A new approach to protect soft-targets from terrorist attacks

Cuesta, A. (cuestaar@unican.es); Abreu. O. (abreuo@unican.es); Balboa, A (balboaa@unican.es) and Alvear, D. (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 method to evaluate hazard level of soft-targets spaces based on their susceptibility to terrorist acts. This contribution illustrates a mixed approach (qualitative-quantitative) to assess an unknown probability of situations which may well put the lives of citizens in serious danger. A case study 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. Potential applications and opportunities of this approach are discussed in detail.

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[1]. 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 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 probability and

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[1] 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.

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 study to analyse and forecast 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). This study highlighted the limitations of using historical data to predict terrorist risks. The major problem 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) suggested 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 underlaying 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 used 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 safest escape routes (Cuesta et al. 2017). Our 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 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:

$$R_{A_i} = P(N_{C_i}) \times N_{C_i} \quad (1)$$

Where
- $P(N_{C_i})$ - probability of the attack in the *i-th* zone causing N_{C_i} casualties;
- N_{C_i} - number of casualties produced by the attack in the *i-th* zone.

The probability $P(N_{C_i})$ can be expressed as:

$$P(N_{C_i}) = P_A \times P_A(Z_i) \times P(T_A < T_{evac}) \quad (2)$$

Where:
- P_A - probability that the attack occurs;
- $P_A(Z_i)$ - probability of the attack in the *i-th* zone;
- $P(T_A < T_{evac})$ - 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. Similarly, there is a great degree of uncertainty in relation to the number of casualties (N_{C_i}) 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 Steward, 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:

$$R_{A_i} = A_A \times P_A(Z_i) \quad (3)$$

Where:

$$A_A = P_A \times P(T_A < T_{evac}) \times N_{C_i} \quad (4)$$

And

$$P_A(Z_i) = const \quad (5)$$

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 $R_{A_i} \propto P_A(Z_i)$.

2.2. The 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 $P_A(Z_i)$. 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 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:

$$P = \frac{1}{m}\sum_{i=1}^{m} q_i \bar{x}_i \quad (6)$$

Where:

$\bar{x}_i = \frac{x_i}{x_{i_{max}}}$	- normalized variable x_i ($0 \leq x_i \leq 1$) for positive correlation;	(7)
$\bar{x}_i = 1 - \frac{x_i}{x_{i_{max}}}$	- normalized variable x_i ($0 \leq x_i \leq 1$) for negative correlation;	(8)
$x_{i_{max}}$	- maximum value of variable x_i;	
$q_i = \frac{k_{q_i}}{\sum_{i=1}^{m} k_{q_i}}$	- normalized weighted coefficient of *i-th* variable;	(9)
$k_{q_i} = k_{q_{i+1}} + \Delta k_{q_i}$	- absolute weighting coefficient of *i*-th variable;	(10)
$k_{q_i} \geq 1$	- absolute weight coefficient of *m-th*;	
Δk_{q_i}	- 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 Δk_{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 $k_{q_i} = k_{q_{i+1}}$.

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:

$$k_{q_i} = \frac{1}{n_e}\sum_{j=1}^{n_e} k_{q_i}\mid^{\,j} \qquad (11)$$

Where:

$k_{q_i}\mid^{\,j}$ - 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	4	3	3	3	2	5	3	3.14	0.21
Sum															**15**	**1**

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

$$P = \frac{1}{5}(0.15\bar{x}_1 + 0.10\bar{x}_2 + 0.27\bar{x}_3 + 0.27\bar{x}_4 + 0.21\bar{x}_5) \quad (12)$$

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

Where:
P_{min}, P_{max} - minimum and maximun P values.

Note that this approach 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 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**	
High	$P_{min} + 2\Delta P_{3level} \leq P \leq P_{max}$	Where: $\Delta P_{3level} = \frac{1}{3}(P_{max} - P_{min})$
Medium	$P_{min} + \Delta P_{3level} \leq P \leq P_{min} + 2\Delta P_{3level}$	
Low	$P_{min} \leq P \leq P_{min} + \Delta P_{3level}$	

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

Likelihood	***P* value**	
Very High	$P_{min} + 4\Delta P_{5level} \leq P \leq P_{max}$	Where: $\Delta P_{5level} = \frac{1}{5}(P_{max} - P_{min})$
High	$P_{min} + 3\Delta P_{5level} \leq P \leq P_{min} + 4\Delta P_{5level}$	
Medium	$P_{min} + 2\Delta P_{5level} \leq P \leq P_{min} + 3\Delta P_{5level}$	
Low	$P_{min} + \Delta P_{5level} \leq P \leq P_{min} + 2\Delta P_{5level}$	
Very Low	$P_{min} \leq P \leq P_{min} + \Delta P_{5level}$	

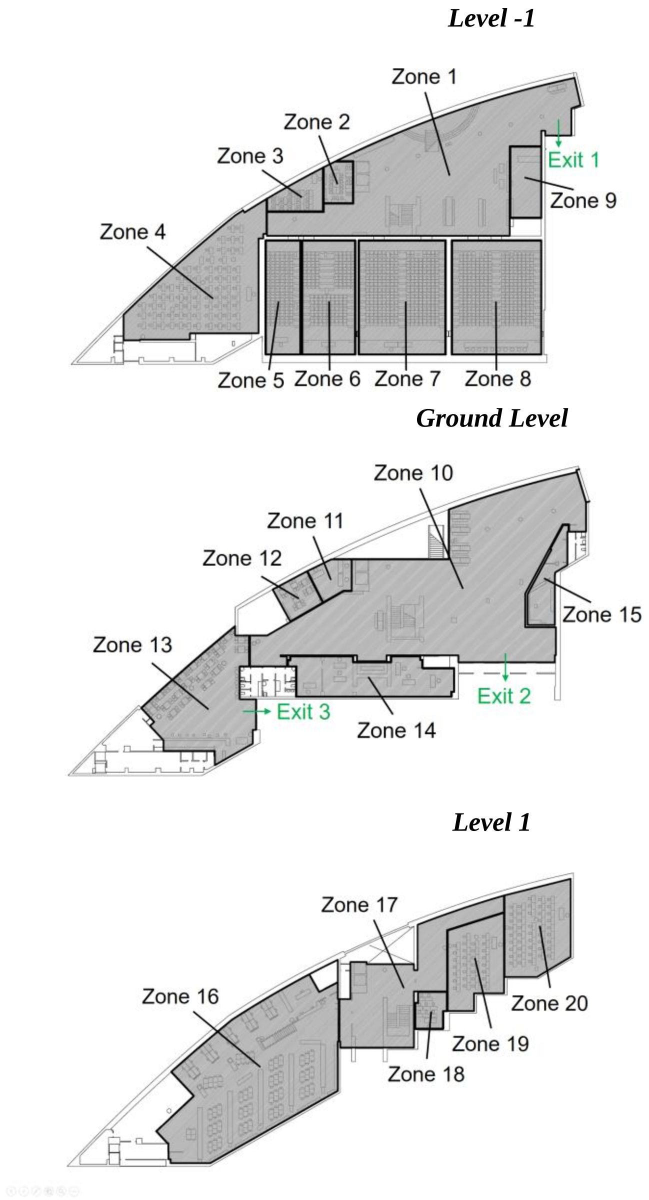
The presented method was conceived as flexible as possible to address any terrorist attacks and targets. The key point is the definition of the variables that characterize different target zones that may have an influence on the relative probability of a given attack. The following section presents a case study that illustrates the application of the method to a representative building in case of an Improvised Explosive Device (IED) placed by a terrorist.

3. Case study

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 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.



Zone 1=Hall 1;
Zone 2=Dining Room 1;
Zone 3=Class 1;
Zone 4=Class 2;
Zone 5=Lecture 1;
Zone 6=Lecture 2;
Zone 7=Lecture 3;
Zone 8=Lecture 4;
Zone 9=Office 1

Zone 10=Hall 2;
Zone 11=Office 2;
Zone 12=Dining Room 2;
Zone 13=Cafeteria;
Zone 14=Office 3;
Zone 15=Office 4

Zone 16=Library;
Zone 17=Hall 3;
Zone 18=Class 3;
Zone 19=Class 4;
Zone 20=Class 5

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 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 $P_{IED}(Z_i)$ 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 assumed. 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 $P_{IED}(Z_i)$.

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

Level	**Definition criteria**	**P_D value**
High	Restricted access and/or security measures along the terrorist path: • Access control (physical barriers, electronic, etc.) • CCTV coverage (IED detection) • Personnel	0.165
Medium	Free public access with some security measures along the terrorist path: • CCTV coverage • Personnel	0.495
Low	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:

$$O_{A_i} = NA_{A_i} - Obs_i \tag{13}$$

Where:

NA_{A_i} - Net assignable area (or circulation area) available for occupants of the *i-th* zone;

Obs_i - 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. Occupancy estimation can be obtained from CCTV, people counters, and access control data and many other sophisticated methods applied for smart buildings such as passive infrared (PIR) sensors, sensor network comprising CO2 sensors among others as well as historic building utilization data (Ahmad et al., 2018; Elkoukhi, et al., 2018). 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^2/per in halls and 1.5 m^2/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***	$\bar{O}_A$	$\bar{T}_D$	$\bar{D}$	P_D
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 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 presented 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:

$$P_{IED_1} = \frac{1}{4}(0.20 \times \bar{O}_{A_i} + 0.14 \times \bar{T}_{AD_i} + 0.36 \times \bar{D}_i + 0.30 \times P_D) \quad (13)$$

Where:

$\bar{O}_A, \bar{T}_D, \bar{D}$ - normalized values of variables O_A, T_D, D respectively.

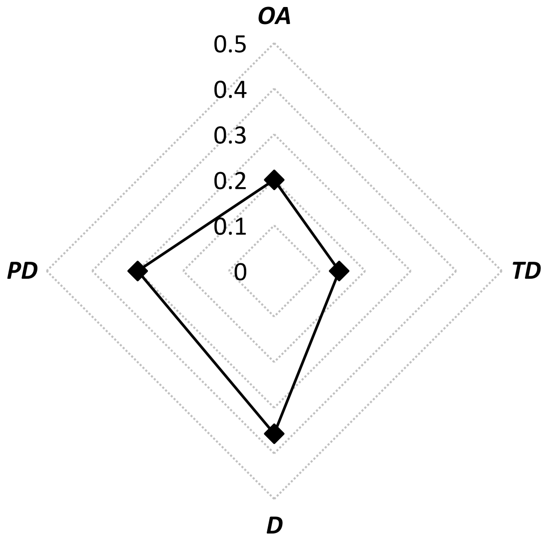


Fig. 2. Weighting coefficients assigned by security experts to the defined variables: O_A = Open area; T_D = Travel distance; D = People density and P_D = Probability of IED/attacker detection.

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 (P_{IED} values ranged from 0.67 to 0.77). In other words, these zones would represent the priority for counter-terrorism efforts.

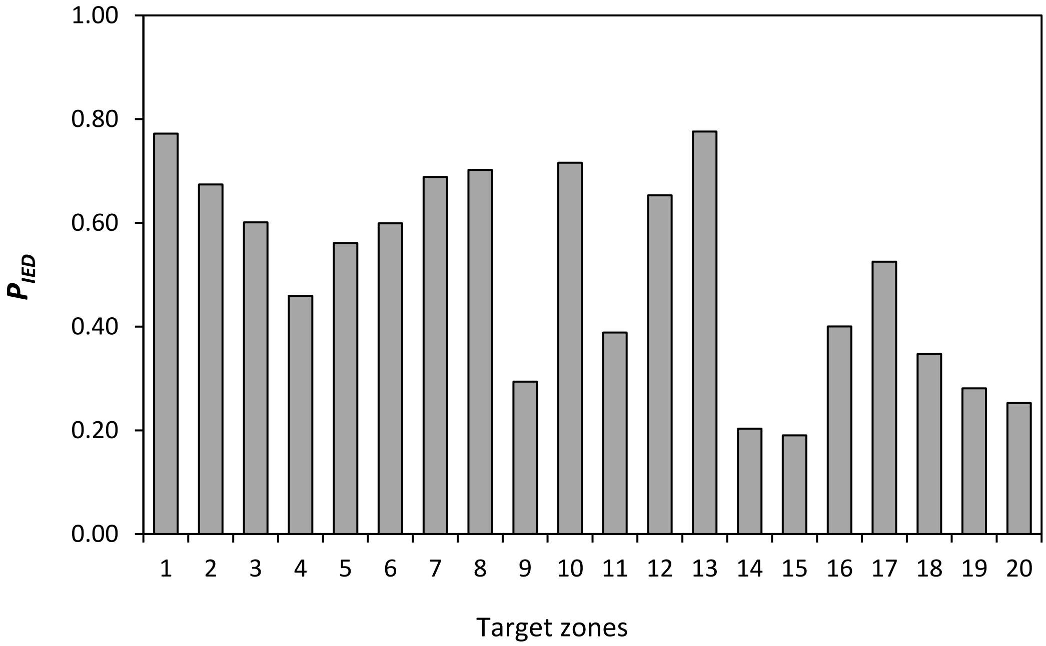


Fig. 3. P_{IED} values produced by target zones of the building (refer to Figure 1 for zones location).

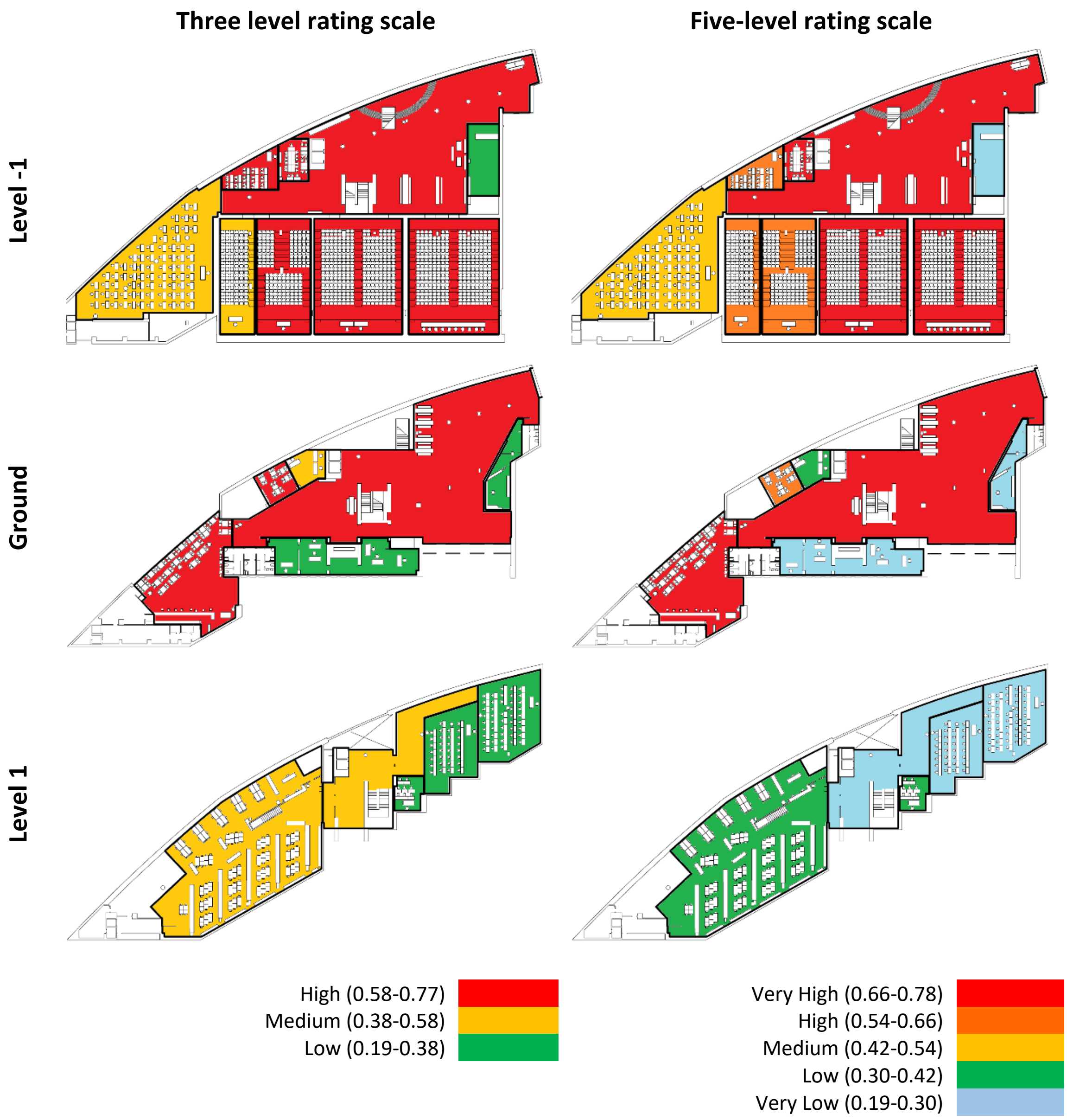


Fig.4. Three-level and five-level rating map representing the susceptibility of an IED attack in the building.

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) 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 produced a high P_{IED} (0.67).

The target zones 3, 5, 6 and 12 (Class 1, Lecture 1, Lecture 2 and Dinning Room 2) have the same characteristics as 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 P_{IED} 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 P_{IED} 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 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) thus reducing the possibility of using pure quantitative approaches. 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 since the assigned 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). 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 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 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 IEDs consequences may be conducted to complement the results of the proposed model. Scientific literature provides information of TNT efficiency for different explosives such as ANFO (Ammonium Nitrate Fuel Oil) and TATP (Triacetone Triperoxide Peroxyacetone) (Price and Ghee, 2009; Salzano, et al., 2014). A benchmark study analysed the effects of shock waves on equipment in industrial plants (Landucci, et al., 2015). The study reported a TNT efficiency between 0.2 and 0.5 of home-made explosive devices. Interestingly, the authors explored different types of domino scenarios and showed the different impacts of the attack position. They suggest the design of rings of protection based on the risk sensitivity of a given zone (e.g. flammable liquids; a reactor that is prone to explode, etc.). Such approach would be desirable to determine the potential consequences of IEDs against soft targets in combination with the proposed approach.

IED attacks against industrial facilities and soft targets are different. For instance, based on GTD, Grant and Steward 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 (Grant and Steward, 2017). An implication of this is the possibility to define the corresponding countermeasures from results produced by the proposed model using 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 (LaTourrette et al., 2006). The current method can be used to support this general approach allowing decision-makers to explore the impact of security alternatives following the principle of "Security by design" (European Commission, 2017). Practical use of this may 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 and avoid creating secondary vulnerabilities (i.e. domino effects). For instance, based the presented results the analyst (decision maker) would easily increase the level of protection to reduce the resulted relative probability of an attack. In the building analysed, the application of CCTV coverage and security personnel in building accesses (Exit 1 and Exit 2) reduces the P_{IED} by 0.1 in target zones 1-8 and 11-13. It should be noted that the probability of detection (P_D) is based on hypothetical deterrence produced by security measures. A rating scale and the corresponding values were assumed based on three levels of protection along the potential terrorist path: 1) high level with restricted access and/or security measures, 2) medium level with free public access and some security measures (CCTV and non-specifically trained personnel) and 3) low level with free public access and minimum or no security measures. This limitation means that case study results need to be interpreted cautiously. In practice, a more detailed analysis of the security measures should be conducted when applying the method to determine the actual chances for the attacker to be detected. Other solutions can concentrate on the inclusion of obstructions (wall-barriers) in the building to reduce the impact of the open area variable (O_A) on the probability of an IED attack and 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 applied to obtain a more comprehensive risk map of the soft target to protect. Furthermore, despite the presented 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 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. Further work includes testing the method in several scenarios and potential terrorist attacks to demonstrate its practical validity.

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