Cross border critical infrastructure: a new approach for the protection evaluation

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The work proposes an operational model for the management of cross-border transport critical infrastructures. Particular focus is given to road and rail network. The main goal is to develop a Decision Support System (DSS) for the management of relevant events that may have impacts on the two countries. The SICt project - Resilience of cross-border Critical Infrastructures is part of the Interreg VA Italy-Switzerland 2014-2020. The project area includes Regione Lombardia (Italy) and Canton Ticino (Switzerland) and has been divided into two areas. The study area where the hazards (events) of both anthropic and natural origin are analyzed. Critical scenarios on critical infrastructure are also evaluated. The impact area is a larger area in which the effects, after the total or partial interruptions of a critical infrastructure in the study area, are evaluated. Specifically, the work illustrates the different operational phases of the proposed model. The first one is the analysis of anthropic and natural hazards related to the study area: road and rail accidents, rail failures, intense rainfall events, floods, landslides, debris flow, etc... The second phase concerns the detailed analysis aimed at managing the events, with particular reference to the first responders' intervention models and the emergency and traffic management plans. This phase also includes the implementation of a monitoring network and an IT platform, used to share data and information about critical infrastructures. The third phase is the test and validation of the IT platform implemented.

Keywords: Transport resilience, critical infrastructures resilience, critical infrastructures safety, emergency management, risk mapping, transport vulnerability, road network, rail network, response and recovery, decision support system, cross-border infrastructures.

1. Introduction

Our society is strongly dependent on the correct functioning of interdependent infrastructure systems, such as transportation (road, rail, air and sea), electricity, and water networks. These systems are often referred to as critical. This is because they are necessary for the organization, functionality and stability of a modern industrialized country, Cohen (2010). The infrastructure system may be vulnerable to failure, unavailability, accidental or malicious breakdowns that could generate consequences and greatly affect the economy, health, safety and welfare of citizens of an entire country or of several neighboring countries, Nan and Sansavini (2017). The disruption of a critical transport infrastructure, road or rail, can have repercussions not only where the event occurs, but also in a wider area. Depending on the type of event, which may be of natural (e.g. landslide) or anthropogenic (e.g. road accidents) origin, it is

Proceedings of the 30th European Safety and Reliability Conference and the 15th Probabilistic Safety Assessment and Management Conference
Edited by Piero Baraldi, Francesco Di Maio and Enrico Zio
Published by Research Publishing, Singapore.
ISBN: 978-981-14-8593-0; doi:10.3850/978-981-14-8593-0_4134-cd

possible to estimate the impacts on the mobility of people and goods in terms of delays (alternative routes), increased traffic (congestion) and possible increase in accidents.

Therefore, the interruption of road and rail sections can have repercussions not only on transport but also on the socio-economic system in a macro-regional context. At the European level, the *TEN-T - Trans-European Transport Network* has been defined as the set of linear (rail, road and inland waterway) and point infrastructure (urban nodes, ports, interports and airports) considered relevant at Community level. In order to promote the coordinated implementation and development of the Trans-European Transport Network, 9 corridors of strategic importance have been identified as illustrated in Fig. 1, European Commission (2013).

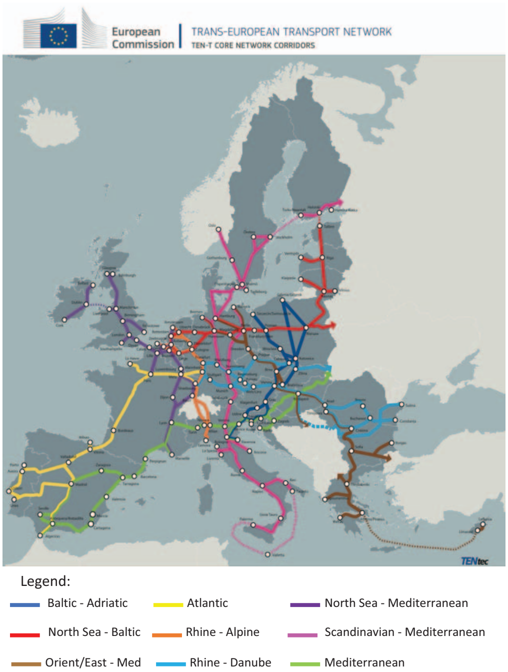

Fig. 1. Representation of the 9 European corridors.

Following a number of significant events, in 2008 the European Directive 2008/114/EC on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection, was issued. The Directive refers to the energy and transport sectors. Among the various definitions included in the legislation, it is useful to specify the following:

- Critical Infrastructure or CI means an asset, system or part thereof located in Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people. The disruption or destruction of this system would have a significant impact in a Member State as a result of the failure to maintain those functions;
- European Critical Infrastructure or ECI means critical infrastructure located in Member States the disruption or destruction of which would have a significant impact on at least two Member States. The significance of the impact shall be assessed in terms of cross-cutting criteria. This includes effects resulting from cross-sector dependencies on other types of infrastructures.

2 Vulnerability and resilience in the transport sector

In order to define whether an infrastructure is critical or not, as previously defined, it is necessary to assess its vulnerability to the most probable events and its importance within the network. Focusing on the first aspect, it arises the necessity to give a definition to vulnerability with respect to the risk; risk can be estimated by calculating the probability of a given hazard, identifying the elements at risk and assessing their vulnerability to that specific hazard, Coburn et al. (1994) and Linkov et al. (2018). It's common ground that vulnerability has many definitions and, for the purpose of this process, it was considered important to highlight the specific definitions of vulnerability of a transport network. Regarding road transportation systems, for example, the one suggested is reported here: *"vulnerability is a susceptibility to incidents that can result in considerable reductions in road network serviceability"*, Mattsson and Jenelius (2015) and Berdica (2002). Moreover, there are several components of vulnerability concerning transport network, Borghetti and Malavasi (2016a): physical, functional, organizational, systemic and topological. To give an overview of the basic concepts mentioned in the project, it is important to define resilience too. In scientific literature, several authors over the years have studied the concept of resilience with emphasis on network systems such as energy, transport and communications, Reggiani (2013); Mattsson and Jenelius (2015). A possible definition of resilience is: *"Resilience is the ability of a system to withstand a major disruption within acceptable degradation parameters and to recover within acceptable time and composite costs and risks"*, Francis and Bekera (2014); Haimes (2009). It results that a resilient system has the following characteristics: reduced probability of failure/malfunction; reduced consequences of failures, in terms of loss of life, damage and negative economic and social consequences; reduction of recovery time, Bruneau et al. (2003); Carlson et al. (2012). For this reason, at the design stage, it would be better to consider the resilience of the infrastructure, not just its efficiency. Indeed, studies have shown that not necessarily an efficient infrastructure is also resilient; the measurement is carried out using the average delay as a comparison parameter between resilience and efficiency, Ganin et al. (2017). In this view, resilience can be defined as " *the ability of an entity - e.g., asset, organization, community, region - to anticipate, resist, absorb, respond to, adapt to, and recover from a disturbance*". Carlson et al. (2012). Fig. 2 shows the operating status of a time-dependent system/activity with reference to a relevant event.

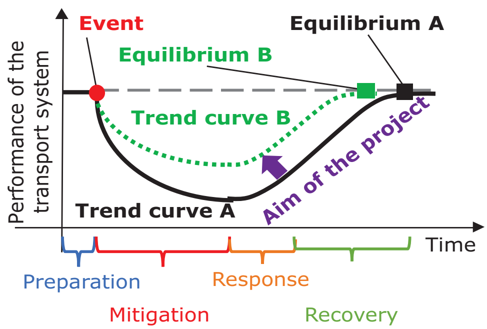

Fig. 2. Generalised disruption profile and stages for a transport system. Adapted from Carlson et al. (2012) and Deublein et al. (2019).

In addition, the various resilience components shown above are illustrated. The disruption profile represents the evolution in time of the performances of the system and can be a valid help for the management of both traffic and emergencies. In particular, for traffic management, it is important to consider the redundancies of routes. These can offer alternatives in case of disruption occurring to an element of the network. The result is that the system has a high resilience not only if it can resist to an event, but also if there are procedures and plans in place as to manage the traffic ensuring alternative routes. Last but not least, the authors consider it essential to highlight one aspect of resilience that is fundamental throughout the project presented in this proceeding: according to Linkov et al. (2018), the assessment of the resilience of the transport network and its management are a way for the system to handle the residual risk that is left unmitigated.

2.1 *Cross-border vulnerabilities: the Rastatt lesson*

The presence of a border is a fundamental aspect to be considered when assessing the resilience of a transport network, especially when intersects many primary links connecting different countries. The issues that need to be taken into account here are the different emergency management procedures, the different traffic management arrangements, the languages, technical issues as, for example, the peculiarities of national rail systems that prevent interoperability. To better understand the problems generated by a loss of functionality of a cross-border corridor, the Rastatt accident and its consequent issues are presented below. The Rastatt event occurred in the Rhine Valley – Germany in 2017 along the Karlsruhe-Basel line, which is part of the Rhine-Alpine Corridor (in orange in Fig. 1) and it is one of the European critical infrastructures. The line was interrupted after the collapse of the tunnel underneath the railway, causing more than two billion Euros economic damage due to an interruption of more than 50 days of the rail freight traffic in Europe. The huge amount of rail traffic (the Rhine-Alpine corridor links Italy to the Ruhr region in Germany and Benelux), in addition to limited availability of alternative routes exasperated the rail traffic problem. Moreover, several vehicles were not suitable to operate on the rail network of adjacent countries and drivers with language skills and technical competence to run a train in another country were not enough. After the Rastatt event, whose resulting effects involved several countries, the need to take into account the differences in the regulatory and procedural aspects of the management of the events by the countries involved arose, alongside the need to plan for shared management practices and tools, to find solutions that offer enhanced resilience.

3. The SICt project

The SICt - Resilience of Cross-border Critical Infrastructures project is part of the Interreg V-A Italy-Switzerland Cooperation Programme 2014 - 2020 which contributes to achieving the goals of the Europe 2020 Strategy. A summary sheet with the main project information is shown in Fig. 3.

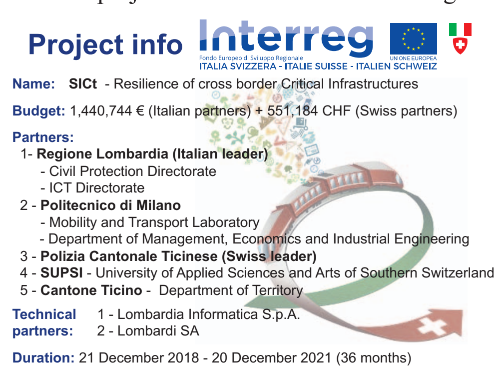

Fig. 3. Main information of the SICt project.

The project is structured in 6 - Work Packages (WP), and its project area includes Regione Lombardia in Italy and Canton Ticino in Switzerland as illustrated in Fig. 4.

Fig. 4. Area of the Interreg SICt project. The area includes part of the Canton Ticino in Switzerland and part of Regione Lombardia in Italy.

3.1 *Aim of the project*

As already mentioned in the previous paragraphs, there are several issues related to the presence of the border that can make the transport networks more vulnerable. Among these, one of the most frequent is the different official language, a problem that has not been addressed within the SICt project because all project partners, both in Canton Ticino in Switzerland and (of course) in Italy, speak Italian. Nevertheless, it is important that there is unambiguous and precise terminology shared by both nations in order to facilitate communication between them. However, there are still problems related to different emergency and traffic management, like not owning shared plans for joint emergency management where possible (joint intervention by the police or other armed forces, for example, is not possible). In this context, the SICt project is aimed at increasing the sharing of knowledge and information on cross-border critical infrastructures. This is important in many situations, e.g. in the event of prolonged closure of a major road in one of the two countries which also affects the other. The achievement of the objectives foresees the realization of joint monitoring systems and communication procedures between different subjects in charge of their management both in ordinary conditions and following relevant events. The main expected change concerns the strengthening of joint risk governance capabilities related to events that may partially or totally damage the continuity of service of critical cross-border transport infrastructures. Particular attention is paid to road and rail infrastructures. These, in fact, represent important and strategic corridors for the transport of people and goods. The three main goals can be summarized as follows:

- Increasing the cooperation of the cross-border governance of events, both of anthropic and natural origin, which affect critical infrastructures. This is achieved by strengthening the monitoring capacities and the information flows between the subjects involved;
- Strengthening the joint capabilities to manage the consequences (impacts) of the interruption of cross-border critical infrastructures;
- Verifying and improving the effectiveness of the cooperation system for the monitoring and management of relevant events in the cross-border area.

4. Project approach

The structure of the SICt project is divided in 3 phases as shown in Fig. 5: analysis, implementation and validation. For each phase there are different activities that allow to obtain the outputs and results expected.

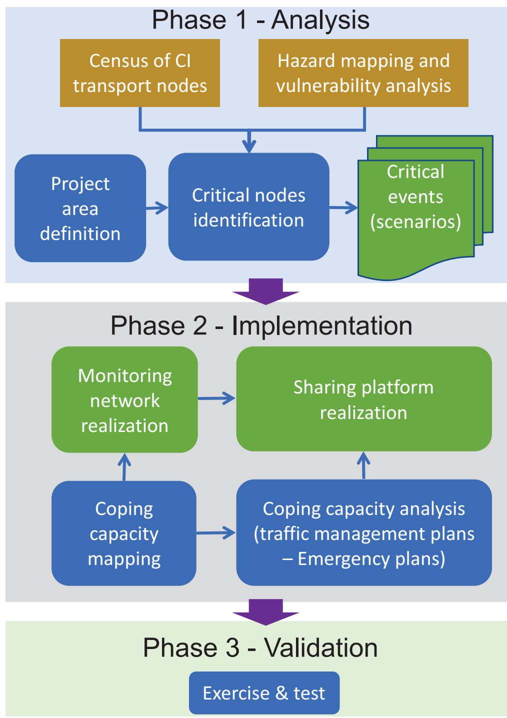

Fig. 5. Structure of the SICt project.

4.1 *Phase 1 – Analysis*

In phase 1 the study area and the impact area of the project illustrated in Fig. 5 were defined.

The study area is the area in which the hazards that can cause partial or total interruption of a section are considered and evaluated. In addition, the study area considers the consequences (impacts on the network) of hazards.

The impact area, larger than the study area, is the one where the impacts of interruptions are analyzed.

The working group has jointly identified the road and rail infrastructure falling within the project area using *OpenStreetMap* cartography and *GIS - Geographic Information System* tools for data analysis. Fig. 6 shows in red the road network considered in the SICt project, in blue the railway network, and highlights the study area (in orange) and the impact area (in violet). The road network includes different levels: mainly highways and state roads, but there are also some provincial and municipal roads.

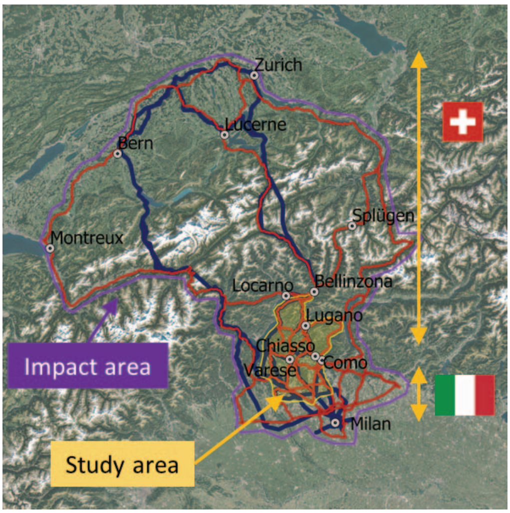

Fig. 6. In red is represented the road network considered in the SICt project, in blue the railway network. The processing data was made using GIS tools.

The extent of the impact area is not symmetrical with respect to the study area which is located near the border between Italy and Switzerland. The impact area extends north to the city of Zurich and south to Milan. This is due to the presence of the Alps, which makes the Swiss road and rail network less dense than the Italian one. As result of several discussions among the project partners, Milan and Zurich are seen as two decisional points where it is possible to undertake and implement management strategies for alternative routes/paths.

Furthermore, the working group identified the critical sections of the road and rail network represented in Fig. 6. The *Vital Node Analysis - VNA* is a technique that allows to analyze the behavior of a whole network following an event that may concern one or more nodes of the network, Petrenj and Trucco (2014). The output of the *VNA* allows to identify the most critical sections (in terms of systemic vulnerability) of the network on which to perform more detailed analyses and evaluations. The systemic vulnerability represents the global effects on a transport network caused by a relevant event considering the interdependencies within the elements of the network.

The last activity of phase 1 is the analysis and identification of hazards that may affect the project road and rail network. The hazards analyzed in the study area may have causes inside or outside the transport system. In the first case they deal with technical failures and accidents (anthropic origin), in the second they concern adverse weather conditions or natural disasters, Mattsson and Jenelius (2015). This activity foresees that the detailed analysis is carried out exclusively on the critical sections identified with the *VNA* according to the systemic vulnerability. Once the elements that would stop the normal operation of the network are identified, it is necessary to analyze the connected hazards both anthropic and natural.

Studying the accidents in the last years was necessary to evaluate the anthropic hazard in road transport, in order to define the most frequent type of accident and the fatal ones. This is the first step to define the relevant events and analyze the consequences looking at both emergency and traffic management. Some authors have studied the issue of vulnerability in road transport, like Zio et al. (2008). In these works, the authors state that the vulnerability of a road section can be estimated using some indicators: depending on road accidents and other jamming causes, the road links are consequently ranked according to their contribution to the loss of safety of the entire road network. In Fig. 7 there is an example of a *GIS* road crash map in the area of the Italy-Switzerland customs, near the cities of Como and Chiasso. The data were provided by ISTAT.

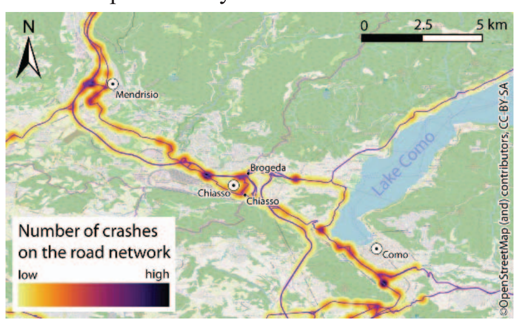

Fig. 7. Extract of a *GIS* crash map in the study area near the border. In yellow, the areas with the lower number of road crashes, gradually darkening as the number of road crashes increases.

This type of analysis is useful to identify the black spots and, for example, to understand if the spatial distribution of the road accidents can cause problems in traffic flow or emergency management in both countries. It is important to define the time of closure (or low operation level) of the network section caused by the different events in order to plan the best response.

Moreover, the authors considered it important to address the problems that arise from emergency management, such as the intervention of rescue in case of need. With reference to the emergency management, several studies have dealt with the location of rescue facilities. Some works, Farahani et al. (2010); Owen and Daskin (1998); Şahin and Süral (2007) have approached the problem and proposed methods of optimisation for the location of structures. Other works, even more specific, analyse the accessibility of the railway network by rescuers using the road network in case of a relevant event considering specific access points, Borghetti and Malavasi (2016a) and Borghetti and Malavasi (2016b).

Similarly to the anthropic hazards, the analysis of the gravitational natural hazards, Getzner et al. (2017) (e.g. landslides, rockfalls, debris flows and floods) that impact on the railway and road networks is mainly based on the landslides inventory and hazard maps of both Canton Ticino and Regione Lombardia. However, it also draws information from the historical data such as the number of events occurred on a particular section, their severity and the associated return period.

Fig. 8 shows an extract of a GIS map of the study area including the landslide inventory dataset for which each point represents an historical event. For a further analysis of the scenario, we assume that the more severe an event is due to natural hazards, the bigger the impact on the network will be and longer the resulting time of recovery.

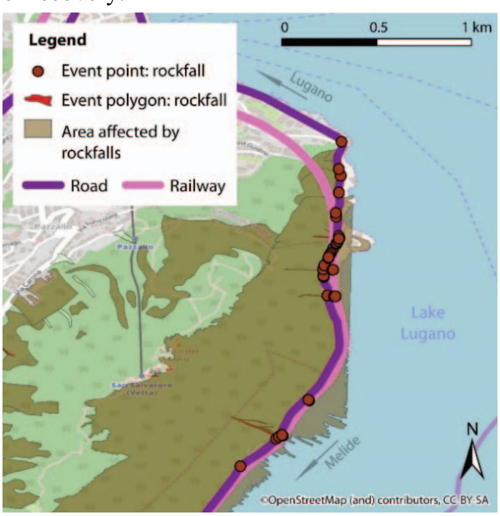

Fig. 8. Extract of a GIS map in the study area between Melide and Lugano, Canton Ticino, Switzerland. The area is affected by rockfalls, each point corresponds to an historical event that had an impact on the transport network.

The landslides inventory maps are the result of detailed studies performed over a long period of time. More recently, the data were implemented using innovative methods for geomorphological and natural hazard mapping. These are 3D digital stereoscopic photogrammetry and analysis of *InSAR - Satellite Synthetic Aperture Radar Interferometry* - data in order to quantify the displacements velocities of ground spatial elements, Ambrosi and Scapozza (2015). The last-mentioned method will also be useful to perform the direct monitoring of the stability of the infrastructures themselves and will be applicable for the further improving of the monitoring network.

The analysis of other natural hazards such as forest fires is based on the cadaster of the areas affected by past events as well as environmental and topographical parameters (e.g. exposure, soil moisture, type of vegetation, elevation, etc.), Conedera et al. (2018). Whereas the analysis of the meteorological hazards considers statistics issued from historical regional datasets of extreme weather events e.g. storms, extreme rainfall, etc.

Other studies have addressed the behavior of a transport network by considering the performance of bridges following earthquakes, Biondini et al. 2020. The integration of the elaborated data for anthropic and natural hazards will enable to evaluate the vulnerability of the studied network. The aim at the end of the analysis phase is to define scenarios related to the total or partial interruption of an infrastructure section and to its vulnerability. Each scenario is associated to a specific hazard and can be characterized in terms of resources needed or response capacity.

4.2 *Phase 2 - Implementation*

The second phase of the project involves first of all the analysis of the scenarios identified in phase 1 with reference to the critical sections of the network. In particular, it is intended to assess the coping capacity in scenario management considering Italian and Swiss resources. In this sense, emergency plans (logistic and accessibility of rescue) and traffic management plans (e.g. rerouting) are evaluated. As far as emergency plans are concerned, the activity foresees the mapping on the territory of the resources necessary for scenario management. The resources concern vehicles, men and equipment. For example, in the case of an accident with dangerous goods it is necessary to map the specialized teams able to intervene and resolve the event (CBRN - Chemical - Biological - Radiological - Nuclear Unit). The next step is to analyze the accessibility of rescuers on the section where the scenario occurs, Borghetti et al. (in press).

With reference to traffic management plans, management measures are identified and analyzed. These can be the storage of heavy goods vehicles along the carriageway or in specific rest/park areas and viable alternative routes. Fig. 9 shows a transport network where the closed critical section is highlighted in red. Moreover, we observe the mapping of three facilities able to intervene to face the scenario on the critical section. For each facility, the routes characterized by the minimum travel time to reach the section are determined. In Fig. 9 two alternative routes that can be used in case of an event that interrupts the critical section are also shown.

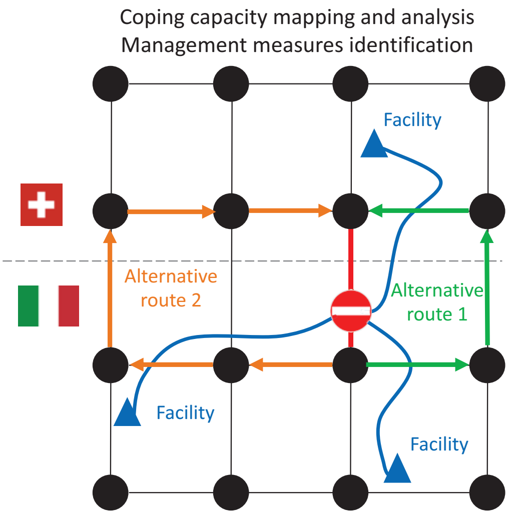

Fig. 9. Graphical representation of the transport network (dark), of the critical section (red line), of the facilities (blue) and of the alternative routes (green and orange).

Phase 2 also foresees the implementation of a monitoring network and a technological platform for the management of the road and rail infrastructures identified within the study area.

The monitoring network will consist of new and existing devices already present in the study area (e.g. drones, cameras and sensors for real-time information or satellite radar monitoring). It is composed by a fixed and mobile monitoring device. The monitoring network is identified and located with reference to the hazards analyzed in phase 1. In this way it is possible to monitor the evolution of a critical situation that could compromise the proper operation of a cross-border road or rail infrastructure.

The IT platform has the main goal of sharing information and data between critical infrastructure operators and first responders. The platform is configured as a *Decision Support System - DSS* able to process and display information on the real-time operation of the road and rail network in the study area. In this way, it is possible to guarantee communication between Italian and Swiss subjects in order to adopt shared strategies regarding intervention methods. Fig. 10 illustrates the functional architecture of the IT Platform.

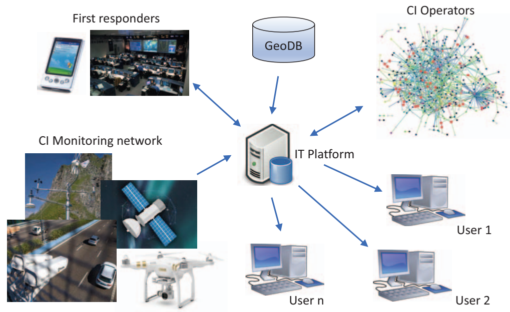

Fig. 10. Functional architecture of the IT Platform.

4.3 *Phase 3 - Validation*

The focus of phase 3 is a test of the IT platform taking into account a relevant event that involves both Italy and Switzerland.

After the identification of the critical infrastructures operators, first responders and stakeholders, the activity is to highlight the strengths and weaknesses of the system in order to improve the collaboration and cooperation among the involved subject from both countries.

5. Conclusions

This paper illustrates and describes the approach of the SICt project that is part of the Interreg VA Italy-Switzerland 2014 - 2020. The main goal of the project is to develop an operational model for the management of cross-border critical infrastructures with particular focus to road and rail networks. An important aspect concerns the difficulty of collecting, harmonizing and processing data between the two countries.

Furthermore, the need to define uniform and shared methods for the follow-up of the project activities is highlighted. The proposed model can be considered a *Decision Support System (DSS)* for the management of relevant events that may have impacts on the two countries.

Acknowledgement

The work presented in this paper was developed within the SICt Project, an Interreg Project co-funded by European Regional Development Fund. This financial support is gratefully acknowledged. In addition, the authors thank the project team, especially the Territory Department of Canton Ticino, Polizia Cantonale of Ticino and Regione Lombardia for providing the data.

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