

# A new approach to protect soft-targets from terrorist attacks

Cuesta, A. ([cuestaar@unican.es](mailto:cuestaar@unican.es)); Abreu, O. ([abreu@unican.es](mailto:abreu@unican.es)); Balboa, A. ([balboaa@unican.es](mailto:balboaa@unican.es)) and Alvear, D. ([alveard@unican.es](mailto:alveard@unican.es))

GIDAI Group – Fire Safety – Research and Technology, University of Cantabria  
Ave. Los Castros, s/n; 39005 Santander (Spain)  
Telf.: +34-942-20-18-26; Fax : +34-942-20-22-76

## Abstract

This paper presents a new approach to evaluate hazard level of soft-targets spaces based on their susceptibility to terrorist acts. This contribution illustrates a mixed method (qualitative-quantitative) to assess an unknown probability of situations which may well put the lives of citizens in serious danger. A case study of this method is conducted on a building adapted from one of the University of Cantabria campus in case of an Improvised Explosive Device (IED) delivered by a terrorist. The present study shows how the method can provide valuable information to decision makers based on quantitative results for use in risk management.

**Keywords:** *Soft targets; Terrorism; Risk Assessment; Mixed method; Improvised Explosive Device (IED)*

## 1. Introduction

Soft targets are public or private spaces relatively vulnerable to terrorist attacks (e.g. shopping malls, transport terminals, schools, mass gathering buildings, crowded events, etc.). These places are often chosen by attackers because of their open nature and mass gathering character as well as their representational or symbolic value, and the likelihood of involving large number of casualties (European Commission, 2017). By 46 % of terrorist attacks carried out in the world in the period of 2000-2016 were against soft targets<sup>1</sup>. The frequency of attacks on soft targets is expected to increase, especially in the Western nations (Martin, 2016). In Europe, recent attacks prove terrorists' preference for attacking people rather than other targets (EUROPOL, 2018). The Europol and the EU Intelligence and Situation Centre (INTCEN) confirm this focus in target selection also openly incited in terrorist publications on the internet (EUROPOL, 2017). Therefore, protecting soft targets from terrorism is a major challenge because of the variety of scenarios ranging from open spaces to areas with some protection, and the different actors involved and the potential mass casualties. In doing so, it is essential a good understanding of how attackers behave and make decisions, what risks are present and what possible mitigation measures may be required, by defining scientific methods, tools and strategies that should be adopted to potentially reduce the vulnerability and enhance resilience of such public spaces while preserving their open nature. In recent years, there has been an increasing number of documents with information and practical guidance for protecting soft targets against terrorist attacks (Vasilis et al., 2018; NaCTSO, 2017; ANZCTC, 2017).

While governments and authorities focus on providing best practices and recommendations, researchers and analysts are attempting to calculate what terrorism risk is. One of the most used approaches for assessing terrorist risk is based on the classical Probabilistic Risk Assessment (PRA) (Garrick et al., 2004). Terrorist risk is defined as a combination of

---

<sup>1</sup> Analysis based on data from the Global Terrorism database of The University of Maryland. National Consortium for the Study of Terrorism and Responses to Terrorism (START). Global Terrorism Database [Data file]; 2017 retrieved from <http://www.start.umd.edu/gtd>.

probability and consequences or as a triplet threats (probability of the attack), vulnerabilities (probability the attack success given it occurs), and consequences (losses that occur given a successful attack). There are examples of risk analyses in the literature using the PRA framework that externally estimate probabilities of terrorist attacks as inputs. Grant and Stewart used PRA for Improvised Explosive Device (IED) attacks in Western nations (Grant and Stewart, 2017) and in commercial buildings in the United States (Grant and Stewart, 2015). In both contributions the Global Terror Database (GTD) (National Consortium for the Study of Terrorism, and Responses to Terrorism (START)) was used as a source of data to conduct the analysis. The GTD was also used in (Li et al. 2016) in a model for analysing and forecasting the conditional probability of bombing attacks. Another contribution for assessing terrorist risk in shopping centres characterized the relative frequency of different types of terrorist attacks and the consequences of those different types of attacks based on data from the RAND–National Memorial Institute for the Prevention of Terrorism (MIPT) Terrorism Incident Database (LaTourrette et al., 2006). Nevertheless, this study highlighted the limitations when using historical data to predict terrorist risks. The major problem of using PRA arises when the underlying probabilities are unknown and estimations cannot be determined rigorously. For example, when assessing the terrorist risk in a specific scenario (i.e. a mas gathering building) and knowledge about historical attacks is insufficient and/or unavailable. In such case the probability of the attack can be the most challenging to estimate. Ezell et al. (Ezell et al., 2010) acknowledged PRA limitations and stated that no single model approach is sufficient. They proposed the use of PRA with event trees in bioterrorism risk analysis. Guikema and Aven (Guikema and Aven, 2010) proposed an integrative approach combining a consequence-based classification of potential attacks with an independent analysis of a sub-set of attack scenarios with different approaches. Given that in many cases terrorist risk cannot be assessed properly by using probabilities and expected values, some researchers propose the use of semi-quantitative risk analysis (Aven, 2008; Aven and Renn, 2009a; Aven and Renn, 2009b; Argenti, et al., 2015), which can provide a more comprehensive risk picture because it allows considering underlying factors that affect the risk, but are often ignored in standard quantitative risk analyses. Nevertheless, this approach strongly depends on expert opinion (Guikema and Aven, 2010). Other solutions focus on the consequences of the attack whether it were to occur, regardless of the probability of the attack occurring. Screening methodologies have been proposed to protect critical infrastructures (Apostolakis and Lemon, 2005; Patterson and Apostolakis, 2007). Outputs are a set of locations/targets to protect. These approaches do not consider either models or expert assessment of attacker behaviour.

What emerges from literature survey carried out is that current scientific approaches to terrorist risk are based on fundamentally different assumptions and they have strengths and weaknesses. Despite their limitations, these approaches can help decision makers when assessing terrorist risk in different ways depending on the focus: involving intelligent and active defence when assessing threats, reducing the success of attempted attacks when assessing vulnerabilities and/or increasing preparedness and response that reduces the effects of damage when the analysis focuses on consequences (Willis et al., 2005). A particular concern of this paper is the use of scientific based approaches for protecting soft targets. We present a new method to determine the relative probability of a given terrorist attack in different target zones of such kind of scenarios. Since, evacuation may well be a key strategy to ensure people security, assessing threat levels of different zones will be essential to define not only fastest but also safest escape routes (Cuesta et al. 2017). The proposed contribution is a scenario-based approach which combines quantitative data and expert judgements to provide

a straightforward but comprehensive screening tool designed for security managers to identify critical locations to prioritize resources allocation.

The paper is organized as follows: Section 2 gives reasons why the mixed approach was adopted and presents the proposed method, Section 3 presents an exemplary case study and Section 4 concludes the paper by discussing results and practical implications of this research.

## 2. Method

### 2.1. Risk assessment approach

Risk is a measure of the extent to which an entity is threatened by a potential circumstance or event and is typically a function of: (1) the adverse impacts that would arise if the circumstance or event occurs; and (2) the likelihood of occurrence (NIST, 2012). The entity is defined here as a soft-target and the threatening event is a terrorist attack. Let's divide the soft target physical scenario into  $n_{ZT}$  zones, where several zones can be accessible to the public ( $n_{ZOA}$ ) and other few ones can be restricted (obviously  $n_{ZOA} \leq n_{ZT}$ ). Then, the risk of a terrorist attack in the  $i$ -th zone of the soft target can be described as:

$$R \quad (1)$$

Where

- probability of the attack in the  $i$ -th zone causing casualties;
- number of casualties produced by the attack in the  $i$ -th zone.

The probability can be expressed as:

$$(2)$$

Where:

- probability that the attack occurs;
- probability of the attack in the  $i$ -th zone;
- probability of attack taking place ( $T_A$ ) before occupants evacuate ( $T_{evac}$ ).

Attempts to estimate the threat likelihood of terrorist attacks are often supported by intelligence assessments and expert opinions (Ezell et al., 2010), although some works are based on historical datasets (Grant and Stewart, 2015, 2017; Li et al. 2016; LaTourrette et al., 2006). However, there appears to be a high level of uncertainty in such estimations. Terrorist attacks rely on attackers who may adapt to changing circumstances. Therefore, the annual probability of a threat likelihood is difficult to predict. There is also a great degree of uncertainty in relation to the number of casualties ( $A_{AA}$ ) produced by the attack. For instance, as long as the attack uses an Improvised Explosive Device (IED), this depends on the weapon size (usually measured in equivalent lb or kg of trinitrotoluene-TNT) and placement, the number of people around, the blast environment, the time of detonation, etc. For instance, there is a little correlation between IED yield (size) and total casualties (Grant and Stewart, 2017). Furthermore, the vulnerability of human body to IEDs is variable. Terrorist bombings inflict injury that affect greater portions of the body and are far more complex than normal trauma associated with accidents (Kluger et al., 2004; Patel et al., 2012). Given this, how can we estimate the likelihood a terrorist attack in a given zone of a soft target? We can consider

that variables in Eq. (1) and (2) do not depend on the characteristics of the zones, with the exception of  $P_A(Z_i)$ . Hence, we assume that:

$$(3)$$

Where:

$$(4)$$

And

$$(5)$$

Eq. (3)-(5) show that the level of risk for a deliberate attack in different zones of a given target scenario can be relatively defined by  $P_A(Z_i)$ , regardless of the value of  $A_A$ , that is  $R$  ).

## 2.2. The proposed method

In many research (engineering) fields the estimation or calculation of a probability can be achieved by analytical methods, experimental methods or combining both. However, in our study, it seems very difficult to decompose the overall complex event (i.e. a terrorist attack in a given zone of the soft target) into other primary stochastic events or variables that can be analytically related with the probability to be calculated  $A_A A A_A A$ . Moreover, it is unsure that the probabilistic characteristics of those hypothetical primary events and/or variables can be known (Flage et al., 20014). This dismiss the analytical way of calculation. On the other hand, the analysis of current information of terrorist attacks and the diversity of situations and scenarios, reveals that the available data is insufficient for the experimental calculation of the required probability. Therefore, we propose a mixed method (qualitative-quantitative) to assess an unknown probability of such a complex event. Although, this method will not provide exact values, it can offer tentative quantities especially useful for comparison purposes. The following contribution illustrates the method for assessing the probability of a terrorist attack in different zones of soft targets.

Suppose that  $P$  is the probability of a given complex event and we can intuitively define a vector of variables  $X$  which influences that probability, and suppose also that the variables  $x_i$  ( $1 \leq i \leq m$ ) could be, some way ordered such that the lower its index the greater its influence (weight) on the value of  $P$ . If we assume a linear model, then:

$$\text{—} \quad (6)$$

Where:

$$\text{—} \quad - \text{ normalized variable } x_i \text{ (} 0 \leq x_i \leq 1 \text{) for positive correlation;} \quad (7)$$

$$\text{—} \quad - \text{ normalized variable } x_i \text{ (} 0 \leq x_i \leq 1 \text{) for negative correlation;} \quad (8)$$

- maximum value of variable  $x_i$ ;

$$\text{—} \quad - \text{ normalized weighted coefficient of } i\text{-th variable;} \quad (9)$$

- absolute weighting coefficient of  $i$ -th variable; (10)
- absolute weight coefficient of  $m$ -th;
- increasing of  $i$ -th absolute weighting coefficient with respect to  $(i+1)$ -th ( $1 \leq i \leq m$ ).

The absolute weighting coefficients  $k_{q_i}$  are assumed to be real numbers greater or equal to 1. These coefficients represent a number of times a given normalized variable  $\bar{x}_i$ , for the definition of the value of probability  $P$ , is more important than less important ones ( $\bar{x}_m$ ). In many cases, choosing the order of importance of the variables is not an easy task since any additional judgement on the relative degree of importance of a variable with respect to another is difficult to appreciate. Therefore, it is common to assume that  $\Delta k_{q_i}$  values are equal to 1. However, it may be apparent that the relative weights of two consecutive variables are approximately equal (i.e. for  $\bar{x}_i$  and  $\bar{x}_{i+1}$ ). In this case, we assume that  $\Delta k_{q_i} = 1$  and  $k$

A more general approach to determine the set of absolute weighting coefficients is relying upon results of individual surveys to a group of experts. Suppose that  $m$  variables are initially sorted in an arbitrary form. Then, each expert of a group of  $n_e$  persons assigns an absolute weighting coefficient to each variable, with the condition that they must be real numbers greater or equal to 1. Let's assume that the corresponding coefficient of  $i$ -th variable is the mean value of the coefficients assigned by the experts to this variable:

$$\text{---} \quad (11)$$

Where:

- value of  $i$ -th absolute weighting coefficient assigned by  $j$ -th expert.

Then, the set of normalized weighting coefficients can be calculated by Eq. (9)-(10).

Now let us see a hypothetical example with a set of variables ( $m=5$ ) with the collaboration of a group of experts ( $n_e=14$ ). Although the person who conducts the survey is expected to be highly qualified, it is important that they do not carry out a preliminary ordering of the variables by their own criterion which may influence the criteria of the surveyed experts. In other words, the initial ordering of the variables should be random. Table 1 displays the results of the hypothetical example using expert opinions. The first column in Table 1 represents the defined variables on which the probability of the event depends. The next 14 columns represent the expert opinions about the level of importance (weight) assigned to each variable (from 1 less important to 5 more important). The last two columns show the values of the absolute and relative weighting coefficients respectively. Note that the sum of the relative weighting coefficients ( $q_i$ ) is equal to 1.

Table 1. Hypothetical example of weighting coefficients for five variables ( $i$ ) assigned by fourteen experts ( $E$ ).

$i$	$E1$	$E2$	$E3$	$E4$	$E5$	$E6$	$E7$	$E8$	$E9$	$E10$	$E11$	$E12$	$E13$	$E14$	Mean $k_i$	$q_i$
1	2	2	1	2	2	2	4	2	2	2	2	3	2	4	2.29	0.15
2	1	1	5	1	1	4	1	1	1	1	1	1	1	1	1.50	0.10
3	5	4	4	4	4	5	2	5	4	4	5	4	4	2	4.00	0.27
4	4	5	2	5	5	1	5	3	5	5	4	5	3	5	4.07	0.27

5	3	3	3	3	3	3	3	3	4	3	3	3	2	5	3	3.14	0.21
<b>Sum</b>																<b>15</b>	<b>1</b>

Based on results in Table 1, the probability of the hypothetical complex event is given by:

$$- \quad (12)$$

$P$  value is  $0 \leq P_{min} \leq P \leq P_{max} \leq 1$

Where:

$P_{min}, P_{max}$  - minimum and maximum  $P$  values.

Note that the proposed method is an estimated evaluation of an unknown probability to compare different conditions and/or potential scenarios of a complex event i.e. whether a probability of a given situation is greater or lower than another. Particularly, it focuses on the relative probability values rather than the absolute probability values. Therefore, it may be opportune to use a rating scale for the assessed probabilities in place of the quantities provided by Eq. (12). Tables 2 and 3 show the suggested rating scales (of 3 and 5 categories respectively) and the conversion rules for the  $P$  values.

Table 2. Three-level rating scale and conversion rules.

Likelihood	$P$ value	Where: —
High		
Medium		
Low		

Table 3. Five-level rating scale and conversion rules.

Likelihood	$P$ value	Where: —
Very High		
High		
Medium		
Low		
Very Low		

### 3. Case study

This case study illustrates the application of the proposed method to a representative building in case of an Improvised Explosive Device (IED) placed by a terrorist.

#### 3.1. The exemplary building

We use an educational building adapted from one of the University of Cantabria as a case study. This building was selected due to the accessibility of the layout, but, for security reasons we have changed the original layout of the building. The first step in the application of the proposed method consists of dividing the building into different target zones according

to their use and geometry. Figure 1 shows the zones considered for the analysis. Non-occupied zones (e.g. technical rooms, broom closets, etc.) were excluded from this analysis. In total, 20 zones were defined with different uses: 3 halls (common circulation spaces), 2 dining rooms (for students and teachers to have lunch), 5 classrooms and 4 lecture rooms, 4 offices, a library and the cafeteria.

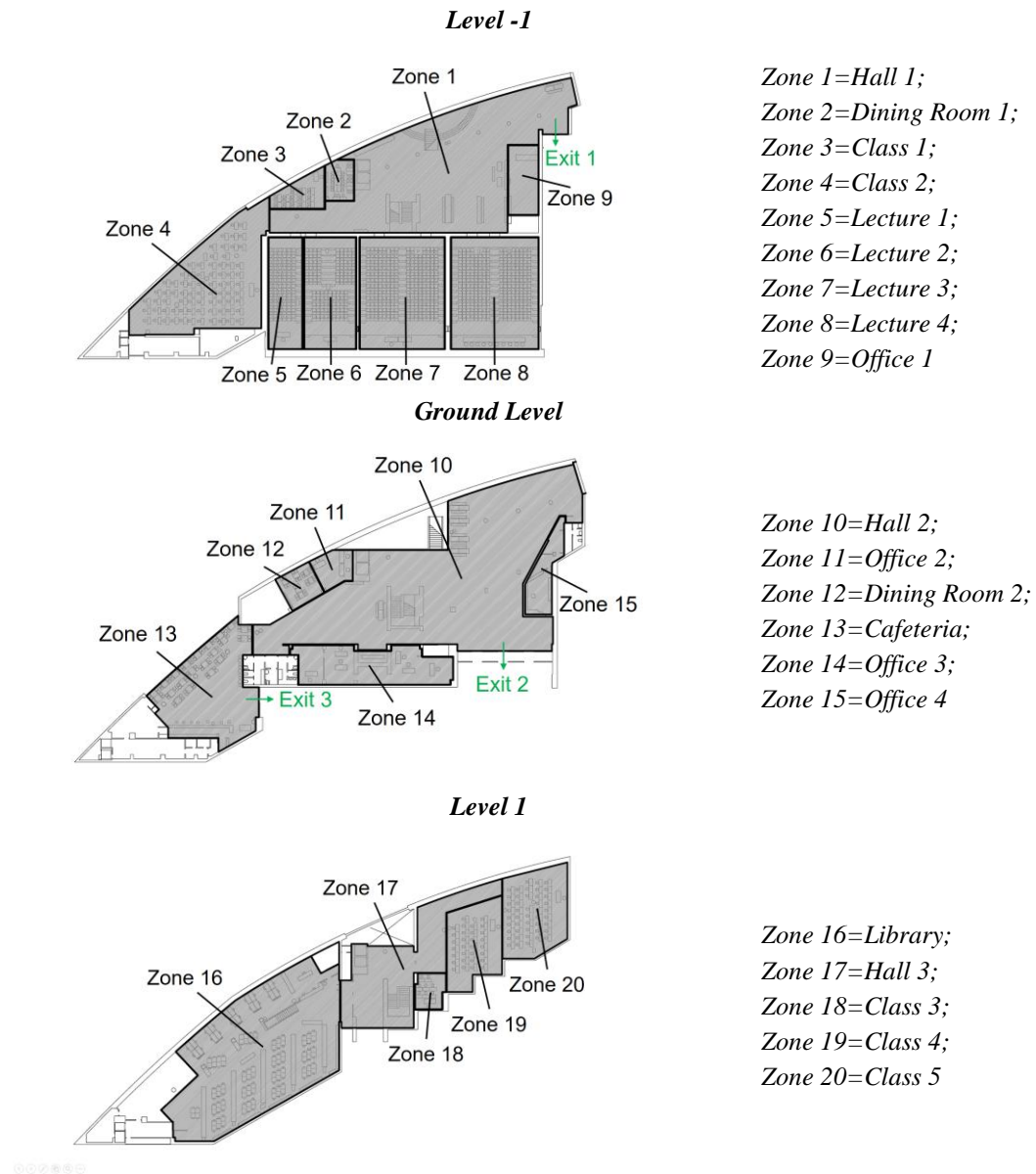


Fig. 1. Layout of the building and Zones selected for the case study.

### 3.2. The IED attack

An Improvised Explosive Device (IED) is defined as a “homemade” bomb and/or destructive device fabricated and used to destroy, incapacitate, harass or distract (Homeland Security, 2019). A more detailed academic definition of IED can be found in (Gill, et al. 2011). IED attacks are a common terrorist weapon of choice against soft targets. According to (Overton et al., 2017) when IEDs were used in populated areas between 2011 and 2016, 91% of casualties were civilians. This may be due to the fact that IEDs are cheap and relatively simple to design and manufacture, especially due to the internet helping (Grant and Steward, 2017). IEDs

generally consist of an initiator, switch, main charge, power source, and a container. Explosives range from commercial explosives (e.g. used in construction and mining such as dynamite, gunpowder and ANFO-Ammonium Nitrate Fuel Oil) to home-made explosives manufactured from consumer goods (e.g. chemicals sold in markets and pharmacies such as fertilizers, firecrackers, sulphuric acid, hydrogen peroxide and acetone).

The IED size (from  $< 1$  Kg to  $100 +$  Kg of TNT equivalent) and the variety of initiation/detonation and delivery systems entail different types of IEDs such as command initiated, suicide, VBIED, thrown, victim operated, projected, mail and timer (Grant and Steward, 2017).

Here we consider a medium-size IED of 5-20 Kg (TNT NEQ) delivered by a terrorist in a specific zone for subsequent detonation (command initiated or timer). Based on attacks in Western nations between 1970 and 2013, the medium-size IEDs had a success rate of 39.47 % with a reliability (i.e. terrorist ability to design and manufacture viable devices) of 92 % for command initiated and 57% for timer activation (Grant and Steward, 2017).

There is a need to establish a difference between a suicide bomber and a hand carried bomber. Whereas, a suicide bomber is assumed to have the objective to kill himself during the attack while causing as many casualties as possible, a hand carried bomber is assumed to place the IED into the interior of the soft target and leave the scene before the explosion, which provides obvious physical safety for the terrorist although the intention is also assumed to harm as many people as possible. In the present case study, we focus on the latter type of attack conducted by an active terrorist rather than a suicidal terrorist who may be responsive to incentives but probably not close to *homo economicus* in relation to narrow self-interest and rational expectations (Caplan, 2006).

### 3.3. The definition of the variables

The next step consists of defining the variables that can have impact on the likelihood of the IED getting placed in a given zone of the building. The perpetrator is expected to assess the situation with the aim to place the IED in the correct location and making it explode at the right time to cause as much human damage as possible. Therefore, we assume the following operational objectives: O1) “reach the target zone”, O2) “not to be discovered during the attack”, O3) “leave the target zone before the explosion” and O4) “harm as many people as possible”. Based on these primary objectives, a set of variables to characterize each target zone that can influence  $A_{AAA}A_{AA}A$  are defined:

$O_A$ .- Open area of  $i$ -th zone ( $m^2$ ).- This variable is related to objective O4 “harm as many people as possible” because the destructive effect of the blast overpressure wave or shock wave (primary, secondary and tertiary injuries) is likely to be reduced by obstacles such as columns, desks, stands, etc.

$T_D$ .- Travel distance from the entrance(s) to the centre of  $i$ -th zone (m).- This variable determines, to some degree, the time spent by the attacker to perform the terrorist action (i.e. reaching and leaving the target zone). Therefore, it is related to objectives O1 “reach the target zone”, O2 “not to be discovered” and O3 “leave the target zone before explosion”.

$D$ .- People density in  $i$ -th zone ( $m^2$ /per).- The people density is closely associated with objective O4 “harm as many people as possible” because the more people in the zone the more potential casualties/injuries. This variable can also be related to objectives O2 “not to be



discovered” and O3 “leave the target zone before explosion” because the attacker, with people around, is more likely to go unnoticed.

$P_D$ .- Probability of IED/attacker detection (three level rating scale: *low*, *medium* or *high*).- Since this variable is difficult to quantify, a three-level rating scale is proposed. Table 4 shows the definition criterion of the conditions and the suggested values for expert judgment. This variable is directly connected with objectives O2 “not to be discovered”, O1 “reach the target zone” and O3 “leave the target zone before the explosion”. Note that this variable must have a value between 0 and 1 to be included in the general formula for calculating the  $A$

Table 4. Rating scale and assumed values for the probability of IED/attacker detection ( $P_D$ ).

Level	Definition criteria	$P_D$ value
<i>High</i>	Restricted access and/or security measures along the terrorist path: <ul style="list-style-type: none"> <li>• Access control (physical barriers, electronic, etc.)</li> <li>• CCTV coverage (IED detection)</li> <li>• Personnel</li> </ul>	0.165
<i>Medium</i>	Free public access with some security measures along the terrorist path: <ul style="list-style-type: none"> <li>• CCTV coverage</li> <li>• Personnel</li> </ul>	0.495
<i>Low</i>	Free access with minimum or no security measures along the terrorist path:	0.830

Table 5 shows the values of the **normalized** variables ( $\bar{O}_A, \bar{T}_D, \bar{D}, P_D$ ) that **characterize** each target zone of the building. The open area ( $O_A$ ) was defined as the amount of space available to the occupants that lack of obstacles or separations (e.g. columns, internal walls, etc.) which potentially reduce the impact of blast effects. The open area for each building zone was calculated as follows:

$$(13)$$

Where:

- Net assignable area (or circulation area) available for occupants of the  $i$ -th zone;
- Area that cannot be occupied because of structural features including walls, partitions, columns, or other obstacles that may potentially reduce the blast effects.

The travel distances ( $T_D$ ) were measured from the entrances (Exit 1, Exit 2 and Exit 3) to the central point of each zone regarding the layout of the building (see Figure 1) and assuming straight lines using the CAD drawings. Then, we selected the shorter distances among the three potential trajectories from the entrances towards each target zone of the building.

The people density ( $D$ ) was obtained dividing the open area ( $O_A$ ) by the expected number of occupants. The number of occupants can be calculated into two ways. The first approach relies on direct observations to determine the number of people that actually use each zone of the building. The second one is dependent on building codes (or standards) to determine the greatest number of people likely to occupy a particular zone within a building. This approach, more conservative, was used by the authors to calculate people densities of each target zone. In those zones with fixed seats (e.g. lecture rooms, classrooms, offices and library), the number of occupants was assumed to be equal to the number of seats. The people density in

circulation spaces (Halls 1-3) and the cafeteria was 2 m<sup>2</sup>/per in halls and 1.5 m<sup>2</sup>/per in the cafeteria. These values were taken from the fire safety Spanish code (CTE-DBSI, 2017).

The probability of IED/attacker detection ( $P_D$ ) was estimated for each zone based on the criteria and values displayed in Table 4 by considering the security measures along the potential trajectories (from each exit to each target zone).

Table 5. Normalized variables and probability of IED/attacker detection assigned to each target zone of the building.

Zone	Designation	Level				
1	Hall 1	-1	0.849	0.684	0.716	0.830
2	Dining Room 1	-1	0.043	0.415	1.000	0.830
3	Class 1	-1	0.060	0.336	0.817	0.830
4	Class 2	-1	0.424	0.061	0.326	0.830
5	Lecture 1	-1	0.118	0.135	0.754	0.830
6	Lecture 2	-1	0.187	0.150	0.815	0.830
7	Lecture 3	-1	0.296	0.317	0.937	0.830
8	Lecture 4	-1	0.301	0.473	0.911	0.830
9	Office 1	-1	0.080	0.795	0.044	0.495
10	Hall 2	Ground	1.000	0.795	0.711	0.495
11	Office 2	Ground	0.042	0.490	0.171	0.830
12	Dining Room 2	Ground	0.044	0.516	0.900	0.830
13	Cafeteria	Ground	0.289	0.892	0.956	0.830
14	Office 3	Ground	0.179	0.636	0.077	0.165
15	Office 4	Ground	0.059	0.766	0.055	0.165
16	Library	+1	0.664	0.112	0.288	0.495
17	Hall 3	+1	0.288	0.455	0.055	0.495
18	Class 3	+1	0.040	0.297	0.416	0.495
19	Class 4	+1	0.166	0.173	0.208	0.495
20	Class 5	+1	0.206	0.000	0.176	0.495

### 3.4. The weighting coefficients

The next step in the application of the proposed method consists of assigning the importance (weight) of the defined variables ( $O_A$ ,  $T_D$ ,  $D$  and  $P_D$ ). This is a critical step as the assigned weights to the variables rely on subjective criteria and might vary among different experts with different background in knowledge (Askeland et al., 2017). Questionnaires and/or round tables with the participation of a great number of security experts is recommended to address this issue. One advantage of the method proposed here is that expert judgments can be used for assessing several buildings/scenarios because the assigned weights are directly linked to variables that characterize any target zones (i.e. identified discrete areas within a soft-target). Figure 2 shows the weighting coefficients arbitrary assigned by the authors to each variable in this example. Hence the resulted formula to calculate the probability of an IED attack in each target zone of the building was:

$$- \quad (13)$$

Where:

- normalized values of variables  $O_A$ ,  $T_D$ ,  $D$  respectively.

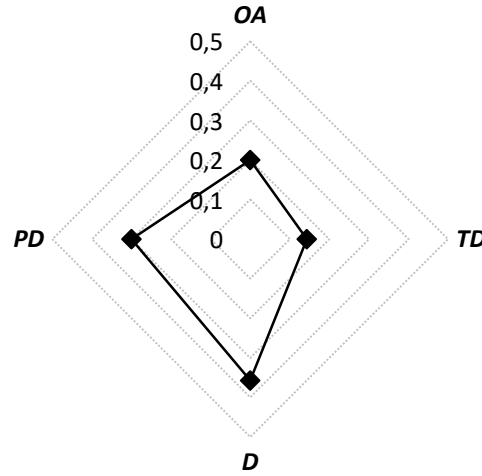


Fig. 2. Weighting coefficients assigned by security experts to the defined variables:  $O_A$  = Open area;  $T_D$  = Travel distance;  $D$  = People density and  $P_D$  = Probability of IED/attacker detection.

### 3.4. Results

Figure 3 shows the relative probability of a small IED attack produced for different zones of the building and Figure 4 represents the three level and five level rating scales produced (according to Tables 2 and 3). As mentioned, the results provided may be used as a comparative analysis between the target zones of the building rather than absolute values. The target zones 1, 2, 7, 8, 10 and 13 produced the higher susceptibility of an IED attack (A values ranged from 0.67 to 0.77). In other words, these zones would represent the priority for counter-terrorism efforts.

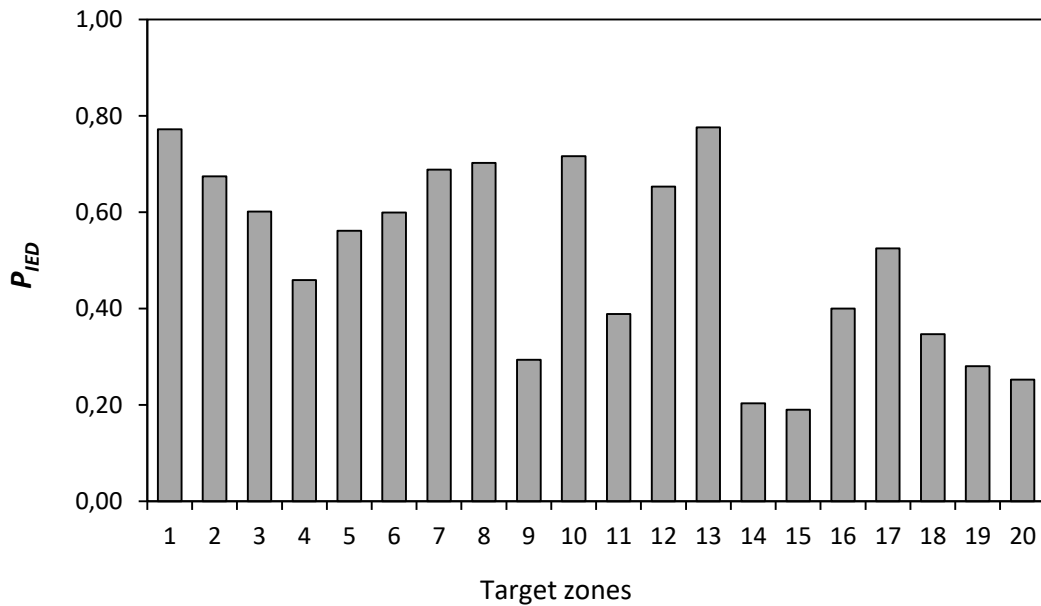


Fig. 3. values produced by target zones of the building (refer to Figure 1 for zones location).

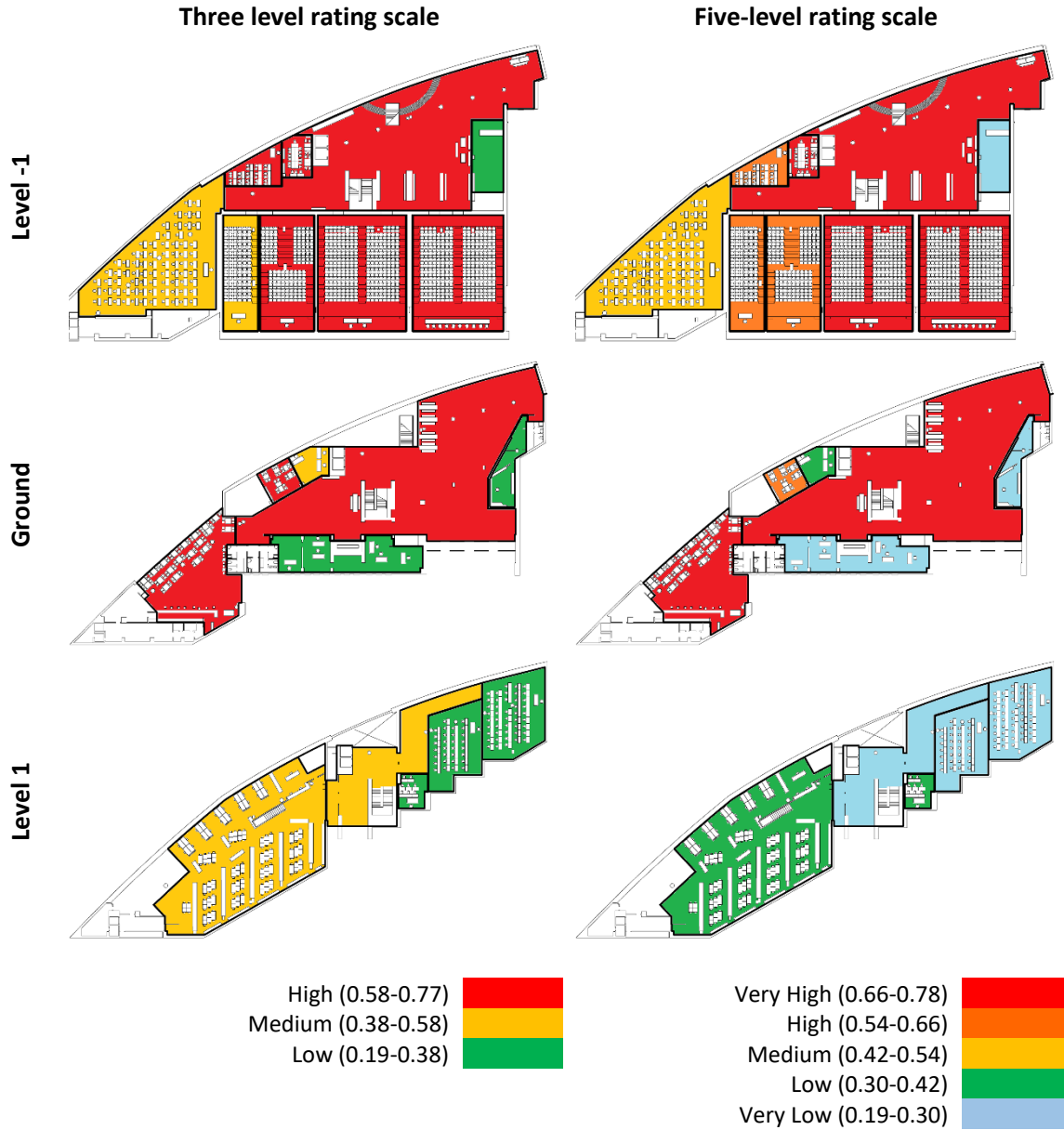


Fig.4. Three-level and five-level rating map representing the susceptibility of an IED attack in the building.

Table 5 can be used as a reference to better understand results in Figures 3 and 4 as it shows the characteristics (values of the variables) considered for each target zone by assuming the operational objectives of a potential attacker. For example, the target zone 1 (Hall 1) that produced  $P_{IED} = 0.77$  combines a wide-open area (assumed as a favourable condition for blast effects), a short travel distance for the attacker (reaching the target zone and abandoning the building as fast as possible), a reasonable people density (according to the operational objective of harming as many people as possible) and no security measures along the terrorist path (as we assumed a hand carrier bomb attacker instead of a suicide bomber). As expected, the target zone 13 (Cafeteria) also produced a high  $P_{IED}$  value (0.77) being one of the more likely target zones for an IED attack. This zone is characterized by a free access without security measures, short travel distance for the attacker and high people density. On the other hand, the target zone 2 (Dining Room 1) lacks open space for blast effects and has a moderate

travel distance for the terrorist, but it has the higher people density and no security measures along the terrorist path. Therefore, this target zone also produced a high  $A_{AAA}$  (0.67).

The target zones 3, 5, 6 and 12 (Class 1, Lecture 1, Lecture 2 and Dining Room 2) have the same characteristics of zone 2 (lack open space, high travel distances for the attacker but high people density and no security measures along the terrorist path) and produced  $A_{AAA}$  values between 0.56 and 0.65 representing the second priority for counter-terrorism efforts. The rest of zones in the building are deemed to be less susceptible or less valuable to the terrorist desires. However, these target zones should not be ignored, especially zones 4 and 17 (Class2 and Hall 3) which produced  $A_{AAA}$  values from of 0.46 and 0.52 respectively (i.e. medium rating in the five-level scale). These zones are more susceptible to a terrorist action than zones 9, 14, 15, 16, 18-20 (Office 1-Office 4, Library and Class 4 and 5) with a low or very low rating according to the five-level scale.

## 4. Discussion

The aim of this study was to present and test a new proposed approach to calculate the relative probability of a terrorist attack (defined here as a complex event) taking place in different zones of soft targets i.e. the likelihood of the attack in a target zone comparing to the likelihood of the same event in other target zones. As mentioned in the literature review, there is a great degree of uncertainty in relation to terrorist actions and potential applications (e.g. design and planning countermeasures and security management) are relevant to increase people protection. Data from manmade hazards are scarce and the magnitude and recurrence of terrorist attacks are almost unpredictable. This makes the determination of a particular threat for any particular site or building difficult and largely subjective (i.e. expert opinions). This reduces the possibility of using pure quantitative approaches for assessing counter-terrorist measures. The presented method represents an alternative solution using quantitative data (variables that characterize each potential terrorist target) and qualitative information (weighting coefficients assigned by security experts to the defined variables). It is interesting to note that the method does not need the participation of experts for every asset to protect. Expert judgments can be used for assessing several soft target scenarios because the weights are directly linked to variables that characterize any target zones. This approach may well be extended to other complex events (defined here as terrorist attacks) and scenarios both indoor (e.g. shopping malls, transport terminals, stadiums, office buildings, etc.) and outdoor (e.g. crowd events). Also, the method can be used independently as a preliminary security assessment or it can be combined with other approaches such as the analysis of the intelligent threats and the potential attack consequences to gain a more complete information for risk management decisions (Gikema and Aven, 2010). Note that these are additional approaches (independent from the method) that interested parties could use in many ways and levels of sophistication to complement and/or improve the analysis.

The case study has shown how the method can support decision makers providing valuable information through a screening of those zones that would represent the priority for counter-terrorism efforts. A key point is the definition of the variables that could be relevant for a terrorist attack suitability. A plausible approach may be the coarse description of the primary operational objectives for the attackers. Hence, a logical relationship between these operational objectives and the variables of interest can be established. The definition of the operational objectives and the corresponding variables may involve modelling terrorists' judgments and behaviour that will guide their choices and actions (Bhasyam and Montebiller, 2016; Caplan, 2006). For instance, if the attacker is assumed to be a suicide bomber, some variables are highly likely to be irrelevant, such as the travel distance ( $T_D$ ) or the probability

of IED/attacker detection ( $P_D$ ) as the perpetrators may be only interested in reaching the target zone (i.e. forced entry). Similarly, the open area ( $O_A$ ) could be inferred in a different way as attackers may chose confined spaces rather than open spaces. In confined spaces the reflection of blast waves from walls and other surfaces create complex waves of long duration thus increasing lethality. The Madrid multiple bombing attacks in 2004 represents a clear example as the explosions were aboard four commuter trains. A total of 191 people lost their lives and over 1.500 were injured (KAMEDO, 2007). An explosion can also have collateral damage or secondary hazards as well (structural damage, shutting down building systems, releasing of hazardous materials, disruption of evacuation routes, etc.). A striking example is the bombing external attack at the Oklahoma City in 1995 that destroyed one third of the Murrah Building and the blast affected other 324 buildings. It has estimated that up to 90 % of the fatalities were the result of crushing caused by falling debris (Corley et al., 1998). An additional analysis of potential IED attacks consequences may be conducted to complement the results of the proposed model (e.g. focusing on the potential effects of blast waves caused by different devices). Scientific literature provides information of TNT efficiency for different types of explosives such as ANFO (Ammonium Nitrate Fuel Oil) and TATP (Triacetone Triperoxide Peroxyacetone) (Price and Ghee, 2009; Salzano, et al., 2014). Also, a reference study conducted an in-depth analysis of the potential effects of shock waves on equipment in industrial plants providing charts for the estimation of the peak overpressure as a function of distance given an explosive quantity (in kg). (Landucci, et al., 2015). This study showed that home-made explosive devices had a TNT efficiency between 0.2 and 0.5. Such approach would be desirable to determine the consequences of IED attacks. However, IED attacks against soft targets seem to be quite different. Based on GTD, Grant and Steward (Grant and Steward, 2017) found a little correlation between IED yield and casualties and suggested the focus of the analysis on the application of countermeasures based on target's characteristics. An implication of this is the possibility to define the corresponding countermeasures from results produced by the proposed model using, for example, the application of the security-in-dept concept through four separated layers: deter, prevent, protect and contain (Nunes-Vaz, et al., 2011) or the design and implementation of security strategies to minimize the risk of terrorism reported in (LaTourrette et al., 2006). The proposed method can be used to support this general approach allowing decision-makers to explore the impact of security alternatives by following the principle of "Security by design" (European Commission, 2017). Practical use of this method can also help decision makers to pursue a balance between maintaining the open nature of mass gathering areas and ensuring effective protection. Protective measures may be as discreet as possible to minimise their impact on society and avoid creating secondary vulnerabilities. For instance, based on results of the use case the analyst (decision maker) could increase the level of protection (i.e. including CCTV coverage and security personnel in the strategic building accesses) to reduce the resulted relative probability of an attack in a given zone of interest. In the building analysed, the application of this measure to the entrances (Exit 1 and Exit 2) reduces the  $A_{AAA}$  by 0.1 in target zones 1-8 and 11-13. Other solutions are likely to concentrate on the inclusion of obstructions (wall-barriers) in open areas of the building to reduce the relative probability of an IED attack but also the range of the blast effects and/or protecting glazes to avoid lacerative injuries.

To sum up, other primary operational objectives/variables and consequence-based approaches could be considered when applying the method to obtain a more comprehensive risk map of the soft target to protect. Furthermore, despite the proposed method is more in line of a screening approach, the authors consider that it is straightforward enough to be used in combination with other approaches.

Obviously, stopping terrorist attacks on soft targets is very difficult. However, the adoption of scientific approaches and methods could potentially reduce the vulnerability and enhance resilience of such public spaces. Despite the proposed method is likely to be improved, the authors believe that the present paper constitutes the first step for further quantitative research in supporting decision-makers and risk managers to improve soft-targets protection. Further work includes testing the method in several scenarios and potential terrorist attacks to demonstrate its practical validity.

## 7. Acknowledgements

The authors would like to thank the European Commission for the LETS-CROWD project received funding from the Horizon 2020 Research and Innovation Programme under the grant agreement N° 740466 and the Spanish Ministry of Economy and Competitiveness for DEFENDER Project Grant, Ref: BIA2015-64866-R, co-funded by ERDS funds. Moreover, authors thank the suggestions, experiences, and comments from LEAs involved in LETS-CROWD project.

## 8. References

- ANZCTC (Australia-New Zealand Counter-Terrorism Committee). (2017). Australia's Strategy for Protecting Crowded Places from Terrorism. ISBN: 978-1-925593-95-2.
- Apostolakis, G. E. and Lemon, D.M. (2005). A Screening Methodology for the identification and Ranking of Infrastructure Vulnerabilities Due to Terrorism. *Risk Analysis*, 25, 361-376.
- Argenti, F., Landucci, G. and Goazzani, V. (2015). The assessment of the attractiveness of process facilities to terrorist attacks. *Safety Science*, 77, 169-181. <http://dx.doi.org/10.1016/j.ssci.2015.02.013>.
- Askeland, T., Flage, R. and Aven, T. (2017). Moving beyond probabilities – Strength of knowledge characterisations applied to security. *Reliability Engineering and System Safety*, 159, 196–205. <http://dx.doi.org/10.1016/j.ress.2016.10.035>.
- Aven, T. (2008). A semi-quantitative approach to risk analysis, as an alternative to QRAs. *Reliability Engineering and System Safety*, 93, 768–775. doi:10.1016/j.ress.2007.03.025.
- Aven, T. and Renn, O. (2009a). On risk defined as an event where the outcome is uncertain. *Journal of Risk Research*, 12 (1), 1–11. DOI: 10.1080/13669870802488883.
- Aven, T. and Renn, O. (2009b). The Role of Quantitative Risk Assessments for Characterizing Risk and Uncertainty and Delineating Appropriate Risk Management Options, with Special Emphasis on Terrorism Risk. *Risk Analysis*, 29(4), 587-600. DOI: 10.1111/j.1539-6924.2008.01175.x.
- Bhashayam, S.S. and Montibeller, G. (2016). In the opponent's shoes: increasing the behavioral validity of attackers's judgments in counterterrorism models. *Risk Analysis* 36(4), 666-80. doi: 10.1111/risa.12422.
- Caplan, B. (2006). Terrorism; The relevance of the rational choice model. *Public Choice*. 128(1):91-107.
- CTE-DBSI (2017). Documento Básico Seguridad en caso de Incendio.
- Corley, W. G., Sr., P. F. M., Sozen, M. A., & Thornton, C. H. (1998). The Oklahoma City Bombing: Summary and Recommendations for Multihazard Mitigation. *Journal of*

- Performance of Constructed Facilities, 12(3), 100–112. doi:10.1061/(asce)0887-3828(1998)12:3(100)
- Cuesta, A., Abreu, O., Balboa, A. and Alvear, D. (2017). Real-time evacuation route selection methodology for complex buildings. *Fire Safety Journal*, 91, 947-954. <http://dx.doi.org/10.1016/j.firesaf.2017.04.011>.
- European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Brussels, 18.10.2017. COM (2017) 612 final.
- EUROPOL. European Union Terrorism Situation and Trend Report 2018.
- EUROPOL. European Union Terrorism Situation and Trend Report 2017.
- Ezell, B. C., Bennett, S., Winterfeldt, D., Sokolowski, J. and Collins, A.J. (2010). Probabilistic Risk Analysis and Terrorism Risk. *Risk Analysis*, 30 (4), 575-589. DOI: 10.1111/j.1539-6924.2010.01401.x.
- FEMA (Federal Emergency Management Agency). (1996). The Oklahoma City Bombing: Improving Building Performance Through Multi-Hazard Mitigation. American Society of Civil Engineers. FEMA 277, August 1996
- Flage, R., Aven, T., Zio, E. and Baraldi, P. (2014). Concerns, Challenges, and Directions of Development for the Issue of Representing Uncertainty in Risk Assessment. *Risk Analysis*, 34(7), 1196-1207. DOI: 10.1111/risa.12247.
- Garrick B, Hall J, Kilger M, McDonald J, O'Toole T, Probst P, Parker E, Rosenthal R, Trivelpiece A, Arsdale L, Zebroski E. (2004). Confronting the risks of terrorism: Making the right decisions. *Reliability Engineering and System Safety*, 86(2), 129–176. doi:10.1016/j.ress.2004.04.003
- Grant, M. and Steward, M. (2015). Probabilistic Risk Assessment for Improvised Explosive Device Attacks That cause Significant Building Damage. *J. Perform. Constr. Facil*, 29(5): B4014009. DOI: 10.1061/(ASCE)CF.1943-5509.0000694.
- Grant, M. and Steward, M. (2017). Modelling improvised explosive device attacks in the West – Assessing the hazard. *Reliability Engineering and System Safety*, 165, 345–354. <http://dx.doi.org/10.1016/j.ress.2017.04.007>.
- Gill, P., Horgan, J. and Lovelance, J. (2011). Improvised Explosive Device: The Problem of Definition. *Studies in Conflict & Terrorism*, 34:732–748.
- Guikema, S. D. and Aven, T. (2010). Assessing risk from intelligent attacks: A perspective on approaches. *Reliability Engineering and System Safety*, 95, 478–483. doi:10.1016/j.ress.2009.12.001.
- Homeland Security. IED Attack: Improvised Explosive Devices. Fact sheet from the National Academies and Department of Homeland Security. [https://www.dhs.gov/xlibrary/assets/prep\\_ied\\_fact\\_sheet.pdf](https://www.dhs.gov/xlibrary/assets/prep_ied_fact_sheet.pdf).
- KAMEWDO (The Committee for Disaster Medicine Studies). (2007). The Terror Attacks in Madrid, Spain, 2004. Kamedo-report 90. [www.socialstyrelsen.se](http://www.socialstyrelsen.se)
- Kluger, Y. et al. (2004). The Special Injury Pattern in Terrorist Bombings. *Journal of the American College of Surgeons*, American College of Surgeons, Elsevier Inc., 875-879. <http://dx.doi.org/10.1016/j.jamcollsurg.2004.09.003>.
- LaTourrette, J., Howell, D. R., Mocher, D. E. and MacDonald, J. (2006). Reducing Terrorism Risk at Shopping Centres: An Analysis of Potential Security Option. RAND Homeland Security. Technical Report.



- Li, S., Zhuang, J. and Shen, S. (2016). Dynamic Forecasting Conditional Probability of Bombing Attacks Based on Time-Series and Intervention Analysis. *Risk Analysis* DOI: 10.1111/risa.12679. DOI: 10.1111/risa.12679.
- Martin R.H. (2016). Soft Targets are Easy Terror Targets: Increased Frequency of Attacks, Practical Preparation, and Prevention. *Forensic. Res. Criminol. Int. J.* 3(2): 00087. DOI: 10.15406/frcij.2016.03.00087
- NaCTSO (National Counter Terrorism Security Office). (2017). Crowded Places Guidance. Counter Terrorism Policing.
- National Consortium for the Study of Terrorism and Responses to Terrorism (START). Global Terrorism Database [Data file]; 2017 retrieved from <http://www.start.umd.edu/gtd>.
- NIST (National Institute of Standards and technology). (2012). Guide for Conducting Risk Assessments. NIST Special Publication 800-30.
- Nunes-Vaz, R. Lord, S. and Cuik, J. (2011). A More Rigorous Framework for Security-in-Depth. *Journal of Applied Security Research*, 6:372–393. DOI: 10.1080/19361610.2011.580283
- Overtom, I. et al. (2017). Improvised Explosive Device (IED) Monitor. AOAV (Action on Armed Violence).
- Patel H, Dryden S, Gupta A, Stewart N. (2012). Human body projectiles implantation in victims of suicide bombings and implications for health and emergency care providers: the 7/7 experience. *Ann R Coll Surg Engl, R Coll Surg*, 94, 313–7. doi 10.1308/003588412X13171221591772.
- Patterson, S. A. and Apostolakis, G. E. (2007). Identification of critical locations across multiple infrastructures for terrorist actions. *Reliability Engineering and System Safety*, 92, 1183–1203. doi:10.1016/j.ress.2006.08.004.
- Price, M. A. and Ghee, A. H. (2009). Modeling for Detonation and Energy Release from Peroxides and Non-Ideal Improvised Explosives. *Central European Journal of Energetic Materials*, 6(3-4), 239-254. ISSN 1733-7178.
- Salzano E., Landucci G., Reniers G., Cozzani V. (2014). Domino effects related to home-made explosives, *Chemical Engineering Transactions*, 36, 349-354 DOI: 10.3303/CET1436059
- Vasilis, K., Martin, L. and Solomos. (2018). Review on Soft target/Public space protection Guidance. JCR Science for Policy Report (2nd edition). European Commission.
- Willis, H. H., Morral, A. R., Kelly, T. K. and Medby, J.J. (2005). Estimating Terrorism Risk. RAND Center for Terrorism Risk Management Policy.