Information-Sharing in Cross-border Critical Infrastructure Resilience: evaluating the benefits of a digital platform

Boris Petrenj, Mariachiara Piraina, Giada Feletti and Paolo Trucco

School of Management, Politecnico di Milano, Italy. E-mail: boris.petrenj@polimi.it,
mariachiara.piraina@polimi.it, giada.feletti@polimi.it, paolo.trucco@polimi.it

Modern Critical Infrastructure (CI) systems are becoming increasingly interconnected across international borders. Even minor disruptions to these complex systems can have significant impacts on the economic and social functions of the affected country and beyond. To increase the resilience of CI, stakeholder organizations must collaborate and exchange information at the local level throughout the Emergency Management (EM) cycle. Public-Private Collaborations (PPCs) allow for a more coordinated and effective response to threats and emergencies that may arise by bringing together the stakeholders. The Critical Infrastructure Platform (PIC) is an ICT tool aimed to support a cross-border regional resilience strategy between Lombardy Region (Italy) and Canton Ticino (Switzerland), by enabling secure and effective information-sharing, inter-organizational risk assessment, monitoring, and operational coordination under critical operating conditions and severe disruptive events. The paper evaluates the benefits of PIC to improve the resilience of networked CI systems in a cross-border region by its capacity to address common barriers and challenges of inter-organizational information-sharing and collaboration.

Keywords: Critical Infrastructure Resilience, Cross-border, Information-sharing, Digital platform, Benefits.

1. Introduction

The increasing frequency of unforeseen disruptive events highlights the importance of the continuity of vital services provided by Critical Infrastructure (CI) systems, which play a vital role in a society's health, safety, security, economy, and social well-being. Interconnections between these systems increase their efficiency but also their vulnerability and susceptibility to disruptions (Wróbel 2019). A loss of functionality of a single CI or its part could lead to widespread cascading disruptions (Lewis and Petit, 2019), emphasizing the need for organizational awareness and resilience (Adini et al. 2017). Critical Infrastructure Resilience (CIR) aims to ensure the continuity of CI services in the event of disruption by preventing or limiting the impacts and enabling fast response and recovery to normal service conditions (Kozine et al., 2018).

Public-Private Collaborations (PPCs) adopt a collaborative approach, which is required to enhance CIR, through the adoption of an all-hazard approach, gathering complementary skills and resources from the public and private sectors (Trucco and Petrenj 2017; Fisher et al., 2018).

CI systems can span national borders, requiring an effective management approach that considers cross-border interdependencies. It is imperative for the EU to improve preparedness and risk mitigation to enhance CIR effectively (EC, 2020). To foster collaboration among countries, it is crucial to design systems that support CI management during both emergencies and routine operations. Despite the acknowledged importance of information sharing, limited empirical research has been conducted in this area (Reilly et al. 2018). Current methods and tools may not be suitable for ensuring collaboration between different actors (Benaben et al. 2017), nor do they often consider the inter-organizational dimension (Noori et al. 2016). Sharing sensitive information about vulnerabilities and dependencies can be difficult, and cross-border communication adds challenges such as administration, economy, culture, language, and technology (Adrot et al. 2018).

The aim of the paper is to evaluate the benefits of a digital platform developed to support a joint cross-border regional resilience strategy between the Lombardy Region (Italy) and Canton Ticino (Switzerland). The main goal of PIC is to

support secure and effective information-sharing, inter-organizational risk assessment, monitoring, and operational coordination during emergencies.

The paper is structured as follows: Section 2 presents the methodology used to assess the benefits of the PIC platform in the context of cross-border PPC. In Section 3, we provide a brief overview of PIC modules and functionalities. The evaluation of the benefits of PIC is discussed in section 4, and the paper concludes with a summary of the main contributions, limitations, and avenues for further research.

2. Methodology

We depart from a taxonomy provided in a comprehensive review study on general issues and barriers to information sharing and collaboration in critical infrastructure crisis scenarios by Petrenj et al. (2013). This taxonomy categorizes issues/barriers by their nature as: social/cognitive, organizational, and technical. As issues and barriers are often described at different levels of detail, the taxonomy provides a two-level description. The first level gives a high-level issue/barrier name, while the second level provides a description of the issue/barrier, which can include several specific (lower-level) issues/barriers or contain examples with characteristics of a particular case from which it had been extracted. In this paper, we keep the first level classification as is, while at the second level, we transform the description into a set of specific issues/barriers as elements of the main one.

As our evaluation focuses on the benefits of the PIC platform, which was developed and used in the context of cross-border collaboration between the Lombardy Region (Italy) and Canton Ticino (Switzerland), we base the evaluation on the issues/barriers that manifested in the same context. We do this by analyzing transcripts of a series of interviews with stakeholders from both countries, mapping issues and barriers as brought up by the interviewees. By adjusting the taxonomy to the application case, we can assess the benefits of PIC based on its ability to address issues/barriers pointed out by the practitioners, who are the primary users of the platform. The interviews were conducted during 2020, involving road and rail operators, Police, Emergency Medical Services, Firefighters, and Civil Protection, both in Lombardy and Ticino.

3. Critical Infrastructure Platform

The Critical Infrastructure Platform (PIC) is a web application developed as part of the INTERREG SICt project (http://www.sict-project.eu/), aimed at fostering a collaborative approach to managing resources and emergency events concerning transportation infrastructure (Petrenj et al., 2021). Its technological features and access mode allow accredited users, such as institutional bodies, infrastructure managers, and first responders, to consult and exchange information in real time. PIC provides information-sharing functionalities that increase knowledge of cross-border CI, create joint monitoring systems and procedures, and strengthen measures and actions for mitigating service disruption risks and enhance coordinated recovery actions. The platform is a modular application consisting of different components that provide specific functionalities (Figure 1), and it is integrated with external applications that interact with the platform.

In the following, we present the main modules and functionalities of PIC.

3.1. *Collaborative Emergency Management module*

The Collaborative Emergency Management (CEM) module manages three main entities: Alerts, Events, and Planned (non-emergency) Activities. The module serves as an information-sharing system to support managing emergencies and coordinating response actions. The module contains a tab for each entity type, which offer tools for inserting new Alerts, Events, and Planned Activities. Each contains sub-tabs that allow users to see/add/edit details, comments, related documents, response measures, support requests, and geo-localization for each entity. The module grants permissions for information consultation and operations based on the user's institution information.
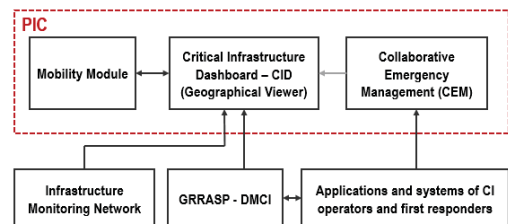

Figure 1. Simplified PIC logical architecture

A new entity can be created by inserting the relevant information through a customized form, and all users receive a notification via email to be informed. After creation, Events and Planned Activities can be geo-located in the specific sub-tab by adding a point, a line, or a polygon to the map. All the geo-located 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 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.

During an event, additional information, such as the presence of dangerous substances and their quantity, numbers of involved persons, and the number and type of vehicles involved, can be added. Operators can also declare their state of emergency, notify about the closure of an event, and implemented response and recovery actions.

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.

3.2. *Geographic Viewer*

The Geographic Viewer (i.e. Critical Infrastructure Dashboard – CID) is the GIS component of PIC that enables users to see, explore, and analyze data on a map. The essential functional tools of the CID are the following.

Traffic Management Measures (Borghetti et al., 2021) tool offers users guidance on implementing measures during a major event that affects the road or rail network, such as alternative routes or replacement bus services. Users can set parameters for the day, time, and duration of the event to display a set of measures with detailed descriptions and responsible persons available in PDF format, and associated with geographic information layers that can be viewed on a map.

Dangerous Goods Transport tool estimates the areas affected by dangerous goods spills and identifies sensitive targets within them. The tool calculates the impact area based on the type of substance, scenario, and spill, and highlights sensitive targets within it. After processing, the tool displays the targets falling within the impact area on the map, along with their associated alphanumeric information.

Emergency Support Search tool helps users locate emergency management facilities in a defined area by inputting an address or drawing a point on a map and selecting the search diameter. The tool then shows the survey area on a map and provides a list of facilities within it, along with their available information. The CEM can then be used to request support.

Re-routing tool helps users plan their route taking into account disruptions or relevant events that may affect their journey. The tool allows users to input addresses or select points on the map, and choose between travel time or distance for route calculation. It also offers an option to identify alternative routes when there are disruptions. The results are displayed on the map, along with a list of detailed information.

GRRASP tool. The *Dynamic Functional Modelling of vulnerability and inoperability of CI – DMCI* (Galbusera et al., 2020) is a simulation that analyzes the behavior of CI systems when a threat impacts one or more infrastructure nodes. It considers the interdependencies between network components, within and between infrastructures, and simulates the propagation of inoperability and demand variations (Trucco and Petrenj, 2023). The model, integrated into the *Geospatial Risk and Resilience Assessment Platform* – GRRASP of the EC's JRC Ispra (Giannopoulos and Galbusera, 2018), helps understand the criticality of nodes, the potential impact of disruptive events, and the benefits of different resilience strategies. The application can be accessed through PIC and customized analyses can be created using pre-populated datasets collected from CI operators and publicly available sources.

4. Evaluation of Benefits

The benefits were assessed by confronting the issues/barriers with the PIC's ability to overcome them. To determine the significance of each issue/barrier (Low/Medium/High) in this particular context, we considered the perceptions of the interviewees, including the specific language they used and the frequency of their occurrence across various organizations that were interviewed. The PIC contribution level (Low/Medium/High) was estimated by the authors based on the way the issue is addressed.

The detailed results of the analysis are reported in Annex A.

5. Conclusions

The present work aims at evaluating the benefits of using a newly developed digital platform (PIC) as a tool for enhancing the resilience of cross-border CI, in the context of the collaboration between Lombardy Region (Italy) and Canton Ticino (Switzerland) under the SICt project. The importance of establishing a proper information-sharing mechanism is recognized in literature, while the empirical investigation is still limited.

The mapping and contextualization of the issues and barriers to information-sharing and collaboration in this study, compared to the full taxonomy, revealed that there is no unwillingness to share and that the social issues are mostly related to situational and team awareness and cognitive information processing. The issues of organizational nature are present and well acknowledged, primarily the differences between the partnering organizations and the information flows. The majority of the technical barriers were present as the main obstacle to the development of cross-border resilience capacities.

PIC effectively addresses all present issues/barriers with satisfactory levels of contribution (medium/high), but its success is not solely attributed to the technical solution itself. It is achieved through the combined efforts of the PPC and other initiatives surrounding PIC. This study highlights the importance of a shared digital platform in enhancing cross-border collaboration and coordination for emergency management, ultimately improving the resilience of the CI network. However, realizing the full potential of such a platform requires a systematic and comprehensive regional approach, such as a CIR strategy and program, and the unwavering commitment of key stakeholders.

Acknowledgement

References

Adini, B. et al. 2017. "Striving to Be Resilient: What Concepts , Approaches and Practices Should Be Incorporated in Resilience Management Guidelines?" *Tech. Forecasting and Social Change* 121: 39–49.

Adrot, A. et al. 2018. "Challenges in Establishing Cross-Border Resilience." *Urban Disaster Resilience and Security*, 429–57.

Benaben, F. et al. 2017. "A Conceptual Framework and a Suite of Tools to Support Crisis Management." *The Annual Hawaii Int. Conf. on System Sciences*.

Borghetti, F., B. Petrenj, P. Trucco, V. Calabrese, M. Ponti, and G. Marchionni. "Multi-level approach to assessing the resilience of road network infrastructure." *International Journal of Critical Infrastructures* 17, no. 2 (2021): 97-132.

European Commission. 2020. "Prevention and Preparedness for Cross-Border Risks, Funding & Tender Opportunities Portal." 2020.

Fisher, R., M. Norman, and J. Peerenboom. 2018. "Resilience History and Focus in the USA." *Urban Disaster Resilience and Security*, 91–109.

Galbusera, L., P. Trucco, and G. Giannopoulos. "Modeling interdependencies in multi-sectoral critical infrastructure systems: Evolving the DMCI approach." *RESS* 203 (2020): 107072.

Giannopoulos, G., & Galbusera, L. (2018). GRRASP version 3.1 User Manual. JRC Technical Manual.

Kozine, I., B. Petrenj, and P. Trucco. 2018. "Resilience Capacities Assessment for Critical Infrastructures Disruption: The READ Framework (Part 1)." *Int. Journal of Critical Infrastructures* 14 (3): 199.

Lewis, L. P., and F. Petit. 2019. "Critical Infrastructure Interdependency Analysis: Operationalising Resilience Strategies." *ANL, IL (USA)*, 1–33.

Noori, N.A., J.J. Wolbers, F.K. Boersma, and X.V. Cardona. 2016. "A Dynamic Perspective of Emerging Coordination Clusters in Crisis Response Networks." In *ISCRAM 2016*.

Petrenj, B., E. Lettieri, and P. Trucco. "Information sharing and collaboration for critical infrastructure resilience–a comprehensive review on barriers and emerging capabilities." *International journal of critical infrastructures* 9, no. 4 (2013): 304-329.

Petrenj, B., M. Piraina, G. Feletti, P. Trucco, V. Urbano, and S. Gelmi. "Cross-border Information Sharing for Critical Infrastructure Resilience: Requirements and Platform Architecture." *ISCRAM 2021*

Reilly, P., E. Serafinelli, R. Stevenson, L. Petersen, and L. Fallou. 2018. "Enhancing Critical Infrastructure Resilience through Information-Sharing: Recommendations for European Critical Infrastructure Operators." *Transforming Digital Worlds, Sheffield, UK.* 10766 LNCS: 120–25.

Trucco, P., and B. Petrenj. 2017. "Resilience of Critical Infrastructures: Benefits and Challenges from Emerging Practices and Programmes at Local Level." In *Resilience and Risk*, 225–86.

Trucco, P., and B. Petrenj. "Characterisation of resilience metrics in full-scale applications to interdependent infrastructure systems." *Reliability Engineering & System Safety* (2023): 109200.

Wróbel, R. 2019. "Dependencies of Elements Recognized as Critical Infrastructure of the State." *Transportation Research Procedia* 40: 1625–32.

ANNEX A – Analysis of PIC benefits against relevant issues and barriers to inter-organizational information sharing

High level issues/barriers	Key elements of issues and barriers / description	Perceived issue/barrier relevance level in SICt (bold) + How is expressed in the SICt context	Estimated PIC contribution level (bold) + How the issue/barrier is addressed
Communication system and information quality (Technical)	Inadequate communication systems (slow and time-consuming communication means)	**High.** Cross-border communication must follow specific protocols that slow down the entire process and the emergency response.	**High.** The communication is streamlined, PIC provides means to instantly reach other users (stakeholders)
	Communications easily distorted and hindered by noisy conditions	**Low** (no remarks brought up)	**Medium.** PIC makes the most important information stand out, but in complex or widespread scenarios it can still be an issue
	Large amounts of imprecise information are generated mismatched in location and/or time	**Low** (no remarks brought up)	**High.** Information is complete (thanks to templates), source and location are tracked
	Acting without awareness of the impact on other organizations	**High.** There is a lack of communication among operators of interdependent CI, both in the phases of alert and during an event.	**High.** There is an improved awareness of specific interdependencies between regional CI, and actors can better understand consequences of their actions
Infeasibility to centrally manage (Technical)	No overarching body to coordinate and develop an information sharing system	**Medium.** The absence of an overarching body to coordinate and develop an information sharing system can pose issues in the cross-border communication.	**High.** The Lombardy Region led the development of a common digital platform (PIC), and together with the Swiss Police coordinated the stakeholder engagement and the requirements collection.
	Multiple levels of coordination and no common authority (central control however limits possibilities in a network-type organization)	**Medium.** The presence of multiple levels of coordination can pose issues in the cross-border communication.	**Low.** Information flows and the quality of shared information is improved by PIC
Poor security (Technical)	Inadequate capabilities for sharing classified and sensitive information	**High**. Some operators, mainly the ones of healthcare sectors, highlighted issues related to sensitive information about the patients that complicates a cross-border collaboration.	**Medium.** There are still no mechanisms to share sensitive info, but permissions to read/write are granted through a specific profiling system based on the user's institution information
	Privacy and authentication	**High.** Due to national legislations, there are issues related to the privacy of the information that should be communicated to operators of another country.	**Medium.** The authenticated organizations are granted the access to PIC (individual accounts). IT and CH are working on a set of shared rules valid at cross-border level to harmonize the organizational and operational emergency response models

High level issues/barriers	Key elements of issues and barriers / description	Perceived issue/barrier relevance level in SICt (bold) + How is expressed in the SICt context	Estimated PIC contribution level (bold) + How the issue/barrier is addressed
Limited system interoperability (Technical)	Physical interoperability; data, information and knowledge interoperability; aligned procedures, operations and high-level objectives.	**High**. The information systems of the operators are not interoperable among them.	**High.** Technical interoperability sorted out - information systems of the users (stakeholder organizations) were integrated to enable automatic data ingestion (e.g. contents of webcams owned by CI operators)
Lines of information flow (Organizational)	Ad-hoc information flows	**High**. Each organization intervening in response must follow ad-hoc information flows. This makes difficult to communicate with the required actors according to the situation.	**High.** PIC makes it much easier to find and contact specific actor. Information flows in different scenarios were revised according to the PIC capabilities.
	Top-down crisis management – organizational (information) silos	**Medium**. A top-down crisis management approach makes the coordination with other actors difficult.	**Medium.** PIC enables horizontal info-sharing but it is up to the member organization how to use it
	Lack of feedback (tracking the usage and performance of the IS)	**Low** (no remarks brought up)	**Medium.** There were no negative remarks, but the feedback collection is still ongoing. PIC has been developed based on the user requirements.
Differences among organizations (Organizational)	Language	**Low**. Both regions use Italian language. However, there were misalignments in technical vocabulary, taxonomies and measurement standards.	**High.** A common dictionary has been established to align the terms related to disaster risk, emergency management and CI.
	Organizational structure	**Medium.** IT and CH organizations work with different organizational structures, which can hinder proper collaboration on cross-border emergencies.	**Medium.** PIC supports various organizational structures
	Procedures and processes	**High**. IT and CH organizations have to follow different processes and procedures and, in some cases, this hinders the possibility to properly collaborate on cross-border emergencies.	**Medium.** Shared rules are being developed (Agreements, Guidelines, documents) valid at cross-border level to harmonize the organizational and operational emergency response models
	Technology, resources and skills	**Medium**. Differences in IT and CH resources and skills make it difficult to identify the correct responsibilities in the event of cross-border emergencies. Even the usage of different tools can make the response operations more complex.	**Medium.** PIC replaces traditional means of communication and is integrated with stakeholders' current systems to avoid duplicating work.
	Culture, knowledge and experience	**High**. Differences in laws and regulations complicates a joint response to emergency events.	**Medium.** Cross-border agreements are being developed. joint training sessions and exercises held.
No incentives for cross-agency info sharing (Organizational)	Incentives for cross-organizational information sharing largely missing at all (institutional, organizational and individual) levels	**Medium**. Incentives for cross-organizational information sharing are not present.	**Low.** No direct incentives to share information

High level issues/barriers	Key elements of issues and barriers / description	Perceived issue/barrier relevance level in SICt (bold) + How is expressed in the SICt context	Estimated PIC contribution level (bold) + How the issue/barrier is addressed
Lack of joint activities causing poor cross-organizational relations (Organizational)	Inadequate joint training programs and training standards	**Low**. Italian and Swiss actors have already started to perform cross-border trainings to test the response coordination	**High.** Common trainings and exercises on PIC are delivered for both countries (or held jointly)
	Contact persons not well defined	**High**. Contact persons are not diffused to all the players involved in the emergency response. This hinders an effective coordination and collaboration between the two countries.	**Medium.** There is a contact list but still the users should know which person/role they need to contact in a particular situation
	Poor understanding of each other's' capabilities and capacities	**High**. The lack of knowledge about capabilities and activation mechanisms of the cross-border emergency operators can be an obstacle for the collaboration and coordination of response actions.	**Medium.** Through PIC, the stakeholders are getting to know about each other's assets, resources and capabilities and they are already able to request support
	No tradition of info sharing	**Low** (no remarks brought up)	**Medium.** Information sharing between some CIR stakeholders has started in 2008 in Lombardy. Cross-border info-sharing existed but was limited.
	Lack of shared communication plan and structure for coordinated planning	**Medium**. There are no shared communication plans and structures for coordinated planning.	**Medium.** Communication plans for relevant scenarios are being developed leveraging the PIC capabilities
Mismatch between goals (Organizational)	Unclear or unspecified incident objectives	**Low** (no remarks brought up)	**Medium.** The objectives are still set by the organization(s) directly involved in the incident. Other stakeholders adjust their activities accordingly to mitigate possible impacts.
Role ambiguity (Organizational)	Poor allocation of responsibilities and conflicting role structures	**Low** (no remarks brought up)	**Medium.** Scenarios used in training improve it.
Unbalanced workload distribution (Organizational)	Inadequate level of participation between personnel	**Low** (no remarks brought up)	**Medium.** Requests for support in emergencies enabled by PIC can improve this aspect between organizations
Team awareness (Social/Cognitive)	Imprecise knowledge on personnel active in the response – real-rime recognition of collaborators' identity and their actions	**High.** The list of personnel active in the response is not always diffused to all the actors involved in the emergency. This increases the response time and complicates the interventions.	**High.** The location of resources is tracked inside the CID. Actors in the field can upload information in real-time.

High level issues/barriers	Key elements of issues and barriers / description	Perceived issue/barrier relevance level in SICt (bold) + How is expressed in the SICt context	Estimated PIC contribution level (bold) + How the issue/barrier is addressed
Situational Awareness (Common Operational Picture) (Social/Cognitive)	Level 1: Perceive – the perception of the elements in the environment within a volume of time and space Level 2: Understand – the comprehension of their meaning Level 3: Think ahead – the projection of their status in the near future	**High.** The lack of an integrated platform that gathers all the information related to the territory, as well as infrastructure status and specific disruptions, does not allow having a common picture of the reference area.	**High.** PIC provides a shared perception of the CI disruption and the environment (Level 1). It also facilitates a comprehension of the meaning for organizations involved in the disruption, such as impacts (Level 2). The estimate/projection of the disruption development (cascading effects of CI disruption; foreseen restoration times) support level 3 of the situational awareness.
Integration of information and cognitive overload (Social/Cognitive)	Difficult to find needed information	**High.** Information related to CI status (e.g., construction sites, blocked rails) are not shared with all the interested operators. This can arise issues during the emergency response.	**High.** All the available information is fused and showed in the CID, including planned activities (e.g. construction works), and can be filtered to easy navigation
	Cognitive overload at individual level	**Low** (no remarks brought up)	**Medium.** The way information is presented can improve users' cognitive capacity
	Ineffective mechanisms to fuse related information	**High.** Each operator uses its own tools and platforms to collect information related to emergency events. Therefore, there isn't any mechanism to fuse and gather all the information.	**High.** Information is fused around each entity (Alerts, Events, Planned Activities), while all entities and resources are fused in the CID.
No awareness of partners' info needs (Social/Cognitive)	No awareness of the kind of information other organizations require neither what information they possess	**Medium**. Actors are not always aware about the information that other operators possess.	**Medium.** Information flows in incidents are being mapped, including the contents. The gaps are identified and filled.
Lack of trust (Social/Cognitive)	Risk of a misuse of the shared information against its provider (e.g. business advantage)	**Low** (no remarks brought up)	**Low.** No mechanisms to prevent this. Still, no sensitive information is currently included in PIC
	Lack of trust in the quality of information provided by the IS	**Low** (no remarks brought up).	**High.** The quality is notably improved with details on geolocation, images, livestreams, and info source.
	No confidence in government's ability to protect strategic info	**Low** (no remarks brought up)	**Medium.** PIC focuses on sharing non-sensitive details of the disruptive events. If needed, the government can get restricted access to specific info.
Mental model (Social/Cognitive)	'One way thinking' and unwillingness to share	**Low** (no remarks brought up)	**Medium.** The key stakeholders are registered to PIC, which should also motivate the remaining ones
Tools not used effectively (Social/Cognitive)	Users not skilled for using tools effectively (e.g. when not used regularly, during normal operations)	**Low** (no remarks brought up)	**High.** A series of webinars and trainings are held for the participating organizations in both countries