Chapter 15
Assessment of the Evacuation Capacity of a Crowd, Including People with Disabilities

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Abstract Vulnerability of population in the terrorist threat is the main idea of the article. Regardless of the threat source, the probability to rescue people of different ages, health conditions and other factors is different. The purpose of this study is to gather information, based to make managerial decisions in optimization of the protective measures for buildings, which can be referred to "soft targets". The goal of optimization is to provide maximum opportunities for rescuing people with different evacuation capacity, taking into account the characteristics of individual groups. This will improve the level of safety of people's staying in public premises.

Keywords Soft targets · Evacuation route · Persons with disabilities

15.1 Introduction

The role of terrorism, as a social phenomenon, has reached frightening levels at present. Terrorist attacks are aimed at undermining civism and violating the basic right of everyone – the right to safety. The urgency of the issue of the population protection from terrorist attacks is increasing day by day. The number of victims in civilian population is estimated in the thousands. The main focus of terrorists, regardless of motives in committing a terrorist act, is focused on causing maximum harm to civilian population, as well as material damage. The ultimate goal of any terrorist attack is to cause moral damage to the world community by causing human and material damage, demonstration of strength and desire for achieving the goal.

In these situations, the most important issue, is saving life and health of people who appear in the zone of terrorist attack, by preventing the perpetration of terrorist acts, reducing the influence on people in case that a terrorist attack has already been committed.

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15.2 Vulnerability of Soft Targets in the Context of Terrorism

Soft targets are the main vector of terrorist attacks direction. The more defenseless and numerous the victims of terrorists are, the greater response this terrorist attack will have in the media. At the same time, terrorist organizations that committed the attack, or an individual terrorist, will consider that their goal has been achieved.

According to the statistics [1], 61 people were killed as a result of terrorist attacks in the EU countries in 2017. Among the series of terrible events that led to the death of people, there were automobile-pedestrian accidents who were peacefully walking along the street, stabbings to death, an explosion in the stadium during a football match, shooting and other organized terrorist acts.

According to the statistics from 2016, the average level of the Global Terrorism Index (GTI) in the European Union countries was: GTI EU-28 = 1.816 (GTI_{max} = 5.964 (France); GTI_{min} = 0 (Latvia, Lithuania, Romania, Portugal, Slovenia) [2].

In Ukraine, terrorist attacks that take place in the context of an armed conflict in the east of the country are estimated by the global terrorism index GTI = 6.557, which is a high indicator, that can be compared with, for example, Sudan (GTI = 6.453) [2]. At the same time, civilian population and soft targets of the eastern region are currently under constant threat of committing terrorist acts.

Analysis of the features of terrorist attacks, both in Europe and in Ukraine, shows that only 6% of all attacks were directed exclusively at infrastructure facilities. The remaining 94% are aimed at the maximum possible damage to people [2].

In last ten years, the number of single terrorist attacks has increased [2]. In general, the consequences of a single terrorist attack are more destructive, because they entail a greater number of victims: on average, one single terrorist attack kills 7 people; while in the case of a group terrorist attack 3 people die [3]. However, it is much harder to prevent this type of a terrorist assault, because a single terrorist can easily get into premises with a large number of people, bypassing security obstacles.

The complexity of protection of soft targets from a terrorist threat is determined by a number of factors, among which we can define the most significant ones [4]:

- the factor of suddenness, difficulty in forecasting;
- security personnel could be unprepared for a serious terrorist attack;
- lack or absence of information on the nature of the threat during the initial period stage;
- large crowds of people;
- lack of special training of stuff;
- diversity within a vulnerable group;
- lack of collective and individual protection equipment;
- Lack of management of the situation.

In these conditions, the use of preventive measures aimed at protecting people from secondary harmful factors, and contributed to effective evacuation is the main way to reduce the number of victims among civilian population.

15.3 Role of the Evacuation Capacity in Assessment the Escape Time

15.3.1 Analysis of a Group of Factors Influencing the Outcome of a Terrorist Attack

The wide variety of objects that relate to the category of soft targets, and diversity of reasons that complicate their safety, leads to the understanding of the importance of solving the issue of ensuring safety.

When a terrorist act is committed at an assets of soft targets, the outcome of an attack for a person who appears in a danger zone depends on the combination of the following factors

$$C = \{A_s, L, S, E_c\} \tag{15.1}$$

where A_s is the total number of characteristics reflecting the peculiarity of the terrorist threat, such as: the type of weapon used to commit a terrorist attack (explosive, toxic or biological substance); defeating capacity, etc.;

L is the total number of factors allowing to localize and disarm a terrorist promptly, it is stipulated by efficiency and operational speed of the rapid response services, and by the means of preventive protection of the soft target;

S is the characteristics of evacuation routes that include: spatial parameters of evacuation routes (length, width, height of evacuation passageways, fire endurance of bearing structures and others);

E_C is the total number of characteristics reflecting the peculiarities of a people crowd who carries out the evacuation in the case of a terrorist attack.

The evacuation capacity E_c characterizes the ability of a person located in a dangerous zone to leave it or to reach a safe shelter in this zone within the allowed time T_a. This index is determined by two main groups of factors: a group of psychological factors A_m, which includes the ability to find the orientation in space, identify the danger, etc.; group of physical factors A_p: physical state, which allows to move at a certain speed in a safe direction; endurance of a person, etc.

$$E_c = \{A_m, A_p\} \tag{15.2}$$

The evacuation capacity is an indicator characterizing the ability of a person to perform actions effectively that are aimed at saving life and health in case of a terrorist attack.

By the evacuation capacity criterion, soft targets can be classified as follows:

- type 1 – soft targets with the greater number of elderly and disabled people (medical institutions, hospices, rehabilitation centers),
- type 2 – soft targets with the greater number of children (schools, child entertainment centers, children's hospitals),
- type 3 – soft targets of mixed type, that includes people who may happen to be present in the defeating area and which is difficult to predict (hotels, public transport).

The issue of ensuring the evacuation of diverse group of people should be resolved in different ways, taking into account the characteristics of each group of people that prevails at a particular assets of a soft target.

15.3.2 Evacuation Capacity as a Method of Determining the Design Parameters of Evacuation Routes

The allowed escape time is the one of the important safety parameter which is determined by the duration and scope of defeating factors of a terrorist attack, the presence and characteristics of the emerging secondary attacking factors and other factors.

The existing methods of estimating the time within which people can be evacuated from dangerous premises basically take into account the following aspects: location and number of evacuation exits, estimation of the shortest distance to the evacuation exit, determination of the optimal route based on mathematical models [5–8]; use of special technical solutions to decrease the time of evacuation [9]; architectural features of buildings and structures affecting the evacuation time [10, 11]; analysis of the features in behavior of people in a stressful situation in the context of the decision-making about evacuation [11–15].

Most of the methods for calculating the optimal evacuation route are focused on the graphic-analytical part of the problem solution and do not personalize the person who needs to be evacuated. At the same time, people who are in assets of soft targets, in most cases, have different characteristics, greatly affect the efficiency of evacuation measures [16]. Basically, the results that can be used to assess the evacuation capacity, obtained either using mathematical models or any volunteers who represent a homogeneous group of people who are often employees at the premises where dangerous situation is simulated. Therefore, these results are difficult to project onto the real situation.

There are some difficulties in predicting human behavior as representatives of individual groups (including persons with disabilities) and it is also hard to foresee human behavior in crowded public areas. Behavioral psychology of people in an extreme situation is studied by many scientists, but it is quite difficult to collect the experimental base. Some researchers, for example [14], use the respondents'

questionnaire method regarding their behavior strategy in an extreme situation, but since this survey was conducted under normal conditions in the absence of a real threat, it is incomprehensible whether they can be used to predict real situations [17]. Controlled experiments [15] are more informative, but in most cases, they are focused on the behavior of a homogeneous group (for example, students aged 18–24), and also draw analogies with the behavior of humans and mice, ants [18].

The evacuation capacity assessment should take into account the fact that people who are in the dangerous zone may have disabilities in the following areas:

- restrictions of movement;
- restrictions of vision;
- restrictions of hearing;
- mental restrictions.

Accordingly, their evacuation capacity will be different.

To research the evacuation capacity, an expert evaluation technique was applied in the article. The group of respondents contained experts in civil safety issues, as well as doctors, whose sphere of activity includes issues relating to determining the functional state of people with disabilities. The respondents were interviewed in order to obtain graded assessment of the abilities of certain groups of people who could potentially be at objects of soft targets to implement certain evacuation stages. For these purposes, groups were formed according to the form of the basic disability and age. For comparison, as an etalon, an adult without any disabilities was selected. The expert assessment did not take into account aspects of psycho-physiological interaction between individuals and groups of people, since the purpose of the expert evaluation was to study the ability of an individual person, as a representative of a certain group, to carry out mental and physical activity to save the life in case of a terrorist attack.

The basis for developing the score scale is the principle of the equivalence of mental and physical abilities to implement the evacuation capacity.

The preparation period, during which the psychological abilities of a person are involved, is divided into 3 stages:

- D_1 – threat identification;
- D_2 – decision making as for evacuation;
- C – selection of the route of evacuation.

Assessment of physical ability to follow the chosen route and pass it effectively is estimated by

- V – ability to reach the sufficient speed of movement;
- S – ability to withstand the pressures;
- O – ability to overcome obstacles that may occur on the way of evacuation.

The score scale is based on the following principle: 3 points – the implementation of the concerned evacuation stage can be carried out effectively, 2 points – the implementation of the concerned evacuation stage is possible under certain conditions; 1 point – the implementation of the concerned evacuation stage is hampered.

The value of the evacuation capacity can serve as a tool for calculating the time of evacuation of people in the event of a terrorist threat in the presence of the average statistical characteristics of the preparatory period and the speeds of movement along evacuation routes.

In general, at the realization of terrorist threat, the total evacuation time can be represented as the sum of certain time periods during which the person's mental and physical abilities are involved:

$$T_e = T_{d1} + T_{d2} + T_c + T_{e1} \leq T_a \tag{15.3}$$

where T_{d1} – time period during which a person who happen to appear is in the zone of terrorist threat realization understands the fact of its committing and identifies it on the basis of the available information;

T_{d2} – time period during which a person makes a decision about the necessity for evacuation from the dangerous zone;

T_c– time period during which a person determines the direction of evacuation and chooses an evacuation route;

T_{e1} – time period when a person follows the chosen route to evacuate from the zone of a terrorist act. This time can also be represented as the sum of the time periods ti on each element of the evacuation route, including movement directly in the premises where the terrorist act was committed, passage time of doorways, staircases, etc., i.e.

$$T_{e1} = \sum_{i=1}^{n} t_i \tag{15.4}$$

The duration of the time intervals that form the preparation period T_p

$$T_p = T_{d1} + T_{d2} + T_c \tag{15.5}$$

can be 25-47 seconds [19], however, this indicator can have essential distinction for various groups of people who may happen to be in assets of soft targets. The period of identification of the threat will be longer for people who are under the influence of stress, alcohol intoxication, medical drugs, children or people with mental disabilities. These categories of people can make a wrong decision regarding to the threat nature, which can lead to the development of an incorrect evacuation strategy in the future. In view of this, these categories of people mostly cannot effectively implement their evacuation capacity at the beginning of evacuation.

It should be noted that analyzing the behavioral strategies of people under conditions of an unexpected threat, it is possible to presume the reaction to a dangerous situation with a certain degree of probability. For example, it is defined [12] that elderly people make a decision about evacuation 0.6 times faster than young people. However, it is obvious that the average speed of movement along the evacuation route of the elderly will be lower compared to the young people.

The decision making as for the necessity for evacuation depends on the degree of personal threat. At the same time, certain categories of people, due to their psycho-physiological characteristics, tend to underestimate the threat, which can lead to fatal consequences. Often the correctness of the decision making to evacuate depends on the degree of uncertainty: the greater the degree of uncertainty is, the more likely it is to make the wrong decision regarding to the necessity for evacuation and the route.

The speed with a person in a dangerous situation moves to the exit, for different evacuation groups, may differ significantly. The estimated speed of movement of people following the evacuation route, according to various sources, is in the range of 0.5–1.4 m/s [19–21]. The real significance for representatives of different groups can have a wider range, which makes it much more difficult to presume the consequences of a terrorist attack. Therefore, the indicator of the evacuation potential can be used to model the evacuation process of various groups of people who are at soft targets facilities.

The evacuation capacity of an etalon person could be estimated as

$$E_{c\max} = A_{m_{\max}} + A_{p_{\max}} \tag{15.6}$$

Taking this into account, the duration of the preparation period T_p, considering the value of the evacuation capacity j of the group A_{mj} and the average time indicator, can be written as follows

$$T_{pj} = \frac{\left(2A_{m_{\max}} - A_{mj}\right) \cdot \bar{t}_{mj}}{A_{m_{\max}}} \tag{15.7}$$

Similarly, the calculation can be carried out for a period of direct movement along the evacuation route T_{e1}.

As an example of implementation of this approach, we would determine the time for evacuation of representatives of different groups for the first rectilinear section of the evacuation route 10 m long. The average time of the preparation period for the basic variant $\bar{t}_{mj} = 36$ s [19] and the average speed of movement $\bar{v} = 0.95$ m/s [20] were selected. In this case, the evacuation time of the reference variant for the first section of the evacuation route will be 10.5 s. Using the values of the evacuation capacity and the time parameters obtained in [12, 19–21], it is possible to calculate the evacuation time for representatives of groups with different evacuation capacity (Table 15.1).

The obtained results, based on the assessment of the evacuation capacity of different groups of people, are concordant to other studies proving that they can be used to determine the design parameters of evacuation time.

Further evacuation time for other sections of the evacuation route can be determined similarly by the formulas (15.3, 15.4, 15.5, 15.6, and 15.7). For sections of the route with various obstacles, the evacuation time can be calculated taking into account the characteristics of the density of the stream of people in the crowded public areas.

Table 15.1 The estimation of the evacuation time taking into account the evacuation capacity

Group	Duration of the preparatory period, s	Duration of the movement on the evacuation section, s	Total evacuation time for the initial section, s
Basic type	36	11	47
Restrictions of vision	52	16	68
Restrictions of hearing	40	11	51
Mental restrictions	60	12	72
Restrictions of movement	40	18	58
Elderly people	36	14	50
Children	52	13	65
Average value	**45**	**13**	**58**

The advantage of the methodology under consideration is the flexibility of the application and the ability to detail the factors that form the evacuation capacity of people, depending on the research objectives. Clarifying the data characterizing the components of the evacuation capacity can increase the accuracy of the results.

15.4 Algorithm for Implementing Preventive Safety for Increasing the Level of Evacuation Capacity

Ensuring the safety of people in the premises and at the territory of soft targets is realized by a complex of organizational and technical measures and means [22] aimed both at increasing the awareness of people considering their disabilities, and at using preventive constructive decisions at the design stage or in the formed space. For increasing the protection level in assets of soft targets, it is essential not to reduce the level of accessibility of safety measures, especially for people with disabilities. Maximum use of the evacuation capacity of the crowd, achieved by a set of preventive safety measures, allows people to carry out effective evacuation from dangerous areas or to reach safety zones following the specific route. This can not only reduce the number of victims, but also simplify the work of specialized anti-terrorist units.

The optimal evacuation route should be determined taking into account the evacuation capacity of each group. Moreover, information about the reasonable route should be provided in an accessible form for understanding. Also, it is necessary to take into account the effect of secondary harmful factors formed after activation of an explosive device or realization of another type of terrorist threat: for example, smoke, fire, fragments of broken glass and other objects. Also it is important to provide the information designation of the evacuation route for different group of people with disabilities that must be duplicated by another source: visual information must be duplicated by sound, etc. It is also possible to use blinking colored light sources or dynamic information screens [23]. The protection of soft targets, in which there are many children (type 2), should be focused on children's perception and take into account the peculiarity of the child's perception.

For people who a priori have low evacuation capacity (people in wheelchair, overweight people, etc.) it is necessary to create safe areas, because during the process of evacuation, they cannot just be effectively evacuated, in addition they could create additional obstacles for other participants of the evacuation process, which can lead to an increase of the number of victims.

The creation of safe zones is carried out within the framework of preventive protection by using architectural and construction methods.

The algorithm for protecting people relevant to soft targets, takes into account the evacuation capacity of groups of people, is shown in (see Fig. 15.1).

Information screens about the evacuation routes can be placed at the entrance and the information there must be encoded. The main emphasis should be put on creating identification marks that allow people with different evacuation capacity to move quickly and make a decision for choosing the best evacuation route. For example, each group of people can be assigned a certain color: the elderly – green, children – orange, people in wheelchair – blue, etc. In the future, the optimal evacuation route, calculated considering the characteristics of each category, should be indicated by the color defined for each category of people.

Providing people with information on a timely manner about a terrorist attack in an accessible form will reduce the degree of uncertainty, increase the probability of a correct assessment of the situation and making adequate decisions to rescue their lives. However, we should take into account the fact that information can lead to panic among people, which can reduce the evacuation capacity and increase the number of victims due to irrational behavior.

15.5 Conclusions

Assessment of the evacuation capacity of people of soft targets is a difficult issue due to the lack of a statistically reliable experimental base on the matter. However, the study of this issue is extremely important, since the probability of terrorist attacks at objects of soft targets remains high.

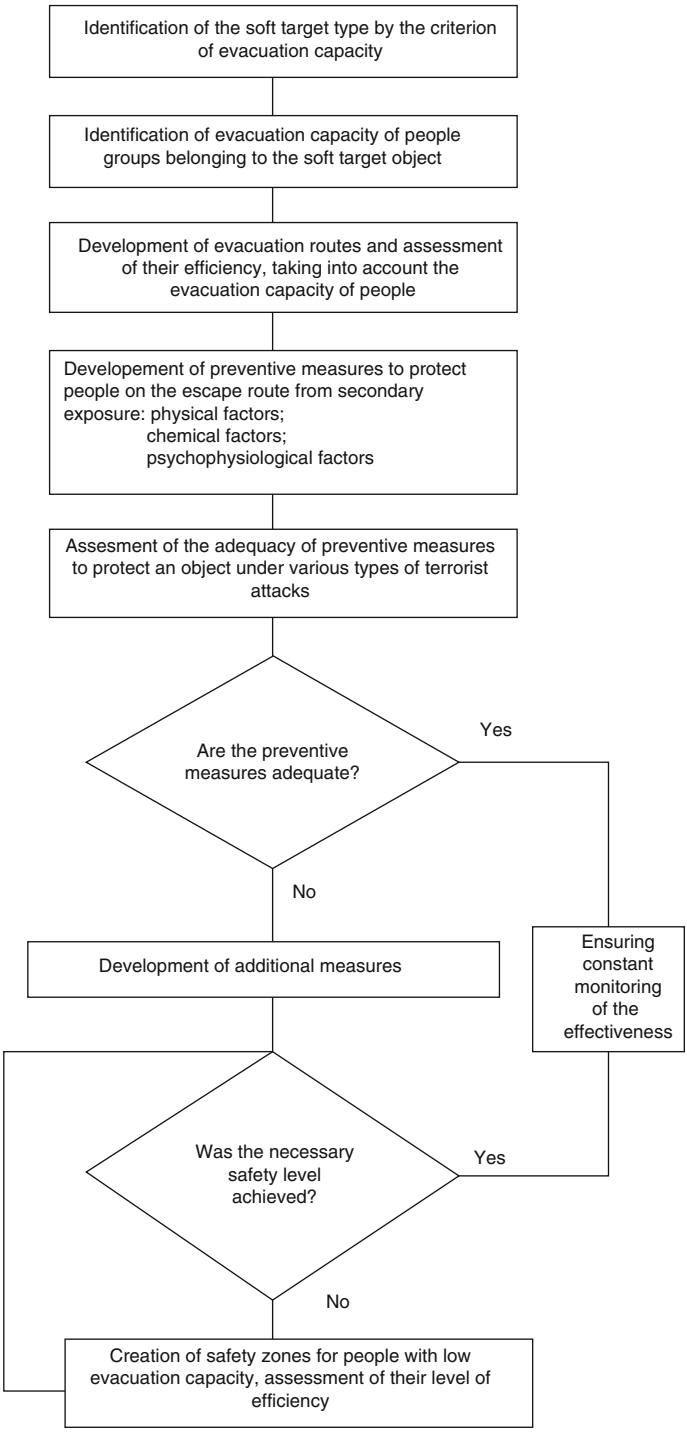

Fig. 15.1 The algorithm for developing preventive protection measures for people, taking into account evacuation capacity

Equally with measures to prevent terrorist acts, the issues of organizing the effective evacuation of people from a dangerous zone should be in the focus of continuative attention, both for owners of facilities and state structures responsible for the safety of citizens.

The article proposes the method for determining the evacuation capacity, taking into account various types of disabilities of people that may find themselves in a dangerous zone. Using the indicator of evacuation capacity, it is possible to generate a calculation model for assessment the parameters of evacuation routes in order to determine the priority directions for ensuring the protection of people in case of a terrorist attack at objects of soft targets.

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