Cross-border Digital Platform for Transport Critical Infrastructure Resilience: Functionalities and Use-case

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ABSTRACT

The resilience of increasingly interdependent Critical Infrastructure (CI) systems hugely depends on the stakeholder organizations' ability to exchange information and coordinate, while CI's cross-border dimension further increases the complexity and challenges. This paper presents the progress in the Lombardy Region (Italy) and Canton Ticino (Switzerland) on the joint capacity to manage disruptive events involving transportation CI between the two countries. We present a cross-border digital platform (Critical Infrastructure Platform – PIC) and its main functionalities for improved cross-border risk and resilience management of CI. A use case, based on a scenario of an intense snowfall along the transboundary motorway impacting both countries, demonstrates how PIC advances the exchange of information, its visualization and analysis in real-time. The use case also shows the practical value of the digital platform and its potential to support the management of cross-border events (and their cascading events) that require the cooperation of Italian and Swiss actors.

Keywords

Critical Infrastructure, Cross-border, Information-sharing, Transport, ICT platform, Resilience, Use-case, Emergency management

INTRODUCTION

The prosperity of modern societies hugely relies on the availability of essential services provided by Critical Infrastructure (CI) systems. Modern CI systems are increasingly interdependent and span countries. In such complex interdependent systems, even simple disruptions easily spread across CI systems and across borders and can significantly affect economic and social functions both in the country where disruption takes place and across borders.

An extreme example of a transportation disruption in the Alpine context is the Mont Blanc Tunnel fire from 1999, when a transport truck caught fire in one of Europe's longest road tunnels, connecting France and Italy via European route E25. The accident resulted in the tunnel's closure for 3 years which impacted a radius of over 300 km in central Europe causing traffic congestions. The repair and renovation costs reached 350 million Euros and the estimated closure cost for the Italian economy alone was 500 million Euros per year (Johansson et al., 2015).

Ground transport CI disruptions can have significant impacts on wide areas, which calls for improved critical infrastructure resilience (CIR) as abilities to prevent or limit the impacts of disruptions and enable fast response and recovery to normal service conditions. This includes ensuring accessibility to rescue sites using available routes (Borghetti et al., 2021). For building CIR, effective coordination and information exchange among stakeholder organizations throughout the Emergency Management (EM) cycle are vital. Cooperation between governments and private sector stakeholders is crucial, but barriers to information-sharing exist (Petrenj et al., 2013). Cross-border transport networks face additional challenges, such as differing EM procedures, traffic management arrangements, languages, and technical characteristics (Borghetti et al., 2020). The ultimate resilience goal is to maintain a minimum level of essential services and quickly recover after disruptive events (Petersen et al., 2020).

In Petrenj et al. (2021), the authors presented the requirements and high-level architecture for the cross-border Critical Infrastructure Platform (PIC) between Lombardy Region (Italy) and Canton Ticino (Switzerland). In this paper, we show how the collected information requirements were turned into the digital platform functionalities in its first release, and provide a use case scenario of an intense snowfall along the cross-border motorway Como (IT) - Chiasso (CH) to demonstrate how PIC can facilitate the exchange of information in real-time, its visualization and analysis for improved cross-border risk and resilience management of the networked CI system.

The paper is structured as follows: first, we provide relevant details on the context and background. Next, we give a high-level overview of prominent digital platforms that aim to improve CI resilience at the inter-organizational level. The main section of the paper introduces PIC, highlighting its key functionalities, and includes a PIC use case that considers a heavy snowfall scenario in a cross-border area. Finally, the paper concludes by summarizing the key findings and outlining potential opportunities for future research.

DIGITAL PLATFORMS FOR INTER-ORGANIZATIONAL CRITICAL INFRASTRUCTURE RESILIENCE

Numerous efforts are aiming to foster closer cooperation between public and private organizations in risk and resilience management of CI and promote information sharing. The practice has repeatedly proved that there are major benefits of information sharing between public organizations and owners and operators of CI. Information systems for emergency/crisis/disaster response are increasingly used to support the management of such events, by providing graphical, real-time information to responders. Information Systems for Emergency Management are used across the entire EM cycle, from mitigating risks and improving preparedness to coordinating the response and speeding up recovery. Many platforms are multi-functional, dealing with a combination of issues related to EM, DRM and CIR, so it is impossible to separate them based on this aspect. In this section, we give a high-level overview of the most prominent digital platforms which include inter-organizational management of risk/resilience of CI systems and/or their disruption management.

The **Critical Infrastructure Warning Information Network (CIWIN)** aims at assisting Member States and the European Commission to exchange information in support of CI Protection and Resilience (EC, 2022). The system facilitates cooperation between EU countries, allowing for a secure exchange of information including strategies for improving the protection and resilience of CI (electronic forum), as well as alerts on risks and threats (a rapid alert system).

The U.S. Department of Homeland Security (DHS) has established several initiatives and tools to support information sharing among the CI sectors. These include:

- **Homeland Security Information Network – Critical Infrastructure** (DHS, 2022) is the trusted network for homeland security mission operations to share Sensitive But Unclassified (SBU) information. It provides real-time collaboration tools including a virtual meeting space, document sharing, alerts, and instant messaging.
- **Infrastructure Visualization Platform** (CISA, 2022a) is a data collection and presentation medium that combines immersive imagery, geospatial information, and hypermedia data of critical facilities and surrounding areas to enhance planning, protection, and response efforts.
- **CISA Gateway** (CISA, 2022b) serves as the single interface through which DHS partners can access a large range of integrated CIP-R tools for data collection, analysis, and response, all through a single user registration, management, and authentication process. For example, *Map View* function can display

numerous GIS layers in real-time (e.g. CI information, weather, traffic, public transit, natural hazards, population data) to increase situational awareness and provide a common operating picture.
- **The Critical Infrastructure Information Sharing Environment** is a unique framework that provides the tools needed to allow partners to share vital information, which helps them manage their infrastructure security and risk, respond to events, and enhance resilience. It is supported by an information-sharing guide, contact information and case studies.

Northwest Warning, Alert and Response Network (NW WARN) is an information sharing platform: a regional alert and warning system to encourage cross-sector information sharing, which is now the communication backbone of the Washington State Fusion Center (WSFC), routinely used for two-way communications with around 3000 CI and Key Resource stakeholders. Inside NWWARN platform information is shared through gatekeepers – trusted sources of information in a particular infrastructure sector. Besides maximizing near real-time distribution of critical information to the members who need to act on it, it also provides a place for a two-way flow of information with the public – crowdsourcing mechanisms and pushing information directly to social media.

The **Trusted Information Sharing Network (TISN)** for CIR was established by the Australian Government in 2003 to assist CI organizations to prevent, prepare, respond to, and recover from disruptions and adverse events. It brings together hundreds of public and private CI stakeholders, including owners and operators, supply chain entities, peak bodies, industry specialists and all levels of government to share knowledge and improve resilience. The Australian Department of Home Affairs has developed an online platform called the TISN engagement platform to support engagement activities. The platform facilitates coordinated response across sectors in the face of all hazards (Australian Gov, 2022).

Information Sharing and Analysis Centers (ISACs) are non-profit organizations that provide a central resource for gathering information on cyber threats, allowing two-way sharing of information between private and public sectors. They exist in many EU states and are supported by European legislations such as NIS Directive and Cybersecurity Act. ISACs typically share information on threats, vulnerabilities, incidents, mitigation, good practices, situational metrics, compliance topics, law enforcement, and intelligence information. Collaboration platforms for ISACs typically comprise a member contact list, calendars, internal document storage, messaging systems, and discussion forums (ENISA, 2022).

The Dutch nation-wide crisis management system - LCMS (NIPV, 2022) is a web-based crisis management system used to share information within and between organizations. It was designed to integrate operational partnerships within and between all 25 Dutch Safety Regions for public-private collaboration for CIP-R. LCMS supports net-centric collaboration and contains modules for communication, coordination, logistics, information exchange, drafting a GIS view, crisis management, and reporting. All responders can view and add information to the common situational picture.

RESOLUTE's **Collaborative Resilience Assessment and Management Support System (CRAMSS)** is a resilience assessment and management system that aims to improve emergency services and decision-making processes. It features the Resilience Dashboard, which provides real-time status of the Urban Transport System and is accessible to different stakeholders, such as Civil Protection, Mobility department, and Urban Police. The Dashboard includes features such as message monitoring from Decision-Support Systems, event mapping, environmental and mobility indicators, resource availability, social media monitoring, and real-time tracking of people's movements (RESOLUTE, 2022).

There are more projects under EU funding frameworks (H2020 and Horizon Europe) building solutions for information sharing and situational awareness within a single infrastructure sector or among infrastructures of the same type (such as PRECINCT, PRAETORIAN, SAFETY4RAILS) but no details on their platforms are publicly available yet.

CONTEXT AND BACKGROUND

The SICt project (Resilience of Cross-Border Critical Infrastructure) goal is to improve the joint capacity to manage accidental events involving transportation CI between Italy and Switzerland through the implementation of joint monitoring systems and communication procedures with particular reference to the cross-border area between Lombardy and Canton Ticino (Figure 1). SICt aims to reduce the disparities in approach between the two countries for risk analysis and management of major disruptive events. The collection and exchange of selected and homogeneous information between the two countries, and involved stakeholders, enables a more effective decision-making process in terms of coordinated response and faster resolution of events. In addition, the development of a cooperative and collaborative approach can foster optimal resource management on the cross-border territory with respect to knowledge, integration, and sharing of resources, equipment, and tools, and an overcoming of internal practices within national borders in the interest of both countries.

The border territory contains a network of transportation CI, roads and rail, for both passenger and freight transport. These infrastructures ensure essential services for the community, and the possible disruption, even partial, could cause non-negligible impacts and effects for the community in several countries. The project area has been divided into (i) the study area, in which risk scenarios are considered, and (ii) the influence area sensitive to the effects/impacts of events occurring in the study area (Figure 1 - right).

Figure 1. SICt Project area.

There are 10 border crossings between Italy and Switzerland in the area with over 1.2 million freight vehicles in transit yearly. About 80 % of freight vehicles cross the border using the corridor consisting of the A9 highway in Italy and A2 in Switzerland (Repubblica e Cantone Ticino, 2021). This means that any prolonged disruption of either of the two highways can cause significant socioeconomic impacts for both countries and requires joint management of vehicles.

CRITICAL INFRASTRUCTURE PLATFORM

The Critical Infrastructure Platform (PIC) aims at fostering a collaborative approach to the management of resources and emergency events concerning transportation infrastructure. PIC was developed as a web application and it represents an environment in which accredited users, such as institutional bodies, infrastructure managers and first responders can consult and exchange information in real time. PIC supports a broader cross-border regional resilience strategy between the two regions by fostering secure and effective information-sharing, inter-organizational risk assessment, monitoring and operational coordination under critical situations. The tools and strategies used in the two regions had interoperability barriers which made collaborative efforts less immediate and effective. In this section, we present the main PIC modules and functionalities.

Collaborative Emergency Management module

The Collaborative Emergency Management (CEM) module represents the application component responsible for managing the three main Entities of PIC:

- Alerts: critical conditions of different nature and intensity relating to main meteorological risks (hydrogeological, snow, wind, forest fire).
- Events: classified in “Cause Event” (the reason for anomalies on the road or rail network) and “Infrastructure Event” (the impact of the event on the road or rail network). An Infrastructure Event can be triggered by an unforeseen accident, or by an escalation of an Alert into an (emergency) Event.
- Planned activities: non-emergency events that can be scheduled, such as a construction site, a public demonstration or a scheduled customs closure for holidays.

The Collaborative Emergency Management (CEM) module serves as an information-sharing system to support managing emergencies and coordinating of response actions. The main screen contains 3 main tabs (Figure 2), one for each Entity type, that offer tools for insertion of an Alert – a warning to be prepared to deal with potential emergencies; an Event – any happening that could undermine the functionality of the CI and that requires an intervention of operators; or a Planned activity – a programmed interruption of services which may impact their efficiency and which must be taken into account in the Alerts and Events management.
Each of the main tabs contains 6 sub-tabs, for consulting Details and inserting Comments, Measures, Support Requests, Documents and Geo-localization into each Entity represented in CEM. Permissions relating to the information that can be consulted and the operations that can be performed by each user are granted through a specific profiling system based on the user's institutional information. A new Entity can be created by insertion of the relevant information through a customized form and all users are informed via mail. After creation,
Events

and Planned activities can be geolocated in the specific sub-tab by adding a point, a line or a polygon to the map. All the geolocated entities will be available in the Geographic Viewer for consultation thanks to the interoperability of the two modules. Users can also see and search through the list of the existing Entities (Alerts, Events, Planned Activities) by any of their properties, open them from a list and then browse through their related information (sub-tabs) for relevant details.

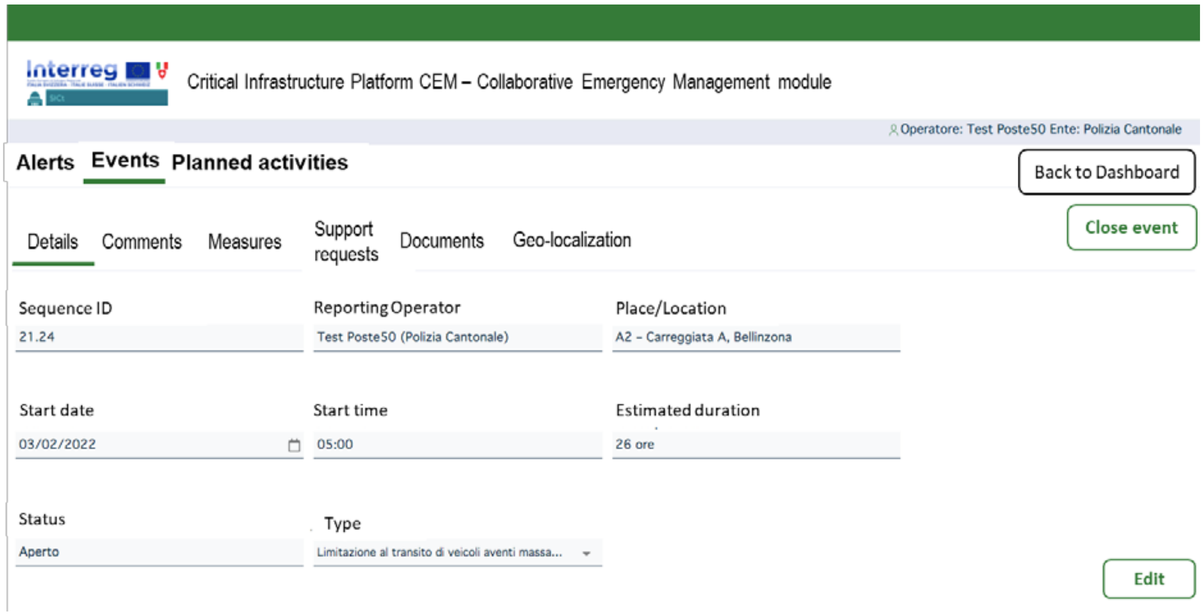

Figure 2: Collaborative Emergency Management (CEM) module: Events-Details tab

During the Event management, it is possible to:

- **Add additional information**, such as the presence of dangerous substances and their quantity, numbers of involved persons, injured persons (and their pathology type), deceased persons, persons to be evacuated, number and type of vehicles involved on the road, number and type of wagons involved on the rail.
- **Update details** whenever new information emerges and/or new measures are implemented (i.e., response and recovery actions), such as restriction on transit for specific vehicles, variable message signs or requests for support. Operators can declare their state of emergency if an ongoing event requires their intervention, and finally, notify about the closure of an event.

The shared details of events on one side of the border, their development and measures taken can help operators on the other side in implementing actions to manage the propagation of the effects.

Geographic Viewer

The Geographic Viewer (i.e., Critical Infrastructure Dashboard) is the GIS component of PIC which enables users to see, explore and analyze data on a map.

The Geographic Viewer consists of 4 essential elements (Figures 3-4):

1. Map area: the basic interface used for viewing published maps
2. Features: widget components that provide analysis tools
3. Areas: subgroups of layers grouped by theme
4. Header and Footer: information bars at the top and bottom of the interface

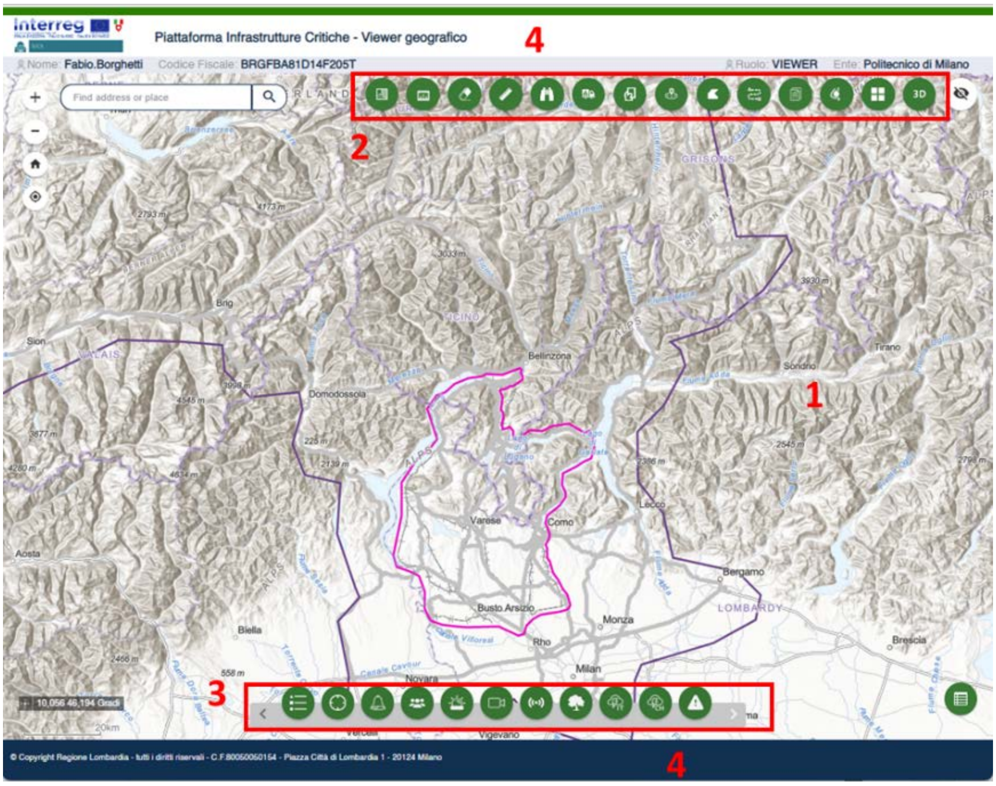

Figure 3. Geographic viewer display

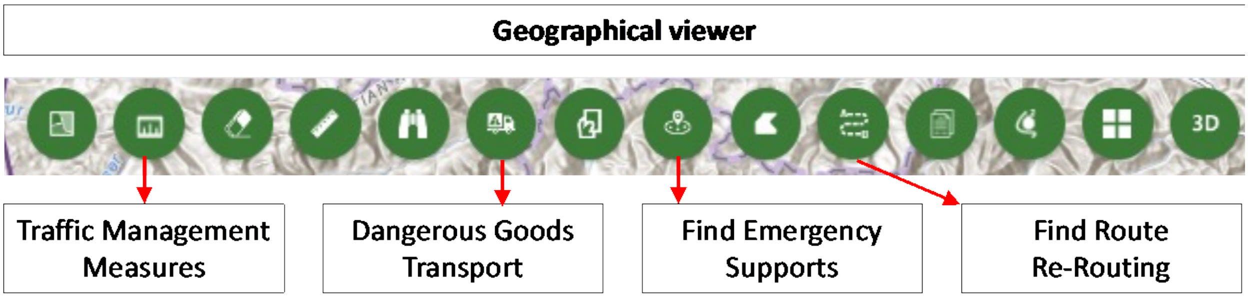

Figure 4: The four essential functional tools of the Geographical viewer

The four essential functional tools of the Geographical Viewer are described below, providing their main features.

Traffic Management Measures

The Traffic Management Measures tool (Figure 5) provides the user with structured and dynamic guidance on measures to be implemented in case of a major event affecting the road or rail network (i.e., plans and procedures for mobility management in emergency conditions). For example, alternative road routes or replacement bus services can be defined in the event of an interruption of a rail route. The feature allows the user to set the following parameters: i) day of the week; ii) time and iii) duration of the event.

The selection of parameters allows a set of measures to be displayed. Each measure contains a detailed description and a responsible person and it is made available in pdf format. The different measures are also associated with geographic information layers that can be viewed on a map.

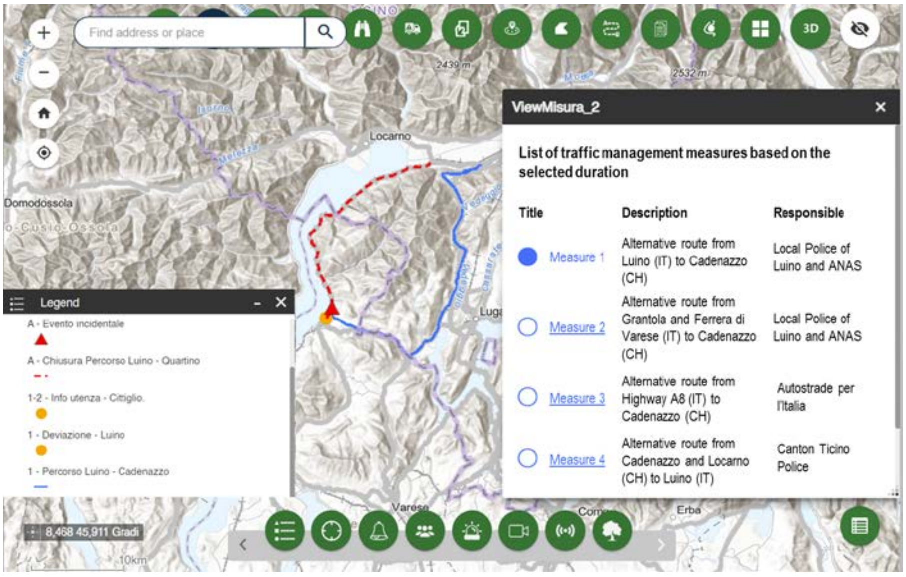

Figure 5: Tool for viewing traffic management plans

Dangerous Goods Transport

The Dangerous Goods Transport tool (Figure 6) allows the estimation of impacted areas in the case of dangerous goods spills and the identification of sensitive human targets (e.g., schools and hospitals) within them. Using this feature, the extent of the impact area can be calculated based on 3 variables: i) type of substance spilt; ii) type of scenario and iii) type of spill. The impact area is calculated as a buffer with respect to the location of the spill (selected by the user, 1060m in Figure 6 – left) which must be drawn on the map by the user in the form of a point (Figure 6 – left), line (Figure 6 – right) or polygon. Having calculated the impact area, it is possible to highlight the sensitive targets that are included in it. The process for using the tool is described below:

1. Definition of the substance-scenario combination
2. Selection of the type of spill (mild and severe)
3. Definition of the dimension of the impact area
4. Selection of sensitive targets (e.g., schools or hospitals)
5. Definition of the origin of the spill

At the end of processing, the targets falling within the impact area are visible on the map and the alphanumeric information associated with them is visible in the results sheet (Figure 6 – right).

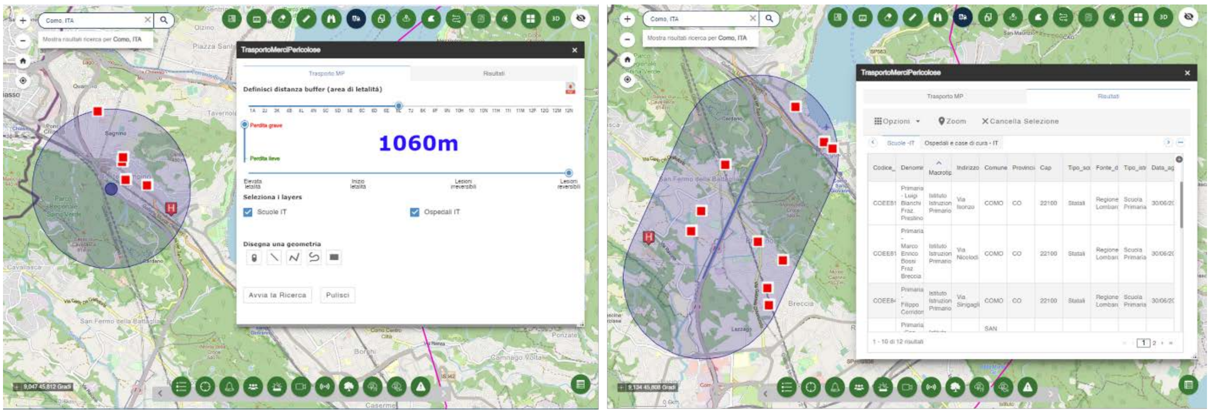

Figure 6: Dangerous Goods Transport tool screenshots

Emergency Support Search

The Emergency Support tool (Figure 7) allows users to locate, within a defined area, the presence of emergency management facilities related to urgent technical and medical rescue. It is possible to input an address or draw a point on a map and choose the diameter of the circle that locates the area within which to search. Based on these settings, the tool shows the survey area on the map, represented by a red circle, and will report the list of facilities within it. In addition, you can view the information available for the facilities highlighted on the map. Once the potential emergency support facility is localized, CEM can be used to request support.

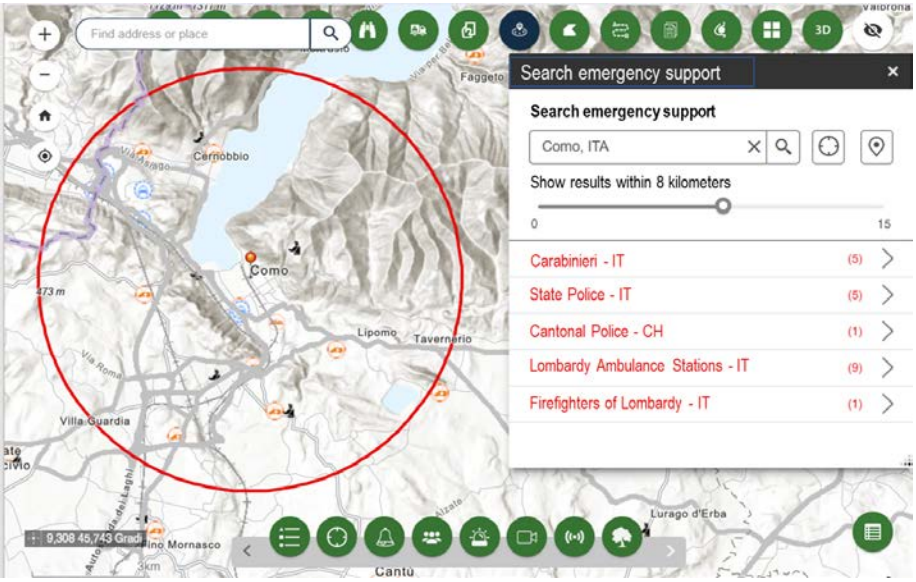

Figure 7: Tool for finding emergency support

Re-routing

The Re-Routing tool allows the user to locate the route by setting the starting and ending point of the trip and giving the option to enter a disruption (relevant event). The user can indicate the origin and destination of the route either by entering an address or by clicking on a point on the map. It is also possible to select the type of route to be searched considering the travel time or the distance between the origin and destination. The tool returns the route plotted on the map and the list of related information in the tool window (Figure 8). In addition, it is possible to enter an interruption of the calculated route and identify a new one that includes the detour (alternative route).

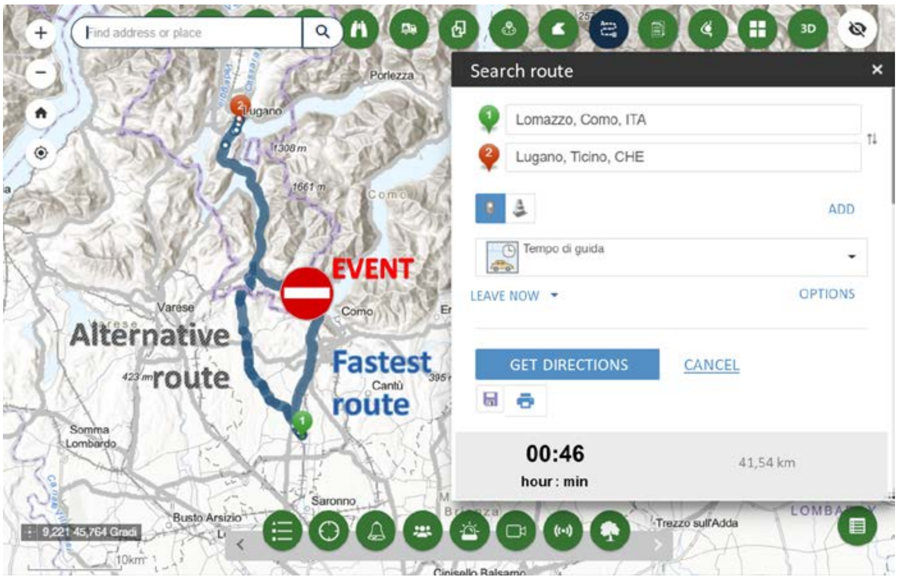

Figure 8: Re-routing tool: finding alternative route

CRITICAL INFRASTRUCTURE PLATFORM USE CASE

Methodology and use case introduction

In software and systems engineering, a use case is generally understood as a usage scenario for a piece of software, users' interactions with the software and, at a higher level, showing missions or stakeholder goals. Use cases can also be used to define the scope, establish requirements and design systems architecture (Cockburn, 1997). The focus of our use case is to outline the ways a user interacts with PIC, what PIC does and how it enables actors to reach their objectives. We show a series of interactions between the actors and the system from the trigger event to the goal.

The essential elements of a use case are typically (Cockburn, 1997; Brush, 2022): **actors** (people/organizations interacting with the platform, stakeholders); **system** (decisions and interactions made by actors; the process and steps taken to reach the end goal, including the necessary functional requirements); **goal** (the results of an actor's interactions with the system); **trigger/precondition** (events that cause the use case to begin); **basic flow** (successful scenario; specific sequence of actions and interactions between actors and the system under discussion; it is also called a use case instance).

The following use case shows how the Critical Infrastructure Platform can be used to support the management of cross-border events requiring the cooperation of Italian and Swiss actors.

The use case includes public and private organizations from Italy and Switzerland. The main actors are public institutions, CI operators (responsible for the management of the infrastructure) and first responders (responsible for managing emergencies). In each event we can broadly distinguish between i) organizations directly involved in the event, who are actively participating in the response and recovery, and ii) organizations indirectly involved in the event, who are in a wider area from an event, who follow the evolvement and possible cascading events and adjust their operations to mitigate the possible impact.

The information about the management of the emergencies and the information flows were collected from official documents, interviews and workshops. Given the multitude of actors involved, sub-groups were identified according to their roles and responsibilities (e.g., road CI operators, railway CI operators, first responders).

The event considered for this use case concerns the management of a heavy snowfall along the A2 - A9 highway (Como-Chiasso) with impacts on Swiss and Italian territory. It shows how PIC can be used to facilitate the exchange and visualization of real-time information related to the operation of CI by supporting and/or replacing the telephone exchange of information. The use case identified did not aim to simulate the management of an event, showing all its criticalities or all the actors involved, but it was an illustrative case that allowed us to visualize the main functionalities of PIC. The use case considers only the stakeholders directly involved in the event and the two key modules of PIC: Collaborative Emergency Management (CEM) and the selected components of the Geographical Viewer (not all of them).

PIC use case: heavy snowfall impacting cross-border transportation system

The entering of the snowfall alert results in the implementation of a series of measures to limit the impacts of heavy snowfall along the Italian and Swiss road infrastructures. The overview of the use case is shown in Figure 9, and the steps of the use case are detailed in Tables 1-5.

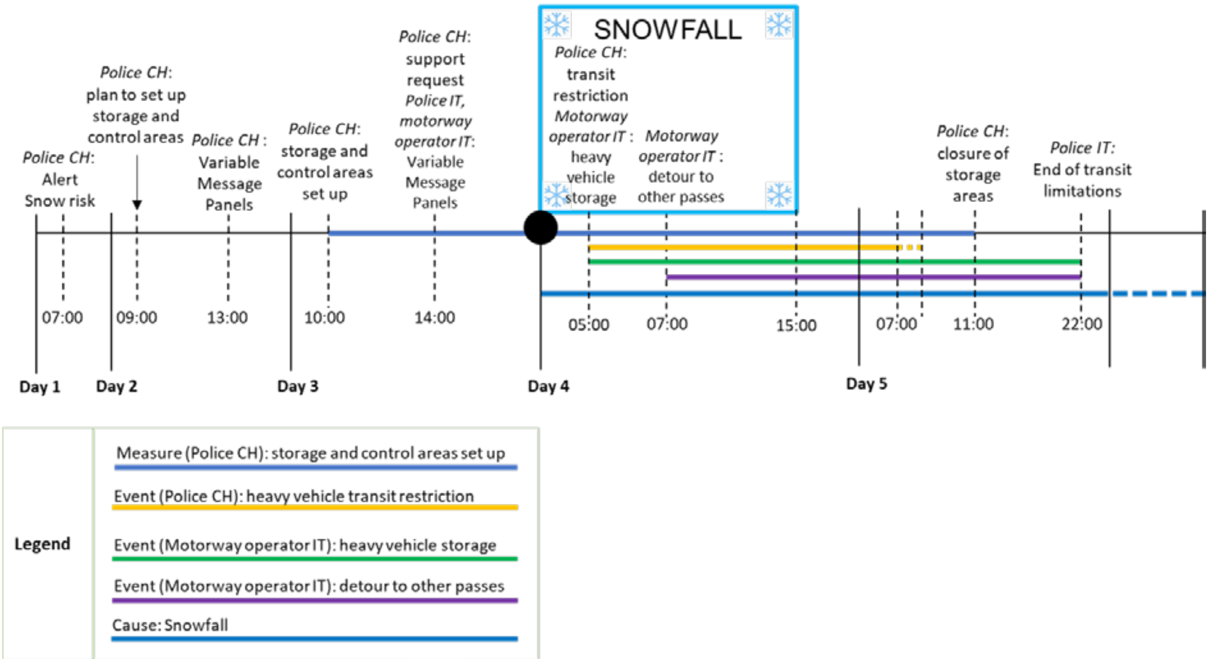

Figure 9: Use case timeline overview

Day 1		
PIC functionality	**Exchanged information**	**Comment**
Alert **(news, comments)**	• The Swiss Police (Police CH) enters the *Alert* of a heavy snowfall along the Italian and Swiss road infrastructure A2-A9, Como-Chiasso-Bellinzona (Figures 10-11). • All authenticated organizations receive an e-mail on the new Alert added to PIC. • Organizations have the possibility to add *comments* or attach documents as the Italian Civil Protection which communicates the issue of the weather report.	All the Italian and Swiss organisations using PIC are informed in real-time about the Alert of a heavy snowfall. The estimated duration of a possibility for a heavy snowfall occurrence is over the next 72 hours.

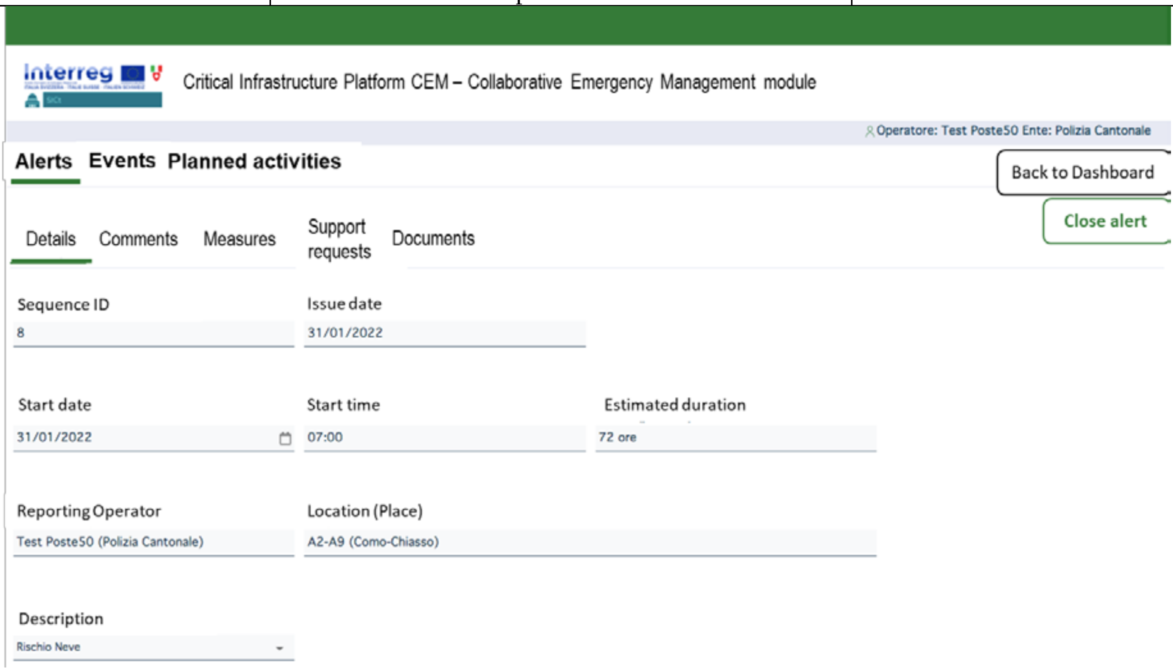

Figure 10. Snowfall Alert issued by Police CH

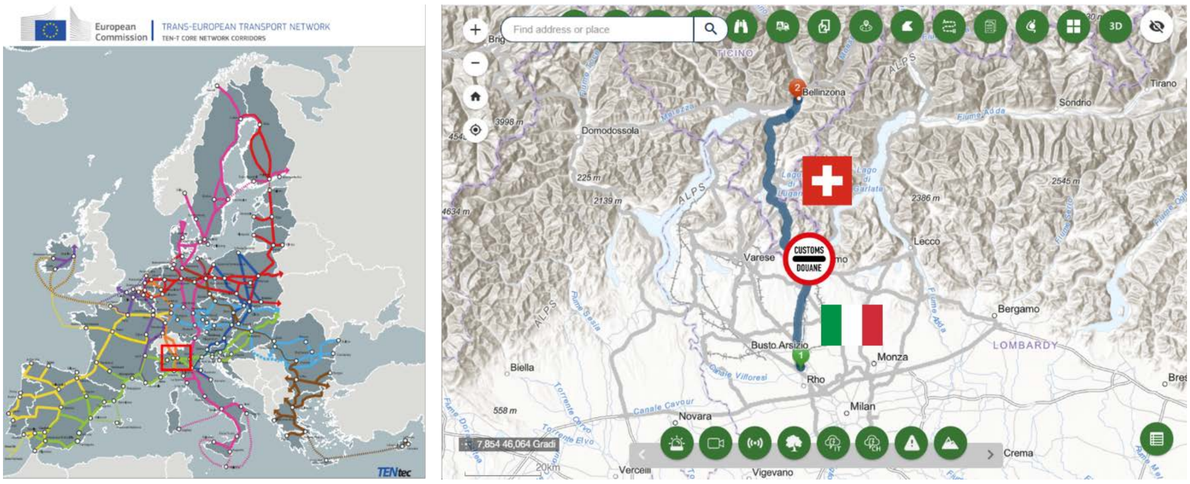

Figure 11. Location of the A9 highway in Italy and A2 highway in Switzerland

Day 2		
PIC	**Exchanged information**	**Comment**

functionality		
Alert (comments, measures)	• The Police CH communicates the plan to set up storage and control areas for heavy vehicles (Figure 12). • The Police CH enters a *Measure* in PIC, communicating the activation of Variable Message Signs (VMS) with the message "Risk of heavy snowfall, possible inconvenience, pay attention" (Figure 13). • Organisations can add comments and/or documents.	Thanks to the entering of this information into PIC, the Italian organisations are informed about the measures that will be implemented in the Swiss territory thus estimating the potential impacts in the Italian area.

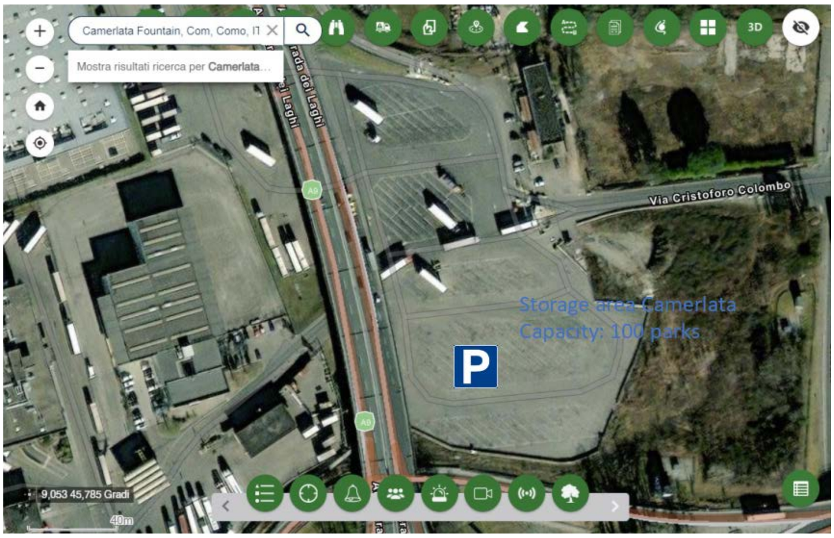

Figure 12. View of a heavy vehicle storage area near the A9 highway in Italy (about 10 km far from the border).

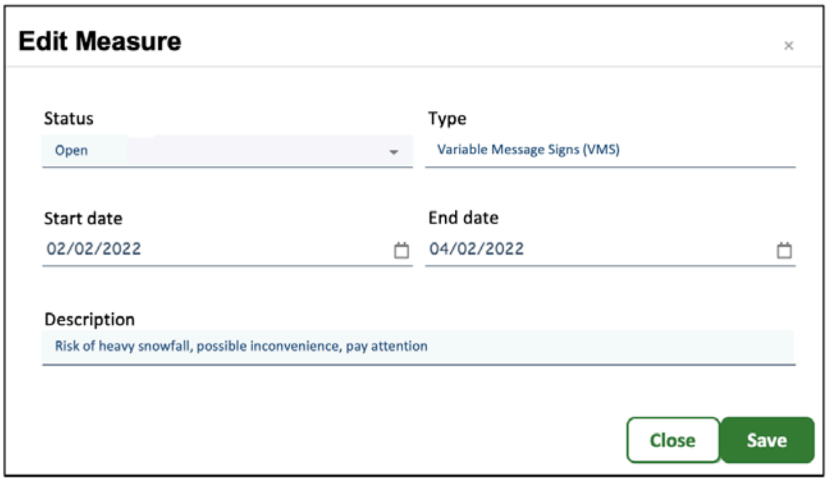

Figure 13: Variable Message Signs (VMS) Measure edited by Police CH

Day 3		
PIC functionality	**Exchanged information**	**Comment**
Alert (comments, measures)	• Once communicated the plan to set up storage and control areas for heavy vehicles, the Police CH decides to implement this measure by communicating the time and day of its activation.	Organisations are aware of the activation of a measure which can

	• Italian organisations, such as the Italian Police (Police IT) and Motorway infrastructure operator can see the measure and add comments (Figure 14). • In addition, the Police CH adds a *Support Request* to the Police IT asking for the activation of the Variable Message Signs (VMS) in the Italian territory (Figure 15). • In that way, the Police IT can directly see the support request and communicate it to the Italian Motorway operator that is in charge of activating the VMS.	have impacts on the traffic in the other state. Moreover, there is no need of using the phone for communicating a Support Request.

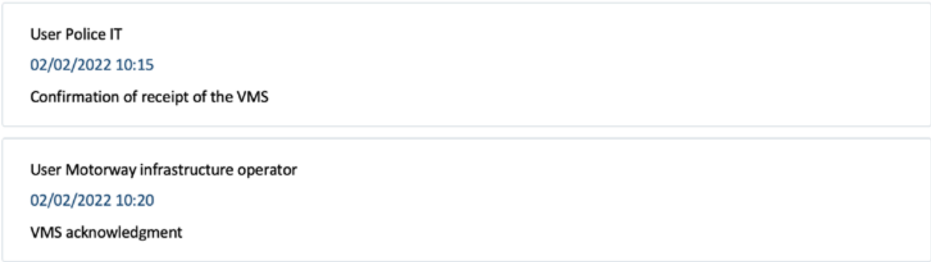

Figure 14: Comments by Police IT and Motorway infrastructure operator

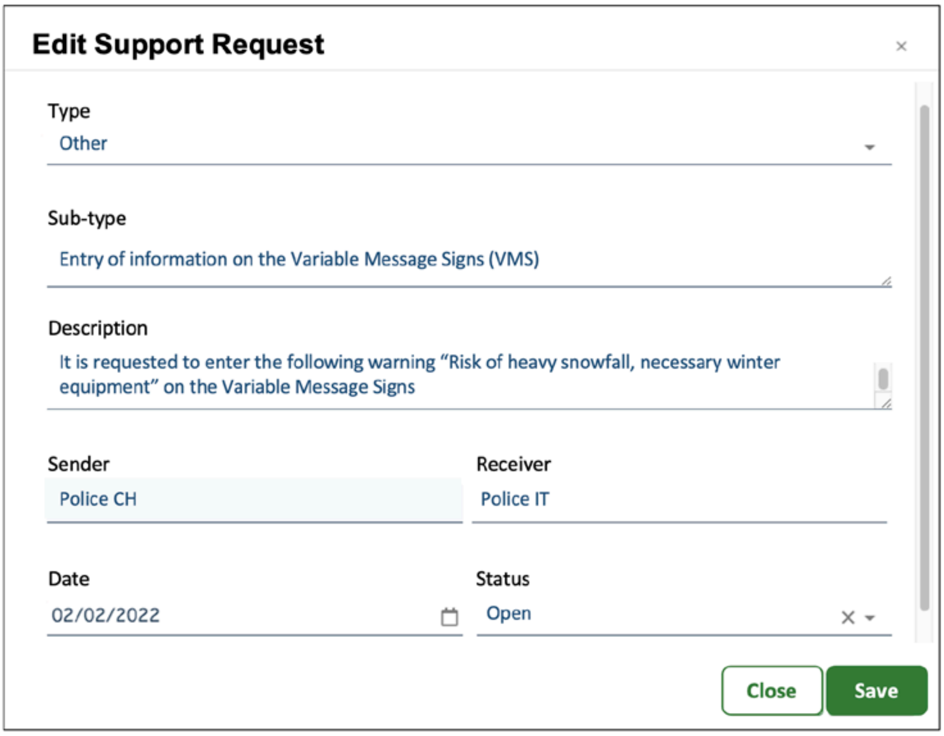

Figure 15: Emergency Support Request from Police CH to Police IT

Day 4		
PIC functionality	**Exchanged information**	**Comment**
Event (activation)	• Due to the occurrence of the heavy snowfall, the Police CH enters an *Event* in PIC (i.e., transit restriction for vehicles with a mass exceeding 3.5 tons along the A2 (which spans from Chiasso to Basel) which has as *Cause* the snowfall itself (Figure 16). • In the same way, the Italian Motorway operator enters other two *Events* (i.e., heavy vehicle storage c/o Grandate and/or along first lane A9; detour to other	The events related to the management of the infrastructure have consequences on the other state, thus it is important to inform all the potentially impacted organisations. By using PIC, this information is

	passes) associated with the same *Cause*. In Figure 17 there is an example of monitoring cameras on the A2 Highway to control the level of traffic during the event activation. • At the end of the day, the snowfall is over and the organisations communicate the end in PIC.	immediately sent and other functionalities present on the viewer allow seeing more information (e.g., traffic management measures).

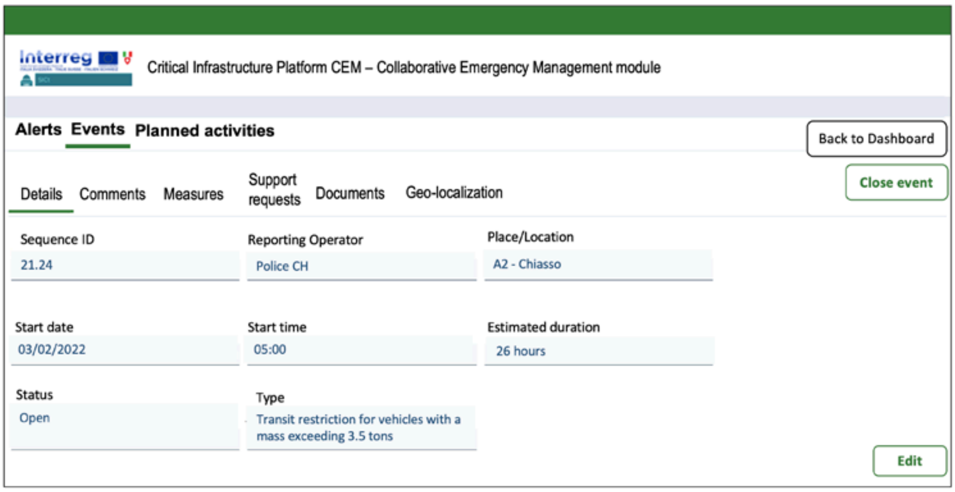

Figure 16. Event issued by Police CH

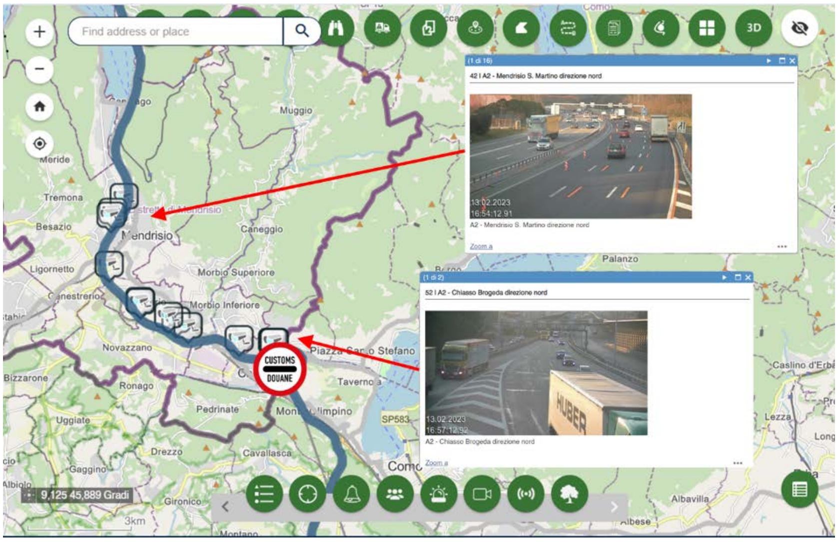

Figure 17. Traffic monitoring cameras located near customs and on the A2 highway in Switzerland.

Day 5		
PIC functionality	**Exchanged information**	**Comment**
Event (closure)	The Swiss Police, as the organisation that entered the events in PIC, can now close the events communicating the closure of storage areas, the end of transit limitations and thus the normalisation of the traffic in the Italian and Swiss territory.	Organisations are simultaneously informed about traffic normalisation.

This simple use case demonstrates the use of the main PIC functionalities, and the advanced ways of sharing information relevant to improved management of CI disruptions. This includes information on the functioning of CI, the insertion of alerts into PIC and the implementation of a series of measures aimed at limiting the impacts of disruption along the Italian and Swiss road infrastructures. In addition, we have shown the potential of PIC to manage all the related cascading events triggered by the snowfall, for example handling the transit and storage of freight vehicles in specific road sections.

DISCUSSION

PIC acts as an omnidirectional communication channel where all the authenticated Italian and Swiss organizations are informed in real time about Entities. Each user has access to the same information, which is kept updated as the situation or measures change. Based on the available information, and previously analysed CI interdependencies (functional, geographical, logical), they can estimate the impact in their area and on their own organization.

PIC addresses common obstacles in inter-organisational information sharing including interoperability, incomplete data, situational awareness, reliability and timeliness of information, cross-border language and standardisation differences and coordination capabilities. PIC is designed to support communication and coordination both in emergencies and in the preparedness/planning phase. In this specific domain, i.e. dealing with i) disruptions of networked CI which ii) span across borders and iii) involve public and private (CI operators) stakeholders – there are few digital platforms, with limited information available. PIC shares many common characteristics with the existing platforms, and it also provides advanced functionalities. PIC allows for effective monitoring, information sharing and operational coordination in critical situations, and it is a technology piece supporting a wider regional CI resilience strategy aimed to harmonise transboundary organizational and operational emergency response models.

The presented use case was also used to validate the software design against the collected requirements, to test the software and its quality and as a framework for the end-user online training and manual for platform use. A series of webinars were conducted based on this use case, while additional trainings on PIC (two in each country) were conducted, involving Swiss and Italian stakeholders and giving them a hands-on experience. Making the regional CI stakeholders familiar with PIC is an essential part of the preparation for a full-scale exercise.

During the webinars and training, the stakeholders pointed out the convenience of having PIC integrated with their current systems to avoid duplicating work. They also appreciated that PIC replaces traditional and inefficient means of communication, such as phone and email, and facilitates missing information-sharing links between regional CI stakeholders, as demonstrated in the use case. The authentication process for PIC was also discussed during training, with some stakeholders preferring organization-level accounts, while the current accounts are individual, providing visibility into individual activities. The proposed option will be further evaluated, while other inputs from the stakeholders were already implemented, as presented in this paper.

PIC is a modular application consisting of different components that could be transferable if supplied with required data. PIC is also integrated with external applications. For example, GRRASP-DMCI tool (Galbusera, et al., 2020), an external module integrated with PIC (Petrenj et al., 2021), allows users to create and run customized simulations of disruption scenarios, taking into consideration functional, geographical and logical interdependencies among cross-border transportation network nodes. The model uses data provided directly by the CI operators, and. was calibrated and validated through the replication of a real event. The simulations help understand i) the criticality of different nodes; ii) the potential impact of disruptive events on interdependent CI systems; iii) the benefits of different resilience strategies. The simulations have also supported the integrated risk analysis which helped to position a fixed and mobile monitoring network for cross-border CI. The live streams accessible through CI operators' webcams are already available and teams in the field can also upload photos and videos. New coordinated response plans for relevant disruption scenarios are established.

CONCLUSIONS

The paper contributes to the empirical investigation of information-sharing which includes CI operators, with a focus on improving cross-border inter-organizational protection and resilience of interdependent CI systems. A collaborative approach among stakeholders, based on information-sharing is crucial within the CIR mission (DHS, 2016). In the European context, the cross-border aspect is extremely relevant – Internal border regions cover 40% of the EU's territory, accounting for 30% of its population (150 million people) and hosting almost 2 million cross-border commuters (EU CoR, 2021).

The technology, which operationalizes interactions and improves information-sharing efficiency, is just one side of the solution since there are organizational and social dimensions of inter-organizational CIR. For different organizations (public and private), coming from different regions and/or countries, there are numerous barriers to working together, which requires a systematic and comprehensive approach to establish collaborative CIR programs (Trucco and Petrenj, 2017; Adrot et al., 2018).

Future work will focus on several directions. One approach is to demonstrate the additional modules of the platform through more use cases or a more complex scenario involving all modules. It is also relevant to evaluate the benefits of PIC in terms of its ability to tackle the common issues and barriers faced in inter-organizational information-sharing and collaboration in CIR. The overall approach is to use PIC as an instrument to support the development of other inter-organizational resilience capabilities, thanks to the new information-sharing abilities. Finally, a full-scale exercise will be conducted to assess the benefits of PIC in a close-to-real environment.

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