TOWARDS RISK ASSESSMENT OF CRITICAL INFRASTRUCTURES: EXPERIENCES GAINED FROM QUASI REAL-TIME VULNERABILITY ASSESSMENT OF THE TRANSPORTATION OF DANGEROUS SUBSTANCES BY ROAD.

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ABSTRACT

Past and recent terrorist attacks have put into question the vulnerability of our society to the terrorist threat. The European citizen has questioned the ability of the Institutions to ensure an adequate and balanced level of security over the territory. In October 2004, the European Commission, prompted by the European Council and an increasing public concern over security, issued a communication on “Critical Infrastructure Protection in the Fight against Terrorism” to undertake a challenging European Programme to Protect Critical Infrastructures and other European key assets against the threat posed by terrorism and other negative intentional acts, in close cooperation with Member States and other stakeholders [1].

But as not all infrastructures can be protected from all threats, harmonized methods, inspired by risk management techniques, are needed to address, in a single comprehensive security management model, the existing and emerging threats to critical infrastructures, their vulnerability and criticality, and the defense layers and other cost-effective protective measures that can be implemented.
This paper highlights the aspects to address in order to apply risk analysis techniques to the analysis of social vulnerability against critical infrastructure disruptions. In particular, it reports on the experience gained during the implementation of SIMAGE–Transportation Pilot system [2]. Notably, the Transport sector is one category of Critical Infrastructure that has been repeatedly the target of terrorist actions. Consequently, Transport has to guarantee an elevated level of protection and security. Moreover, it is especially important for the case of the transport of dangerous substances, where the nature of the shipment can be exploited by terrorists to disrupt or destroy other critical infrastructures.

1.0 INTRODUCTION

Some infrastructures are considered critical because they are providing vital services and support to societies. Such infrastructure can be damaged, destroyed or disrupted by deliberate acts of terrorism, natural disaster, negligence, accidents or computer hacking, criminal activity and malicious behaviour. This is the incipit of the Green Paper issued by European Commission in November 2005 [1]. The scope of the Green Paper was to define the role of the Commission with respect to establishment of European Programme to Protect Critical Infrastructures. This Program aims at ensuring that there are adequate levels of protective security on critical infrastructure, minimal single points of failure and rapid, tested recovery arrangements throughout the Union.

The risk analysis approach is a valuable method for supporting the analysis of critical infrastructures it is paramount that the assessment of the consequences of their failure/disruption takes into account the direct effect in the infrastructures as well as other coupled infrastructures and in the society at large. This paper aims also to show how information technology can provide the necessary data to support the protection of critical infrastructures.

During the past years we have tested the capability of number of information and communication technologies (ITC) to develop monitoring system, possibly working in real time, to support risk management of dangerous goods transportation.

In the first part of this paper the key elements that need to be defined in order to characterize a critical infrastructure will be illustrated.

The second part of the paper will report the results of a 3-year development and testing of a pilot system that monitors in real time the transport of hazardous substance by road in Italy (SIMAGE – Transportation Project) and the experience gained in order to highlight the advantages and the bottlenecks of such an approach for the protection of critical infrastructures. The implementation and the initial results of this project have already been presented at previous VGR conferences; this paper will focus only on further potential developments [2, 3, 4, 5].

2.0 CRITICAL INFRASTRUCTURE

Critical Infrastructures are systems or networks or supply chains that support the delivery of an essential product or service [1]. Many other definitions of Critical infrastructures may be found in the literature.[e.g. 6, 7, 8, 9] Essentially an infrastructure can considered as an integrated socio-technical system. More difficult is the interpretation of the concept of criticality. [e.g. 8, 9, 10]. If, on the one hand, it is rather clear and intuitive what is an infrastructure, on the other hand, it is unclear to define why some infrastructures should be considered critical. The etymological root of "critical" is linked to the term of "crisis" referring to a "change of state of a system" which implies a time of great difficulty or danger. Most often, the definition of critical infrastructures has been elaborated in the context of critical infrastructure protection [7]. Reviewing world-wide critical infrastructure protection activities, Ritter and Weber state that "the definitions of critical infrastructures in different countries are as diverse as the concepts of infrastructure protection that have been developed in those countries" [11]. Therefore, the notion of "critical infrastructure" that emerges from a technical scientific context is coloured with socio-political attributes [8]. With this view, an infrastructure can be considered critical because it affects areas of vital sustainable social life.

2.1 The role of risk analysis on Critical Infrastructures protection

Past and recent terrorist attacks have put into question the vulnerability of our society to the terrorist threat. The European citizen has questioned the ability of the Institutions to ensure an adequate and balanced level of security over the territory. Given the importance of their reliable and secure operations, understanding the behaviour of infrastructures – particularly when stressed or under attack - is crucial for modern societies. According to a theoretical approach, the analysis of criticality of infrastructures can be made referring to risk analysis methodology. Kaplan and Garrick argued that when one asks: "What is the risk? One is really asking three questions [13]:

- What can happen?
- What is the likelihood of it happening?
- If it does happen, what are the consequences?

The application of this approach to infrastructures is complex, considering that the failure of these infrastructures can cause extensive consequences for populations and upon socio-economic activities. To a certain extent, the first two questions can be easily investigated even for critical infrastructures [14, 15]. Regarding the third question, it is extremely complicated to assess what can be the consequences due to the interdependent nature of these systems. Effectively, lifeline infrastructures are generally characterised by strong interrelations, which favours the propagation of vulnerabilities from one system to another through cascading effects. [16, 17, 18]

Interdependency effects occur when an infrastructure disruption spreads beyond itself to cause appreciable impacts on other infrastructures, which in turn cause more effects on still other infrastructures. When an infrastructure system suffers an outage, it is often possible to estimate the impact of that outage on service delivery (direct effects). However, that outage may also diminish the ability of the infrastructure to deliver the level of services that they normally provide.

Considering the multitude of effects that an infrastructure failure can generate, it becomes rather difficult to assess scenario's using top-down conventional mathematical theories (e.g. PRA) [9, 14, 15]. This difficulty is manly due to the evaluation of the interdependency of overall infrastructures and to the assessment of impacts to societies.

Therefore, it is required to consider the effects of interdependencies among networks and systems that constitute potential targets. In the literature four different types of interdependency have been suggested:

- **Physical interdependency** – two infrastructures are interdependent because the exchange material or energy and the status of one is related to status of the other one.
- **Cyber interdependency** – two infrastructures are interdependent because the exchange information.
- **Geographical interdependency** – two infrastructures are interdependent because the geographical proximity.
- **Logical interdependency** – two infrastructures are logical interdependent if the state of each infrastructure is not one of the type mentioned above. (e.g. policy and regulatory activities).

The Table 1 reports some of the methodology and techniques that can be used to simulate interdependency.

It could be argued that considering the different ways of propagation of impacts of an infrastructure failure, a society can be exposed to different types of impacts. For such reason the typical risk analysis methods can be adapted in order to assess the criticality of a complex system but it can not be used to quantify impacts on societies. Risk analysis methods typically measure the morbidity, but other effects such as for example economical loss or political instability can be considered more relevant to a society. Apostolakis, on the base of Multi-attribute Utility Theory, suggested evaluating the expected disutility as basis for ranking the infrastructure elements [9]. It could be argued that disutility for a civil community can be multifaceted and it must reflect the perception and preferences of stakeholders. In these terms the availability and the integration of multi-source information is a crucial issue.

Decision-making processes for managing and defining policies related to the protection of infrastructure is still in early stage but becoming more and more relevant in the agenda of politicians. Raising public concerns on social infrastructure role requests public authorities to collect more accurate information. Unfortunately, this multifaceted information is spread throughout multiple repositories. Thus, there is a need to integrate the available information within a structured network and to design a decision support system suitable for helping decision makers in defining protection policies. The successful integration of disparate pieces of information into a coherent risk assessment requires the evaluation of the validity or truth of the data elements used in the assessment. More and more IT capabilities help infrastructure managers to control the functionality of system but the available information is not coherent with a risk management approach.

Table 1: some methodologies to analyse interdependent Critical infrastructures [10]

Methodology	Description
Aggregate supply and demand tools	This category of tools evaluates the total demand for infrastructures services in a region and the ability to supply those services. Multiple infrastructures can be linked by their demand for commodities or services provided by other infrastructures and the ability of those infrastructures to satisfy demands. The ability of an infrastructure to meet its instantaneous or forecast demands can provide an indication of its health or early warning of potential problems (e.g. the inability to meet demand in multiple infrastructures). Prototype models exist, allowing what-if analyses, so that the consequences and cascading effects of the loss of additional infrastructure assets can be determined in terms of aggregate supply and demand.
Dynamic simulations	Dynamic simulations are employed to examine infrastructures operations, the effects of disruptions, and the associated downstream consequences. The generation, distribution, and consumption of infrastructure commodities and services can be viewed as flows and accumulations in the context of dynamic simulation. Interdependencies among infrastructures are readily incorporated into system dynamics models as flows of infrastructure commodities among multiple infrastructures. Moreover dynamic simulations can examine the effects of policies regulations and laws upon infrastructure operations.
Agent-based models	They have been used in a wide spectrum of interdependency and infrastructure analyses. Physical components of infrastructures can be readily modelled as agents, allowing

	analyses of the operational characteristics and physical states of infrastructures. Agents can also model decision and policy makers involved with infrastructure operations, markets and consumers (firms, households…). Agent-based models of supply chains allow examining the consequences of the losses of infrastructure services upon manufacturing supply chains. These micro economic analyses have enabled to examine how infrastructure disruptions affect firms, their relative ability to compete during disruptions, and the effects of infrastructure related policies on the ability of firms to survive disruptions.
Physics-based models	Physical aspects of infrastructures can be analysed with standard engineering techniques. For example, power flow and stability analyses can be performed on electric power grids and hydraulic analyses can be used with pipeline systems. These models can provide highly detailed information down to the individual component level, on the operational state of the infrastructures. These techniques have been applied to interdependent energy infrastructures examining issues such as outages areas associated with single and multiple contingencies.
Population mobility models	It evaluates the movement of entities through urban regions. Entities interact with one another, generating and consuming infrastructure commodities in the process. For example the entities may be people following their daily routines in a city. By generating and simulating these routines, a population mobility model can determine the use of multimodal transportation assets and assist with urban transportation or evacuation planning. An important characteristic is that these models develop detailed insights into social networks which can be critical for certain types of studies such as epidemiology. Population mobility models have been used for extremely high resolution and fidelity urban interdependency studies of multimodal transportation, electrical power grids, wireless telecommunications, and epidemiology
Leontief input-output models	Leontief's model of economic flows can be applied to infrastructure studies. The basic model provides a linear, aggregated, time-independent analysis of the generation, flow and consumption of various commodities among infrastructure sectors. This model has been extended to include nonlinearities and time dependencies and applied to examine the spreading of risk among interdependent infrastructures.

3.0 EXAMPLE – TRANSPORTATION OF DANGEORUOS GOODS

Transportation networks like for instance, motorways and inter-regional main roads are some of the main infrastructures of modern society. Considering the key role of such infrastructure and the related socio-economical implications for societies, a lot of attention is been paid to evaluating the vulnerability of these networks, but less knowledge is available about the consequences of hazardous events like any major accident or perturbation of connectivity between different regions.

Moreover, as one category of critical infrastructures, the surface transport sector has been repeatedly the target of terrorist actions. Consequently, Surface Transport has to guarantee an elevated level of protection and security for the transported passenger and shipment, – the latter being especially important in the case of the transport of dangerous substances, where the nature of the shipment can be exploited by terrorists to disrupt or destroy other targets. To improve their protection and security, Surface Transport, with its different services and modes, can benefit from the convergence and emergence of new technologies (such as Galileo, low-cost mobile data communication and video surveillance).

Sometimes the transportation network passes through highly populated areas, so that, in case of an accidental spill, a large number of persons could be affected. Even if the probability of a major spill during transport is very slight, some accidents with major consequences on population have shown that the risks related to the hazardous materials transportation can be of the same magnitude of those arising from fixed installations, like process and storage plants [20, 21, 22]. This means that also areas which are only crossed by transportation routes, without having plants nearby, can be exposed to high risk values.

Moreover the damage caused by an accident involving dangerous substance transport can affect people, natural resources, the environment and other infrastructure in the vicinity of the accident.. This is especially true since the new trend is to build the so called “infrastructure highways” where all these facilities are very close to each other.

3.1 State of the art of risk analysis in the field of transportation of dangerous goods

Risk assessment is typically structured as a process resulting from the integration of information of the following three types [23, 24]:

a) Transportation Network that can be considered as a composition of links and nodes. The ‘link properties’ to take into account for each link are its geographical position in the impact area, the amount of the yearly shipments for each substance, the accidental frequency. The accident frequency variable is generally function of both the link features and the traffic conditions.

b) Vehicle or travelling risk source characterisation consists firstly of the estimation of the release probability which is the (conditional) probability of a spill or leakage given an accident; this parameter is usually assumed to depend only on the vehicle construction standards and not on the link, but SIMAGE Transport Pilot system data could be used to determine whether this assumption is correct or if it can depend also upon the vehicle speed (and indirectly upon the link itself). Another required information is the transport conditions for each substance, i.e. the temperature and pressure values and the road tanker capacity. Finally some reasonable hypothesis on a quantified event tree after the release should be made. It appears more complex to use additional information given by he monitoring system to improve these part of the analysis.

c) Impact area has to be defined through meteorological data, other parameters (average terrain roughness; the terrain typology, and so on) and population distribution.

Some advances in the direction of accounting also for environmental aspects related to hazardous materials transportation have also been made [25], but a comprehensive methodology is still under investigation with the aim to try to take into account especially the interdependency between transport of dangerous goods and other critical infrastructure. In particular, it is considered important to improve the emergencies services and to control the territorial risk, i.e. to characterise a region according to the distribution of the sources of hazard and its vulnerabilities. In order to reach this goal it is necessary to increase the availability of information and to improve the its interpretation.

3.2 Implementation of quasi real-time of monitoring system

In order to increase the availability of information about the dynamic distribution of dangerous substance over a region, a pilot project has developed a system for monitoring in real time, trucks transporting dangerous goods. A truck can be set up with an on-board system, which mainly acts as a communication and localization platform. Installing this system on both in the truck tractor and on the trailer, allows the recording the following data:

- Identification number of the vehicle (can be the license plate)
- Time and position of the vehicle
- Speed and direction
- Quantity of goods in the tanker (measured by a liter-meter)
- Plus other pertinent information from on-board sensors (temperature, pressure ..etc).

The data are recorded from each monitored vehicle every 15 seconds, and then they are validated, and post-processed in order to obtain suitable information for risk analysis. Moreover, as the collected data can be used either in real-time or stored (after post-processing) in a database to improve the reliability of probabilistic data needed for the quantitative risk assessment.

3.3 Evaluation of full scale application

The full scale implementation of a monitoring system of transportation of dangerous goods has some advantage and disadvantages. The system allows identifying territorial hot-spots, i.e. to highlight the region were over a certain period, there is a high frequency of hazard sources. The analysis of these areas allows defining the most relevant risk scenarios and investigating the potential impacts on people and critical infrastructures. A territorial analysis of the hot-spot gives the opportunity to analysis the regional distribution of rescue services and infrastructure, in order to plan an efficient and prompt response of the emergency services during an accident.

From a security point of view, the real time monitoring system allows the control all the movement of the trucks and signal immediately if there is any unforeseen change of route. During an emergency the system provides immediately the most relevant information for the rescue service, such as for example the exact position of the accident, the type and the quantity of the dangerous substance. Moreover, combining this information some other territorial information it allows the evaluation of the potential impact on other infrastructures (highways, harbors, chemical plant, railways, etc.)

The disadvantages of this system are essentially related to the cost of the equipment and sensors. Moreover it still necessary to define precisely who might be the end-users of the monitoring system and what are the goals and priorities of the decision-makers. If these two aspects are not set, it will difficult to define how the information collected by the monitoring system can be exploited.

Finally, it should be noted that improvement of the transportation of dangerous goods relies on the synergy with a telecommunication infrastructure. Thus it should be noted that the system becomes more complex.

4.0 CONCLUSION

The paper highlights some new challenges related to the protection of Critical Infrastructure. Many analytical techniques may be mutated from the risk analysis domain. However, there is a need to continue to discuss with all the stakeholders the policy options and technical implementations that would lead to better protected critical infrastructures and, in the long-term, to a more resilient society. The European Commission started to address these issues publishing a Green Paper, which has been discussed by Member States and stakeholders.

The protection of Critical Infrastructure leads to two major challenges:

- The increase of technical analysis required to investigate the role of critical infrastructures within modern societies, in particular for the evaluation of the multi-dimensional vulnerability of the territory against the disruption of interdependent critical infrastructures systems;

- The identification of the main stakeholders that should be involved to define a coherent strategy for Critical Infrastructure Protection and of their goals and priorities.

The experience gained in this the real-time monitoring of the transportation of dangerous substances shows that a correct application of such technologies can be technically instrumental for the protection of critical infrastructures. What remains to be asserted in the economic and political interests for such an approach.

One may argue that it is still unclear how available technologies can improve the management of critical infrastructures and how timely information can drive an efficient decision-making process during the phases of emergency planning and management. However, the real issue to address is not of a technical nature, but is socio-political. Above all, infrastructures are there to serve the society, and, conversely, the societies, or more precisely its individuals, have a perception and appraisal of the role played by such infrastructures for sustainability. Metzger raised the following question: “Is it really the infrastructures that a society needs to protect above anything else or does it actually make more sense to speak of critical services robustness or critical services sustainability rather than critical infrastructures?” [8] In other terms, is it necessary to change paradigm and to move from the analysis of the vulnerability of infrastructure to the analysis of vulnerability of societies?

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