

**RISK EVALUATION OF TERRORIST ATTACKS AGAINST
CHEMICAL FACILITIES AND TRANSPORT SYSTEMS
IN URBAN AREAS**

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Abstract: Terrorist actions have increased in recent years. In the past, terrorist attacks or sabotage have been considered as a security problem but their frequency means they must also be considered from the safety point of view. A complete risk analysis must include scenarios caused by terrorist attack or sabotage. As well as chemical plants and storage facilities, characterized by the presence of large quantities of dangerous substances, also road/rail tankers used for their transport constitute potential targets. The hazard associated with transportation depends on the vulnerability of the territory. This paper focuses attention on the description of a methodology for the analysis of incidental scenarios caused by terrorist attacks in urban areas and the identification of some aspects where improvements can be made. Finally, an application of this method is illustrated. Furthermore, in order to obtain a complete risk analysis, it is necessary to take into account that, beyond substances transported, the consequences depend on the mode of attack and the characteristics of the infrastructure and territory.

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Keywords: terrorism; sabotage; transport; dangerous goods; risk analysis; accidental scenario

1. Introduction

Terrorist attacks have increased in recent years. As result of 09/11/2001, the attack to the Twin-Towers and the Pentagon, it has been considered necessary to develop and implement counter terrorist measures for all activities involving the handling and transport of dangerous substances. Particular attention must be paid to the transport of dangerous substances as the hazard may be greater than that for chemical plants because of territorial vulnerability.

There are also other meaningful events that have taken place in transport systems, in particular, the incident of the 03/11/2004 in the suburban rail system of Madrid. There were a series of explosions aboard trains and in some railway stations, with a total of 198 dead and 1,274 injured.

On the 07/07/2005, the first day of the 31st G8 Conference, three bomb explosions occurred on London Underground trains, and another bomb destroyed a bus in the city center, 56 people were killed and 700 injured in the four explosions. The attacks are the first suicide attacks in Western Europe. Some days later, on 07/21/2007, there were three small explosions on the London Underground system and on a double-decker bus. This was called as a “major incident” rather than an attack, and only minor injuries were reported. These bombs were intended to cause as much damage as the 07/07/2005 London bombs, but the explosives had deteriorated and failed to detonate. It is necessary to mention the incidental scenarios caused by terrorist attacks or sabotage during the transportation of dangerous substances. On the 07/22/2005, in Iraq, there was a very serious terrorist action, an attack caused the explosion of a road-tanker transporting gasoline, while it was parked near the Shiite Mosque of Musayyib, south of Baghdad. At least, 60 dead and 82 injured were reported. More recently, on 03/27/2007 in Tal Afar, Iraq, the explosion of two road-tankers transporting a toxic product, probably chlorine, killed 152 people and injured 347. Chlorine has been used in suicide attacks in Iraq five times. In May, a suicide truck bomb killed 50 people and injured 115 in Makhmur; in June, a

truck bomb blast on a square near to a mosque in Baghdad killed 75 people and wounded 204.

In June 2007, police found two car bombs in central London and was able to prevent their explosion. Less than 38 hours later, two men rammed a jeep into the terminal building of Glasgow airport. The three car bombs contained large amounts of propane and gasoline. The bombs were possibly meant to be an explosively-actuated incendiary devices. Such devices, more commonly called firebombs, work by using a relatively small low-intensity explosive charge to ignite a more volatile flammable material. This results in an intense, rapidly spreading fire that can quickly engulf a confined space such as a building, or a semiconfined space such as an urban area. Powerful explosively-actuated incendiary devices are extremely difficult to make, the main problem is getting the explosive charge to ignite the flammable material. In many cases, the initial explosion merely hurls the tanks or otherwise fails to puncture them or ignite the gas or it damages them to the point that the gas leaks out harmlessly. The amount of flammable gas apparently recovered in these incidents would have been sufficient to create massive fireballs, though in order for the device to reach its full explosive potential, it would have to be carefully designed with a precise mixture of fuel and air.

2. Aims

The main aim of this paper is to combine security and safety in order to study events which concern both. The topic of security is to prevent actions such as thefts, sabotage, intrusion, etc. and generally security is managed with intelligence measures, physical measures, and procedures to defend the patrimony. Safety mainly regards the risks associated with human activities (production, handling, storage, and transport of dangerous substances) and natural phenomena (earthquakes, hurricanes, etc.). In context of industrial risks, safety aims to identify and prevent all the potential undesired events due to errors or unexpected failures, causing process deviations. Thus, safety is managed with preventive and protective measures.

This work tries to determine an effective approach that allows the measurement of the possible damage due to a terrorist action during the transport of dangerous materials (safety) and give some fundamental

elements for more effective actions of prevention and protection (security) for people who have to manage such incidents. As well as chemical plants and storage facilities, characterized by the presence of large quantities of dangerous substances, also road/rail tankers used for the transport of such goods constitute a potential target; moreover, the hazard associated with transportation depends on the vulnerability of the territory. This paper focuses attention on the description of a methodology for the analysis of incidental scenarios caused by terrorist attacks and the identification of some aspects to improve. Finally, an application of this method has been shown. In order to obtain a complete risk analysis, it is necessary to take into account that, beyond substances transported, the consequences depend on the modality of the attack, the characteristic of infrastructure, and territory.

3. Risk Assessment of a Terrorist Attack

The management of the terrorism risk is very complex, it requires a systematic and structured methodology that permits an exhaustive analysis of the possible modes of attack and the definition of the vulnerability for the system concerned. The main object of this paper is to outline an approach for the analysis of incident scenarios generated from terrorist attacks in the transport of dangerous substances (Lisi *et al.*, 2007), this method will be a useful support in order to define the best actions for their prevention and mitigation.

The approach used in this paper can be summarized in the following scheme:

- Characterization of the areas considered potential targets for terrorist actions
- Definition of the characteristics of the area (manufacturing site and/or characterized by transport of dangerous substances)
- Qualitative study (identification of incidental scenarios) and
- Quantitative study of the incidental scenarios.

The first and the second phase of the method regard the census of all the information characterizing the area in which there is the potential terrorist target, such as a manufacturing site which can also be characterized by the transport of dangerous substances. These steps therefore

comprise the collection of information regarding chemical plants and the associated transport.

3.1. IDENTIFICATION OF POTENTIAL TERRORIST TARGETS

The aim of sabotage or terrorist attack is not only to create the greatest possible damage, but also to destabilize normal life. As a consequence, urban areas and critical infrastructures should be protected against terrorist actions. Generally, the sites, considered potential targets, are characterized by some strategic elements. This list shows a sufficient number of elements but it is not exhaustive:

- Public buildings
- Areas with a great presence of people for particular events
- Public transport systems
- Telecommunication systems
- Public utilities, gas, water, electricity
- Areas of great commercial importance
- Areas of historical importance
- Handling and transporting activities of dangerous substances
- Chemical activities classified as major hazards.

In order to identify potential terrorist target, it is necessary to develop a methodology based on an index method. In 2003, the American Petroleum Institute and National Petrochemical & Refiners Association (API-NPRA) have developed a methodology to provide assistance by facilitating the development of sector-specific guidance on vulnerability analysis and management for critical asset protection for the chemical manufacturing, petroleum refining, and liquefied natural gas (LNG) sectors. This activity involves two key tasks for these three sectors:

1. Development of a screening to supplement the Department of Homeland Security (DHS) understanding of the assets that are important to protect against terrorist attack and to prioritize the activities.

2. Development of a standard security vulnerability analysis (SVA) framework for the analysis of consequences, vulnerabilities, and threats.
3. A second approach to the problem of the vulnerability of chemical plant to terrorist attack is described in a report by the Stör-Fall Kommission (SFK), German Hazardous Incident Commission. In view of 9/11/2001, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) requested the Hazardous Incidents Commission (SFK) to investigate the consequences arising from the new threat situation in the field of installation safety. The results of its deliberations are set out in a Guideline.

This Guideline describes the following issues:

- Proposals regarding the extent to which the safety report and the emergency plans should cater for preventing attacks and minimizing the consequences of attacks.
- Proposals on the extent to which the General Administrative Provision on the Major Accidents Ordinance, prepared by the Ministry, should take account of interference by unauthorized persons in its requirements regarding safety precautions and scenario descriptions.
- Proposals on achieving a balance between the legitimate public interest in information on the safety of industrial establishments and the potential security risks arising from such information.

In Italy, a project supported financially by the Italian Department of Civil Defence is in course, the aim of this project is the mapping of potential objects of terrorist attack in Italy. The study is carried out by the CONPRICI Consortium (CONsorzio interuniversitario per la PREVENZIONE et la Protezione dai Rischi Chimico Industriali), an association of seven Italian universities (Bologna, Messina, Politecnico di Milano, Napoli, Padova, Pisa, and Roma "La Sapienza"). The consortium is a scientific and technical consultant to the Italian Department of Civil Defence and the National Commission for the prevention of Major Hazards. The impact areas including data of population and vulnerable centers have been determined, the data has been implemented in a Geographical Information System (GIS) platform.

An evaluation of the risk of an installation against terrorist attacks, called “Attractiveness” of the target, has been carried out using a multi-criteria approach based on:

- Quantity and physical and chemical properties of dangerous substances in the site
- Characteristics of the plant and
- Vulnerability of the surroundings

Using this approach, sites at greatest risk (Highly Attractive) in Italy can be selected.

The project will have a profound and positive impact on all sectors when it is fully developed and implemented. It will help to define the facilities and operations of national and regional interest for the threat of terrorism, define standardized methods for analyzing consequences, vulnerabilities, and threats, and describe best industrial security practices. This study has provided the damage curves derived from incidental scenarios caused by terrorist attacks for the examined area. The effects map can constitute an important source of information for those have to enact specific emergency civil defence plans and also for those have to apply protection and/or mitigation measures for the exposed population.

3.2. DESCRIPTION OF INCIDENTAL SCENARIOS FROM TERRORIST ATTACKS

Recently, an approach (Lisi *et al.*, 2007) has been proposed which allows the description of the sequence of events following a terrorist action. This approach has the aim of describing the overall scenario, defining the evolution of such actions starting from the initial cause and ending with the final catastrophic event; thus, the overall scenario can be studied considering it a sequence of simple steps. The proposed approach for the analysis of accidental events from terrorist attacks is outlined in the scheme shown in Figure 1. The study of the incidental scenarios caused by sabotage or terrorist attack can be made by considering these phenomena as primary events whose consequences hit a target. The hit target generates a secondary event which is able to widely

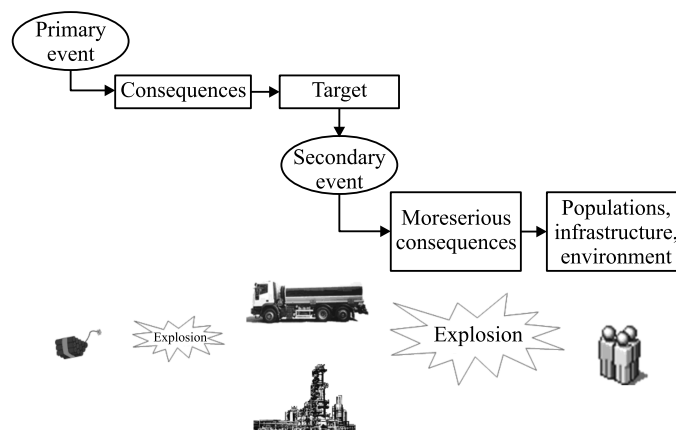


Figure 1. Evolution of terrorist actions.

spread the hazardous consequences of the first one. The primary event causes the release of a great amount of energy or toxic substances; thus, the final consequences cause serious effects to the population, infrastructure, and environment.

This approach allows the identification and characterization of the incidental scenarios due to terrorist attacks that is fundamental for the successive phase of the work in which the emergency measures will be identified. These measures must be developed on the basis of the type of incident and the magnitude of the risk.

3.3. QUANTITATIVE RISK ANALYSIS

Quantitative risk analysis including terrorist actions can be executed using the classical procedure adopted for chemical plants and the transport of dangerous goods (Advisory Committee on Dangerous Substances, 1991; CCPS, 1995); furthermore, this methodology must take into account also the scenarios caused by terrorist attacks and therefore, it must quantify the increased risk due to this type of event. This methodology must include the following phases:

- Frequency evaluation for the primary event
- Frequency evaluation for the overall scenario and
- Consequences evaluation for the overall scenario.

Taking advantage of the approach proposed in the previous paragraph the quantitative risk analysis can be simply executed.

3.4. FREQUENCY EVALUATION

The frequency evaluation involves the following phases: first, the frequency of the primary event should be estimated using data regarding this kind of event; then, it should be necessary to calculate the probability of success of the terrorist action and, thus, the frequency of the overall scenario could be defined according to the probability theory. Frequency evaluation is important because the phase of prevention is related to the determination of the likelihood that such events occur. Unfortunately, at present, these are still difficult to estimate, this represents a limit of the proposed approach (Lisi *et al.*, 2007). As described above, the main problem is data collection regarding incidents caused by terrorist attacks to evaluate their frequency. Due to the complexity, of phenomenon, in terms of target type and geography of the areas, it appears to be very difficult to use classical safety methodologies and new techniques such as neural networks, fuzzy logic, etc. for this purpose.

A much more effective approach could be the definition of probability classes for the primary event relatively to the targets. Probability classes could be obtained on the basis of the available data, collected using governmental databases. Such classification, written up as tables, can be used together with the results of the consequences analysis of the incidental scenarios and would allow to define an index of risk. This index could be useful in the phases of emergency planning and location of the protection measures for the possible targets.

3.5. CONSEQUENCE ANALYSIS

The consequence analysis aims to quantify the negative impacts of the likely events, the consequences are normally determined in terms of the number of fatalities, although they could also be measured in terms of the number of injuries or the value of the property changed. The consequences estimation is necessary only for the secondary events because their effects are more severe compared to those due to the primary event.

The consequences estimation consists in the identification of the damage zones. The effects of the incidental events on the territory decrease in magnitude with increasing distance from the point of origin, based on the type of effects the territory is divided into the following zones:

- **“Zone of sure impact” (RED ZONE):** characterized by a high percentage of human fatalities.
- **“Damage Zone” (ORANGE ZONE):** characterized by possible serious and irreversible damage for people who do not take correct measures of self-protection.
- **“Attention Zone” (YELLOW ZONE):** characterized by light damage also to vulnerable subjects and destabilization of normal life.

4. Case Study

The proposed methodology has been applied to a real but anonymous area. It is an urban area of high density of population, with a number of vulnerability centers distributed along the main road routes. Chemical plants and storage tanks are not present in this area, however, a large number of road-tankers transporting dangerous substances across the downtown; for this reason, the area is characterized by high level of risk.

The route under investigation is the connection between the main urban road and the highway exit; approximately, the traffic flow is 1,200 vehicles/ hour, this meaningfully increases the number of subjects exposed to potential incident scenarios. The high population density, the characteristics of the route (steep slopes), the presence of a great number of centers of vulnerability distributed along the route are some of the factors that make this area a potential target for terrorist attack.

4.1. IDENTIFICATION OF CRITICAL AREAS AND SCENARIOS DUE TO TERRORIST ACTIONS

The identification of the critical areas for terrorist actions can be made on the basis of a census of the substances and the targets.

- **Census of the substances** obtained on the basis of the type of hazard and of the quantities of dangerous products present in chemical plants, storage, and transport; it is possible to identify the worst substances that could be involved in an attack.
- **Census of the targets** obtained on the basis of the dangerous substances, the quantities, the operating conditions, and the territorial vulnerability, it is possible to identify all potential targets.

In order to mitigate the effects of the incidental scenarios, it is necessary to define the damage zones and to produce a map of the effects. In this study, attention has been focused on two types of incidents, toxic dispersion and explosion, since these can be considered the most catastrophic events.

According the census of dangerous substances and of targets, the critical areas are localized as shown in Figure 2. In this paper, the study has been focused on the study of the releases of chlorine and liquid fuels. The damage zones have been identified using the threshold values of Table 1 and are shown in Figure 3 and Figure 4.

The damage maps, supported by GIS tools, can constitute an important source of information to develop specific emergency plans.

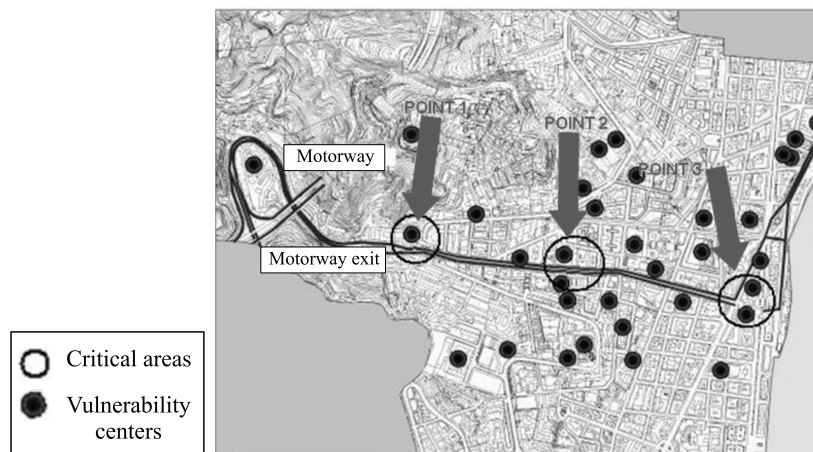


Figure 2. Critical areas and localization of potential incidents.

On the basis of the threshold value of Table 1, Table 2 shows the number of vulnerable centers and people involved in a potential incident for each critical point identified above.

TABLE 1. Threshold values and damage zones

	Zone I (Zone of sure impact)	Zone II (Damage zone)	Zone III (Attention zone)
Concentration	$C \geq LC50$	$IDLH \leq C < LC50$	$C < IDLH$
Chlorine (dispersion)	High fatalities	Irreversible damage	No damage or light
Overpressure	$\Delta p \geq 0.3$ bar	$0.07 \leq \Delta p < 0.3$ bar	$\Delta p < 0.07$ bar
Liquid fuels (VCE)	High fatalities, structural damage	Fatalities and serious damage	No effects

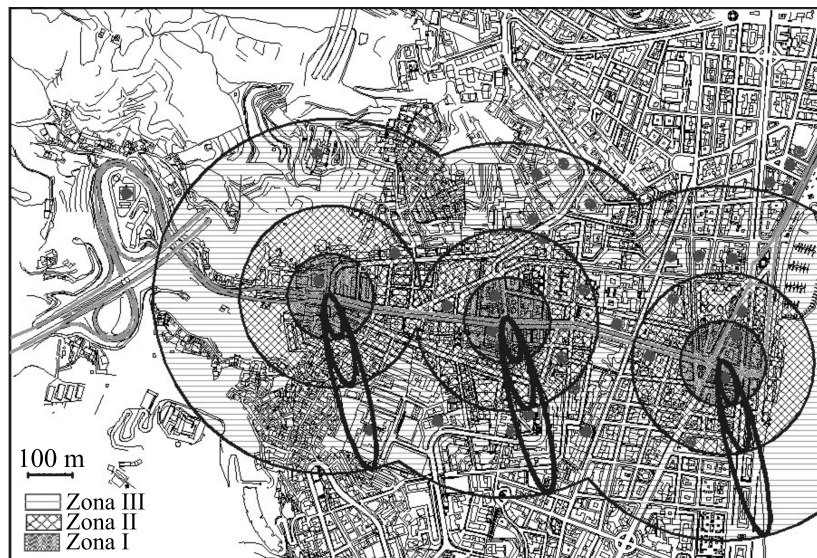


Figure 3. Effects of a catastrophic release of chlorine.

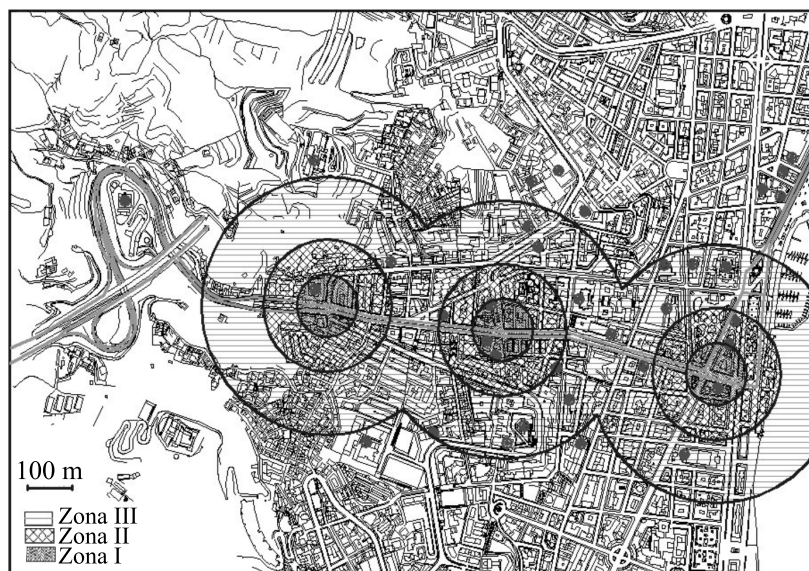


Figure 4. Effects of a catastrophic release of liquid fuels.

TABLE 2. Number of vulnerable centres and people involved (fatalities and injuries) in a potential incident.

	Point 1	Point 2	Point 3
Chlorine toxic dispersion	8 vulnerable centers 17,997 people	22 vulnerable centers 25,179 people	13 vulnerable centers 9,852 people
Liquid fuels VCE	2 vulnerable centers 8,948 people	12 vulnerable centers 12,378 people	6 vulnerable centers 1,551 people

4.2. GIS TOOL FOR EMERGENCY MANAGEMENT

The damage map can constitute an important source of information to develop specific emergency civil defence plans and to apply protection and/or mitigation measures for the exposed population. A very efficient tool is represented by the implementation of the map of the consequences on a GIS platform. Two examples of this kind of application are reported.

Figure 5 shows the scheme of car bomb containing propane and gasoline similar to those found in central London in June 2007.

Figure 6 shows the results of a simulation of the consequence of a fireball generated by the car bombs in the case of complete success of the event. The map of the consequences of the attack is shown in Figure 7. The circle represents the area in which a high probability of fatalities is observed. The GIS interface permits an immediate visualization of the target area including the presence of vulnerable centers.

Using a GIS tool developed in our laboratory, it is possible to have a dynamic description of the time evolution of the plume generated by the incident and as a consequence the determination of damage area as

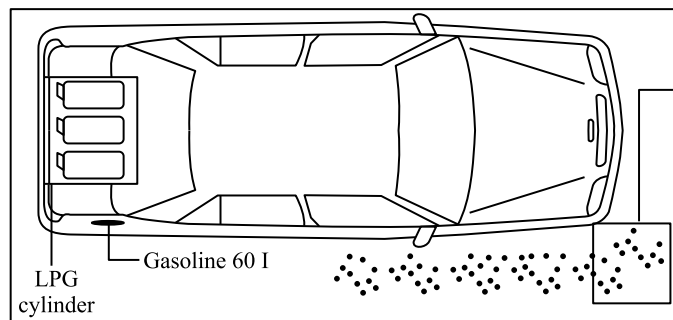


Figure 5. Scheme of a car bomb.

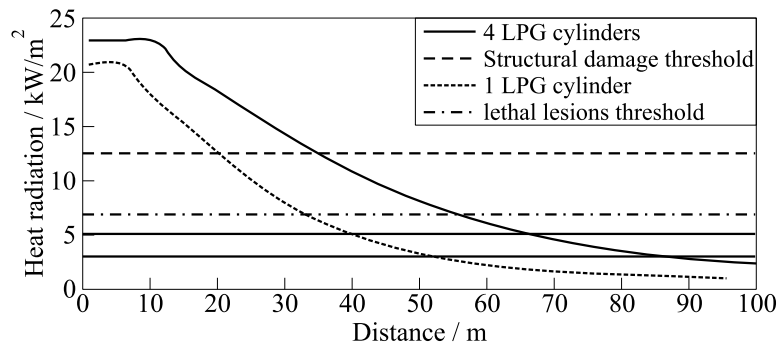


Figure 6. Consequence of a fireball generated by the car bomb.

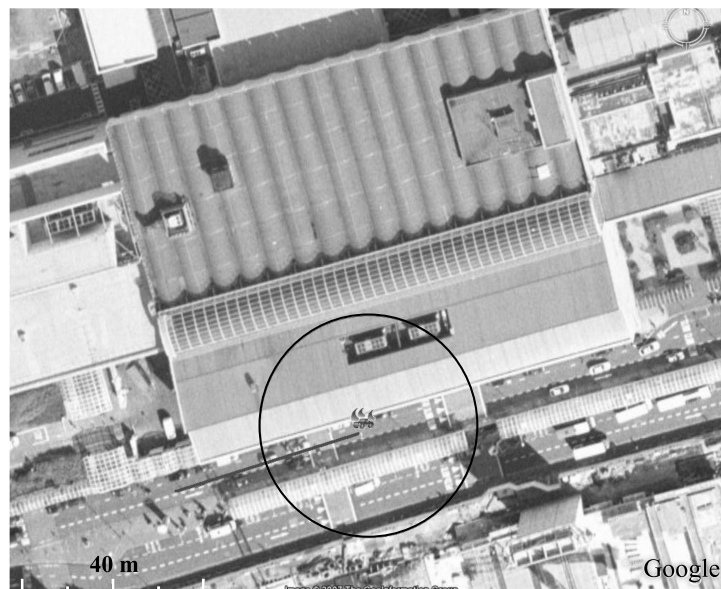


Figure 7. Map of the consequences of the attack.

a function of time. This kind of dynamic effects map can constitute an important source of information for those who have to enact specific emergency civil defence plans and, moreover, also for those who have to apply protection and/or mitigation measures for the exposed population. Figure 8 shows an image of the dynamic simulation of a catastrophic release of chlorine due to the explosion of a road tanker in an urban area.

5. Concluding Remarks

The problem considered in this paper is of great interest, because in recent years, the areas susceptible to terrorist attacks have been widening. The methodology applied in this work has the aim of outlining the scenario associated with a terrorist attack or sabotage. The case study is a city characterized by the transport of large quantities of hazardous materials. Even if it may not be the principal object of a terrorist attack, this kind of city has all the characteristics of a potential target in terms



Figure 8. An image of the dynamic simulation.

of territorial vulnerability. The high number of road and rail tankers transporting dangerous substances in the urban area and the presence of numerous vulnerable centers along the main transportation routes are typical of areas subject to terrorist attacks.

This study has provided the damage curves that would derive from incidental scenarios caused by terrorist attacks for the examined area. The effects map can constitute an important source of information for those who have to enact specific emergency plans of civil defence and, moreover, also for those who have to apply protection and/or mitigation measures for the exposed population. The damage curves also allow considerations to be made regarding possible alternatives in the transport of dangerous substances using different routes at different times of the day.

In particular in this study, the continuous monitoring of road/rail tankers and the typologies of substances crossing the urban areas has been suggested. This is possible using appropriate control systems located at the motorway exits and the ferry terminals or at critical points along the main routes used for the transport of dangerous goods.

Finally, emergency plans must be updated and performed taking into account the vulnerability of the territory and they must include the

definition of services, procedures, and emergency resources. Emergency plans have to be periodically tested in order to verify their validity.

The methodology applied needs to be implemented in order to improve the use of safety methodology also for security problems. In this work, the definition of probability classes for the primary event relative to the targets has been proposed. Combined with the consequences results, this permits the identification of risk indices. These indices could be useful in emergency planning and for the location of the protection measures for the possible targets.

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