifies a substitution phenomenon when efforts to strengthen the defense of a terrorists target pass to alternative objectives (Enders and Sandler, 1993, 2004). Thus, metal detectors in airports decreased suddenly air piracy, leading, at the same time, to a huge increase in other types of incidents such as hostage taking and kidnappings. The new defensive measures determine a predictable response from the terrorists.

In recent years, the most important source of forecast, in terms of defense allocations, comes from understanding how terrorists and governments become strategic players who respond to these variables. Powel claims in his model (Powel, 2007) that a government has two objectives to ensure the protection, denoted by i = 1, 2. At target i, the government must consider the probability of an attack (p), losses in the case of a successful attack (L1) as well as the location vulnerability (vi). The probability of an attack at location 1 or 2 is p1 ≥ 0 and $p_2 \geq 0$, with $p_1 + p_2 = 1$. Vulnerability indicates the probability of a successful attack against this target.Thus, v_i depends on the defensive resources existing at this location, so that $v'_i , (d_i) <0$. The estimated losses at the target i are $p_i L_i v_i (d_i)$, so that a government with at least two risk objectives will choose protection d1 if:

$$\min [p_1L_1 v_1 (d_1) + p_2 L_2 v_2 (D - d_1)], \tag{1}$$

in conditions when:

$$p_1L_1 v'_1 (d^*_1) = p_2 L_2 v'_2 (d^*_1) \tag{2}$$

This first condition indicates that the defender allocates protection resources between different locations based on the possibility of minimizing the marginal losses. If the analysis stops here, the allocation will not be optimal because it should also consider probability of location choice based on the estimates made by the attackers. Terrorists, choose p1 for:

$$\max[p_1G_1 v_1 (d_1) + (1- p_1) G_2 v_2 (d_2)] , \tag{3}$$

when terrorists gain, G1 is done considering the selection of target i. Resource allocation by the government i is independent of G1, as the defender (government authority) probably does not know terrorist`s preferences. Obviously, the selections are given by the two opponents' game and whether they are interdependent, they must be solved together.

In the analysis of Powell (2007), the loss of defender is shown on the vertical axis and d1 factor on the horizontal axis. If the terrorist group is treated in a non-strategic way, than the defender`s loss is minimized at $d^*_1$. If the group does not adapt to the attack strategy based on the defender`s option, the defense continues to strengthen through the protection of location 1 (the highlighted parabolic curve). This allocation is considered by the terrorist group as a change in the probability to attack and it manifests by shifting his interests to location 2, so that if d1 increases, then d 2 decreases. In this case the problem is intuitive: the intersection of curves represents, in strategic terms, the marginal losses anticipated in locations 1 and 2. When d1 = 0, the marginal loss estimated by the defender in location 1 is the largest and the expected marginal loss from location 2 is zero, because the latter is well defended. As d1 increases, location 1 becomes a less attractive target to terrorists if compared to location 2. Therefore, the expected marginal loss at location 1 decreases while it increases at location 2. Strategic equilibrium is from (d1 , D-d1), the intersection of two thinner curves. If d1<d*1, terrorists' strategic responses determined the defender to manage the resources differently, with less emphasis on a single location. A recent study (Farrow, 2007) indicated the allocation of resources among objectives of different interesting scenarios, however, the terrorist group is not a strategic player in his model.

Powell (2007) presented a version with N targets and he introduced for the government a function of loss L (d, p) as well as a function of gain for the terrorist group. G (d, p), where d = (d1 ,..., d N) şi p = (p1,…. p N ,). These loss and gain functions involve the expected losses and gains at the N locations. To solve the game we can use a min-max algorithm. Powell introduced border protection in addition to location protection and the resource allocation for protection against terrorism.

Bier, Oliveros and Samuelson (2007) and Zhuang and Bier (2007) have efficiently expanded Powell`s idea, allowing for the interdependence of several variables. For example, an attacker or a defender asseses gains / losses associated with the terrorist operations based on the attack effort, a = (a1,… a N ), and the defense of potential target d = (d1 ,..., d N ). Defender`s problem consists in maximizing the expected utility, U D (a,d), while the attacker is maximizing the expected utility, U A (a, d). These expected utilities depend on the probability of damage (pi) at location i, which itself depends on a i and d i. Moreover, UA and UD include the total cost of the attacker`s effort and all the investments to protect defenders from all the locations of interest.

If the organization of defense involves a greater effort from the attacker, causing an increased defense, this may result in reducing the welfare for both opponents, involving their interest in a ceasefire. Second, it shows that the defender has a strategic advantage when he is moving, primarily because of its welfare which is at least as important in the sequential game as it is in the simultaneous game. Moving first, the defender may attract terrorists to hit targets relatively less valuable. Third, it is up to the government to make public its defense costs, situation that it is not always properly understood by the officials. Fourth, according to these results, Farrow (2007) and Lee (2007), some potential targets can be left defenseless because the government's expected losses are not very significant and the defensive resources are low. Fifth, border protection must be considered together with the individual defense location, because border security reduces the vulnerability in all the interest locations.

Regarding the anti-terrorist defense resources, Sandler and Lapan (1988) claim that the centralized policy provides the best results in several locations than does the decentralized decision. This findings were reconfirmed in several recent contributions (Bier et al., 2007; Lee, 2007, Zhuang and Bier, 2007). Sandler and Lapan (1988) emphasized the need to choose between pairs of potential strategic players. In this context, it is very difficult to form a game with three independent strategic players without introducing simplified assumptions. The authors focused on target governments to show that they should cooperate, because otherwise the terrorists would take advantage. They also built a model that enables high volumes and low volumes of defense measures, based on the mix of interests (country-abroad) of the target countries. But there is no reference concerning the interests in multinational objectives where the terrorist group and the centralized government are strategic players.

Zhuang and Bier (2007) have criticized in a discreet manner the decision-making methods, but they have concluded that there can be minimal losses. This only served to illustrate that relaxing in one area requires tightening in other areas. For example, Zhuang and Bier have not considered the transnational terrorism, where several countries are strategic players.

In most of the defense studies there is a mix between the proactive system and the defense policy. The proactive responses weaken the strength of terrorist groups and certainly affect the defense strategies. Several proactive measures should be imposed only once against a common threat of terrorism, while defense measures should be consistently applied as the threat remains.

Conclusions

Many benefits are due to the ability of mathematical models to clarify the logical implications of empirical knowledge that have been used to build the dynamic model. Thus, since the empirical data used to construct a model should be uncontroversial, the expected results should bring new information. We appreciate that the presented models related to the activity of the extremist organizations have allowed clarifying many important aspects concerning the international terrorism.

Acknowledgements

This article was written within the research projects entitled *"Integrated Management Systems for economic-financial security of the critical infrastructure and of personnel against any kind of terrorism - SMEFIP*, funded by the National Plan for Research, Development and Innovation, Program 4 - Partnerships in priority areas.

REFERENCES

1. Bier, V. M., Oliveros, S., & Samuelson, L. (2007), "Choosing what to protect: Strategic defensive allocation against an unknown attacker", *Journal of Public Economic Theory*, 9(4), pp. 563-587.
2. Enders, W., & Sandler, T. (1993), "The effectiveness of anti-terrorism policies: Vector auto-regression intervention analysis", *American Political Science Review*, 87(4), pp. 829-844.
3. Enders, W., & Sandler, T. (2004), "What do we know about the substitution effect in transnational terrorism?" In A. Silke (Ed.), *Research on terrorism: Trends, achievements and failures,* London: Frank Cass, pp. 119-137.
4. Farrow, S. (2007), "The economics of homeland security expenditures: Foundational expected cost effectiveness approaches", *Contemporary Economic Policy*, 25(1), pp. 14-26.
5. Ganor, B. (2005), *The Counter-Terrorism Puzzle: A Guide for Decision Makers*, Transaction Publishers, NJ.
6. Ganor, B. (2008), Terrorist organization typologies and the probability of a boomerang effect, *Studies in Conflict and Terrorism,* 31, pp. 269–283.
7. Hanson, M. A. and Schmidt, M. B. (2007), "The impact of coalition offensive operations on the Iraqi insurgency", *Research Papers in Economics* (RePEc), 56.
8. Harmon, C. C. (2000), *Terrorism Today*, Routledge, UK.
9. Hoffman, B. (2003), "Al–Qaeda, trends in terrorism, and future potentialities: An assessment", *Studies in Conflict and Terrorism*, 26(6), pp. 429–442.
10. Hoffman, B. (2006), *Inside Terrorism*, Columbia University Press, USA.
11. Horgan, J. (2005), *The Psychology of Terrorism*, Routledge, UK.
12. Jongman, A. J. and Schmid, A. P. (2005), *Political Terrorism*, Transaction Publishers, NJ.
13. Laqueur, W. (2001), *A History of Terrorism*, Transaction Publishers, USA.
14. Lee, S. (2007), "Counterterrorism alliance". Unpublished manuscript, City College of New York.
15. Manningham-Buller, E. (2006), "The international terrorist threat to the UK", *MI5 Publication*.
16. Powell, R. (2007), "Defending against terrorist attacks with limited resources", *American Political Science Review,* 101(3), pp. 527-541.
17. Sageman, M. (2004), *Understanding Terror Networks*, University of Pennsylvania Press, PA.
18. Sandler, T., & Lapan, H. E. (1988), "The calculus of dissent: An analysis of terrorists' choice of targets", *Synthèse*, 76(2), pp. 245-261.
19. Udwadia, F., Leitmann, G., and Lambertini, L. (2006), "A dynamical model of terrorism", *Discrete Dynamics in Nature and Society*, 2006(85653).
20. Zhuang, J., & Bier, V. M. (2007), "Balancing terrorism and natural disasters—Defensive strategy with endogenous attacker effort", *Operations Research*, 55(5), pp. 976-991.
21. Wolf, J. B. (1989), *Antiterrorist Initiatives*, Plenum Press, NY.