Balanced scorecard method for predicting the probability of a terrorist attack

G. A. Beitel, D. I. Gertman & M. M. Plum
Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho, USA

Abstract

A research and development project at the Idaho National Engineering and Environmental Laboratory (INEEL) built and tested a quantitative threat-risk index model (QTRIM) to predict the risk of a terrorist attack against a national infrastructure. A key component of the threat-risk index model, the “targeting model”, estimates the probability of a terrorist attack. This paper describes that targeting model. In general, risk from a terrorist attack is calculated as the product of an attack’s probability by probable damage. Defence strategists often assume that a probability of attack is impossible to predict and assign a value of one (a chance of certainty), in which case “risk assessment” is reduced to “vulnerability assessment.” In other cases, defense strategists may assume qualitative vulnerability measures such as high, low, or medium. Our research selected a quantitative approach where risk is calculated using terrorist specific constraints, objectives, value systems, logistics, and opportunities within a business decision framework of a balanced scorecard. QTRIM was exercised on a limited data set of terrorist organizations: Al-Qaida and the Earth Liberation Front. Specific to INEEL’s research, the nation’s inventory of infrastructure was evaluated on a macroeconomic level, which was then followed by an evaluation of a specific infrastructure sector. Resulting probabilities were compared to historical terrorist attack data with sufficiently accurate results to warrant further studies and model improvements.

Keywords: quantitative risk assessment, QTRIM, SAPHIRE, balanced scorecard, terrorist targeting strategies, probabilities of attack.
1 Introduction

INEEL developed and applied a risk assessment model known as QTRIM to a system of high-risk dams located in the Western United States. Developed to demonstrate the possibility in calculating a quantitative value of risk for terrorist attack, a key component in demonstrating validity was calculating quantitative values for the probability of attack, the probability of damage, and the expected damage. QTRIM’s unique approach integrates models in human response, physical systems and spatial relationships, as well as engineering knowledge, probabilities, economic analysis, and decision-making.

QTRIM consists of five individual models:
1. The targeting model, consisting of a model to estimate the probability of terrorist attack
2. The human reliability model, consisting of a series of human response logic models
3. A physical system model, which, applied to a hydroelectric system included dam failure models, a flood inundation model and a loss of service model
4. SAPHIRE, the NRC sponsored / INEEL developed and maintained probabilistic risk software using event tree and fault tree methodologies
5. The consequence / loss model, which inherently provides a socio-economic account for the infrastructure owner as to the probable attractiveness and potential loss depending to the degree of terrorist success in carrying out an event.

This paper addresses the development of the targeting model. The other QTRIM models are not described in this paper.

2 Approach

Risk is the combination of the probability and the consequence of a hazard [1]. Since defensive actions reduce risk, risk may be written as products of the probability of attack, one minus the probability for successful defense, and the expected consequence:

\[
\text{Risk} = P(\text{attack})*(1-P(\text{effectiveness}))*C(\text{damage}).
\] (1)

In developing the probability of attack, \(P(\text{attack})\), we assume, that contrary to Western values, terrorists behave rationally. Secondly, we assume terrorists are constrained as any people and organizations by the simple, economic realities of limited resources. Resources such as people, knowledge, funding, and an enemy’s lack of preparedness must be managed to achieve terrorist missions, goals, and objectives. Economic theory suggests that people manage these inputs in terms of investments and returns. Therefore, similar to any other organization that seeks long-term success, terrorists must optimise their inputs and outputs through a system of measures that ensures outputs are greater than inputs. Moreover, similar to modern organizations, terrorist organizations must
manage more than one simple measure. Truly successful organizations balance social, cultural, and environmental objectives as well as employee empowerment, market share, and vision. This approach of balanced success assures long-term market dominance through broad market support and control. Recent developments in investment analysis attempts to balance multiple goals through a process known as balanced scorecard (BSC) [2, 3]. We propose that terrorists use a process similar to BSC, whether it be calculated or unknowingly.

3 Understanding the terrorist mind


In general, terrorists are fighting to preserve their social structure based on the rule of Islam. From the above sources, appropriate measures driving Fundamentalist Islamic terror may be summarized as follows:

- Terrorists must be patient; holy wars can last forever; terrorists must commit whatever it takes to rid the world of infidels
- Terrorists must manage limited resources; in fact, they may impose limits to minimize attention and reduce their risk of being discovered
- Terrorists must have training in basic engineering, and they will use these skills in attempts to bring down Western institutions
- Terrorists must be committed to their cause and social status is judged according to this commitment
- Terrorists believe the path toward worldly goals is by ridding the world of infidels; they have no reservations on methods in achieving this goal
- Terrorists believe the path from an evil world toward a godly world is hastened through destruction of infidel societies, symbols of those societies, and institutions that provide personal pleasure and satisfaction
- Terrorists believe the loss of Western conveniences will bring change and ultimate destruction of the weak-minded Western culture
- Terrorists believe that diminishing the Western presence and consumption habits will reduce corruption and return people to their original intent
- Terrorists seek to return Islamic presence to the original Islamic lands and increase the presence in other areas of the world
- Terrorists seek opportunities to work with other terrorist groups for power, strength, and diversity while reducing vulnerabilities
Using this over simplified summation of our understanding of Fundamental Islamic terrorists, we developed a list of measures from which to construct a targeting model. These will be discussed in the following section.

4 Targeting model quantification

There are many good reasons to assume the terrorist’s targeting model is limited in size and scope. First and foremost, terrorists reduce their vulnerabilities to infiltration and observation by remaining small and close-knit with decision powers controlled by few; adding a large organization for information gathering and analysis would increase vulnerability. Thus, analysis of targets must be limited to a reasonable sized list. Too many targets and too much required information would consume the limited management resources. Secondly, simple mental models discussed and maintained within a roundtable format fit the constraints of their organization and structure. However, for purposes of simulation, the QTRIM team constructed a mathematical representation for the terrorist thought process.

4.1 Measures, weighting factors, and normalization

The targeting model uses ten measures of success: four investment and six return measures. Why ten and which ones? Successful organizations usually capture 80% to 90% of investor demands with “enough” measures [2]. Furthermore, the more successful applications of BSC assume more than five but less than fifteen. Although some organizations may be able to evaluate their success with two or three measures, twenty or more tend to reduce its effectiveness. Whether or not any terrorists formally employ such a methodology, any process that balances multiple issues successfully gravitates to a system such as a BSC.

This approach is consistent with other decision theories such as the Analytical Hierarchy Process [10], which suggest that when there are more than 7 to 10 factors, they must be grouped into a natural hierarchy of 7 to 10 factors to increase overall efficiency as a mental model [10, 11]. Thus, our 10 measures is a two-tiered hierarchy of investment and returns, and is consistent with most economic and decision models. In theory and in practice, such a model may be analysed with the fingers on two hands.

The next most difficult component in developing our model is to weight the measures for relative importance. A natural choice would be to use some form of linear weighting scheme as proposed by Kepner and Tregoe [12]. Because of the wide range of outcomes, we ultimately selected a logarithmic weighting process based on Fechner's Law [13]. Gustav Fechner postulated that “within limits, intensity of a sensation, S, increases as the logarithm of the stimulus, R,” or,

\[ S = k \log R \] (2)
Fechner’s law has been shown to be applicable to “just noticeable differences,” right and wrong, average error, tactual and visual distance, visual brightness, and weights.

This logarithmic relationship appears in three areas. For all measures for which the natural values range over many orders of magnitude, the log to the base 10 is used. The measures are each normalized to a realistic value prior to further mathematical operation. Instead of multiplying the measures by a linear set of weights, we chose to weight the measures by raising the measure to a power. Finally, the developed scores are multiplied instead of added as is traditional in the Kepner-Tregoe method.

4.2 Calculating the investment measures

Our first set of measures considers the investments (cost, schedule, and expected success) a terrorist must make for any terror scenario.

4.2.1 Number of terrorists

Managing human resources, x, is one of the most important objectives of any organization. In terrorist organizations, trust is a most important asset, as relationships are developed over long periods and are not easily replaced. Fewer terrorists associated with a scenario would be preferred. However, although this rationale suggests that a score of one is best, we have reasoned that up to four terrorists is probably optimum. Thus, we divide the number of terrorists by four for any scenario. Thus, one, four, and sixteen terrorists have scores of 16.0, 1.0, and 0.0625, respectively. The people factor, \( x' \), is:

\[
x' = \left( \frac{1}{(x/4)} \right)^2
\]

4.2.2 Terrorist resources

This metric addresses resources, y, such as funding, weapons, explosives, and knowledge. These resources cannot be physically measured by a common factor. Since most of these resources are substitutes for each other, it is possible to measure these in terms of explosive equals. In defining the bounds of this measure, we know that 20,000 lbs. (9000 kg) of high explosives or 40,000 lbs. (18,000 kg) of readily available explosives are natural limits in material acquisition, storage, and movement. Furthermore, the largest (available to terrorists), a nuclear warhead, would have an equivalent of 1,000,000 lbs (450 tonne) of TNT. Again, our inverse investment/return relationship suggests that less is better – zero being best and a scenario requiring more than 1,000,000 pounds (log value of 6) would not be logistically acceptable and have a score of 0. A most simple measure is obtained by subtracting six and then dividing by six. We weight this by squaring. The resource factor, \( y' \), is:

\[
y' = \left( \frac{6-y}{6} \right)^2
\]

Thus, a 25,000 lbs bomb results in a resource score of 0.085 \(( (6-4.25)/6)^2 \).
4.2.3 **Terrorist schedule**
Time, $z$, is required for planning, deployment, and implementation. The longer the time, the worse the investment, since time allows for terrorist activities to be detected, assumptions to change, targets to move, and costs to increase. As an inverse relationship, we have assumed that ten years is the longest period in planning a terror act. Target opportunities of longer periods drop off because this value is raised to the 1.25 power. The calculated schedule factor, $z'$ is:

$$z' = \left( \frac{1}{z} \right)^{1.25}$$  \hspace{1cm} (5)

4.2.4 **Likelihood of success**
The fourth investment metric assigns an estimate of the probability of success, $zz$, for each scenarios based on skill, ease in execution, and past performance. Scenarios of a certain target will have different success values as investments are increased to increase the likelihood of success. Linear values between 0% and 100% are selected.

4.3 **Calculating return on investment measures**

The second set of measures considers the returns on investment (output, power, fear, etc) a terrorist hopes would be the result of a terror scenario.

4.3.1 **Loss of life**
Loss of life, $a$, is one desired consequence of terrorism. One must consider that many terror events resulting in lower death numbers may create more terror than one large event with thousands of deaths. The maximum assumed value of 6 [log$_{10}(1,000,000)$] is divided by 6 for a unity score and then squared. The calculated loss of life score, $a'$, is:

$$a' = \left( \frac{a}{6} \right)^2$$  \hspace{1cm} (6)

4.3.2 **Primary economic loss**
Economic Loss measured in dollars, $b$, is another consequence of a terrorist act. We fixed the maximum value at 12 (1 trillion dollars). A weight of 3 was chosen. The calculated loss of life score, $b'$, is:

$$b' = \left( \frac{b}{12} \right)^3$$  \hspace{1cm} (7)

4.3.3 **National economic stress and inconvenience**
Stress and inconvenience, $c$, measures the impacts on Western lifestyles. This score is particularly subjective as terrorists assume outcomes that are difficult to predict. A maximum value of 10 was selected and weight of 3 was chosen. The calculated stress and inconvenience score, $c'$, is:

$$c' = \left( \frac{c}{10} \right)^3$$  \hspace{1cm} (8)
4.3.4 Decrease Western presence
Decreasing Western presence, d, is one of the most important objectives of Fundamental Islamic terror groups. We used the number of people potentially impacted as the primary measure with a maximum value of 10 billion (everyone). A weight of 1.5 was chosen to account for an increased importance at lower levels of outcome. The decrease in Western presence score, d’, is:

\[ d’ = \left( \frac{d}{10} \right)^{1.5} \]  

(9)

4.3.5 Increase in Islamic presence
Increasing Islamic presence, e, is the also an important objective of Fundamental Islamic terror groups. The score was selected similar to that for decreasing Western Presence.

The calculated increase in Islamic presence, e’, is:

\[ e’ = \left( \frac{e}{10} \right)^{1.5} \]  

(10)

4.3.6 Opportunity to leverage with other terrorists
This measure accounts for the possible opportunity where two or more terror groups work together on the same target, f, based on organizational goals, objectives, or mandates. All targets assume an initial score of 1, but this can be increased up to a value of 3 due to access created through this outcome. Subjective and based on intelligence, the value, f’, is a perspective from intelligence:

\[ f’ = (f \times d’ \times e)^2 \]  

(11)

4.4 Calculating investment and returns on investment scores
These ten measures are used to calculate investment and return scores for each identified target/scenario. The investment score, A’, is calculated by taking the product of the investment measures:

\[ x’ \times y’ \times z’ \times zz = A’ \]  

(12)

The return on investment score, B’, is the product of the investment return measures (except that, since d and e are similar they are added), normalized for the addition of three measures more than that of the investment calculation by an additional the factor of 1000, thus:

\[ a’ \times b’ \times c’ \times (d’ + e’) \times f’ \times 1000 = B’ \]  

(13)

4.4.1 Calculating the overall score
The overall score, C’, is calculated by multiplying the values of the investment and return scores:

\[ A’ \times B’ = C’ \]  

(14)
4.4.2 Normalized strategy score per scenario

The ranking score, $R$, for each target and each target scenario is calculated dividing each overall score, $C_i'$, by the summation of all target overall scores. Thus, the contribution of each target scenario is weighted against all targets evaluated.

$$\frac{C_i'}{\sum C_i'} = R$$  \hspace{1cm} (15)

5 Testing the targeting model

The project team performed a field test of the targeting process where qualified team members assumed the role as a hypothetical team of Fundamental Islamic terrorists. Their job was to evaluate the selected targets for scoring against the total list of targets. The only target data available was that which is readily accessible from the Internet, library, site visits, and knowledge of a general expert. Clearly, not all targets were evaluated, only those known to the “terrorist” team, as would be the case with real terrorists. The model was populated with knowledge of the “Terrorist Mind” described in the section above. With the support of a vivid imagination, the INEEL team of weekend “terrorists” evaluated these targets in a two-step process.

5.1 Selection by major category

First, an inventory of all infrastructures thought possible was identified and organized into a hierarchy of targets. All infrastructure assets were considered as viable targets since they could serve an avenue of terror. These assets were public and private, military and non-military, utility, transport, manufacturing, production, distribution, and consumption assets as sporting events, malls, etc. Because our project was interested in hydroelectric infrastructure, we specifically included dams in the initial cut of infrastructure systems. These macro-assets were evaluated according to strategic value as potential targets of opportunity. A summary of the macro-evaluation is shown in Table 1.

Results are specific to macro-asset target groups. This, high-level evaluation cannot select a specific target. It is, instead, a pre-screening activity to concentrate and focus efforts and resources. Note that buildings, particularly those of Western significance are the highest value targets. Specific to QTRIM development activities, our initial evaluation suggests that dams of any arbitrary kind have a likelihood of 0.082% of being attacked (in Table 1, fractional values less than 0.01 lead to the total utilities having a value of 0.1%).

5.2 Target selection within a category

The next step is to identify specific targets and attack scenarios within the macro-asset target group chosen. Results of Table 1 suggest that it would be unlikely that a terrorist group would target a dam, however, since our Project was focused on dams and dam systems, we proceeded to select specific dams from the set of dams known to us. In reality, terrorists are influenced by specific
target knowledge and previous terror scenarios from which economic, symbolic, and terror impact values are based, given their vision, mission, objectives, and goals. In effect, they do not operate from a clean slate. Furthermore, terrorists work with limited information, as obscure and unknown targets have higher information costs and low returns on investment.

Table 1: Results in probabilities in attack, initial cut.

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Target Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>96.4%</td>
<td>Total Buildings</td>
</tr>
<tr>
<td>2.35%</td>
<td>US Corporate in Foreign Lands</td>
</tr>
<tr>
<td>12.11%</td>
<td>US Cultural Intrusions in Foreign Lands</td>
</tr>
<tr>
<td>2.35%</td>
<td>US Corporate in US</td>
</tr>
<tr>
<td>1.68%</td>
<td>Foreign Corporate in US</td>
</tr>
<tr>
<td>77.93%</td>
<td>US Embassies in Foreign Lands</td>
</tr>
<tr>
<td>3.14%</td>
<td>US Military Bases in Foreign</td>
</tr>
<tr>
<td>0.27%</td>
<td>US Military Bases in US</td>
</tr>
<tr>
<td>0.00%</td>
<td>Total Transportation</td>
</tr>
<tr>
<td>0.01%</td>
<td>Total Manufacturing</td>
</tr>
<tr>
<td>0.10%</td>
<td>Total Utilities</td>
</tr>
<tr>
<td>0.00%</td>
<td>Nuclear Power Plants</td>
</tr>
<tr>
<td>0.08%</td>
<td>Dams</td>
</tr>
<tr>
<td>0.00%</td>
<td>Coal-Fired</td>
</tr>
<tr>
<td>0.00%</td>
<td>Gas Turbine</td>
</tr>
<tr>
<td>0.00%</td>
<td>Electric switch -yard</td>
</tr>
<tr>
<td>0.07%</td>
<td>Simple acts of terror</td>
</tr>
</tbody>
</table>

Let us suppose that, based information gleaned through tourist excursions and foreign student travels, the terrorist planner has the following dams to consider: Grand Coulee, Hoover, Fort Peck, and our Project Dam (because we had access to facility sensitive information, we are not allowed to identify this particular dam.) Each dam and dam system has differing scenarios for input and output considerations. Each must be evaluated based on known information. This second screening then justifies the allocation of additional resources for target pre-planning and planning activities.

These results must then be combined with all other target specific evaluations, adjusted to the original screening process. After the second screening process, it is easy to see that evaluating any large, complex economy can be an overwhelming process (although not as difficult as a problem in protecting assets). A summary of the initial total utilities ranking, and specific analysis of some dams is presented in Table 2. Obviously, since the total value for “Dams” shown in Table 2 is 0.08% and the sum of those shown is only...
0.0003% most of those evaluated are not shown. Only four examples are shown here due to the article size limitations. The scenarios are not spelled out here but were extremely specific in approach and operation, including number of attackers, amount of explosives, placement of explosives, and means of delivery. Consequences, (deaths and economic loss) were calculated based on resulting flood depth, population densities, time of the day, property values, etc.

Table 2: Results in probabilities of attack, facility and attack scenario specific.

<table>
<thead>
<tr>
<th>Probability</th>
<th>Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.100%</td>
<td>Total Utilities</td>
</tr>
<tr>
<td>0.082%</td>
<td>Dams</td>
</tr>
<tr>
<td>0.0001290%</td>
<td>Grand Coulee</td>
</tr>
<tr>
<td>0.0000084%</td>
<td>Grand Coulee – Scenario One</td>
</tr>
<tr>
<td>0.0000325%</td>
<td>Grand Coulee – Scenario Two</td>
</tr>
<tr>
<td>0.0000197%</td>
<td>Grand Coulee – Scenario Three</td>
</tr>
<tr>
<td>0.0001160%</td>
<td>Hoover Dam</td>
</tr>
<tr>
<td>0.0000017%</td>
<td>Fort Peck</td>
</tr>
<tr>
<td>0.0000004%</td>
<td>Project Dam</td>
</tr>
<tr>
<td>0.0000002%</td>
<td>Project Dam – Scenario One</td>
</tr>
<tr>
<td>0.0000001%</td>
<td>Project Dam – Scenario Two</td>
</tr>
<tr>
<td>0.0000001%</td>
<td>Project Dam – Scenario Three</td>
</tr>
</tbody>
</table>

There are more than 78,000 dams in the United States of America, of which 1,700 are considered dams of high risk. From our analysis, we conclude that there is a probability that any dam would be a target ranging from 0.082*(1/1700) to 0.082*(1/78000), or 1.3E-06 to 5.9E-5 assuming a single terrorist group with an intent to hit a single target.

Our proposed methodology in determining the probability of a terrorist attack considers and balances the terrorist resources and objectives through a simple analysis technique that models the decision processes of small groups of rational individuals who are devoted to simple and symbolic causes.

6 Comparison against historical data

We tested the QTRIM targeting model against the 35 years of data tracked by the Memorial Institute for the Prevention of Terrorism (www.mipt.org), an institute established in memory of the bombing of the Oklahoma City Federal Building. This database contains approximately 16,000 worldwide events over a 35 years period. It includes all terrorist incidents including those for which arrests were made in the absence of an attack. In the past 35 years, there have been five terrorist events against dams, none of which led to any damage. Thus, the average probability of attack on any one dam is 5 in 35 years = 0.14 per year.
There are 41,000 large dams worldwide; therefore, the probability of attack by all terrorists, on any single dam, in any year is 0.14/41,000 = 3.4E-06. Assuming the U.S. Navy Graduate School Library list of 73 different terrorist groups in the world (http://gis.idl.state.id.us/), the probability by any one single group becomes less than 5E-08 per year. This is consistent with the values predicted by our model.

7 Discussion

In summary, we believe the BSC format provides an excellent framework within which to make reasonable and realistic predictions of the probability of an attack on infrastructure facilities by terrorists. Our scoring and weighting processes are unique but provide much better freedom to describe human behaviour than linear models. The selection of the four measures used to describe investment is well founded based on modern day organization management. The selection of measures to describe returns on investment is more controversial. Clearly, we recognize that these measures should be tailored to each subject terrorist group requiring specific research into group motivations, philosophies, and political schemas. Additionally, a measure to account for intelligence information should be included if it is accurate suggests cause and effect.

The results of the QTRIM targeting model were much better than we originally anticipated. The results are certainly in agreement with experience. However, we are aware that the field in predicting the future is fraught with uncertainty. To resolve a shortcoming, modelers seek more data and more functionality, believing more is better, and bigger gets you closer to truth. Universally, modelers adopt this progression. People seek better paths but scarce resources force structuring the decision process with the data available. The simplicity of our model, with all of its flaws, could be the model of reality. Models are simply conceptualizations of some reality, to be used for a purpose, and they may converge on that reality.

How do we justify the polynomial relationships we used? Principally, because they work in describing human behaviour. The relationships were constructed to represent our view of how a terrorist might value investments and returns on investment. The model was run and then compared to historical data; the comparison was quite good. It seems that if one is willing to make decisions using the Kepner-Tregoe linear score/linear weighting scheme, then one should be more than willing to base the scoring on a non-linear scheme since we know that human behaviour is non-linear. The model could, however benefit from a more theoretical basis for the scoring.

8 Conclusion

Our research proves that defense strategists should not assume that all infrastructure assets are equally at risk from terrorists; nor do they need to assume qualified values of low, medium, and high. Instead, it is possible to rationalize a target ranking based on traditional business analysis methodologies.
In conclusion, QTRIM’s targeting model is simple spreadsheet compiled to represent the thought process of a terrorist planning an attack, with the primary assumptions that (1) Terrorists want to maximize his return on investment and (2) Terrorists are skilled in the rationalizing inputs and outputs.

Our research suggests that it is possible to model the terrorist’s process of valuation if we understand the terrorist’s perceptions, value systems, scenario requirements, spatial relationships, and likely outcomes. The QTRIM did it and it predicts the past event very well. Nonetheless, we recommend improvements in the approach. When verified and validated, the targeting model will be used along with the balance of QTRIM models to predict the final probability of attack of specific targets and target systems.

References


