

# Mobility Network and Safety<sup>1</sup>

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## ABSTRACT

Mobility network is crucial for ensuring territorial safety with respect to natural and technological hazards. They represent a basic support to community's everyday life although being exposed elements often characterized by high vulnerability to different hazards and, in the meanwhile, strategic equipments for emergency management. Physical damages or the lack in functioning of those networks may greatly increase the loss of human lives caused by hazardous events as well as produce relevant economic damages at medium and long term. Although the relevance of the mobility networks in assuring territorial safety is at present largely recognized, risk analyses have been long focused on buildings' vulnerability or, even where they have paid attention to mobility network, they have been mainly focused on the physical damages that a given hazard could may induce on individual elements of such network. It is recent the awareness that mobility network represents a system, characterized by relevant interdependences both among its elements and among network infrastructures and urban systems. Based on these assumptions, this paper points out the heterogeneous aspects of the mobility network vulnerability and their relevance in increasing the overall territorial or urban vulnerability to hazardous events. Therefore, an in-depth investigation of the concept of mobility network vulnerability is provided, in order to highlight the aspects mostly investigated and more recent research perspectives. Finally, a case study in the Campania Region is presented in order to point out how traditional risk analyses, generally referred to individual hazards, can sometimes led to invest in the mobility network improvement or development which, targeted to increase the security of a territory result, on the opposite, in an increase of the territorial vulnerability.

A key point to explore the relationship between mobility and security is the role of mobility network for ensuring territorial safety with respect to natural and man-made hazards. For many years, increasing the security of settled communities against hazards has represented one of the main target of the strategies addressing a sustainable urban and territorial development: a community, indeed, can be defined as sustainable and resilient when it is organized in such a way to minimize the effects of a disaster and to assure a fast process of recovery (Tobin 1999). The mobility network plays, in this context, a crucial role in that it represents one of the basic elements of the wider system of lifelines, which supply the communities with essential services for everyday life – on which health, comfort and socio-economic welfare depend – allowing in the meanwhile an effective response in case of emergency (Paton and Johnston 2006). Therefore, mobility network represents, on the one hand, exposed elements often characterized by high vulnerability levels to different hazardous events and, in the same time, strategic equipments both for everyday life of a community and for emergency management, being crucial elements to guarantee the access and the exodus from the hit areas in the immediate post event. Physical damages or failures affecting the

functioning of mobility network may increase, also significantly, the loss of human lives caused by a hazard as well as induce relevant economic damages on medium-long term too.

Besides, by shifting the attention from the mobility network itself toward the relevant flows of people and goods they generally support, the impact of a given hazard may even trigger secondary, even remarkable, events such as explosions or toxic releases: transportation means carrying dangerous substances or hazardous plants placed along the network should be directly affected by the hazard itself or by its consequences on the network.

Although the relevance of the mobility network in assuring territorial safety is nowadays largely recognized, risk analyses have been long focused on physical vulnerability of building stock; even when more attention has been paid to road infrastructures, physical damages that a given event may induce on individual elements have been mainly investigated.

It is still quite recent the awareness that mobility network represents a system, characterized by relevant interdependences: either because each element of the network is linked to all the others, or because there are several interdependences not only among the different typologies of network infrastructures, but also

among network infrastructures and urban systems. Road and railway networks, for example, should be not directly damaged by a hazard, but suffer indirect damages due to the direct ones affecting other network infrastructures, such as the electric or the sewerage ones. In the same way, inside urban areas, road and railway networks could suffer functional damages due to obstructions caused by the partial or total collapse of buildings. Starting from the above assumptions and grounding on several past disasters, in the following pages, the numerous facets of mobility network vulnerability and their influence on the vulnerability of a territorial or an urban system to hazardous events will be analyzed. Therefore, an in-depth review of the concept of vulnerability in relation to mobility network will be provided, in order to point out the most investigated aspects up to now. Finally, the last part of the paper will be focused on a case study in the Campania Region aimed at pointing out how traditional risk analyses, usually based on single hazardous events, can lead to invest into the improvement and adjustment of mobility network which, targeted to increase the security of a territory result, on the contrary, in an increase of the territorial vulnerability. The case study is part of a wider study developed by the authors within the Italian Research Project (PRIN) 2006-2008 entitled "Early Warning Systems: technical, urban planning and communication aspects".

#### **Hazardous events and mobility network: which impacts?**

The impacts of natural and technological hazards on mobility network are numerous and include not only direct physical damages to networks themselves, but also indirect or secondary damages such as loss of accessibility to hit areas, often with dramatic consequences on the rescue operations and/or economic damages at local and regional scale over long temporal span.

The most common damages, and the most investigated ones in current literature too, are the physical ones caused by different natural and, to a lesser extent, technological hazards: in particular physical damages caused by earthquakes, landslides and floods on road and railway networks.

Earthquakes may affect road networks in several ways. Very often a hit road, although damaged, still performs its purpose: in many cases, after an earthquake minor cracks appear on the road surface; such minor damages do not directly affect the road functioning but may induce faster degradation phenomena of the road quality over time, as highlighted by the Hokkaido Tohoku earthquake occurred in 2003. Nevertheless, very frequently physical damages to the road networks are so relevant that they severely affect also the functionality of the roads. Such damages, often due

to the ground shaking or to site effects, produce a total loss in road functioning, because of the physical damage to the road itself or, in some cases, to the collapse of critical elements of the network such as bridges, viaducts, tunnels. The Japanese and North-American earthquakes provide relevant examples of those types of damages. The Hokkaido Toho-Oki Earthquake occurred in 1994 caused relevant damages to road infrastructures, with relevant cracks due to local liquefaction phenomena; the Kobe earthquake in 1995 severely affected the road network, by dividing the road surface into big plates and causing the collapse of important road axes (Tung 2004).

Besides, it should be considered that road infrastructures often play a crucial role in the wider mobility system: the interruption of a road can have repercussions on the overall mobility system at both local and regional scale producing, sometimes, relevant consequences also in terms of loss of human lives.

The total or partial collapse of viaducts and bridges represents one of the most typical damage due to seismic events as highlighted by several past events: during the Northridge earthquake in California occurred in 1994, 6 bridges collapsed and 157 elements among bridges and viaducts were seriously damaged; the Loma Prieta earthquake in 1989 caused relevant damages to more than 80 road infrastructures; the earthquake occurred in Alaska in 1964 caused the collapse of the Cooper River Highway; the San Fernando earthquake in California in 1951 caused the partial destruction of the bridges on the Golden State Freeway<sup>2</sup>.

Losses in functioning of the road networks might also occur without relevant physical damages to the roads themselves, as a consequence of secondary events triggered by the earthquake or due to the obstruction of the road by debris materials. Sometimes, damages to mobility network may be due to secondary hazard, such as landslides induced by earthquakes, floods caused by breaks in not seismic-resistant dykes and embankments, fires or technological accidents. The obstruction of the roads due to triggered landslides are very frequent in mountain areas outside urban centers, whereas in the urban centers, mainly in the historical areas, one of the main problem to deal with during the emergency phase is the obstruction of numerous roads due to building collapses.

In the first case, the induced landslides, although not causing relevant damages to the road, can determine loss of functioning which can be quickly restored, as it occurred after the Miyagiken-Hokubu earthquake in Japan in 2003.

Roads interrupted by building debris are very frequent in urban areas: in these cases, damages to the road surface might be light, but consequences in terms of accessibility or efficacy of rescue activities might be very relevant. Several examples of such types of damages have been recorded in past earthquakes, even not severe

ones, which hit historic urban areas characterized by a compact morphology. This kind of urban settlements is very common in Italian cities but also in numerous other Mediterranean areas, such as Greece, or east areas such as Japan and Taiwan. Hence, relevant obstructions along the road networks due to building total or partial collapses have been largely recorded during the earthquake which has recently hit the Abruzzo Region in Italy, or in other events, such as the one occurred in 1997 in the Umbria and Marche Regions or the ones which hit Friuli (1976) and Irpinia (1980).

Apart from earthquakes, landslides, volcanic phenomena such as lava and pyroclastic flows, other hazardous phenomena, such as tsunamis, hurricanes or floods may induce relevant direct damages to the road network too. Such phenomena may cause physical damages to the road surfaces or induce obstructions which interrupt the links among different territorial areas and require relevant interventions to restore road functionality. During the 2008 flood in Piemonte, for example, relevant damages and interruptions of road networks occurred, also with the collapse of bridges and supporting walls caused by lateral erosions and mud and debris flows (Provincia di Torino 2008).

Many examples of different types of damages which may affect road networks in case of hazardous events are provided by the Katrina hurricane. The latter represents an emblematic case for showing how chains of events, being apparently "improbable", can be more frequent than it could be thought: from a "large aircraft fuel tank transported by storm surge to freeway roadside", to boats "dragged inland by storm surge until finally colliding with Interstate Highway Bridge", with the consequent closure of road for repairing the bridge that "sustained many similar collisions along its span" (Wyndham Partners 2005). When rail networks are involved, the damages caused by hazardous events are very similar to those described for the road networks, with the addition of the likely running off of the trains conveying hazardous substances. That is what happened in the dramatic accident occurred in 2009 in Viareggio (Italy), where a freight train carrying GPL went off the rails very close to the railway station, in a densely built up area where numerous buildings were located along the railroad: the explosion of the GPL spilt out the tank wagon provoked 20 dead, 50 injured people and the collapse of two buildings close to the station. Furthermore, there was the need for evacuating other buildings damaged by the explosion and consequent fire. Generally speaking, as concerns technological accident, it is possible to distinguish those occurring along the mobility network, because of the transport of hazardous materials, and those that, occurring in hazardous plants located nearby mobility network, hit elements of the networks themselves. In relation to the first typology of events, it is possible to remind, apart from the above-mentioned Viareggio disaster, the accident occurred

in San Carlos de la Rapita (Spain), in 1978, where a fireball due to the overflowing of a tanker carrying 22 tons of propylene, provoked 200 dead in a camping, or that occurred in Houston in 1976, when a tanker carrying 19 tons of ammonia fell from a height of 10m. producing a toxic cloud which killed 6 people. In Italy it can be mentioned the event of Capannori, occurred along the Firenze-Mare Highway in 1982 where 4 people died and 2 were injured because of a pile-up caused by fog<sup>3</sup> or the disaster of Casalguidi in 1985<sup>4</sup> in which 2 people died and 4 people were seriously injured.

Among the most well-known technological accidents occurred along railway networks, the one occurred in San Luis Potosi (Mexico) in 1981 – when a train went off the rails into an urban area causing the break of a rail tank carrying 100 tons of chlorine which, in turn, provoked a toxic cloud which killed 20 people – and the one occurred in Georgia (USA) in 1959 – when the break of a rail tank carrying 18 tons of GPL as a consequence of a derailment caused an explosion in a pic-nic area killing 23 people – can be mentioned.

There are also several examples of disasters caused by sea transports, like the one occurred in Bantry Bay (Ireland) in 1979, when a French oil tanker burnt during the unloading, causing the explosion of an oil terminal, in which 50 people died.

Roads and railways are not the only targets of hazardous events. Also the damages to port infrastructure and navigable channels due to seismic events are relevant, even though less investigated. Not surprisingly, the several damages to port infrastructures caused by the Kobe (1995) and the Tokachi-Oki (2003) earthquakes in Japan and the Lefkada earthquake (1999) in Greece have led to work out technical advices and guidelines for port seismic safety.

Other relevant seismic targets are the airports; in detail, whereas the main airport structures are generally built up according to high safety standards, some vulnerable elements are often located within the airports, such as control towers or fuel tanks. Other natural phenomena have also affected air mobility: it is worth mentioning, for example, the consequences of the 1944 Vesuvius' eruption, which produced damages and delays to the Anglo-American air forces or, more recently, the closure of important Sicilian airports due to the Etna eruptions in 2001 and 2007.

As already said, even if there are no important physical damages, losses in functioning of the road networks may occur, causing a reduction in the accessibility to some areas with consequent delays in rescue operations and relevant difficulties in emergency management. The Katrina hurricane showed that also in case of floods, the main problem is the evacuation of population both in alert phase – before the occurrence of the phenomenon – and in post event phase, when the mobility network is seriously damaged or completely interrupted or where, as in New Orleans, most of people depend on public transport. In New Orleans, indeed, the

evacuation plan was largely based on private cars, whereas “hundreds of thousands of residents were unable to evacuate because they lacked transportation” (Litman 2006). Also in case of earthquakes, the lack of accessibility causes relevant failures, mostly when the hazardous event involves big urban centres, like the earthquake occurred in 1980 in the Campania Region (Galderisi and Ceudech 2005).

Physical and functional damages suffered by the mobility network may also induce relevant socio-economic medium and long term consequences, involving both the block of the travels from the working places to residential areas and the freight flows to and from the hit area. Moreover, when the network infrastructures link distant places crossing the area hit by a hazardous event, the consequences of the disaster might reverberate on areas very far from the disaster core, with social and economic consequences too (systemic damages). These types of consequences have been largely stressed in relation to some disasters: in Kobe earthquake, the damages to port infrastructures, mainly due to the liquefaction of the soil, had big repercussions on the national and international trade (Kajitani et al. 2000). Also the Midwest flood in 1993 highlighted the relevance of economic damages caused by the block of port activities (Tierney et al. 1996): 5000 river cargo ships were hit and the cost of the delay in the freight traffic was estimated in several million dollars per day. An in-depth study on the economic impacts of the Northridge earthquake (Tierney 1997) has shown the importance of medium and long term damages to the economic activities and the central role that the interruption of transport networks can play (Gordon et al. 1998).

### Analyzing networks vulnerability: approaches and methods

Methods and techniques addressed at analyzing vulnerability of mobility networks have been mainly developed in the field of seismic hazard studies. Furthermore, many European research projects aimed at deepening network infrastructures vulnerability (Risk-UE, LessLoss) have been mostly focused on earthquakes too. Nevertheless, starting from the Nineties, the investigation field has been progressively widened not only in relation to the typology of the considered hazards, but also in relation to the types of vulnerability which are taken into account.

In respect to the first of the two mentioned points, first of all it is worth underlining that in the mid-Nineties, in Australia, USA and New Zealand, the methodologies used to analyze lifelines vulnerability to earthquakes were applied to investigate vulnerability toward other hazard factors, such as wind storms, floods and tsunami. In Europe, among the recent projects based on a multi-risk

approach, the following should be mentioned: the ESPON project – which, although dealing with exposure and vulnerability of mobility network, did not provide any indicators to evaluate them – and the Armonia project – which, grounding on the knowledge-base already available in scientific literature, pointed out some vulnerability indicators, both on regional and local scale, with reference both to the physical vulnerability of mobility infrastructures and to the crucial role they play in the capacity of settled communities to cope with hazardous events (*copying capacity*) (Galderisi and Menoni 2007). Moreover, even the research studies focused on individual hazard factors are more and more taking into account the impacts caused by the likely chains of hazardous events that can issue from a triggering event. An interesting study on vulnerability of transport systems to seismic events in the USA central area, questioning about the typologies of impacts that such events may cause on infrastructures, takes into account not only those directly produced by the earthquake, but also those due to all likely – natural and technological – hazards that the earthquake might cause (such as landslides or toxic releases) (Central U.S. Earthquake Consortium 2000). In respect to the second point, related to the shift of the research focus from physical to other typologies of vulnerability, the widening of the investigation field can be attributed to several factors. The first one is undoubtedly related to the widespread awareness that vulnerability analyses have a crucial role in the knowledge of the risk features of a given area.

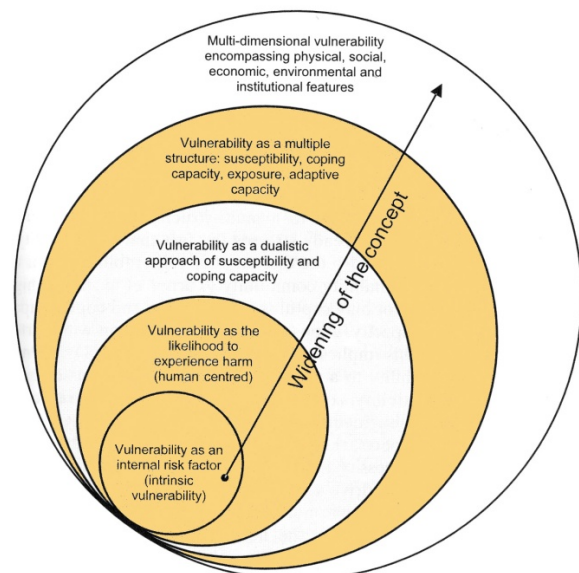


Fig.1 - The widening of vulnerability concept has largely influenced method and techniques for vulnerability analysis, shifting the focus from physical toward functional and systemic damages.

Depends on	Water Supply	Gas Supply	Sewerage	Storm Water	Mains Electricity	Standby Electricity	VHF Radio	Telephones	Roads	Rail	Air transport	Fuel Supply	Fire Fighting	Air-conditioning	Total Importance	
Water Supply	*	*	1	*	*	*	*	*	*	*	*	*	*	3	2	6
Gas Supply	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0
Sewerage	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0
Storm Water	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0
Mains Electricity	2	1	2	2	*	2	3	*	1	3	2	*	3	21	21	
Standby Electricity	3	1	3	3	*	1	3	*	3	2	*	2	21	21	21	
VHF Radio	3	3	3	2	3	*	2	2	2	3	*	3	*	26	26	
Telephones	2	1	1	*	1	1	2	*	1	1	1	2	*	13	13	
Roads	2	2	2	2	3	2	1	2	*	2	3	2	3	1	27	
Rail	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	
Air Transport	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	
Fuel Supply	3	1	1	1	*	3	1	2	3	2	3	*	3	*	23	
Fire Fighting	*	*	*	*	*	*	*	*	*	*	2	1	*	*	3	
Air-conditioning	*	*	*	2	2	*	3	*	2	*	*	*	*	*	9	
Equipment	3	3	3	2	3	3	3	3	3	3	2	3	3	3	40	
<b>Total Dependence</b>	18	12	16	12	12	11	10	18	8	11	23	10	17	11		
<b>Priority Factor</b>	24	12	16	12	33	32	36	31	35	11	23	33	20	20		

Note: 3 = High Dependence  
2 = Moderate Dependence  
1 = Low Dependence  
\* = No Dependence

Fig.2 - The acknowledgement of the interdependences among network infrastructures has driven several scholars to focus on the multiple cascade effects that the impact of a hazard on each element may trigger on all the others.

In the current international literature, it is nowadays widely acknowledged that the measurement of vulnerability features is a key step toward an effective prevention and mitigation of natural and technological risks (Birkmann 2006).

The second factor is mainly related to the widening of the vulnerability concept itself, largely due to the relevant changes in scientific paradigms in the field of vulnerability and risk analysis too which started in the Seventies. In detail, vulnerability analysis, traditionally focused on the knowledge of the vulnerability features of individual exposed elements (buildings, roads, etc.), grounding on a systemic approach, have moved their focus toward the relationships among the elements and mainly toward the behaviors of complex systems in face of hazardous events.

Although the numerous and heterogeneous meanings of vulnerability in scientific literature, it is largely shared the idea that vulnerability of an urban or a territorial system to a given hazard is something more than the sum of the vulnerability of all their elements. Finally, a further factor can be identified in the growing importance of mobility network in current socio-economic context, characterized by economic macro-regions where interdependences among cities or economic activities are due, more than to spatial contiguity, to the presence of relevant material and immaterial communication networks (Sassen 2001).

Thus, mobility network – apart from being itself a system characterized by relevant interdependences among its elements – represents the basic support to those relationships. Therefore, it can be described as a network of different networks (road network, rail network, etc.): each network is constituted by linked elements and is characterized by mutual interdependences with all the others. Hence, in case of hazardous event, damages to the road network might cause, as above mentioned, a loss of accessibility to elements of other networks, such as railway stations, airport, with relevant consequences, for example, on the distribution of first aids in the immediate post-event. Besides, mobility network represents the basic support of people, goods, freight flows both inside a given territorial context and between it and the outside. Hence, the impact of a hazardous event on the elements of the mobility network at local scale (railway stations, airports, ports, highways, etc.) might reverberate on a global scale too, according to the level of “centrality” of the hit area in the wider regional, national or global context. Those assumptions point out the complexity of the spatial dimension of vulnerability: such an aspect has been largely emphasized in the European Project “Scenario” that, grounding on qualitative-quantitative scenarios of events, impacts and damages, has explored the “systemic” component of vulnerability, often neglected in the traditional risk analyses, because of its difficult quantification and modeling. As highlighted in the mentioned Project, systemic vulnerability has to be referred to the interrelationships, or better the interdependences, among elements or systems even located very far one from the other, which may influence their capacity to adequately perform their purposes. The concept of “systemic vulnerability” has been crucial for the improvement of the networks vulnerability analyses: the awareness of the interdependences among the networks, and between them and the territorial systems they belong to, leads to move the investigation field toward concepts and topics different from physical vulnerability. At present, great attention is devoted either to the interdependences between mobility network and the other network infrastructures (electric power, gas, etc.) or, mostly in urban areas, between network infrastructures and the overall urban tissue. Due to the broadening of the vulnerability concept, new investigation categories and, accordingly, new methods have come out. Besides the most traditional analyses on physical vulnerability of individual elements of each network, vulnerability analyses are currently mainly focused on the interdependences and cascade effects between the different elements of mobility network, the elements of different network infrastructures (Moselhi et al. 2005; Paton and Johnston 2006; O'Rourke 2007; Tang and Wen 2009) and between mobility network and urban areas they cross (Goreti and Sarli 2006).

Very often, indeed, the reduced functionality of road network in the emergency phase is due more to indirect damages (total or partial collapses of buildings and consequent obstructions of the roads) than to direct damages to the network itself (Hazus 1997).

Furthermore, damages to road network, apart from representing a damage per se, may cause losses of accessibility to other strategic equipments in the emergency phase (hospitals, barracks, etc.) or may isolate some urban areas from others. The strong emphasis on interdependences inside the network infrastructures and among them and territorial contexts has driven to assign a key role, in vulnerability analysis, to the concept of redundancy, interpreted as the availability of different components within a systems playing the same role so that, in case of damages to one component, the others can continue to perform their purposes (Berdica 2002, Bruneau et al. 2003). Thus, if an element of the road network which guarantees the access to strategic equipments in emergency is damaged, the availability of alternative links or, in other words, the replaceability of such an element is crucial. In this case, although a direct damage to a single element occurs, relevant consequences, such as the potential loss of human lives due to the lack of accessibility to hospital services, can be avoided.

It is worth noting that although the concept of redundancy is very useful to analyze road or railway network vulnerability in face of localized hazardous events, it is less effective when relevant nodes of mobility network (such as airports or ports) or widespread hazards affecting numerous elements of the mobility network are at stake: "a serious snow storm may", for example, "disable all alternative routes in a large area" (Berdica 2002).

Finally, other relevant concepts that, issuing from transportation field, are more and more frequently applied in network infrastructures vulnerability analysis are those concerning "serviceability" and "reliability" (Berdica 2000, Jenelius 2009) of such networks. In detail, if vulnerability of an element or a network generally refers to the propensity of such element or network to be damaged, in the case of network infrastructures, and especially of mobility network, such a damage has to be mainly referred to the loss of usability ("serviceability") of individual elements or of the whole network in a given time span, which can also depend on obstructions of network elements that, although not being strictly as a physical damage, yet compromise the use.

In a similar way, the concept of "reliability" refers to the regular functioning of mobility network in a given time span. In case of hazardous event, such a regular functioning can be compromised, also without any physical damage to the network, because of congestion phenomena, for example, which can depend on several factors: such as network features, type of facilities served by the network, people and activities' density in the crossed areas (etc.).



Fig.3 - The case-study area within the Siano Municipality in the Campania Region. The area is characterized by a slope potentially affected by mudflows at whose base an LPG plant is located.

Finally, the growing importance of the resilience concept in the disaster field open the floor to new research perspectives. Despite the several meanings of the word resilience, according to different disciplinary fields, in the disaster field, it can be defined as "the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure" (UN/ISDR 2004). From the above assumptions, it clearly issues that the resistance of mobility infrastructure, or its more or less quick recovery to functionality in the post event phase, greatly affects the overall capacity of a community to cope with a calamitous event (O'Rourke 2007).

In particular, some scholars have suggested quantitative approaches to assess the resilience of network infrastructures, essentially based on the loss of quality/functionality of those systems and on the time necessary for their recovery (Bruneau et al. 2003).

#### **Mobility network vulnerability and territorial safety: the case of Siano in Campania Region**

Based on the above-said assumptions on mobility network vulnerability to natural and technological hazards, this paragraph focuses on the inadequacy of traditional vulnerability and risk analyses, highlighting through a case-study, how such analyses – usually referred to individual hazards neglecting both the likely synergies among different typologies of hazardous events and the likely chains of impacts and damages that those synergies can trigger – can often lead to investments on mobility network which,

originally targeted to improve territorial safety, result on the contrary in an increase of the overall vulnerability.

In detail, the case-study is the Municipality of Siano in the Campania Region: the area is periodically affected by relevant hydro geological phenomena; it is classified as seismic zone 2 by the Decree 3274/2003 and it is included in the yellow zone of the Vesuvius National Emergency Plan. Actually, the municipality of Siano, together with Sarno and Bracigliano, was severely hit by the multi-site mudflow occurred in May 1998: the phenomena affected different hill slopes, running over the settlements and causing 160 victims. After those events, warning systems linked to the monitoring of rainfall levels and the attainment of critical thresholds have been set up. Furthermore, numerous measures aimed at preventing future events and mitigating their impacts have been implemented. Those measures can be divided into four groups: structural mitigation measures on the hill slopes, recovery of the building stock, recovery of the hit facilities, recovery and improvement of network infrastructures and, mainly, of the lifelines. As the last group of measures is concerned, a main road has been built in the Siano Municipality in order to facilitate the exodus from the built-up area of Siano, escaping the built-up area of the surrounding Municipality of Castel San Giorgio. Such a road has been built on a previous route and it is located out of the "red zone", namely the area characterized by the highest hazard levels, according to the Decree 4816 of the Government Commission for Hydro Geological Emergency in Campania Region.

Therefore, since the strategic role of the road in case of emergency, the location of the road has been correctly defined according to an individual hazard factors, the hydro-geological one. Nevertheless, very close to the lifeline, a Liquefied Petroleum Gas (LPG) plant is located. The latter, according to the law in force (art.8, D. Lgs. 334/99) is classified as a plant with major potential for the quantity and the quality of handled substances. That plant covers an overall area of 6,690 sqm which, apart from a small area in the Castel San Giorgio Municipality, is mostly included in the Municipality of Siano. It is placed at the base of one of the slopes potentially affected by mudflows and is part of the "red zone" and, specifically, it is included in the sector A, where the above-said Decree, because of its high hazard levels, laid down strict rules for civil protection management and rigid limitations for future land uses.

At present, The Municipality of Siano is provided with an Interprovincial Emergency Plan – which, approved by the Decree 2586 issued in 2002, lays down the procedures for the warning, evacuating and safety sheltering the population in the risky areas – and with the Municipal Plan for Landslide Emergency, updated in 2007. Besides, in June 2006, the Prefecture of Salerno has worked out the Emergency External Plan for the LPG plant.

It should be noticed, that the likely trigger of a technological accident due to a mudflow has not been mentioned neither in the Interprovincial Plan nor in the Municipal one, both dealing only with landslides. Moreover, it is worth even noting that, following the current national legislation, the Emergency External Plan for the LPG plant defines the most probable major accident scenarios only in relation to "ordinary" conditions. Hence, it does not take into account mudflows as a likely triggering factor for technological accidents. The case study has been deepened within the Italian Research Project (PRIN) 2006-2008 entitled "Early Warning Systems: technical, urban planning and communication aspects" .

In detail the research work, focused on an area placed inside the Municipality of Siano which includes one of the slopes potentially affected by mudflows phenomena and the LPG plant, was addressed at setting up a comprehensive scenario of hazardous events, impacts and damages. In detail, the likely chains of natural hazardous events (mudflows) and technological accidents (due to the impact of a mudflow on the plant itself) and the consequences of such coupled events on the area surrounding the plant have been analysed<sup>5</sup>. Although it can be assumed that the examined chains of natural and technological (na-tech) events have a low probability of occurrence, there are numerous studies showing the constant growth, in number and severity, of coupled or chained na-tech events in the last decades. By referring to the above-considered case-study, the scenario techniques have been applied to grasp the dynamic features of hazardous events over time, the complex network of relationships between the damages suffered by some elements and the trigger of likely further hazards, the mutual influences between physical and functional damages, etc.

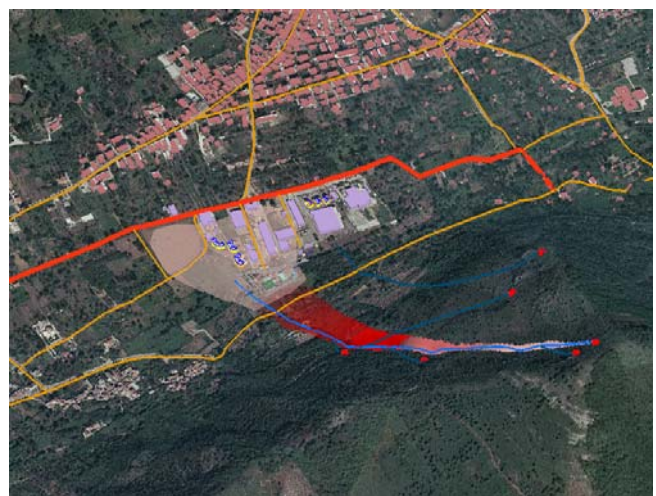


Fig.4 - Based on a 3D data animation in GIS environment a comprehensive scenario of hazards, impacts and damages has been developed.

Nevertheless, the difficulties in carrying out comprehensive scenarios are numerous, especially in the case of coupled natural and technological hazards: not only the description of such complex chains of events, impacts and damages requires indeed heterogeneous competences, but the scarce availability of data related to past events, which the necessary back-analyses should be based on, increases the uncertainties in defining the numerous and heterogeneous types of likely damages.

In order to outline the comprehensive scenario, first of all a likely hazardous event has been defined: grounding on in-depth geo-environmental investigations, the potential triggering points of the likely mudflows have been identified on the considered slope.

Moreover, according to the slope morphology and features, two typologies of likely mudflows have been singled out: the first one occurring on a plane slope; the second one that could be canalized into the gully dominating the LPG plant.

Furthermore, the temporal span which the scenario is referred to has been chosen, starting from the triggering of the mudflow to the first emergency phase.

Due to the relevant dependence of the mudflows' trigger and evolution on the morphological characteristics of the slopes, a 3D model of the site can be very useful to better understand the dynamic evolution of the phenomenon at stake, according to the local peculiarities (scarps, gullies, and so forth).

Moreover, the physical damages due to the investigated phenomena largely depend, apart from the hazard features, on the features of the exposed settlements.

Therefore, a 3D model both for site and settlement has been developed into a GIS environment, which has been arranged to support the different steps of the comprehensive scenario: from the trigger of mudflows up to the different impacts and damages due to the hazardous event.

In detail, the GIS includes different data-bases related to numerous themes, such as site morphology, buildings, population, activities and so forth. Based on these data-bases, the 3D model of site and settlement has been created.

Furthermore, the model represents also the preventative structural measures built up after the 1998 disaster along the investigated slope (e.g. drainage channels, check dams, etc.). Then, the building up of a 3D data animation in GIS environment allowed us to provide a simulation of the dynamic evolution of the mudflows starting from the selected triggering points, identifying the affected area, the involved territorial targets and the main impacts and damages due to the mudflows.

In detail, the scenario dynamic simulation shows, according to the features of the exposed targets, the likely physical damages (to buildings and infrastructures), the consequent damages to people,

the potential functional and systemic damages (loss of accessibility to emergency facilities, unemployment due to the temporary block of industries, and so on).

Besides, since among the exposed targets the LPG plant is included, physical damages to the plant as a consequence of the mudflow and the likely accident scenarios, which those damages might induce, have been identified. In detail, due to the physical damages to the plant, an immediate release of LPG (in a quantity which might vary from 200 to 600 cubic meters according to the number of the involved tanks) warehoused in the tanks located just below the hill slope. That release can produce, because of the specific morphological conditions of the site, a gas concentration until reaching the inflammability threshold: when that threshold is reached, any triggering factor may cause the explosion, involving the area surrounding the plant in which residential buildings, other industries and, above all, the main escape route within the municipal territory are located.

The explosion would cause not only the temporary lack of road serviceability but, more seriously, since such an event represents an un-expected one in the present emergency planning, it should greatly increase the damages produced by the triggering natural hazard – the mudflows – by hitting flows of people and emergency vehicles passing along the road.

As already mentioned, in fact, mudflows are a typical example of likely multi-site event, which could start firstly along one slope, bringing into action the emergency procedures, and then hit that one dominating the LPG plant.

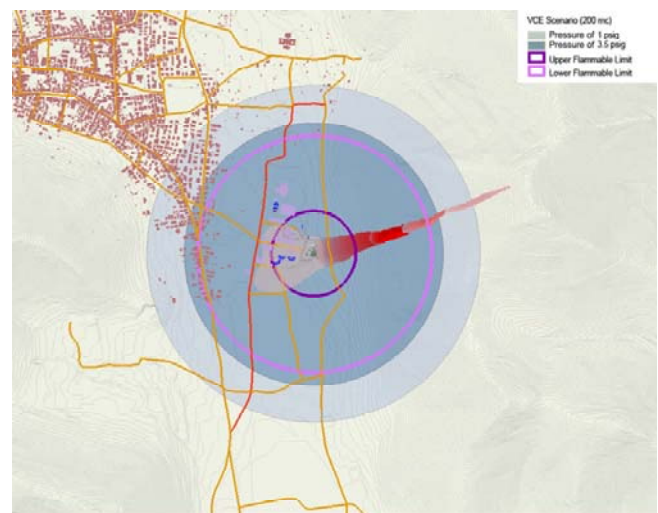


Fig.5 - The likely accident scenario due to the impact of the mudflow on the LPG plant might involve a wide area, in which not only residential buildings and other industrial activities but even the main escaping road in case of emergency are located.



Therefore, this study aims at highlighting that – since the improbability of chained events is only apparent, as the numerous examples mentioned above largely show – in order to support effective prevention and mitigation measures and mainly to improve the efficacy of the emergency management, it should be very useful to combine traditional risk analyses with comprehensive scenarios of events, impacts and damages. They represent, indeed, an essential support for a better understanding and communication of the likely dynamic evolutions and the synergies among different hazard factors and of the complex chains of consequences that each factor and their coupled effects may induce in a given time span and in a given area.

Those scenarios can be expressed both through quantitative and qualitative data: the latter, generally related to functional damages not easily quantifiable (e.g. congestion phenomena along roads) should not be undervalued. In many cases the description of such failures or troubles may help to avoid “crises”, mostly in terms of emergency management, which generally depend on the occurrence of unexpected or beyond the expected events.

#### Notes

- <sup>1</sup> Even though this paper is based on a common research work, the first, the third and the fourth paragraphs have been edited by Adriana Galderisi; the second paragraph has been edited by Andrea Ceudech.
- <sup>2</sup> Total damage was estimated in 100 million dollars.
- <sup>3</sup> In the pile-up a tanker was involved too: a fire caused a BLEVE from the petrol tank of the motor followed by a firewall, while a jet fire 10 meters long came out of the broken tank.
- <sup>4</sup> The disaster was caused by a tanker which ran into a building. The collision induced the break of a valve from which GPL come out and vaporized inside the building causing an explosion.
- <sup>5</sup> The scenario was carried out by a multidisciplinary research group constituted, apart from the authors, by the prof. Franco Ortolani, for the geological aspects, and by the prof. Davide Manca for the likely industrial accident scenarios due to the mudflow.

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### Images References

Fig.1: source Birkmann, 2006; Fig. 2: source: Paton and Johnston, 2006; Figs 3-5: elaborations of the authors.