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Vulnerability and Resilience of the Territory Concerning Risk of Dangerous Goods Transportation (DGT): Proposal of a Spatial Model

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Each year millions of tons of Dangerous Goods are transported between France and Italy using especially road and rail transportation systems. These DGT cross the territories that gather dense urbanized places, critical infrastructures (highways, tunnels, bridges etc.) and organizations (hospitals, police and firemen centres, rail stations etc.), and protected areas (national, regional and departmental natural reserves and parks). According to the definitions of vulnerability and resilience, the authors propose a spatial model based on two indices in order to characterize the level of vulnerability and resilience of the territory induced by the DGT. Those two indices are implemented into a Geographical Information System (GIS) in order to define a Spatial Decision Support System (SDSS) dedicated to the decision-makers (infrastructures managers, public authorities and transport companies). As a conclusion, the authors discuss the levels of vulnerability and resilience of the territory according to the different kind of transportation systems, i.e. rail and road in order to underline recommendations for DGT planning.

1. DGT and risk for the territory

Dangerous Goods Transportation (DGT) is a crucial activity that participates to the development of industry and the use of transport means. The main transportation means for dangerous goods are the transportation by road and by rail (Eurostat web site). The role of DGT in our economy is significant but, in another hand, this activity carries risks for the territories crossed by such transports has it is mentioned by different technological accidents databases like ARIA in France.

If major accidents of DGT remain rare, their consequences are usually severe: many victims, damages on the environment and infrastructures, and economic loss.

Risks associated with DGT raise many questions about their probability of occurrence, their potential consequences and the vulnerability and resilience of territories crossed by DGT. The need to assess the territorial vulnerability and resilience seems essential in order to manage the territory and the afferent risks generated by DGT.

The main goal of the SECTRAM project is the development of common logistics solutions to improve the security services and transport infrastructures at interregional levels. It is a collaborative effort between ARMINES, University of Genoa, Operating Group of Fréjus Tunnel and the Liguria Region. In this frame and starting form the definitions of vulnerability and resilience, the authors developed a spatial model based on two indices in order to characterize the level of vulnerability and of resilience of the territory induced by the DGT in the considered transborder area (figure 1). The implementation of such indices into a Geographical Information System (GIS) give maps of vulnerability and resilience that can be used by decision-makers in order to support theirs activities on territorial management, risk prevention and crisis management.

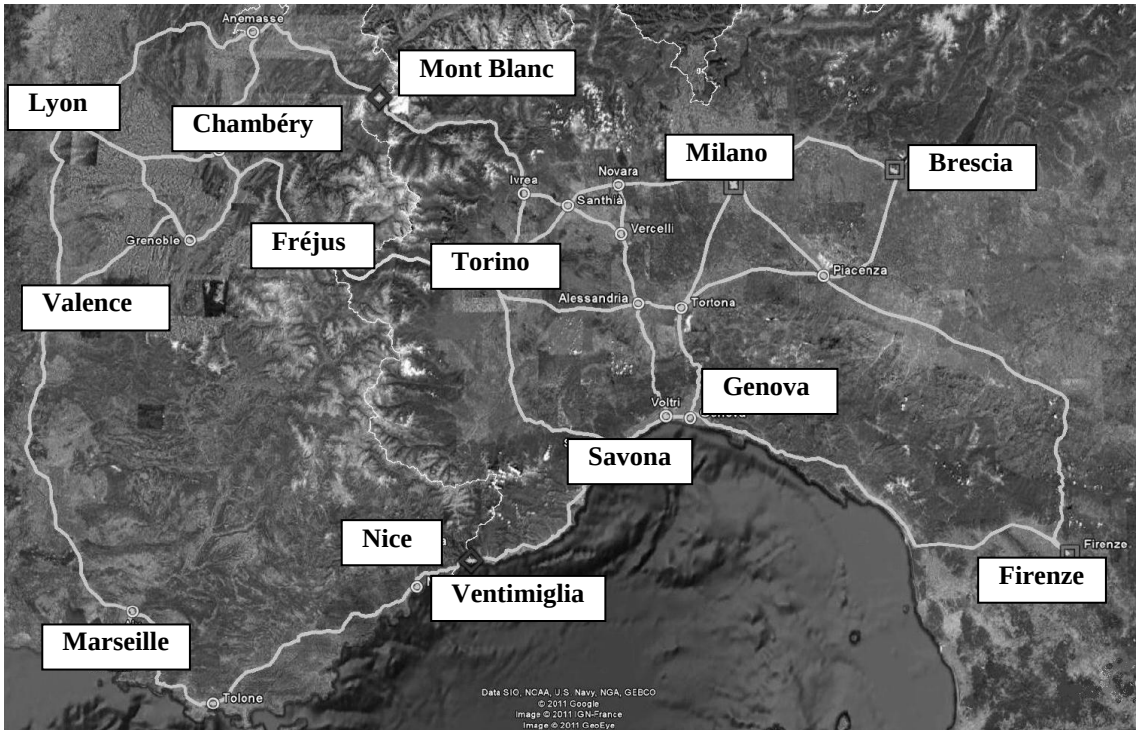

Figure 1: Transborder area of the SECTRAM project (map obtained with Google Maps support) with the main cities and the tunnels

2. Vulnerability and Resilience of a territory: proposal of two indices

2.1 Definitions

The term "*vulnerability"* comes from the Late Latin word "*vulnerabilis"* meaning "*capacity to be injured*" or "*wounding*". This term is mainly used in medical science and nature, and it has been gradually introduced into the field of natural and technological risk (Garbolino, 2010).

D'Ercole and Metzger explain that "*territorial vulnerability refers to the idea that there is, within any area, identifiable elements likely to generate and disseminate their vulnerability to the entire territory, causing effects that can disrupt, compromise or discontinue its operation and development. In this sense, the analysis of territorial vulnerability aims primarily to identify, characterize and prioritize the areas from which territorial vulnerability is created and diffused. It can therefore enable the definition of areas for which risk prevention measures are highly efficient, thereby taking an approach opposite to that of routine interventions aimed at reducing risk, which are often just ad-hoc contingency measures.*" These authors thus propose to focus on the identification and localization of the major vulnerable entities, regardless of the type of hazard, as they are the elements essential to the functioning of the territory.

At the opposite, we can introduce the concept of resilience. According to Rebotier (2007), the territorial resilience is considered as "*the ability of a social space to recover from disturbance and reduce impacts expected during a future disturbance, thanks to learning and the integration of feedback experience in system characteristics*". In this case, the territorial resilience can be defined by the elements that support the organizations to face hazardous events and crisis situations.

2.2 Proposal of a methodology to assess the territorial vulnerability and resilience

Starting from these two main definitions of territorial vulnerability and resilience, the authors propose two spatial indices:

- A territorial vulnerability index: the aim of this index is to assess the exposure of people, goods and infrastructures to a specific scenario of DGT accident on the transportation network in order to support the decision-makers in their activities of risk prevention;
- A territorial resilience index: the goal of this index is to assess the number of structures and organizations that can contribute to manage a crisis situation, like fire departments, police, etc.

The authors propose a methodology (figure 2) to implement and apply these two indices on the whole territory and to generate maps. This methodology is based on the definition of a territorial model (Garbolino *et al.*, 2012) where the territory is described by different elements such as population centers, private properties, buildings open to the public, waterways, transport infrastructures, conservation areas, etc. Territorial modeling uses software to manipulate the geographic information. It integrates spatial data derived from national bodies, government ministries, local authorities or private companies into a GIS. To implement this data, a GIS must provide several modules for the display and manipulation of geographic information; a geo-database module, a geo-visualization module and a geo-manipulation module.

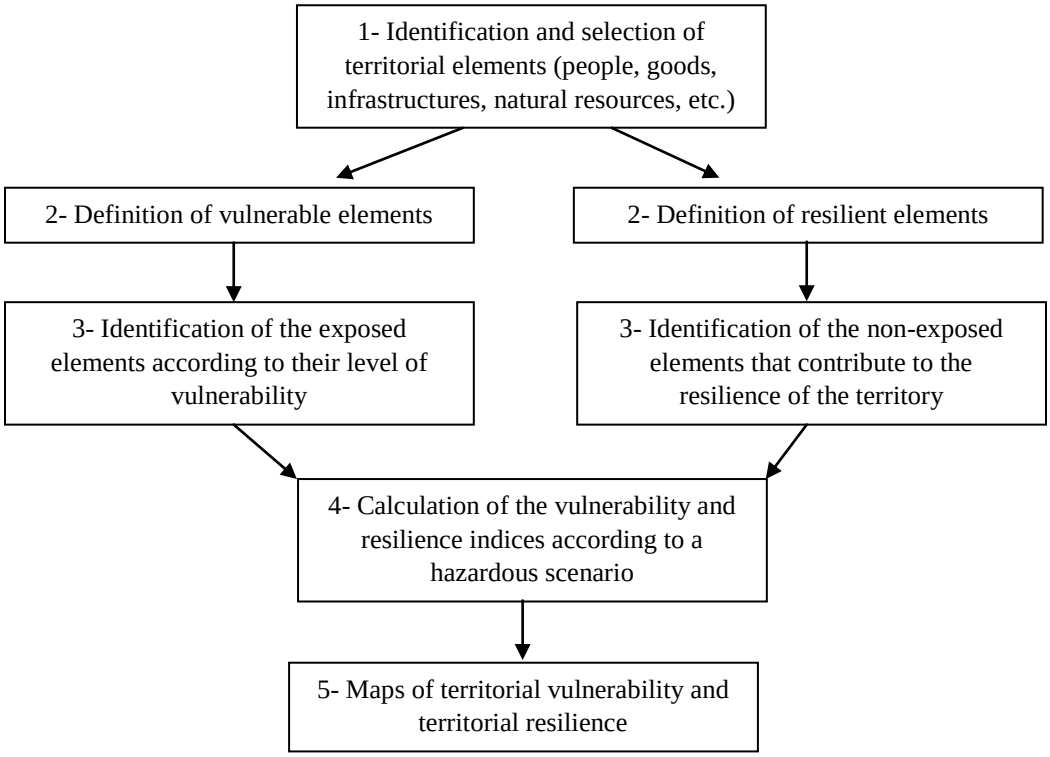

Figure 2: Methodology of implementation and application of territorial vulnerability and resilience indices.

In this methodology, it is important to do the distinction between vulnerable and resilient factors: we consider as vulnerable factors all elements of the territory that can be affected by a hazardous event. These vulnerable factors are represented by:

- Exposed people: Population density, Establishments Receiving Public ERP - (hospitals, schools, stadiums, churches, etc.), daily average road traffic for each road section...
- Exposed goods: Elements of roads (roads, bridges, tunnels), service stations, administrations centres, industries, train stations...

The spatial data come from the National Institute of Statistics and Economy (INSEE) for the description of the population, the National Institute of Geography (IGN) for the administrative information, the ERP, service stations etc., the Regional Direction of Environment and Planning (DREAL) for the localisation of SEVESO industries, and the Regional Observatory of Transports (ORT) for the estimation of the daily average road traffic.

2.3 Definition of vulnerability levels

The definition of the vulnerability levels is based on the decree of September 2005 the 29th, supervised by the Directive n ° 96/82 of 09 of December 1996 on the control of major accidents involving dangerous substances, that defines classes of our vulnerability index. This decree establishes the severity of an accident involving a dangerous substance according to its human consequences. Table 1 presents the characterization of a disaster in terms of casualties. According to this scale of severity, we propose five levels of vulnerability in order to characterize the vulnerability of a territory.

Table 1: Severity scales of accidents involving hazardous substances according to the decree of September 2005

Severity level of consequences	Amount of exposed people in the lethal area
disastrous	More than 100 people exposed
catastrophic	Between 10 to 100 people exposed
important	Between 1 to 10 people exposed
serious	More than 1 person exposed
moderate	No people exposed in the lethal area

The levels of territorial vulnerability have the following values: disastrous =4, catastrophic =3, important =2, serious =1 and moderate =0.

For the variable named "*population"*, the level of vulnerability is directly calculated with the amount of exposed people in the lethal area and taking into account the percentage of killed people. The percentage of killed people is estimated according to the recommendations provided by the French government and it depends on the vulnerability thresholds taking into account the different kind of hazardous phenomena like overpressures, thermal flux and atmospheric concentration of toxic substances. The French regulation usually defines three main levels of effects on people:

- The level of irreversible effects: it corresponds to the level below which there are no deaths, only injured people.
- The level of the first lethal effects: in this zone, 1 % of the exposed people can die;
- The level of the significant lethal effects: in this zone, there are at least 5 % of the exposed people who can die.

The definition of the vulnerability levels of the other territorial elements such as the ERP - Establishments Receiving Public (hospitals, schools, stadiums, churches, etc.), the Seveso sites, the service stations and the average traffic on road was validated with the partners and beneficiaries of the SECTRAM project. Table 2 gathers the different levels of vulnerability according each considered territorial elements.

Table 2: Definition of the vulnerability levels for the considered territorial elements.

Territorial elements	Moderate (0)	Serious (1)	Important (2)	Catastrophic (3)	Disastrous (4)
Population	POP=0	0≤POP<1	1≤POP<10	10≤POP<100	POP≥100
ERP	ERP=0	ERP=1	ERP=2	3≤ERP≤4	ERP≥4
SEVESO sites	SEVESO=0	SEVESO =1	SEVESO =2	SEVESO=3	SEVESO≥4
Service Stations	SS=0	SS=1	SS=2	SS=3	SS≥4
Daily Average Road Traffic	DART=0	0≤DART<1	1≤DART<10	10≤DART<20	DART≥20

The calculation of the Territorial Vulnerability Index (TVI) according to a specific accident scenario is based on the sum of the whole scores for each element and for a specific hazardous area.

$$\text{Territorial Vulnerability Index (TVI)} = V_{pop}+V_{ERP}+V_{SEVESO}+V_{SS}+V_{DART} \quad (1)$$

With :

V_{POP} = Vulnerability level of Population
V_{ERP} = Vulnerability level of ERP
V_{SEVESO} = Vulnerability level of SEVESO sites
V_{SS} = Vulnerability level of Service Stations
V_{DART} = Vulnerability level of Daily Average Road Traffic

For example, if in the studied territory 25 people are affected by an explosion, the value of the variable POP is equal to 3 (catastrophic). If there are two exposed ERP, the vulnerability level of this territorial element is 2 (important). If there is 1 service station, its level of vulnerability is 1 (serious) and if the DART is 15, its vulnerability level is equal to 3 (catastrophic). In this simple case, where there are no SEVESO sites exposed, the TVI is equal to 10, which is disastrous. This denomination derives from the levels of the TVI defined as follow: disastrous ≥ 9, 7 ≤ catastrophic ≤ 8, 5 ≤important ≤ 6, 3 ≤serious ≤ 4 and 0 ≤ moderate ≤.2.

2.4 Definition of resilience levels

The resilient factors are represented by the following elements: fire stations, hospitals, police stations and military headquarters. To be considered as resilient factors, theses elements must be localized at less than 4 km from the hazardous event and they must be not exposed to this event. This distance was chosen taking into account that the emergency means intervene in a very short time, less than 15 min.

It is important to understand that as long as these elements are not exposed to the consequences of a hazardous event, they contribute to the resilience of the territory. However, if these elements are exposed to the consequences of a hazard, they increase the vulnerability of the territory.

Table 3 indicates the levels of resilience of each resilient element according to its distance to an exposed area of a DGT accident.

Table 3: Resilience levels of each resilient element according to their distance to an accidental area.

Territorial elements	Very Important (5)	Important (4)	Average (3)	Low (2)	Very Low (1)
Firemen Stations	500m>FS	500m≤FS<1000m	1000m≤FS<2000m	2000m≤FS<3000m	3000m≤FS<4000m
Hospitals	500m>H	500m≤H<1000m	1000m≤H<2000m	2000m≤H<3000m	3000m≤H<4000m
Police and Military	500m>PM	500m≤PM<1000m	1000m≤PM<2000m	2000m≤PM<3000m	3000m≤PM<4000m

The calculation of the Territorial Resilience Index (TRI) according to a specific accident scenario is based on the sum of the whole scores for each element at a certain distance to a specific hazardous area.

$$\text{Territorial Resilience Index (TRI)} = R_{FS}+R_{H}+R_{PM} \quad (2)$$

With :

R_{FS} = Resilience level of Firemen Stations

R_{H} = Resilience level of Hospitals

R_{PM} = Resilience level of Police and Military

For example, if in the studied territory there is a firemen station located at 1km from a DGT accident and this firemen station is not exposed to this hazardous event, the resilience level is equal to 3 (average). If there a hospital located at 700m, the level of resilience is 4 (important), and if there is a Police headquarter at 3 km, the resilience level is 1 (very low). In this case, the TRI is equal to 8, which is average. The classes of the TRI are the followings: very important ≥ 12, $9 \leq$ important ≤ 12, $7 \leq$average ≤ 9, $4 \leq$low ≤ 6 and $0 \leq$ very low $\leq .3$.

The mapped results for the TVI and the TRI allow a quick identification of the most vulnerable and resilient areas through a colour scale of 5 levels. In the following paragraph, the authors discuss the interest of this application.

3. Application on a transborder territory and assessment for two transportation modes

The reference scenario is an accident of LPG (Liquid Petroleum Gas) transported by road (with a truck having an amount of 19 tons of LPG) and by rail (with an amount of 50 tons of LPG). This accident provokes a BLEVE (Boiling Liquid Expanding Vapour Explosion) with distances of lethal effects superior to 200 m. In this example, the two transportation modes (road and rail) for LPG are taken into account in order to assess the territorial vulnerability and the territorial resilience of this area.

Table 4: Scoring of TVI and TRI from the whole territory to the municipality level.

Territorial levels	Average TVI With rail DGT	Average TVI With road DGT	Average TRI With rail DGT	Average TRI With road DGT	Exposed population by rail DGT	Exposed population by road DGT	Difference of exposed population (rail – road)
Whole territory	3.73	4.39	4.38	4.36	887.913	758.398	+ 129.515
Alpes-Maritimes (Department)	5.44	5.79	6.92	6.85	134.176	106.879	+ 27.297
Nice (Municipality)	6.6	6.33	9.68	7.04	63.728	45.060	+ 18.668

The results for the TRI show that they don't vary a lot at regional and departmental level, but they vary a lot at municipally level, due to the same reasons evoked before.

The calculations of the TVI and the TRI are applied on the whole territory and a zoom was performed in order to underlines specificities of urbanized territories. The results are presented in table 4. They show that at the scale of the whole territory, the rail DGT seems to be safer because its TVI (3.73) is lower than the road DGT TVI (4.39). But, if we compare the amount of potential exposed population of each transportation means, we can identify that rail DGT exposes more people to hazardous events than road DGT (+ 129.515). This result seems related to two main reasons: rail DGT carries a bigger amount of DG than road DGT, two to three times more. In this case, the hazardous distances in case of accident are bigger for the rail DGT and more people may be exposed. The second reason is related to the spatial property of railways that cross the urbanized areas, and especially the city center. At the opposite the roads used by DGT trucks are highways and/or specific roads to deliver their DG, where there are less people when it is possible. By changing the geographical level, the results show a higher TVI for rail DGT than road DGT, especially for the reasons evoked before.

4. Conclusion and perspectives

The definition of TVI and TRI is a first tool that contributes to identify, with maps and statistics, the level of vulnerability and the level of resilience of a territory. These indices are a continuation of the researches developed by Garbolino *et al.* (2007) and Tomasoni *et al.* (2010). It is important to underline that these indices need to be considered with other variables like the amount of exposed population, in order to bring a better accuracy for decision-makers. This study also focuses on the differences between the risks generated with two different DGT: the road and the rail ones. It is well known that rail DGT is safer than road DGT because of the less probability of occurrence of accident with rail (Nicolet-Monnier and Gheorghe, 1996). But trains carry a larger amount of hazardous materials than trucks and they cross cities centres. So, they expose more people to a probable hazardous event than truck transportation systems. The goal of this paper is not to decide and generalize a solution for urban and infrastructures planning, but it aims to highlight that the choice of a transportation system for dangerous goods should be evaluated at different geographical levels and should take into account to the spatial properties of the territory.

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References

D'Ercole R., Metzger P., 2009, Territorial vulnerability: a new approach of risks in urban areas. Cybergeo : European Journal of Geography, Dossiers, Vulnérabilités urbaines au sud, document 447, (in French).

Garbolino E., Lachtar D., 2012.- Dangerous Goods transportation and Biophysical Vulnerability: the contribution of GIS and simulation softwares. In Transport of Dangerous Goods: Methods and Tools for Reducing the Risks of Accidents and Terrorist Attack. NATO Science for Peace and Security Series C: Environmental Security, Springer Editor: 1-43.

Garbolino E., 2010, Transposition of the Defence in depth concept to Hazmat Transport to mitigate territorial vulnerability. Security and Environmental Sustainability of Multimodal Transport, Springer, Bell M.G.H., Hosseinloo S.H. and Kanturska U. editors: 37-56.

Garbolino E., Sacile R., Olampi S., Bersani C., Tomasoni A., Alexandre N., Trasforini E., Benza M., Giglio D., 2007, A Spatial Decision Support System prototype for assessing road HAZMAT accident impacts on the population in

a dense urban area: a case study of the city of Nice, French Riviera. Chemical Engineering Transactions, 11, 413-418.

Nicolet-Monnier M., Gheorghe, 1996, Quantitative Risk Assessment of Hazardous Materials Transport Systems. Kluwer Academic Publishers, the Netherlands.

Rebotier J., 2007, What role for institutions in resilience?: An interpretation through the case of Caracas. Conference Building Resilience of territories IRD-UCV), Valparaiso, Chili, (in French).

Tomasoni A.M., Garbolino E., Rovatti M. and Sacile R., 2010.- Risk evaluation of real-time accident scenarios in the transport of hazardous material on road. Management of Environmental Quality: An International Journal,21(5), 695 – 711.