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The "car-bomb" as a terrorist tool at metro stations, railway terminals and airports

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Abstract The purpose of this research is the protection of transport facilities, such as metro stations, railway terminals and airports, against terrorist acts. The research includes statistics on terror acts committed in the metros of the world. The author has formulated a definition of transport security. Statistic analysis revealed a major potential terrorist threat for transport facilities. The author has also classified and ranked possible methods of delivering explosive devices to transport facilities according to the threat level. The author has ascertained the method of delivering explosive devices of the highest threat level and has studied deterrents deployed for the protection of transport facilities against "car-bomb" terrorist acts. Comparative analysis and natural experiment showed that deployed fenders do not completely secure against all types of motor vehicles. The author has developed a new protection facility capable of 100% counter-terrorist protection of transport facilities against "car-bomb" terror attacks.

Keywords Transport security · Explosive device · "car-bomb" · Terrorist attack

Introduction

According to the Global Terrorism Database of the National Consortium for the Study of Terrorism and Responses to Terrorism (START) at the University of Maryland (USA) (Global Terrorism Database 2016), during the period between 1970 and 2015

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more than 1000 terrorist acts were committed on various transport facilities. The terrorist attacks mentioned below exemplify the most noted of them:

> March 29, 2010, Moscow (Russian Federation): two terrorist acts were committed: female suicide bombers exploded two explosive devices at the stations of the Moscow metro "Lubyanka" and "Park Kultury"; forty one person killed, 88 injured (Dikanova 2010);
> March 11, 2004 Madrid (Spain): explosive devices stuffed with mails exploded practically simultaneously in 4 suburban trains arriving at the Madrid railway station Atocha during the morning rush hour, 192 people killed, 1856 people injured (Golub Golub 2007);
> July 7, 2005 London (Great Britain): suicide-terrorists almost simultaneously put into action explosive devices in three cars of metro trains on the stages between stations "Aldgate" and "Liverpool Street", "King's Cross" and "Russell Square" and near the station "Edware Road", 84 people died, over 700 people were injured (Krupnye terroristicheskie akty 2013).

The research conducted shows that the frequency of terrorist attacks on transport facilities has considerably increased since the end of the twentieth century and transport has become one of the major targets of terrorists. (Loukaitou-Sideris et al. 2006).

Major targets of terrorist attacks are metro stations, railway terminals and airports (hereinafter – Stations).

The statistics of terrorist acts at metro stations of the world exemplify the urgency of protection against terrorist attacks for Stations that resulted in 739 fatalities and 8720 injuries (Table 1).

The public transportation system appears to have become a preferred target by terrorists because of the potential for disruption, destruction, and escape of the perpetrator(s), due to its size, openness, accessibility, lack of passenger identification, and the number of people it carries (Jenkins 2001; Wilson et al. 2007). According to terrorism researcher Brian Jenkins (2004), terrorists who target transportation systems are often seeking slaughter; the percentage of terrorist attacks resulting in fatalities has been much higher for attacks on transportation than terrorism in general.

Unsatisfactory situation with the protection of Stations against terrorist acts presses for development of new scientifically substantiated approaches towards the counterterrorist proofing of Stations.

Terrorist tools

Toxic substances (TS) and explosive devices (ED) were employed as the tools for terrorist acts listed in Table 1. The percentage is shown in Fig. 1.

Explosive devices (ED) are the most common method of carrying out terrorist attacks not only in metros but also on railways (Standberg 2013). An example of this is the terrorist attack committed on the morning of 11th March 2004, when ten explosions took place in four commuter trains in Madrid, Spain (Larcher et al. 2015). This terrorist method is the most destructive compared to other methods such as armed assaults, subversive activities or arson (O'Neill et al. 2012). Bombs are relatively easy

Table 1 Terrorist acts at metro stations of the world

Year	City metro system	Terrorist tool	Injuries	Fatalities
1977	Moscow	Explosive device (ED)	37	7
1993	London	ED	29	0
19.03.1994	Baku	ED	49	14
03.07.1994	Baku	ED	42	13
15.12.1994	New York	ED	0	0
21.12.1994	New York	ED	50	0
1995	Tokyo	toxic substance (TS)	6300	13
25.07.1995	Paris	ED	117	8
06.10.1995	Paris	ED	13	0
17.10.1995	Paris	ED	30-	0
1995	Baku	ED	300	289
1996	Moscow	ED	14	4
1996	Paris	ED	92	3
1997	Tbilisi	ED	0	1
1998	Moscow	ED	3	0
2000	Moscow	ED	61	13
2000	Düsseldorf	ED	10	0
2001	Moscow	ED	20	0
2001	Montreal	TS	45	0
2002	Milan	ED	0	0
2003	Taegu	ED	150	198
06.02.2004	Moscow	ED	250	42
31.08.2004	Moscow	ED	50	10
2005	London	ED	700	54/30*
29.03.2010	Moscow	ED	76	28
29.03.2010	Moscow	ED	12	13
2011	Minsk	ED	200	15
2016	Brussels	ED	70	14

*54 died, 30 are considered lost

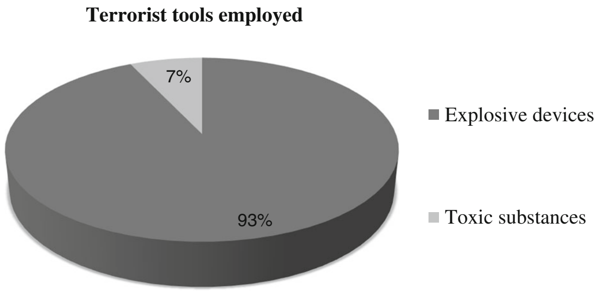


Fig. 1 Terrorist tools employed in metros

and cheap to construct, with detailed instructions on how to build various forms of explosives readily available online (Weimann 2004), and can injure enough people to overwhelm the resources in many communities (DePalma et al. 2005). We investigated the types of EDs employed in metros and ways of introducing them. The results of the investigations are described in (Shvetsov 2015c; d; Shvetsov 2016a).

Major potential terrorist threat for stations

The graph presented in Fig. 1 shows that 93% of terrorist acts were committed with EDs. This proves that potential terrorist threats committed with EDs constitute the major threat for Stations.

In the author's opinion, these threats can be combined into one major potential terrorist threat aimed at the Stations: the threat of the introduction and use of EDs.

Methods of delivering EDs to the stations

Major anti-terrorist measures aimed against EDs deployed presently at Stations are:

- inspection of incoming passengers;
- inspection of the baggage of incoming passengers.

Passengers and their baggage are inspected with special inspection security systems and the inspection is intended for detection of forbidden objects and substances including EDs (Shvetsov 2015a, b, c; d; Shvetsov 2016a, b, c, d, e, f; Muratov 2015).

However, deployed protection methods fail to take into account all available methods of delivering EDs to Stations. Author's classification of possible methods of delivering EDs is presented in Fig. 2.

Ranking of methods of ED delivery according to threat level

The classified methods of ED delivery (Fig. 2) are ranked according to the threat level in Table 2.

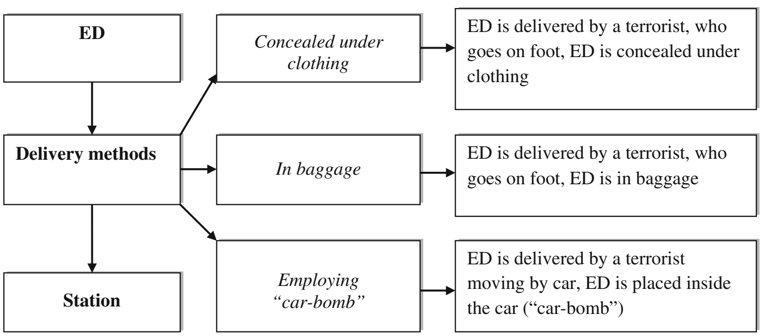


Fig. 2 Methods of delivering EDs

Table 2 Ranking of the methods of ED delivery according to the threat level

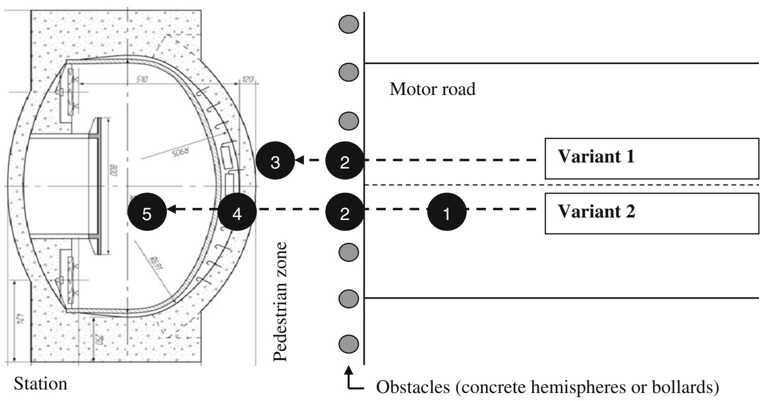
Method	Threat level	Substantiation
Concealed under clothing	2	The methods are referred to as the second threat level in connection with limitations of the weight of EDs; the weight of EDs carried by a human cannot exceed 20–30 kg.
In baggage	2	
Employing a car (“car-bomb”)	1 (the highest)	The method is referred to as the first (the highest) threat level as the weight of EDs delivered by a car (“car-bomb”) is only limited by the carrying capacity of the car used and can reach several tons (depending on the carrying capacity of the car). The explosion of an ED of such power can result in complete or partial destruction of the Station.

The analysis of the threat level of the classified methods of delivering EDs to Stations (Table 2) shows that delivery of an ED employing a car (“car-bomb”) is of the highest threat level.

Modeling a “car-bomb” terrorist attack

Analysis of the world experience of terrorist attacks resulted in a model of a “*car-bomb*” terrorist attack (Fig. 3). According to the model formed, a “car-bomb” terrorist attack can be committed in two ways:

– *the first way*, a “car-bomb” arrives at the pedestrian zone right against the entrance to the Station, then an ED is exploded;



Stages of terrorist attack:

1. “Car-bomb” starting.
2. Penetrating beyond obstacles.
3. ED explosion.
4. Ramming the entrance.
5. ED explosion.

Fig. 3 Model of “car-bomb” terrorist attack

– *the second way*, "car-bomb" penetrates beyond the barriers at high speed and rams the entrance to the Station, then an ED is exploded (Fig. 3). If the vehicle penetrates beyond the obstacles and gets into the entrance hall of the Station, the explosion occurs inside the building which substantially increases the blast effects on the building.

Stations susceptible to the threat of the "car-bomb" terrorist attacks

The threat of the "car-bomb" terrorist attacks is actual only for the Stations as follows:

- those located adjoining motor roads;
- those having no insuperable for a car obstacles on the way from the motor road to the entrance to the Station;
- those having an entrance door aperture exceeding the width and height of a car (when a second way of committing a terrorist attack is deployed).

Metro station "Prospekt Mira" (overground entrance hall in the premises of the building of engineering services of the Moscow Metro) can serve as an example of a station susceptible to a "car-bomb" terrorist act.

The research conducted by the author resulted in a corpus of data on the total number of Moscow metro station entrance halls susceptible to the threat of a "car-bomb" terrorist act, including both *first* and *second* ways of implementation. (Fig. 4).

Problems in the protection of metro stations against "car-bomb" terrorist attacks

We have examined artificial obstacles deployed for protection of Stations against "car-bomb" terrorist acts (Table 3) at the Moscow Metro Stations (similar artificial obstacles are deployed for protecting Stations in many countries of the world).

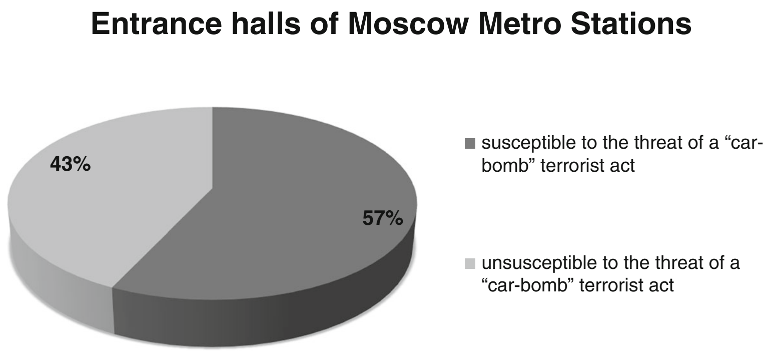


Fig. 4 The number of Moscow Metro entrance halls susceptible to the threat of a "car-bomb" terrorist act

Table 3 Protective means against “car-bomb” terrorist attacks

Method of ED delivery	ED type	Protective means	Protection ensured/partially ensured/ not ensured
“Car-bomb”	ED, placed in a car	Artificial obstacles in the form of concrete hemispheres installed near Stations Artificial obstacles in the form of steel retractable posts (bollards)	Protection partially ensured

Comparative analysis of artificial obstacles in the form of a concrete hemisphere

Comparative analysis of the overall sizes (Fig. 5) of:

- artificial obstacles implemented in the form of a concrete hemisphere (deployed at the Moscow Metro stations);
- entrance to the aboveground entrance hall of a metro station (four doors);
- and a car (Hummer H1), showed that certain models of cars are, due to their overall sizes, capable of:
- passing through above the concrete hemispheres ;
- ramming the metro station entrance.

The research results ascertained 6 models of heavy off-road vehicles (gross weight from 3200 to 5800 kg) which are, due to their overall sizes, capable of passing through above the concrete hemispheres and ramming the metro station entrance (Table 4).

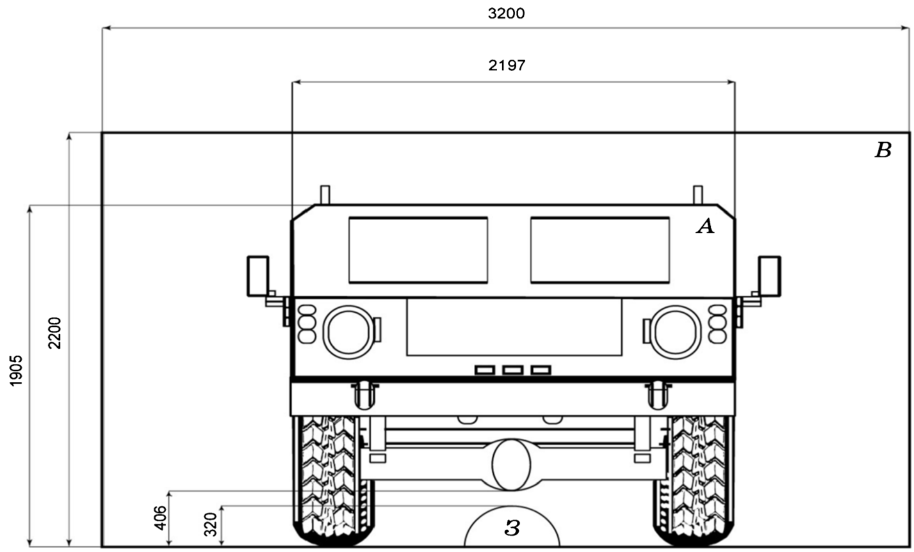


Fig. 5 Comparison of overall sizes: **a** vehicle; **b** metro station entrance; *3* obstacle

Table 4 Cars with road clearance exceeding the height of an artificial obstacle (concrete hemisphere)

Model of vehicle	Clearance (mm)	Height (mm)	Total weight (кг)
Hummer H 1	406	1905	4671
Mercedes-Benz G-class 6 × 6	460	2280*	4500
Toyota Mega Cruiser	420	2075	3780
Volvo Laplander	380	2170	4400
Uro Vamtac	452	1900	5800
Dongfeng EQ2050/2058	406	1960	3250

*the elevation of the vehicle can be reduced to 2200 mm and even lower due to the employment of non-standard wheels of a lesser height

Natural experiment testing bollards

The author(s) conducted a natural experiment testing bollards (the object of the experiment was a bollard with the following manufacturer declared specifications: collision resistance against ram hit of a 7 ton vehicle moving at the speed of 80 km/ph). The experiment conducted showed that bollards cannot stop a vehicle (Uro Vamtac model), driving at 40 km/ph equipped with a reinforced ramming bumper (Fig. 6). The reinforced ramming bumper was made of metastable austenic steel (TRIP[1]-steel) of 30X9H8M4Г2C2A (RUS) type with (ultimate) strength (σB = 250–280 kgf/mmI or kp/mmI), and was mounted on the chassis under the front bumper of the vehicle. During the bollard ramming experiment the car cut off the post of the bollard and continued its movement in the specified direction with a speed loss of 10–15%.

Conclusions from the comparative analysis and natural experiment

The comparative analysis and natural experiment conducted by the author showed the availability of vehicles (Table 4) capable of penetrating beyond deterrents (road bollards and concrete hemispheres) and eventually ramming the Station entrance. The results obtained indicate there is a problem of insufficient protection of Stations against "*car-bomb*" *terrorist attacks*.

Resolution of the problem of insufficient protection of stations against "car-bomb" terrorist attacks

In our opinion, the revealed problem can be resolved through the development and deployment of a protective device (barrier) that would guarantee blocking the unauthorized penetration of vehicles into pedestrian zones adjoining Stations.

[1] transformation induced plasticity

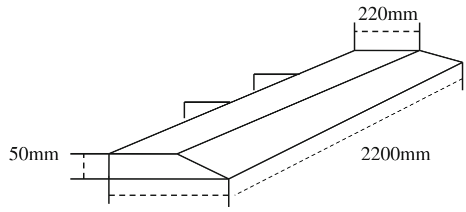


Fig. 6 Reinforced ram bumper

Design of a protective device (artificial barrier)

While designing the anti ram bollard (ARB) (patent № RU 162412) (Shvetsov 2016g) the author took into consideration the specific features of the Stations (Fig. 7.). The ARB blocks the vehicles by a retractable post. The ARB is located in places of possible penetration of vehicles into pedestrian zones adjoining the Stations.

The ARB consists of the following components: casing 1, mounted on the concrete foundation 2; the concrete foundation 2 is leveled with asphaltic-concrete covering surface 3; a blocking element consisting of cylindrical foundation 4, with a screw hole 5 in the central part and barrage pillar 6, that has a mounting hole 7 in the upper part, and in a screw element 8 in the lower part; a rubber tightening ring 9; and an installation tool (not shown in the Figure).

The ARB has the function of an energy independent raise/lower back of the barrage post. This function is necessary for emergency situations at the Station (fire, terrorist attack, etc.) to lower the ARB barrage post when the power supply is off. The post needs to be lowered to let emergency services vehicles into the entrance to the station (rescue workers, firefighters, ambulance, etc.).

The ARB is guarded against a reinforced ramming bumper (Fig. 6) by a bi-layer casing: the external layer is made of high-strength steel of the 5XHM (RUS) type (US analogue - L6 (AISI/ASTM); Germany (DIN/BOHLER) - 1.2713 55NiCrMoV 6); the internal layer is made of case-hardened steel of the 12XH3A (RUS) type (US – no analogue; Germany (DIN) - 1.5732 14NiCr10).

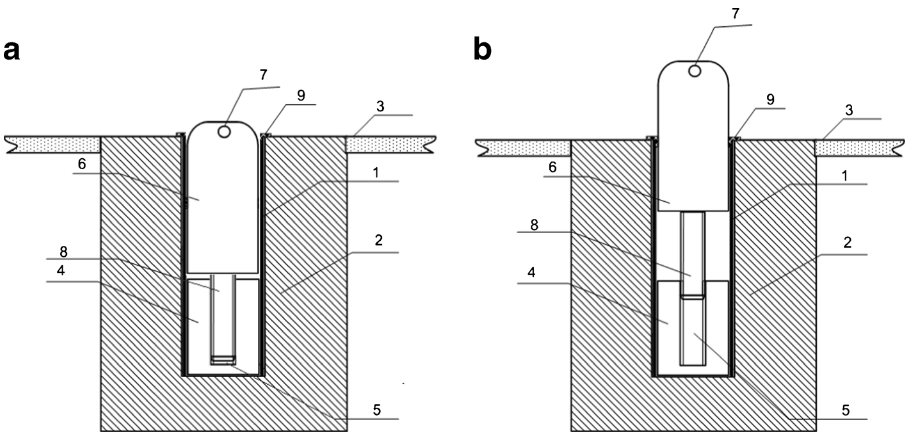


Fig. 7 Anti ram bollard: **a** deterrent post in lowered position; **b** in raised position

In order to calculate the maximum gross vehicle mass to be blocked by the ARB, the author studied the gross vehicle masses of the “car-bombs” that had been used in terrorist attacks to blow up buildings. The study showed that the maximum all-up total weight of a vehicle and ED was the one used during the terrorist act committed on August 1st 2003 in Mozdok (Russia). Terrorists used a 9 ton truck (US – medium duty Class 6) as a “car-bomb” with a 10 ton ED mounted on the vehicle (Istoriya terrora na kolesah 2016). The terrorist attack resulted in the complete destruction of the five-storey building of the military hospital.

The study showed that the maximum total mass of vehicle and ED may be 19,050 kg. In the author’s opinion the maximum total mass of a vehicle with an ED should be increased to 20,000 kg. The author considered 40 km/h as the estimated approach speed. As a result, an ARB must be capable of blocking a vehicle of up to 20 tons driving at the speed of 40 km/h and equipped with a reinforced bumper (Fig. 6).

The natural experiment (crash test) showed that the ARB designed by the author is capable of blocking a 20 ton vehicle moving at 40 km/h. The experiment was conducted by a ramming impact against an ARB by a “KamAZ” truck (total weight 20 ton) moving at 40.7 km/h and equipped with reinforced bumper. The deformation of the ARB barrage post after the impact was 137 mm in the center of percussion, and the foundation in the mounting area cracked. No other ARB deformations were observed.

After the crash test, the vehicle was seriously damaged (chassis and cab) and penetrated into the guarded territory only by the distance of the barrage post deflection value.

Blocking vehicles of a larger mass and moving at a higher speed is possible with a more dense mounting of ARBs when a “car-bomb” vehicle collides with not one but two or more ARBs.

Locating ARBs near stations

ARBs should be installed on the edge between the pedestrian zone and the motor road at the maximum distance from the entrance to the Station which in case of the explosion of a “car-bomb” will minimize the blast effects on the Station (Fig. 8):

When locating ARBs near Stations an important factor is the right selection of the proper maximum distance between the deterrents.

The maximum distance between deterrents can be determined by the formula:

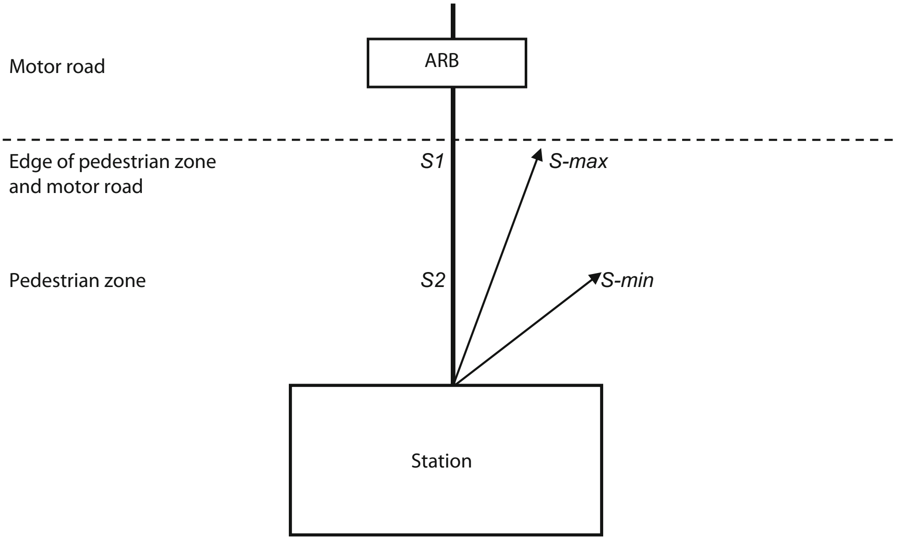
$$P = P_i – (P_i \cdot P_t) – P_{s,} \tag{1}$$

where P is the distance between ARBs;

P_i is the width of a vehicle;
P_t is the vehicle blocking reliability index;
P_s is the width of the protecting post.

Given the source data as follows:

- the width of the vehicle: 1475 mm (the width data obtained through the author’s study of the minimum overall sizes of existing vehicles) (Shvetsov 2015c; d; Shvetsov 2016a);



Key:
S-max – maximum protection level;
S-min – minimum protection level;
S1 – location of ARB on the edge between pedestrian zone and motor road on the pedestrianside;
S2 – location of ARB in the pedestrian zone.

Fig. 8 Layout of possible location of ARBs

– the vehicle blocking reliability index is 10% of the specified vehicle width;
– the width of the protecting post: 350 mm,
– the minimum distance between ARBs for calculation according to the formula (1) is 977.5 mm.

Conclusions

The research conducted has shown unsatisfactory situation with the protection of Stations against terrorist acts which, in its turn, shows urgent need for development of new scientifically substantiated approaches towards the counterterrorist proofing of Stations.

The research determined the major potential terrorist threat for Stations, namely the threat of the conveyance and use of EDs. According to the research results the "*car-bomb*" *method* of ED delivery is of the maximum threat level.

The research conducted allows the conclusion that Stations are insufficiently protected against "car-bomb" terrorist attacks.

Deployment of ARB developed by the author allows of the resolution of the problem of insufficient protection of Stations against the "car-bomb" terrorist attacks.

The resolution of this problem will prevent terrorist acts committed with "car-bombs" at Stations and as a result will rescue hundreds lives all around the world.

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