Good Practices for Critical Infrastructure Resilience: a framework for assessment and selection

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Abstract

Accidental and intentional disruptive events affecting Critical Infrastructure (CI) systems are dramatically increase on a global scale and put pressure on governments and CI operators to further improve technical and organizational capacities for securing the continuity of service. Experts in the field call for collaborative approaches to managing CI interdependencies and mitigate domino effects, which amplify the impact of disruptions over space, time and social functions. This paper presents an *integrated framework for the classification, assessment and selection of Good Practices (GPs) in the Critical Infrastructure Resilience domain* ï ó CRAFTER ô from the perspective of collaborative Emergency Management (EM) capacity building. The GPs mainly come from local and national level actions and programmes, emphasising the importance of fostering collaborative processes among stakeholders. The study identified 53 GPs through a systematic analysis of available scientific literature and research projects in the CI domain, which were used in the development of the CRAFTER framework. The framework was refined and validated through a questionnaire administered to CI experts, as a way to integrate theory-based and practitioner-based knowledge. The GPs were then classified and assessed according to their intended application context, the activities and functionalities covered, and the EM capabilities they support. The CRAFTER framework enables the assessment and benchmarking of GPs showing their strengths and weaknesses when used to build EM capabilities. It also supports practitioners in selecting a minimal effective bundle of GPS under different institutional and operational contexts, making sure that all the EM phases and capabilities are adequately covered.

Keywords: Critical Infrastructure, Resilience, Good Practice, Emergency Management, Capability, Collaborative approaches.

1. Introduction

The term Critical Infrastructure (CI) refers to assets or systems that provide essential goods and services for the health, safety, security, economy and well-being of a society (European Commission, 2008). They are deemed as critical since their ñincapacity or destruction would have a debilitating impact on the defense and economic securityò (President ô s Commission on Critical Infrastructure Protection, 1997). Some examples of CI systems are communications, energy supply, IT and networks, food and water supply, healthcare, transport and financial services or the public administration operations (Wróbel, 2019).

Due to their multiple vulnerabilities and (inter)dependencies, CI systems are increasingly susceptible to the occurrence of unexpected disruptions and accident events, highlighting the need of enhancing organizational awareness and of improving the ability to effectively respond to unforeseen events (Adini et al., 2017). Moreover, under the influence of (inter)dependencies, an event affecting a specific CI can produce large-scale cascading disruptions, spreading ripple or domino effects throughout interconnected CI systems (Wróbel, 2019).

The level of complexity in interconnected CI systems justifies the need of adopting collaborative efforts among various organizations and calls for a shift from a purely protective strategy (Moteff et al., 2003) to a more holistic resilience perspective (Pursiainen and Gattinesi, 2014; Pant et al., 2014; Alsubaie et al., 2015). Critical Infrastructure Resilience (CIR) is aimed at ensuring functional continuity of critical services when a disruption occurs, not only by preventing or limiting the extent of related impacts, but also enabling a faster response and recovery to normal service conditions even when CI is severely damaged (Trucco and Petrenj, 2015a). In this regard, a system can be considered resilient if it embeds ñabilities to prevent disruptions, absorb disruption consequences, restore lost performance, adapt to different possible scenarios (short-term) and circumstances (long-term), and overall, prepare to achieve those goals and develop those abilitiesò (Kozine et al., 2018). In order to reach these abilities, Resilience management guidelines are needed to support stakeholders in making strategic decisions to guarantee the continuity of operations, effectively respond and recover from failures and adaptively meet unpredictable demands. As a result, the actors involved would have a clear understanding of their responsibilities and shared knowledge about Resilience management (Adini et al., 2017).

In the last decade, governments, agencies and business organizations designed, implemented and tested a plethora of strategies, programmes and measures to improve CIR. However, a clear view on the suitability, effectiveness and conditions for a successful application of these practices is still lacking. Furthermore, in spite of the large number of documented Good Practices (GPs) ï which can be defined as methods or techniques that are applied to solve existing problems producing effective results and bringing benefits to the users - in the context of CIR, these have often proved to be insufficient to cover the wide spectrum of EM and resilience capabilities needed to cope with severe events (Jonathan Clarke et al., 2015). In addition, the importance of implementing coherent and aligned practices within and between various organizations is a prerequisite for an effective management of (inter)dependencies, which emphasizes the importance of relying on a structured and robust framework for effective EM of interconnected CI systems.

In light of the previous considerations, this study wants to answer the following RQs:

RQ1: How to characterize Good Practices (GPs) in the field of Critical Infrastructure Resilience (CIR)?

RQ2: What is the contribution of existing GPs to the enhancement of Emergency Management capabilities in the context of CIR programmes?

RQ3: How to identify minimal effective bundles of GPs to achieve higher resilience against CI disruptions?

We depart from the identification of the dimensions that enable the classification of CIR related GPs. Each GP is then analysed to understand how it contributes to building core EM capabilities and ultimately enhancing CIR. Finally, minimal effective bundles of GPs are selected in order to suggest the most effective combinations of GPs under different organisational and operational contexts. The study collectively answers the RQs by developing a comprehensive framework for the classification, assessment and selection of CIR related GPs. Results are expected to foster a better harmonized and collaborative EM model for coping with accidents and disruptions affecting interconnected CI systems.

The remainder of the paper is organized as follows. Section 2 presents the theoretical background, while Section 3 describes the research method. Section 4 presents the review of the selected GPs that leads to the development of an assessment framework for CIR related GPs, detailed in Section 5. The results are presented and discussed in Section 6. Finally, the contributions, limitations and future developments of this study are summarized in the Conclusions section.

2. Background

In the last decade Public-Private Collaborations (PPCs) have emerged as the most promising and effective approach to deal with CIR issues (Dunn-Cavelty and Suter, 2009). PPCs are based on joint efforts of national, regional or local governments with the involvement of private sector (DHS, 2009; Dunn-Cavelty and Suter, 2009), given that CI systems span geographical borders and are in many cases owned by private operators (Clark et al., 2018). PPCs represent ña *comprehensive way for enhancing proactive risk management through an all-hazard approach, as well as for increasing the effectiveness of responsiveness and recovery by matching complementary skills, expertise and resources from public and private sectors*ò (Trucco and Petrenj, 2017). In many instances, CIR strategies are implemented through PPCs as the way for enhancing coordination, collaboration and information-sharing as stated by The US Presidential Policy Directive (PPD-21) on Critical Infrastructure Security and Resilience (The White House, 2013). Looking at the practical side of PPCs, they can take a variety of forms due to different focuses, sizes and governance models (Trucco and Petrenj, 2017).

Nevertheless, the establishment and management of PPCs is often challenging, failing to bring results as expected. The implementation of effective CIR strategies could therefore hugely benefit from proven approaches and GPs that support the collaboration of numerous stakeholders (e.g. CI operators, first responders, civil protection), at different institutional and operational levels (Trucco et al., 2015). While approaches ñ*are methods, ways of working or strategies that may be integrated and implemented in guidelines and procedures*ò, practices ñ*represent a solution that has been incorporated and implemented in a real environment*ò (Adini et al., 2017). Among the GPs, Best Practices (BPs) are ñ*commercial or professional procedures that are accepted or prescribed as being correct or most effective*ò (Oxford dictionary), thus they are the ones showing results superior to those achieved with other means (Trucco and Petrenj, 2015a). Firms and organizations rely on BPs, since they have proved to be effective in addressing similar past problems. However, BPs are not static, they have to be adjusted according to the new emerging applications and adapted to the specific needs of practitioners. Consequently, BPs are continuously improved and updated versions are released as soon as the conditions in the real application field evolve. By collecting evidence about the practices used in a particular context, it is possible to identify the one that represents the BP in a given context.

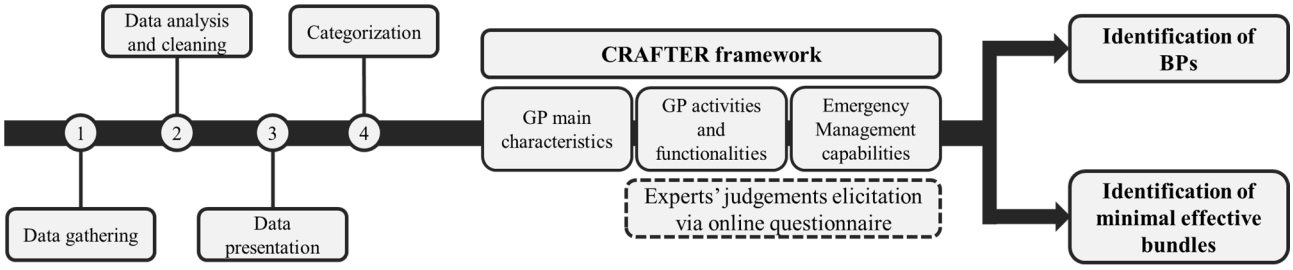
The shift from protection to resilience of CIs is also accompanied by a shift from an EM perspective based on procedure and plans (Penadés et al., 2017) to a resilience perspective focused on capability building (Kozine and Andersen, 2015; Lindbom et al. 2015; FEMA 2020). The adoption of this new approach is justified by the presence of a variety of threats and risks, which cannot be managed simply by analysing specific risk scenarios, but require an in-depth capability assessment (Lindbom et al. 2015). In this perspective, an organization that invests in enhancing its resilience capabilities should experience a progressive shift from a reactive approach to a proactive preparedness and finally to an adaptive capacity (Gibson and Tarrant 2010). In this work we refer to a capability as ña description of an [organisationôs] ability to do somethingò (NATO, 2018). This definition implies that organisational resilience can be measured by assessing how the range of EM capabilities can bring benefits in a changing and evolving context (Gibson and Tarrant 2010). However,

even if different definitions of EM capability are present in the literature (Lindbom et al., 2015), this concept is still not used on a practical level. In fact, organizations do not rely on the capability concept, but they refer to practices based on the aggregate adoption of resources, technologies and competencies. Considering the capability approach, the focus is not only on the amount of resources available, but also on the ability to properly use them (Clark et al., 2018). In particular, the attention is on the identification of those EM capabilities that are general enough to be applicable in different contexts and hazardous conditions, thus enabling an all-hazard approach (Kozine et al., 2018). Both intra- and inter- organizational capabilities are considered, i.e. those built within a single organization or built on the relationships between various organizations involved in the EM cycle.

3. Research method

The study departed from the identification and analysis of the GPs currently in use for managing CI-related disruption events. The method used to collect and systematise information consisted of the following four steps (Figure 1).

Figure 1. Research method



1. **Data gathering**. The most important projects in CIR domain were analysed (Trucco and Petrenj, 2015a; The Rockefeller Foundation, 2015; Horizon 2020; DARWIN Project, 2015; Resilens Project, 2016; SMR Project, 2015; Resolute Project, 2015) with the aim of collecting information about the most effective practices currently in use. Additional practices were identified by consulting scientific literature and institutional websites, where searches combined the keywords ñCritical Infrastructure*ò, ñResilienceò and ñPractice*ò.
2. **Data analysis and cleaning.** The information on every single practice was analysed to select the ones that were already implemented in practice, or at least piloted, and that are reasonably transferrable to other similar contexts using the information made available by the authors. At the end of this step, 53 GPs were selected.
3. **Data presentation.** Each GP was documented in a standardized way, using a common template, to clearly report the main objectives and features.
4. **Categorization.** Each GP was categorized against a unified classification taxonomy. From the previously collected information have emerged three relevant classification dimensions useful to properly characterize the different GPs and enable an effective comparison. These classification dimensions are: GP main characteristics, GP activities and functionalities, and EM capabilities directly supported.

The information collected from scientific literature, project reports and institutional websites were complemented with expertsô judgement, collected through an online questionnaire. The questionnaire intended to link the classified activities

and functionalities of GPs to the taxonomy of EM capabilities. In particular, the experts were asked to express an informed judgement on the importance (i.e. positive contribution) that different types of activities or functionalities, covered by the selected GPs, may have in building or improving a specific EM capability. The questionnaire was administered to about 150 international experts directly by email or through professional associations and 23 anonymous answers were collected.

The results of the questionnaire enabled to assess to what extent the EM capabilities are covered by the GPs. A Pareto analysis was then performed to identify the range of EM capabilities fully covered by each GP (i.e. its degree of comprehensiveness). The final ranking led to the identification of the BPs.

The assessment of GPsô contribution to EM capabilities revealed that only few GPs are able to fully cover the wide spectrum of capabilities required for an effective EM. Therefore, the study proceeded with the identification of minimal effective bundles of GPs that, combined together, are able to provide an optimal coverage of the EM capabilities needed to cope with CI disruptions.

4. Review of the selected GPs

The 53 selected GPs have the common aim of supporting organizations in the management of emergencies where CI systems are involved. However, they achieve this goal by adopting different methods, tools, technical solutions (e.g. specific IT systems) or organizational arrangements. To this end, GPs were clustered according to the main purpose and the most relevant functionalities. Annex 1 provides the list of GPs taken into consideration in the present study and their grouping into the six clusters.

The *Information sharing* cluster includes GPs aimed at facilitating the sharing of situational information or knowledge at an intra-organizational or inter-organisational levels and at different geographical scales (e.g. national or multinational. The GPs in this cluster are mainly web-based information-sharing platforms that facilitate collaboration and coordination between public, private and non-profit organizations, providing greater visibility of impacts and strengthening the resilience of communities. The constant collaboration among institutions leads to the development of integrated strategies for the management of CI emergencies, which take into consideration the presence of system interdependencies. This strategic alignment can help to avoid delays in the response phase and better organizing resources for rescue and recovery operations. This cluster includes also tools or programs that allow access to researches, knowledge and best practices, highlighting what has proved to work well in the implementation of specific policies by other partners. In this way, users can exploit these lessons learned, avoiding mistakes and guiding a more effective implementation of a resilience strategy, increasing their knowledge and expertise about CIR.

The *Geographical visualization and information sharing* cluster consists of GPs with the main purpose of sharing useful information and monitoring the areas of interest through geographical mapping tools that allow for a georeferenced visualization of resources, events, strategic places and possible dangerous situations. The GIS (Geographic Information System) mapping included in these tools enables showing the geolocation of emergency situations and monitoring areas through awareness systems supporting risk management and emergency response. This cluster also includes apps that can provide tailored instructions during emergencies and allow the public to upload content. The geographical visualization

provided by these GPs can support operators by showing the quickest way to reach the affected areas, as well as citizens by diverting traffic towards alternative routings, thus reducing congestions near the location of the emergency event.

The *Planning* cluster includes GPs that provide ad-hoc instructions, guidance notes, templates or structured steps to support CI operators and other stakeholders to cope with CI disruptions and to develop strategic resilience planning. In particular, they provide instructions on how to manage CI systems, focusing on the collection of relevant data and information, the identification of relevant stakeholders and (inter)dependencies between systems, the setting of priorities and needs for interventions, and finally, the development and implementation of a strategic plan. These GPs require a comprehensive and targeted organizational setup which includes the formation of teams, sub-teams and working groups, assigning them well-defined objectives, clear tasks and responsibilities according to expertsô background. The continuous communication and engagement with stakeholders, in some cases even including the general public (e.g. citizen associations and activated citizens), provides an important contribution in developing effective plans.

The *Training, exercising and simulations* cluster includes GPs - either in the form of tools (e.g. simulation platforms) or processes (e.g. workshops and exercise programs) ï aimed at providing adequate preparedness for CI operators, institutions and experts to deal with all the EM phases. Simulations platforms are based on a virtual environment where users can visualize the impacts of a CI disruption, testing specific response operations or policies and considering potential disruptions to resource availability. The obtained results allow validating the impacts of implementing different policies that could potentially be included in the resilience strategy of an area. By testing different scenarios, users can identify the implications of different policy options in the resilience improvement process and they can, therefore, use simulations as a training environment to find the right path towards improving local resilience. On the other hand, exercise programs deal with response, recovery and mitigation activities. They try to ensure better visibility of the available resources and needs present in affected areas, also finding a way to guarantee first aid. The analysis of cascading impacts is made through the development of different scenarios aimed at increasing awareness about vulnerabilities and interdependencies of CIs, so that it is possible to identify potential gaps in current plans and intervene to improve them. Indeed, starting from the results obtained by exercises, stakeholders have the opportunity to discuss emergency plans and to prioritize the actions needed to update them. Finally, workshops engage stakeholders, experts, and sometimes citizens, to communicate existing problems, trying to effectively understand their root causes and learn about new ways to solve them. These discussions lead to the identification of challenges and barriers that hinder opportunities and enable developing a vision statement and planning next steps to achieve these opportunities considering existing and needed resources.

The *Risk and Resilience assessment* cluster consists of GPs that supports the analysis of interdependencies and the risk and resilience assessment at different system levels. On the one side, tools based on flexible cartography approaches are used for the analysis of the interdependencies and the simulation of the domino effects, showing the location sectors where the consequences of the system failures are synthesized. Thanks to constant monitoring of the territory, they are able to assign a risk level to the areas that could be impacted by an emergency event. On the other side, practices that are based on structured steps or templates guide users throughout the whole process of risk or resilience assessment. In this regard, they support an assessment of how local shocks and stresses interact to impact specific assets, locations, business sectors, residents and users. This leads to a prioritization of shocks and stresses and to the identification of vulnerable physical assets. Based on the risk level assigned to the key hotspots, these GPs can provide access to policies recommendations supporting the identification of measures to mitigate risks within the area. A similar approach is followed to evaluate resilience levels of a region: starting from the identification of critical functions and

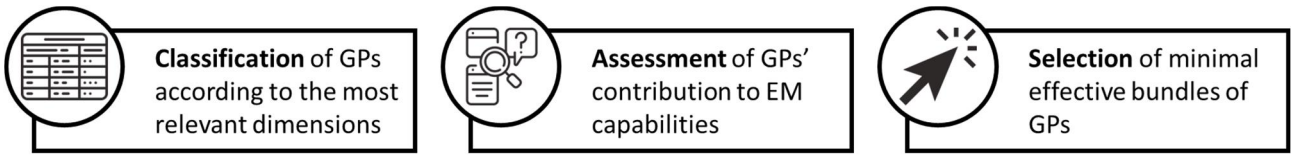
interdependencies of systems, resilience assessment tools generate a quantitative overall resilience score for CIs and individual resilience scores for specific assets, finally providing guidelines to enhance those resilience levels.

The *Business Continuity Management* (BCM) cluster refers to programs for embedding business continuity into organizations (BCM of an enterprise) and regions (Area BCM) helping them in coping with CI disruptions. On one side, traditional BCM systems are designed to prevent the interruption of the companyôs core business in emergency circumstances. On the other, Area BCM is aimed at securing critical resources (i.e. external goods and services) that are essential for supporting the business operations within and around an industrial area. The resulting plan addresses different issues: CI protection, coordinated disaster preparedness and response, quick recovery from damages, supply chain cooperation and monitoring of BCM activities.

5. CRAFTER: an assessment framework for CIR related GPs

The aim of this study is to develop a comprehensive framework for the classification, assessment and selection of GPs for CIR ï shortly named óCRAFTERô(Figure 2). In this perspective, we took the 53 selected GPs as a reference to identify the main features that can be used to characterize them and to recognize their most suitable application context. The identified features correspond to the dimensions that we introduced in the framework to enable an effective classification of GPs. Starting from this, we developed an approach to perform an assessment of GPs based on their contribution to the EM, so that it is possible to identify the best ones. Finally, the CRAFTER framework can be used to select optimal combinations of GPs that are able to enhance different mixes of EM capabilities to better fit with the peculiarities and needs of different operational and organisational contexts.

Figure 2. The three levels of the CRAFTER framework



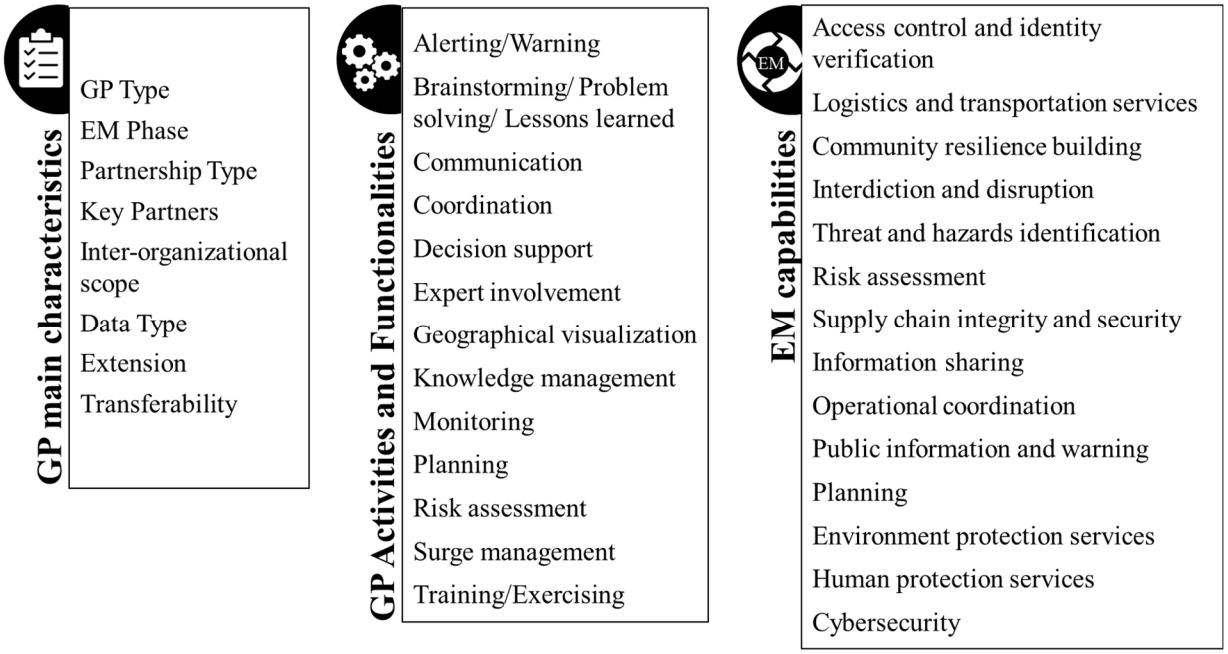
5.1. GPs classification

The classification level of the CRAFTER framework is made of three pillars related to the relevant aspects of the GPs:

- Specification of GPôs main characteristics;
- Specification of GPôs Activities and Functionalities;
- Specification of EM capabilities supported by the GP.

Figure 3 shows the structure of the integrated classification framework highlighting its components and the correspondent dimensions of classification.

Figure 3. Integrated classification framework



The pillar related to *GPõs main characteristics* includes several dimensions that highlight the relevant characteristics of each GP, considering the type of support they are able to provide, the stakeholders involved in its implementation, and the original context of application.

First, ***GP Type*** dimension specifies the GPs according to their nature (Trucco and Petrenj, 2015b):

- *Tools & Technologies* can be described as a piece of equipment or a software whose features are adequate to achieve a specific aim (Cambridge Dictionary, 2020). These GPs achieve their specific goals through a set of means, technologies, methods and techniques and can be described as a set of functionalities.
- *Processes* can be described as procedures or sets of actions and tasks performed by a single organization or a group of them to achieve a specific aim (Cambridge Dictionary, 2020). These GPs achieve their specific goals through actions, tasks, organizational arrangements and procedures and can be described as a coherent set of activities.

The ***EM Phase*** dimension identifies the phases of the EM cycle supported by a specific GP (Trucco and Petrenj, 2015b). Following the classification and the definitions provided by FEMA (2020), EM encompasses four phases: Preparedness, Mitigation, Response and Recovery. ***Partnership Type*** concerns the type of organizations involved in the collaboration (i.e. public organizations, private ones, or both). To further detail the Partnership Type, the ***Key Partners*** dimension is used to specify the stakeholders involved (i.e. public institutions, CI operators, universities, local communities, public and private companies, CI and resilience experts). The ***Inter-Organizational Scope*** dimension has been introduced to understand if the GP can be autonomously implemented by a single organization or requires collaboration with other actors (i.e. intra- or inter-organizational GPs). ***Data Type*** indicates if the GP is able to provide real-time support during an emergency, by showing real-time situational information. The ***Extension*** is concerned with the largest geographical area of documented applications of the GP (i.e. city, region, country, or more countries) ï according to the flexibility of the GP it may be possible to start using it for a limited area just as a pilot test and then to extend it to a larger area of

application. Finally, ***Transferability*** indicates if a GP can be applied only within a specific context or it can be flexibly and broadly applied in different cases (i.e. specific or broad).

The specification of *GPôs main characteristics* allows an exhaustive profiling of the 53 GPs ï it characterizes the nature of the GPs and the context of their use, thus highlighting their specificities or similarities as well as limitations in scope and the level of transferability.

The pillar related to *GPôs Activities and Functionalities* introduces an exhaustive set of activities and functionalities useful to specify the main features of both groups of GPs (Table 1), identified through the analysis of the 53 GPs taken as a reference. The specification of *GPôs Activities and Functionalities* enables to assess the level of support granted by the 53 GPs to the different types of activities and functionalities. Each element is defined as functionality (F), activity (A), or both (A&F). This is aligned with the division of GPs according to their type, i.e. Processes and Tools & Technologies, so Processes are mapped against Activities and Tools & Technologies against Functionalities. A score from zero (activity/functionality not supported) to five (activity/functionality fully supported) was assigned by the authors to each GP for all the identified activities and functionalities.

Table 1. Definitions of types of activities (A) and/or functionalities (F) supported by the GPs and included in the framework

Term	Definition	Class.
Alerting/Warning	It represents a signal that makes you understand if there is a possible danger or problem, especially one in the future (Cambridge Dictionary 2020).	F
Brainstorming/ Problem solving/ Lessons learned	It includes activities aimed at suggesting new ideas to find solutions to problems and at sharing knowledge or understanding gained by experience (TRP 2020).	A
Communication	It refers to the process of exchanging information among entities (organizations, people and technologies).	A&F
Coordination	It is the process of allocating and managing all the resources during the response phase of EM.	A&F
Decision support	It is based on an information system that supports businesses, organizations or authorities in decision-making activities.	A&F
Expert involvement	It is related to the involvement of experts to share lessons learned, guidelines and BPs for continuous improvement.	A
Geographical visualization	It refers to a set of tools and techniques supporting the analysis of geospatial data through the use of interactive visualization.	F
Knowledge management	It includes the sharing of lessons learned, guidelines and BPs for continuous improvement.	F
Monitoring	It is based on the collection of routine data that are used to track changes in the situation over time and to provide regular feedbacks and early indications of possible disruptions (ERM Insights 2020).	A
Planning	It is a fundamental management function, which includes ñdeciding beforehand, what is to be done, when is it to be done, how it is to be done and who is going to do itò (Business Jargon 2020).	A&F
Risk assessment	It refers to the overall process or method of hazard identification, risk analysis, risk evaluation and risk control (CCOHS 2020).	A&F
Surge management	It includes all the activities that are performed during the response phase of EM as a first response to a crisis or disruption.	A
Training/ Exercising	It includes exercises, training and simulations performed to improve all hazard incident management, as well as integration and interoperability (TRP 2020).	A&F

The pillar related to *EM capabilities* identifies the set of relevant capabilities required to effectively manage an emergency where interdependent CI systems are involved. The capabilities considered for this study (Table 2) were identified starting from the classifications provided by FEMA (2020) and CDC (2018). The covered areas include:

- Resource management, related to the allocation and deployment of resources in an effective and efficient way (ISO 22325 2016);
- Risk management, related to the activities performed to control risks affecting an organization (ISO 73 2009);
- Communication and coordination, related to the ability of ensuring a timely inter-organizational information exchange and of integrating response operations (ISO 22325 2016);
- EM planning, related to the provision of guidelines and the assessment of needs (CDC 2018);
- Surge management, related to human support and environment protection (CDC 2018).

Table 2. Definitions of EM capabilities included in the framework

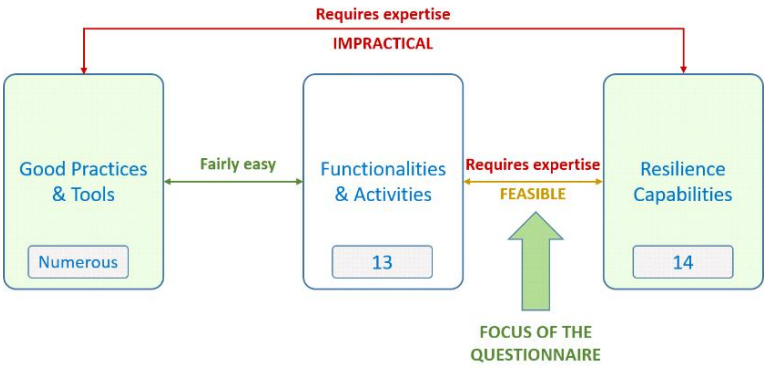
Capability	Description
Access control and identity verification	It concerns the adoption of physical, technological and cyber measures to verify the access to critical locations and systems.
Community Resilience building	Starting from the identification, communication and planning for risks, it is the ability of organizations to empower communities to withstand and recover from short- and long-term incidents.
Cybersecurity	It is related to the adoption of measures to protect (or restore) ñelectronic communications systems, information, and services from damage, unauthorized use, and exploitationò.
Environment protection services	It includes all the services aimed at protecting and restoring the surrounding environment (e.g. natural and cultural resource protection) from hazards.
Human protection services	It includes all the services aimed at providing support to affected populations (e.g. mass care, emergency medical services, mass search and rescue operations). For instance, it wants to protect public and workers by delivering emergency supplies as soon as possible.
Information sharing	It is the exchange of timely and accurate information and data among governments or other organizations to better respond to disruptive events.
Interdiction and disruption	It is the ability to ñdelay, divert, intercept, halt, apprehend, or secure threats and/or hazards.ò
Logistics and transportation services	It is related to the provision of logistics and transportation services in the affected areas to deliver necessary items and services, and to evacuate people and animals.
Operational coordination	It concerns the presence of a coordinated operational structure and process to integrate emergency responderséoperations.
Planning	It is the ability to ñconduct a systematic process engaging the whole community as appropriate in the development of executable strategic, operational, and/or tactical-level approaches to meet defined objectivesò.
Public information and warning	It is related to the delivery of information to the whole community regarding the threats or hazards, the actions implemented and available assistance.
Risk assessment	It includes identification, assessment and prioritization of risks in order to implement adequate measures.
Supply chain integrity and security	It is the ability to ñstrengthen the security and resilience of the supply chainò. It relies on improving the security and resilience of key nodes and the related movements between these nodes.
Threat and Hazards identification	It is the identification of threats and hazards in a given area (including frequency and magnitude determination) with the aim of understanding the needs on the ground.

The objective of the specification of *EM capabilities* is to map the contribution of the 53 GPs in managing emergencies involving CI systems. The GPs information collected through the review projects, literature and websites were still not sufficient to perform an accurate assessment of GPôs contribution to EM capabilities, since it is a task that requires a high level of expertise. To overcome this issue, the study proceeded with the drafting of a questionnaire addressed to CIR experts. The final result we look at is assessing the contribution of each GP to EM capabilities, as explained in the next paragraph.

5.2. GPs assessment

The CIR Questionnaire was administered to international experts to assess (on a scale from one to five) the contribution that the different types of Activities and Functionalities (A&F) provide to each EM capability. This quantifies to what extent each Activity or Functionality is relevant in building a specific capability. As shown in Figure 4, Activities and Functionalities (A&F) serve as an intermediary between GPs on one side and EM Capabilities on the other. Their goal is to bridge GPs (which are numerous and will further grow in number) with Resilience Capabilities. This approach not only solves the problem of the impracticality of directly assessing GPs against Resilience Capabilities (which would require an enormous effort by experts), but ensures the scalability and sustainability of the framework application. Once A&F are mapped against capabilities by experts, the structure of the framework enables simple expansion of the analysis by adding new GPs which are then easily connected to F&A.

Figure 4. The logic and the need for the questionnaire



The questionnaire was structured in the following way:

- Section 1 ï Background Information: aimed at understanding the educational background, the current function and the main areas of involvement of the respondents. In this section, questions are in an open form and their answers are mandatory.
- Section 2 ï Capabilities vs. Functionalities/Activities: aimed at understanding the importance of each functionality and/or activity in supporting a specific capability. In this section the questions are mandatory and are structured using the Likert scale form, ranging from one (low importance of the activity/functionality in guaranteeing the capability)

to five (high importance of the activity/functionality in guaranteeing the capability). For each capability, the questions are structured as shown in Figure 5.

Figure 5. Likert scale questions structure

	1 Low	**2** Medium Low	**3** Medium	**4** Medium High	**5** High
Communication	○	○	○	○	○
Geographical Visualization	○	○	○	○	○
Alerting/Warning	○	○	○	○	○
Training/Exercising	○	○	○	○	○
Planning	○	○	○	○	○
Coordination	○	○	○	○	○
Risk Assessment	○	○	○	○	○
Knowledge Management	○	○	○	○	○
Decision Support	○	○	○	○	○
Expert Involvement	○	○	○	○	○
Surge Management	○	○	○	○	○
Monitoring	○	○	○	○	○
Brainstorming/Problem Solving/ Lessons Learned	○	○	○	○	○

- Section 3 ï Additional Questions: aimed at further analyzing the classification framework, by increasing its consistency. In this section, questions are in an open form and answering is optional. In particular, the aim is to verify if other important capabilities could expand the list of the already mentioned one, to investigate if additional GPs for CIR could be integrated into the study, and to collect additional suggestions or comments in order to get interesting insights for further analyses.

The experts targeted by the questionnaire were first responders, operators, consultants, researchers or other practitioners active in the CIR domain. The answers included in the analysis are the ones received before April 28, 2021. During the considered time frame, the questionnaire received 23 responses, 20 of which complete and consistent, coming from 13 different countries.

After having excluded the inconsistent data, the individual judgements provided in Section 2 of the questionnaire were aggregated by calculating their geometric mean, since in our study all experts are considered of equal importance (Forman and Peniwati, 1998). The geometric mean is the average value representing the central tendency of a set of numbers, calculated as the root of the product of their values (Cuemath, 2021). The aggregation of expertsô judgements led to the assessment of the importance of an activity or functionality in supporting a specific capability. The obtained results are summarized in Table 3.

Table 3. Evaluation of GPsô Activities and Functionalities against EM capabilities according to experts (geometric mean; scale: 1-5)

		Capabilities													
		Access Control and Identity Verification	Cybersecurity	Logistics and Transportation Services	Community Resilience Building	Interdiction and Disruption	Risk Assessment	Supply Chain Integrity and Security	Information Sharing	Operational Coordination	Public Information and Warning	Planning	Threat and Hazards Identification	Environment Protection Services	Human Protection Services
Functionalities/Activities	Communication	4.15	4.38	4.26	4.06	3.35	2.98	3.90	4.80	4.45	4.74	2.96	4.01	4.46	4.27
	Geographical Visualization	3.48	4.01	3.35	3.70	3.86	3.52	3.64	2.57	3.85	3.18	3.15	3.99	4.00	2.50
	Alerting/ Warning	4.39	3.37	3.67	4.51	3.80	3.07	3.98	3.04	3.79	4.50	2.57	3.96	4.05	4.25
	Training/ Exercising	3.65	4.03	4.34	4.03	3.24	3.10	3.46	3.80	4.27	3.54	3.64	3.62	4.39	3.90
	Planning	3.65	4.53	4.57	3.99	3.47	3.50	4.22	3.57	4.06	3.56	4.44	4.14	4.05	3.98
	Coordination	3.69	4.51	4.30	4.30	3.51	3.48	4.41	4.34	4.62	4.23	4.40	4.37	4.62	4.37
	Risk Assessment	4.00	3.79	3.63	3.88	4.26	4.74	3.72	2.86	2.86	2.92	3.76	3.96	3.67	4.04
	Knowledge Management	3.01	3.02	3.78	3.40	3.93	4.17	3.80	3.77	3.47	3.30	3.67	3.61	3.88	3.60
	Decision Support	3.03	3.79	3.58	3.72	2.99	3.74	4.07	3.38	4.05	3.11	3.53	3.66	4.26	3.95
	Expert Involvement	3.24	3.72	3.89	3.99	4.27	4.37	3.80	3.49	3.39	3.84	3.73	4.02	4.17	4.50
	Surge Management	2.58	3.09	2.97	3.14	2.63	2.63	3.06	2.52	3.04	2.76	2.53	2.68	3.56	2.61
	Monitoring	4.13	3.72	3.20	3.87	3.76	2.90	3.78	3.60	3.62	3.60	2.53	3.91	4.07	4.11
	Brainstorming/ Lessons Learned	3.02	3.47	4.09	3.68	3.56	3.89	3.63	3.57	3.57	3.33	3.65	3.38	3.99	3.90

The GP mapping against the 14 EM capabilities was performed by combining the values of Table 3 with the ones assigned by authors to *GPô Activities and Functionalities*: for each GP, the scores attributed to each A&F were multiplied by the scores assigned by experts, thus obtaining the level of coverage granted by each GP to the EM capabilities. More specifically, for each GP, the level of coverage of each EM capability was calculated with the formula reported in Eq.1.

$$\text{Level of coverage}_{\square} = \max_{\square}(\text{Expert value}_{\square\square} * \text{Score}_{\square\square}) \quad (1)$$

Where:

$\text{Level of coverage}_{\square}$ = Score obtained for capability $\square$ $\quad \square = 1, 2, \dots, 14$

$\text{Expert value}_{\square\square}$ = Importance of activity/functionality $\square$ in guaranteeing capability $\square$ $\quad \square = 1, 2, \dots, 13$

$Score_{ij}$ = Value attributed by authors to activity/functionality i j

First, the obtained results allowed to assess the degree of comprehensiveness of each GP (i.e. range of capabilities fully covered); next, as a consequence, to identify the BPs of each cluster as the GPs that cover the widest spectrum of EM capabilities. To this end, we performed an ABC analysis on the overall scores, where class A is represented by those capabilities that are better covered by a GP. The degree of comprehensiveness of each GP was then calculated as the number of class A values.

5.3. GPs selection

The third level of the CRAFTER framework gives the possibility of identifying combinations of GPs that can exploit their synergies to fully cover all the EM capabilities, thus creating minimal effective bundles (MEBs). This logic is adopted since practices are not used individually, in most cases, but are aggregated with others to produce better performances (Bello-Pintado, 2015). The final result is a group of aligned practices which provides a higher contribution to the achievement of a specific goal in a particular application context (Bello-Pintado, 2015). In the CIR domain, GPs are bundled to fully cover the entire spectrum of EM capabilities, selecting the minimum number of practices and ensuring interoperability among them. In light of this, the composition of the MEBs was determined by setting an objective function for minimizing the number of selected GPs and by adding the following constraints:

- Each bundle has to include at least one practice classified as Process and one classified as Tool & Technology in order to fully exploit synergies among GPs.
- Each bundle has to provide a class A coverage for all the EM capabilities[a] in order to ensure an optimal EM. This means that each capability has to be covered with a class A value by at least one of the GPs belonging to the bundle.

The optimization problem was run using the MS Excel™ Solver.

6. Results

6.1. Classification of the most relevant CIR GPs

The 53 GPs included in the analysis were mapped against the classification dimensions of the CRAFTER framework.

In order to allow better interpretability of the classification, the notation reported in Table 4 is adopted. Table 5 shows the classification based on *GPs' main characteristics*.

Table 6 and Table 7 show respectively the classification of Tools & Technologies based on the functionalities they support, and the classification of Processes based on the activities.

[a] The GPs that do not cover any capability with a class A value were excluded from the identification of the minimal effective bundles, since they do not provide any contribution.

Table 4. Notation to interpret GPôs main characteristic

Dimensions	Notation	Meaning
GP Type	TT	Tool and Technologies
	PR	Processes
EM Phase	P	Preparation
	M	Mitigation
	RES	Response
	REC	Recovery
Partnership Type	PU	Public
	PR	Private
Key Partners	PI	Public Institutions
	CI-O	CI Operators
	U	Universities
	COM	Communities
	PPC	Public and Private Companies
	CIR-E	CIR Experts
Inter-organizational scope	INTRA	Intra-organizational
	INTER	Inter-organizational
Data Type	RT	Real-Time
	D	Deferred
Extension	C	City
	R	Region
	S	State
	NC	Neighboring Countries
Transferability	BR	Broad
	SP	Specific

Table 5. GPs mapping according to their main characteristics

List of GPs	GP Type		EM Phase				Partnership Type		Key Partners						Inter-organizational scope		Data Type		Extension				Transf.	
	TT	PR	P	M	RES	REC	PU	PR	PI	CI-O	U	COM	PPC	E	INTRA	INTER	RT	D	C	R	S	NC	BR	SP
Big Business-Small Business		■	■	■		■		■					■			■		■			■			■
DARWIN Wiki	■		■	■	■	■	■	■	■	■						■		■	■				■	
Focus on Flows		■	■		■	■	■	■	■	■	■					■		■			■		■	
Louisiana Disaster Recovery Alliance		■	■	■		■		■					■			■		■			■			■
MATRICS	■		■		■	■	■	■	■	■						■	■			■			■	
Multi-State Fleet Response Initiative		■	■		■	■	■	■	■	■						■	■					■	■	
NWWARN	■		■	■	■	■	■	■	■	■		■		■		■	■					■	■	
Resilience Building Policies	■		■	■	■	■	■	■	■	■						■		■	■					■
SATool	■		■	■	■	■	■	■	■	■		■				■	■				■		■	
V-BEOC	■		■	■	■	■	■	■	■	■	■					■	■				■		■	
Copernicus Emergency Management Service	■		■	■	■	■	■	■	■	■						■	■					■	■	
CRAMSS	■		■	■	■	■	■	■	■	■		■				■	■		■					■
EM Dashboard	■				■	■	■	■	■	■						■	■			■			■	
ESSMA	■				■		■	■	■			■				■	■		■					■
GIS Mapping for CI Assets	■		■	■	■		■		■	■						■	■				■		■	
Resilience Information and Communication Portal	■		■		■		■	■	■	■						■	■		■					■
Traffic Scotland Information Service	■		■	■	■	■	■	■	■	■						■	■				■		■	
COLAB		■	■				■	■	■	■				■		■		■	■					■
European Resilience Management Guideline		■	■	■	■	■	■	■	■	■				■		■		■	■					■
Partnership Alignment for Enhanced Security		■	■	■	■	■	■		■	■						■		■			■		■	
PRISM	■		■	■			■	■	■	■					■			■			■		■	
Public Safety Canada		■	■	■	■	■	■		■	■					■			■			■		■	
TTF		■	■	■	■		■	■	■	■				■		■	■	■		■			■	
Blue Cascades Exercise Series		■	■	■	■	■	■	■	■	■						■		■				■	■	
CATEX		■	■	■	■	■	■	■	■	■						■		■				■		■
City Resilience Dynamics	■		■	■	■	■	■	■	■	■						■		■	■					■
GINOM	■		■	■	■	■	■	■	■	■						■	■			■			■	
MICC		■	■	■	■	■	■	■	■	■						■	■				■		■	
Opportunity Assessment (Tool) Workshop		■	■	■	■	■	■	■	■	■				■		■		■	■					■
Problem Framing		■	■	■	■	■	■	■	■	■				■		■		■	■					■
Project Scan (Tool) Workshop		■	■	■	■	■	■	■	■	■				■		■		■	■					■
Resilience Accelerator		■	■	■	■	■	■	■	■	■				■		■		■	■					■
Resilience Garage		■	■	■	■	■	■	■	■	■				■		■		■	■					■
Resilience Value Realization		■	■	■	■	■	■	■	■	■				■		■		■	■					■
Serious Games based on Virtual Reality	■		■	■	■	■	■	■		■						■		■	■					■

SimEnv	■		■	■	■	■	■	■		■						■		■	■						■
Tactical Urban Resilience		■	■	■	■	■	■	■	■	■				■		■		■	■						■
100 RC Systems Studio		■	■	■	■	■	■	■	■	■				■		■		■	■						■
Assets and Risk Tool	■		■	■			■	■	■	■						■		■		■					■
CI System Definition Tool	■		■				■	■		■						■		■			■				■
City Resilience Index		■	■	■			■	■	■	■						■		■	■						■
DOMINO Tool	■		■	■			■	■	■	■						■	■							■	
GIS based Resilience Mapping Tool	■		■	■			■	■		■						■		■	■						■
GRRASP	■		■	■			■	■	■	■						■		■	■					■	
Local Area Risk Assessment	■		■	■			■	■	■	■						■		■	■						■
Resilience Actions Inventory and Stakeholder Perceptions Review	■		■	■	■	■	■	■	■	■						■		■	■						■
Resilience Management Audit Tool	■		■	■			■	■		■						■		■	■						■
Resilience Management Matrix Tool	■		■				■	■		■						■		■	■						■
Resilience Maturity Model		■	■	■			■	■	■	■						■		■	■						■
Risk Systemicity Questionnaire	■		■	■			■	■	■	■						■		■	■						■
Smart Resilience Indicators		■	■	■	■	■	■	■		■						■		■	■						■
THREVI2	■		■	■			■	■		■						■		■	■					■	
Area BCM		■	■	■	■	■	■	■	■	■			■			■		■				■	■		
BCM for enterprises		■	■	■	■	■	■	■					■		■			■			■		■		

Table 6. Tools & Technologies mapping against Functionalities (scale: 0-5)

List of Tools and Technologies	Communication channel	Geographical visualization	Alerting/ Warning	Training/ Exercising	Planning	Coordination	Risk assessment	Knowledge management	Decision support
DARWIN Wiki	0	0	0	0	0	0	0	5	0
MATRICS	4	0	0	0	5	0	0	5	5
NWWARN	5	0	5	0	0	0	0	0	0
Resilience Building Policies	0	0	0	0	0	0	0	5	0
SATool	4	0	5	0	0	4	0	0	0
V-BEOC	5	0	5	2	3	5	0	0	0
Copernicus Emergency Management Service	5	5	5	0	0	0	0	0	0
CRAMSS	3	3	3	0	0	5	2	0	4
EM Dashboard	5	5	5	0	0	1	0	0	0
ESSMA	5	5	5	0	0	5	0	0	0
GIS Mapping for CI Assets	5	5	3	4	0	0	0	0	0
Resilience Information and Communication Portal	0	3	0	0	0	0	0	5	0
Traffic Scotland Information Service	5	5	5	0	0	0	0	0	0
PRISM	0	0	0	0	4	0	5	4	4
City Resilience Dynamics	0	0	0	5	1	0	0	0	0
GINOM	4	5	0	5	1	0	2	4	4
Serious Games based on Virtual Reality	0	0	0	3	1	0	0	0	0
SimEnv	0	0	0	5	1	0	0	0	0
Assets and Risk Tool	0	0	0	0	1	0	3	0	0
CI System Definition Tool	0	0	0	0	1	0	2	0	0
City Resilience Index	0	0	0	0	1	0	4	0	0
DOMINO Tool	4	5	4	0	1	0	5	0	0
GIS based Resilience Mapping Tool	0	4	0	0	1	0	3	0	0
GRRASP	4	5	0	0	1	0	5	0	0
Local Area Risk Assessment	1	0	0	0	1	0	3	0	0
Resilience Actions Inventory	1	0	0	0	1	0	3	0	0
Resilience Management Audit Tool	0	0	0	0	1	0	3	3	0
Resilience Management Matrix Tool	0	0	0	0	1	0	3	0	0
Resilience Maturity Model	0	0	0	0	1	0	4	4	0
Risk Systemicity Questionnaire	1	0	0	0	1	0	4	4	0
Smart Resilience Indicators	0	0	0	0	1	0	5	3	0
THREVI2	1	0	0	3	1	0	4	0	0

Table 7. Processes mapping against Activities (scale: 0-5)

List of Processes	Communication	Expert involvement	Training/ Exercising	Planning	Coordination	Risk assessment	Surge management	Decision support	Monitoring	Problem solving/ Lessons learned
Big Business - Small Business	4	4	0	3	0	0	0	0	0	0
Focus on Flows	4	5	0	4	0	0	0	0	0	5
Louisiana Disaster Recovery Alliance	4	4	0	3	0	0	0	0	0	0
Multi-State Fleet Response Initiative	5	0	2	4	5	0	4	0	0	5
COLAB	0	5	0	5	0	0	0	0	0	5
European Resilience Management Guideline	0	0	0	5	0	0	0	5	0	0
Partnership Alignment for Enhanced Security	3	0	0	5	0	4	0	4	0	0
Public Safety Canada	0	0	0	5	0	0	0	5	0	0
TTF	4	5	0	5	0	4	0	3	0	5
Blue Cascades Exercise Series	4	0	5	1	0	0	0	2	0	0
CATEX	4	0	5	1	0	0	0	2	0	0
MICC	4	0	5	1	0	0	0	2	4	0
Opportunity Assessment (Tool) Workshop	4	5	5	5	0	0	0	4	0	5
Problem Framing	4	5	5	1	0	0	0	3	0	5
Project Scan (Tool) Workshop	4	5	3	3	0	3	0	3	0	5
Resilience Accelerator	4	5	3	1	0	0	0	3	0	5
Resilience Garage	4	5	3	1	0	0	0	3	0	5
Resilience Value Realization	4	5	4	4	0	0	0	2	0	5
Tactical Urban Resilience	4	0	3	1	0	0	0	2	0	5
100 RC Systems Studio	4	5	4	3	0	0	0	3	0	5
BCM	1	0	3	5	0	0	0	2	0	0

6.2. Assessment of GPsô contribution to EM capabilities

Combing the results of the questionnaire with the scores presented in Table 6 and Table 7, the 53 GPs were mapped against the EM capabilities (Table 8).

The most interesting findings resulting from the GPs assessment are summarized in the following. As mentioned in paragraph 5.2, the BPs of each cluster were identified considering the degree of comprehensiveness that is calculated as the number of capabilities fully covered by a GP (class A values in Table 8).

GPs belonging to the *Information sharing* cluster include solutions and approaches aimed mainly at enabling information sharing among a variety of institutions and operators. The constant situational updates contribute to a prompt detection of interdictions and disruptions and support operators in coordinating response and recovery actions, thus providing protection and logistic services to people and the environment. These GPs can also contribute to community resilience building through platforms accessible by citizens, not only to warn them in case of emergencies but also to involve them in the information sharing with operators (e.g. giving them the possibility to upload videos or share tweets related to the emergency event). The BPs of the *Information sharing* cluster are V-BEOC (National Business Emergency Operations Center 2020) and Multi-State Fleet Response Initiative (All Hazards Consortium 2020). In both cases, information sharing is guaranteed before, during and after an emergency, in order to collect inputs to support decision-making in all the EM phases. In particular, V-BEOC is a web-based platform through which public and private institutions can communicate and share real-time information about national CIs, while Multi-State Fleet Response Initiative is a Working Group where partners share sensitive information to improve cross-border resources and fleet movements with the support of the SISE platform (Sensitive Information Sharing Environment). V-BEOC and SISE platforms show constant operating status updates, thus ensuring an effective deployment of resources and providing a complete situational awareness to operators and citizens. Moreover, meetings and conferences organized by partners allow developing a common and integrated strategic planning to manage CI emergencies.

GPs belonging to the *Geographical visualization and information sharing* cluster include solutions mainly aimed at enabling information sharing among actors and at detecting interdictions and disruptions. The study showed that these GPs can facilitate the coordination of response operations by integrating map visualization tools with instruments able to support resource deployment during emergencies. Additionally, they offer the possibility to represent on the map the location of potential threats and hazards. This is fundamental to enhance community resilience as it enables to warn citizens in case of threats or emerging events, and possibly provide guidelines and support to evacuate them from critical areas. The BP of *Geographical visualization and information sharing* cluster is ESSMA (Resolute Project, 2015). It provides a georeferenced visualization of strategic places, resources and possible dangerous situations. This supports a prompt identification of emergencies, giving the possibility to intervene immediately in the affected area. Since it is an application available also for the public, it is able to warn citizens and to support them in dealing with emergencies. On top of this, it provides instructions and guidelines to the operators that have to intervene in the area, showing the routings to reach the location and suggesting evacuation procedures to be followed.

Table 8. GPs mapping against EM capabilities, with class A values (higher than 18.11) in green, class B values (between 14.3 and 18.11) in yellow, class C values (lower than 14.3) in red.

List of GPs	Capabilities													
	Access Control and Identity Verification	Cybersecurity	Logistics and Transportation Services	Community Resilience Building	Interdiction and Disruption	Risk Assessment	Supply Chain Integrity and Security	Information Sharing	Operational Coordination	Public Information and Warning	Planning	Threat and Hazards Identification	Environment Protection Services	Human Protection Services
Big Business-Small Business	16.60	17.52	17.04	16.24	17.08	17.48	15.60	19.20	17.80	18.96	14.92	16.08	17.84	18.00
DARWIN Wiki	15.05	15.10	18.90	17.00	19.65	20.85	19.00	18.85	17.35	16.50	18.35	18.05	19.40	18.00
Focus on Flows	16.60	18.60	20.45	19.95	21.35	21.85	19.00	19.20	17.85	19.20	18.65	20.10	20.85	22.50
Louisiana Disaster Recovery Alliance	16.60	17.52	17.04	16.24	17.08	17.48	15.60	19.20	17.80	18.96	14.92	16.08	17.84	18.00
MATRICS	20.00	18.95	18.15	19.40	21.30	23.70	18.60	15.08	16.20	14.60	18.80	19.80	18.35	20.20
Multi-State Fleet Response Initiative	20.75	22.55	21.50	21.50	17.80	19.45	22.05	24.00	23.10	23.70	22.00	21.85	23.10	21.85
NWWARN	21.95	21.90	21.30	22.55	19.00	15.35	19.90	24.00	22.25	23.70	14.80	20.05	22.30	21.35
Resilience Building Policies	15.05	15.10	18.90	17.00	19.65	20.85	19.00	18.85	17.35	16.50	18.35	18.05	19.40	18.00
SATool	21.95	18.04	18.35	22.55	19.00	15.35	19.90	19.20	18.95	22.50	17.60	19.80	20.25	21.25
V-BEOC	21.95	22.55	21.50	22.55	19.00	17.40	22.05	24.00	23.10	23.70	22.00	21.85	23.10	21.85
Copernicus Emergency Management Service	21.95	21.90	21.30	22.55	19.30	17.60	19.90	24.00	22.25	23.70	15.75	20.05	22.30	21.35
CRAMSS	18.45	22.55	21.50	21.50	17.55	17.40	22.05	21.70	23.10	21.15	22.00	21.85	23.10	21.85
EM Dashboard	21.95	21.90	21.30	22.55	19.30	17.60	19.90	24.00	22.25	23.70	15.75	20.05	22.30	21.35
ESSMA	21.95	22.55	21.50	22.55	19.30	17.60	22.05	24.00	23.10	23.70	22.00	21.85	23.10	21.85
GIS Mapping for CI Assets	20.75	21.90	21.30	20.30	19.30	17.60	19.50	24.00	22.25	23.70	15.75	20.05	22.30	21.35
Resilience Information and Communication Portal	15.05	15.10	18.90	17.00	19.65	20.85	19.00	18.85	17.35	16.50	18.35	18.05	19.40	18.00
Traffic Scotland Information Service	21.95	21.90	21.30	22.55	19.30	17.60	19.90	24.00	22.25	23.70	15.75	20.05	22.30	21.35
COLAB	18.25	22.65	22.85	19.95	21.35	21.85	21.10	17.85	20.30	19.20	22.20	20.70	20.85	22.50
European Resilience Management Guideline	18.25	22.65	22.85	19.95	17.35	18.70	21.10	17.85	20.30	17.80	22.20	20.70	21.30	19.90
Partnership Alignment for Enhanced Security	18.25	22.65	22.85	19.95	17.35	18.96	21.10	17.85	20.30	17.80	22.20	20.70	20.25	19.90
PRISM	20.00	18.95	18.28	19.40	21.30	23.70	18.60	15.08	16.24	14.60	18.80	19.80	18.35	20.20
Public Safety Canada	18.25	22.65	22.85	19.95	17.35	18.70	21.10	17.85	20.30	17.80	22.20	20.70	21.30	19.90
TTF	18.25	22.65	22.85	19.95	21.35	21.85	21.10	19.20	20.30	19.20	22.20	20.70	20.85	22.50
Blue Cascades Exercise Series	18.25	20.15	21.70	20.15	16.20	15.50	17.30	19.20	21.35	18.96	18.20	18.10	21.95	19.50
CATEX	18.25	20.15	21.70	20.15	16.20	15.50	17.30	19.20	21.35	18.96	18.20	18.10	21.95	19.50
City Resilience Dynamics	18.25	20.15	21.70	20.15	16.20	15.50	17.30	19.00	21.35	17.70	18.20	18.10	21.95	19.50

GINOM	18.25	20.15	21.70	20.15	19.30	17.60	18.20	19.20	21.35	18.96	18.20	19.95	21.95	19.50
MICC	18.25	20.15	21.70	20.15	16.20	15.50	17.30	19.20	21.35	18.96	18.20	18.10	21.95	19.50
Opportunity Assessment (Tool) Workshop	18.25	22.65	22.85	20.15	21.35	21.85	21.10	19.20	21.35	19.20	22.20	20.70	21.95	22.50
Problem Framing	18.25	20.15	21.70	20.15	21.35	21.85	19.00	19.20	21.35	19.20	18.65	20.10	21.95	22.50
Project Scan (Tool) Workshop	16.60	18.60	20.45	19.95	21.35	21.85	19.00	19.20	17.85	19.20	18.65	20.10	20.85	22.50
Resilience Accelerator	16.60	18.60	20.45	19.95	21.35	21.85	19.00	19.20	17.85	19.20	18.65	20.10	20.85	22.50
Resilience Garage	16.60	18.60	20.45	19.95	21.35	21.85	19.00	19.20	17.85	19.20	18.65	20.10	20.85	22.50
Resilience Value Realization	16.60	18.60	20.45	19.95	21.35	21.85	19.00	19.20	17.85	19.20	18.65	20.10	20.85	22.50
Serious Games based on Virtual Reality	10.95	12.09	13.02	12.09	9.72	9.30	10.38	11.40	12.81	10.62	10.92	10.86	13.17	11.70
SimEnv	18.25	20.15	21.70	20.15	16.20	15.50	17.30	19.00	21.35	17.70	18.20	18.10	21.95	19.50
Tactical Urban Resilience	16.60	17.52	20.45	18.40	17.80	19.45	18.15	19.20	17.85	18.96	18.25	16.90	19.95	19.50
100 RC Systems Studio	16.60	18.60	20.45	19.95	21.35	21.85	19.00	19.20	17.85	19.20	18.65	20.10	20.85	22.50
Assets and Risk Tool	12.00	11.37	10.89	11.64	12.78	14.22	11.16	8.58	8.58	8.76	11.28	11.88	11.01	12.12
CI System Definition Tool	8.00	7.58	7.26	7.76	8.52	9.48	7.44	5.72	5.72	5.84	7.52	7.92	7.34	8.08
City Resilience Index	16.00	15.16	14.52	15.52	17.04	18.96	14.88	11.44	11.44	11.68	15.04	15.84	14.68	16.16
DOMINO Tool	20.00	20.05	18.15	19.40	21.30	23.70	18.60	19.20	19.25	18.96	18.80	19.95	20.00	20.20
GIS based Resilience Mapping Tool	13.92	16.04	13.40	14.80	15.44	14.22	14.56	10.28	15.40	12.72	12.60	15.96	16.00	12.12
GRRASP	20.00	20.05	18.15	19.40	21.30	23.70	18.60	19.20	19.25	18.96	18.80	19.95	20.00	20.20
Local Area Risk Assessment	12.00	11.37	10.89	11.64	12.78	14.22	11.16	8.58	8.58	8.76	11.28	11.88	11.01	12.12
Resilience Actions Inventory and Stakeholder Perceptions Review	12.00	11.37	10.89	11.64	12.78	14.22	11.16	8.58	8.58	8.76	11.28	11.88	11.01	12.12
Resilience Management Audit Tool	12.00	11.37	11.34	11.64	12.78	14.22	11.40	11.31	10.41	9.90	11.28	11.88	11.64	12.12
Resilience Management Matrix Tool	12.00	11.37	10.89	11.64	12.78	14.22	11.16	8.58	8.58	8.76	11.28	11.88	11.01	12.12
Resilience Maturity Model	16.00	15.16	15.12	15.52	17.04	18.96	15.20	15.08	13.88	13.20	15.04	15.84	15.52	16.16
Risk Systemicity Questionnaire	16.00	15.16	15.12	15.52	17.04	18.96	15.20	15.08	13.88	13.20	15.04	15.84	15.52	16.16
Smart Resilience Indicators	20.00	18.95	18.15	19.40	21.30	23.70	18.60	14.30	14.30	14.60	18.80	19.80	18.35	20.20
THREVI2	16.00	15.16	14.52	15.52	17.04	18.96	14.88	11.44	12.81	11.68	15.04	15.84	14.68	16.16
BCM	18.25	22.65	22.85	19.95	17.35	17.50	21.10	17.85	20.30	17.80	22.20	20.70	20.25	19.90

GPs belonging to the *Planning* cluster include instructions aimed mainly at guiding the development and implementation of strategic plans, including methodologies for the identification of threats and hazards and for the assessment of the risk level of an area. It emerged that these GPs can guarantee the integrity and security of the supply chain by fostering a collaboration among actors that leads to the development of common EM strategies. The BPs of the *Planning* cluster are TTF (Alberto Ceriani, 2011) and COLAB (The Rockefeller Foundation, 2015). COLAB provides a set of guidelines to develop strategic plans to improve local resilience: it guides stakeholders through the identification of current challenges and the development of solutions to face them. On the other side, TTFs involve a variety of operators that work jointly on a specific theme to achieve aligned plans and procedures.

GPs belonging to the *Training, exercising and simulations* cluster include platforms and programs mainly aimed at supporting planning activities. This cluster can be better discussed by introducing a distinction between workshops, simulation platforms and exercises. The former can support community resilience building by involving citizens in the discussions, thus having the opportunity to develop better-integrated solutions in line with the expectations and needs of the whole community. Workshops start by analyzing the current situation in order to identify issues or threats that could potentially undermine the functionality of CI systems, and try to find solutions to safeguard the security of people and the environment. When it comes to simulation platforms, the results of the questionnaire highlighted the importance of using these tools throughout an emergency event, by performing real-time simulations to support resource deployment during response and recovery phases. Finally, the main contribution provided by exercises is to support actors in dealing with mitigation, response and recovery activities by guaranteeing better visibility on available resources and by ensuring the alignment of partners to common procedures. The BPs of *Training, exercising and simulations* cluster are Opportunity Assessment (Tool) Workshop (The Rockefeller Foundation, 2015) and Problem Framing (The Rockefeller Foundation, 2015). Both are workshops where stakeholders discuss existing problems affecting a city and learn about new ways to solve them. More specifically, they teach participants to identify barriers that hinder opportunities and to prioritize resilience actions with the aim of achieving those opportunities.

GPs belonging to the *Risk and Resilience assessment* cluster include methods, templates or platforms mainly aimed at assessing risk or resilience levels of a system/area. Starting from this, some GPs provide also instructions to develop a strategic plan or improve already existing ones with the aim of enhancing community resilience. The BPs of *Risk and Resilience assessment* cluster are DOMINO (Centre Risque & Performance 2020) and GRRASP (EC 2020). Both are tools based on a cartography approach used to locate system infrastructures and simulate domino effects; by analyzing situational information of CIs, they assign a risk level to the areas that could be impacted by the emergency event and provide information about the propagation of the disservice.

GPs belonging to the *BCM* cluster include steps and activities mainly aimed at developing plans in order to avoid the interruption of critical systems and processes or recover them as soon as possible. From this perspective, it is essential to guarantee the integrity of the supply chain and the provision of logistic services in case of need by fostering cooperation and collaboration among all the involved actors. Given the very limited number of GPs in the cluster, no BP was identified.

6.3. Selection of minimal effective bundles

By solving the optimization problem mentioned in paragraph 5.3, it was possible to identify 17 MEBs composed of two GPs. Due to the imposed constraints, each bundle consists of a Tool & Technology and a Process that, combined together, are able to cover all the EM capabilities with a score higher than 18.11 (class A values).

The information initially collected about the GPs supported us in identifying the most suitable application context of each bundle, specifying the following dimensions (Table 9):

- CI sector: a bundle that can be used to manage a single CI sector enables to perform low level analyses of small-scale scenarios; on the other hand, a bundle that considers cross-sector interdependencies is useful to identify complex cascading impacts resulting from a single CI failure (Stergiopoulos et al., 2016).
- Geographical scope: since the failure of a CI has impacts on a wide geographical area, it could happen that the inoperability spreads not only at the national level but also among neighboring countries (Borghetti et al., 2020). Therefore, this dimension defines if a bundle is able to support the management of local/national CIs or cross-border ones.
- EM cycle scope: EM enables stakeholders to cope with CI disruptions, reducing the impacts of disasters and adapting to unforeseen crisis situations (Kozine and Andersen, 2015). In this regard, a bundle can contribute to Risk Assessment & Planning, to Preparedness & Response, or to the entire EM cycle.
- Hazard/threat scope: emergency preparedness can focus on specific types of hazards or it can consider all types of risks (Adini et al., 2012). Thus, this dimension determines if a bundle adopts a hazard-specific or an all-hazard approach.

Table 9. Specification of the application context

PPC scope	**Characteristics**		
CI sector	Single/few	Multi	
Geographical scope	National/local	Cross-border	
EM cycle scope	Risk assessment & Planning	Preparedness & Response	Full EM cycle
Hazard/threat scope	Hazard specific	All-hazard	

Classifying each bundle against the above-mentioned dimensions, it was possible to define how the resulting PPCs can contribute to enhancing the resilience of CI systems. This classification was done considering the current application of the GPs belonging to a bundle, thus without considering their possible extension. The obtained results are summarized in Table 10.

Table 10. Minimal effective bundles: composition and application context

	Minimal effective bundles	Bundle characteristics	Application context
1	GIS Mapping for CI Assets	GP Type: Tool & Technology Cluster: Geographical visualization and information sharing	Multi-sector Cross-border Preparedness & Response All-hazard
	Opportunity Assessment (Tool) Workshop	GP Type: Process Cluster: Training, exercising and simulations	
2	V-BEOC	GP Type: Tool & Technology Cluster: Information sharing	Multi-sector Local Preparedness & Response Hazard specific
	Resilience Garage	GP Type: Process Cluster: Training, exercising and simulations	
3	Copernicus Emergency Management Service	GP Type: Tool & Technology Cluster: Geographical visualization and information sharing	Multi-sector Local Full EM cycle All-hazard
	COLAB	GP Type: Process Cluster: Planning	
4	Traffic Scotland Information Service	GP Type: Tool & Technology Cluster: Geographical visualization and information sharing	Single sector Local Full EM cycle All-hazard
	TTF	GP Type: Process Cluster: Planning	
5	PRISM	GP Type: Tool Cluster: Planning	Multi-sector Cross-border Full EM cycle All-hazard
	Blue Cascades Exercise Series	GP Type: Process Cluster: Training, exercising and simulations	
6	ESSMA	GP Type: Tool Cluster: Geographical visualization and information sharing	Single sector Local Preparedness & Response All-hazard
	Tactical Urban Resilience	GP Type: Process Cluster: Training, exercising and simulations	
7	MATRICS	GP Type: Tool Cluster: Information sharing	Single sector Cross-border Preparedness & Response All-hazard
	Multi-State Fleet Response Initiative	GP Type: Process Cluster: Information sharing	
8	SimEnv	GP Type: Tool Cluster: Training, exercising and simulations	Single sector Local Preparedness & Response Hazard specific
	100 RC Systems Studio	GP Type: Process Cluster: Training, exercising and simulations	
9	EM Dashboard	GP Type: Tool Cluster: Geographical visualization and information sharing	Multi-sector Local Preparedness & Response All-hazard
	Focus on Flows	GP Type: Process Cluster: Information sharing	
10	NWWARN	GP Type: Tool Cluster: Information sharing	Multi-sector National Preparedness & Response All-hazard
	Partnership Alignment for Enhanced Security	GP Type: Process Cluster: Planning	
11	GRRASP	GP Type: Tool Cluster: Risk and resilience assessment	Multi-sector National Risk assessment & Planning Hazard specific
	Public Safety Canada	GP Type: Process Cluster: Planning	
12	DOMINO Tool	GP Type: Tool Cluster: Risk and resilience assessment	Multi-sector Cross-border Full EM cycle All-hazard
	CATEX	GP Type: Process Cluster: Training, exercising and simulations	

13	SATool	GP Type: Tool Cluster: Information sharing	Multi-sector National Full EM cycle All-hazard
	European Resilience Management Guideline	GP Type: Process Cluster: Planning	
14	City Resilience Dynamics	GP Type: Tool Cluster: Training, exercising and simulations	Multi-sector Local Preparedness & Response All-hazard
	Resilience Value Realization	GP Type: Process Cluster: Training, exercising and simulations	
15	Smart Resilience Indicators	GP Type: Tool Cluster: Risk and resilience assessment	Multi-sector Local Full EM cycle Hazard specific
	MICC	GP Type: Process Cluster: Training, exercising and simulations	
16	GINOM	GP Type: Tool Cluster: Training, exercising and simulations	Multi-sector Local Preparedness & Response All-hazard
	Resilience Accelerator	GP Type: Process Cluster: Training, exercising and simulations	
17	CRAMSS	GP Type: Tool Cluster: Geographical visualization and information sharing	Single sector Local Preparedness & Response All-hazard
	Project Scan (Tool) Workshop	GP Type: Process Cluster: Training, exercising and simulations	

The classification matrix of the different bundles is shown in Figure 6: the dimensions represented on the two axes are the EM cycle scope and the CI sector, while the geographical scope and the hazard scope are expressed respectively with a square/triangular shape and a black/white coloring.

Considering the bundles focused on a single sector and covering Preparedness & Response, MEB 6 (ESSMA and Tactical Urban Resilience) and 17 (CRAMSS and Project Scan Workshop) are both aimed at protecting local transportation CIs from all types of hazards and evaluating local resilience-building programs. MEB 8 (SimEnv and 100 RC Systems Studio), instead, enables to identify systems interdependencies and to simulate different resource allocation options in case of damage to a transportation vehicle. Finally, MEB 7 (MATRICS and Multi-State Fleet Response Initiative) supports partners from neighboring countries in sharing situational information to facilitate cross-border resource movements in case of emergency.

Moving to the upper right quadrant of the matrix, MEB 4 (Traffic Scotland Information Service and TTF) focuses on a single sector and covers the entire EM cycle: it enables to manage local transportation CIs by showing real-time traffic conditions that support response activities and by developing plans to protect CIs from all types of hazards.

MEB 11 (GRAASP and Public Safety Canada) focuses on a variety of CI sectors and covers Risk Assessment & Planning. In particular, it enables to perform risk and resilience assessment of different national CIs and to develop a plan to manage specifically insider threats.

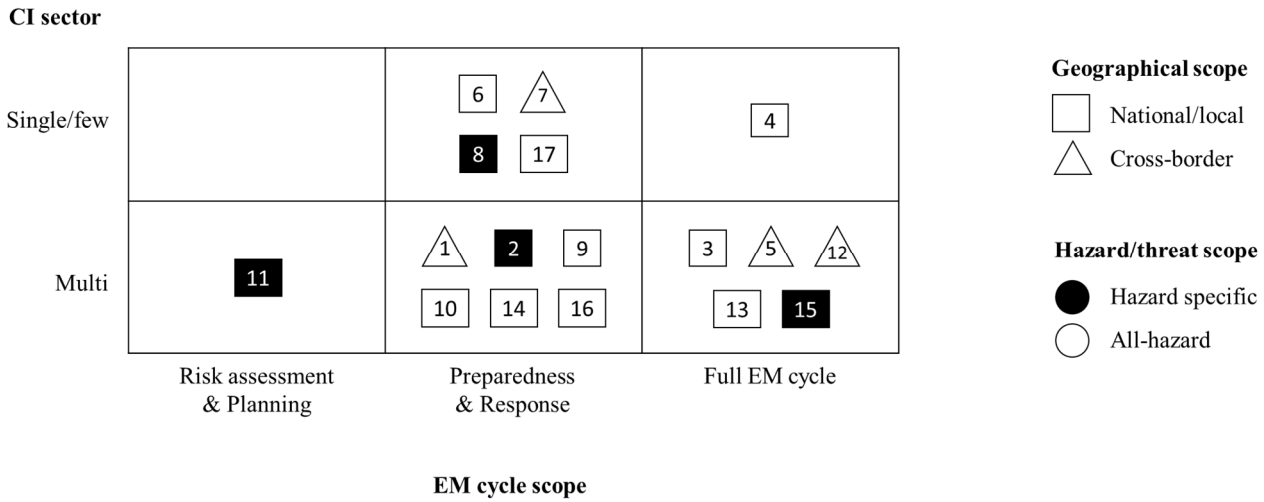
Concerning the bundles focused on multi-sector analyses and covering Preparedness & Response, MEB 1 (GIS Mapping for CI Assets and Opportunity Assessment Workshop) allows visualizing cross-border CIs showing different types of threats and gathering stakeholders with the aim of prioritizing resilience-building actions. MEB 2 (V-BEOC and Resilience Garage) fosters collaboration among stakeholders in order to cope with specific threats affecting local CIs and coordinate response actions in case of emergency. Then, MEB 9 (EM Dashboard and Focus on Flows) enables to visualize local CIs, showing emergency events or threats and supports stakeholders in sharing situational information protecting

the system from different types of hazards. Another bundle is MEB 10 (NWWARN and Partnership Alignment for Enhanced Security) that allows managing national CIs by promoting information sharing among stakeholders and by ensuring their alignment to the procedures in case of emergency. MEB 14 (City Resilience Dynamics and Resilience Value Realization) and 16 (GINOM and Resilience Accelerator) are both based on simulations that enable to explore the impacts of different resource allocation strategies following an emergency and to promote discussions among stakeholders to enhance the resilience of local CIs.

Finally, considering the bundles focused on multi-sector analyses and covering the entire EM cycle, MEB 3 (Copernicus Emergency Management Service and COLAB) enables to visualize local CIs showing different types of threats that affect the CI and to develop plans aimed at addressing existing problems of a city. MEB 5 (PRISM and Blue Cascades Exercise Series) enables partners to analyze cascading impacts by performing exercises and supporting them in the identification of risks and in the definition of strategic plans to manage cross-border CIs. MEB 12 (DOMINO Tool and CATEX), instead, aims at achieving a rapid restoration of cross-border CIs by performing a series of exercises to promote coordination among partners; in addition, it allows to identify system interdependencies and assign a risk level to the different CI assets. Then, MEB 13 (SaTool and European Resilience Management Guideline) enables partners to share information about national CIs and to support them in the development of a resilience plan considering all the threats that could affect the system. In conclusion, MEB 15 (Smart Resilience Indicators and MICC) aims at training and exercising local institutions to be prepared to manage an emergency and at offering a methodology for assessing the risks of a CI system taking into consideration a specific threat.

As shown in Figure 6, none of the bundles is focused on a single sector covering just Risk assessment & Planning. However, MEB 4 (Traffic Scotland Information Service and TTF) could be used to fill this gap since it focuses on a single sector and takes into account the entire EM cycle, thus including risk assessment and planning activities.

Figure 6. Classification matrix



7. Conclusions

The increasing number and intensity of interdependencies within CI systems, frequently leading to significant domino effects and cascading failures even after minor CI disruptions, justify the establishment of collaborative approaches and partnerships at regional, national or international level. Despite the high number of Good Practices (GPs) in the context of CIR, they are often insufficient to cover the wide spectrum of capabilities required for an effective Emergency Management (EM) in such complex operational environments.

This study contributes to the advancement of the CIR state-of-the-art by developing a comprehensive classification and assessment framework for a robust multidimensional comparison and selection of GPs. Besides the 53 GPs included in the paper, the CRAFTER framework can be adopted for the assessment and selection of future additional GPs.

The practical contribution of the paper is the support to the CIR enhancement ï the analysis leads to a better understanding of how a specific GP may support the deployment of different EM capabilities and their possible limitations in terms of practical implementation and transferability. Practitioners can use the CRAFTER framework to efficiently compare GPs and select the most suitable ones according to the context of application and the specific requirements. The classification dimensions of the GPs adopted in the framework can support practitioners in the understanding of GPs key features, so as to avoid overlaps or conflicting factors and exploit possible synergies. In this regard, the mapping against EM capabilities allows an informed selection of BPs given the range of capabilities covered. Moreover, the study led to the identification of Minimal Effective Bundles (MEBs), i.e. groups of GPs that ensure optimal coverage of EM capabilities. The classification of MEBs according to the CI sector, the EM scope, the geographical scope and the hazard/threat scope can support practitioners in selecting the most suitable MEB based on the specific application context.

The limitation of the study is the robustness of the results obtained from the online questionnaire since the number of received responses was limited due to time constraints. This weakness can be improved by involving a higher number of CI experts to ensure greater consistency of the results. Another issue that emerged during the design of the CIR questionnaire is that the two taxonomies ï Activities & Functionalities and EM capabilities ï are not fully orthogonal, thus this may induce some ambiguities if used only by labels.

As a future development, the study can be extended by involving experts in the assessment of the MEBs. It would also be relevant to better investigate the adoption of the MEBs in different application contexts and provide more specific information about their transferability and implementation in practice.

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The authors make materials available upon request.

Code availability

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Authors' contributions

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Annex 1 ï List of selected GPs

	Good Practices	Objective
Information sharing cluster	Big Business ï Small Business *NIMSAT (2012) Big Business-Small Business Mentorship program*	It is a mentorship program that prepares small businesses to face and recover from disasters, through the involvement of big businesses in the role of mentors.
	DARWIN Wiki *DARWIN Project (2015) A research project to improve responses to crises arising from natural and man-made disasters. https://h2020darwin.eu/. Accessed 8 Mar 2021*	It is a knowledge management platform facilitating the interpretation of Resilience Management Guidelines.
	Focus on Flows *Resilient Regions Association (2020) Resilient Regions. http://www.resilientregions.org/english/. Accessed 8 Mar 2021*	It is a program providing access to researches, knowledge and best practices, whose aim is to ensure the continuity of flows, and thus a functional region.
	Louisiana Disaster Recovery Alliance *LDRA Consortium (2020) Louisiana Disaster Recovery Alliance. http://louisianarecoveryalliance.org/. Accessed 8 Mar 2021*	It is a program developed by local businesses with the aim of sharing knowledge and experience, as well as collaborating during disasters by leveraging resources and competencies of all members.
	MATRICS Multi Actor Threat Recognition, Information and Collaboration System *Astir (2020) Matrics. https://www.astir.com/innovazione/matrics/. Accessed 8 Mar 2021*	It is a platform that supports decision-making process, information sharing and collaborative plan execution.
	Multi-State Fleet Response Initiative *Trucco P, Petrenj B (2015) MIRACLE-Deliverable 2.2: International Case Studies on Regional CIP-R Programmes and related Good Practices*	It is a program where members organize conferences and meetings to develop an integrated strategy, with the aim of ensuring fleet and resources movements across different state borders in case of disasters.
	NWWARN Northwest Warning, Alert and Response Network *CRDR (2020) Center for Regional Disaster Resilience. http://www.regionalresilience.org/. Accessed 8 Mar 2021*	It is a platform enabling cross-sector information sharing through gatekeepers (i.e. experts in a particular infrastructure sector).
	Resilience Building Policies *SMR Project (2015) Smart Mature Resilience. https://smr-project.eu/home/. Accessed 8 Mar 2021*	It is a database of practices and policies adopted by European cities, which allows exploiting lessons learned and avoiding mistakes in the implementation of a resilience strategy.
	SATool Situational Awareness Tool *Trucco P, Petrenj B (2015) MIRACLE-Deliverable 2.2: International Case Studies on Regional CIP-R Programmes and related Good Practices*	It is a centralized portal though which private and public organizations share day-to-day information and communicate during critical events.
	V-BEOC Virtual Business Emergency Operations Center *National Business Emergency Operations Center (2020) Next Generation Business Emergency Operations Center (Next Gen BEOC). https://nimsat.louisiana.edu/resources/virtual-business-emergency-operations-center. Accessed 8 Mar 2021*	It is a platform that facilitates collaboration and coordination among stakeholders, providing visibility on disasters impacts and strengthening resilience of local communities.

Geographical visualization and information sharing cluster	Copernicus Emergency Management Service *European Commission (2020) Copernicus Emergency Management Service. https://emergency.copernicus.eu/. Accessed 8 Mar 2021*	It provides a geographical view of incidents, affected areas and early warnings in relation to different types of hazards (e.g. meteorological, geophysical).
	CRAMSS Collaborative Resilience Assessment and Management Support System *Resolute Project (2015) RESilience management guidelines and Operationalization appLied to Urban Transport Environment. http://www.resolute-eu.org/. Accessed 8 Mar 2021*	It is an application that supports reference stakeholders in their choices in case of potential hazards or during emergencies.
	EM Dashboard (*Cruscotto Emergenze* in Italian) *Regione Lombardia (2020) Cruscotto emergenze. https://www.cruscottoemergenze.servizirl.it/html/login.jsf. Accessed 8 Mar 2021*	It is a platform providing a georeferenced visualization of events, strategic places, resources and possible dangerous situations.
	ESSMA Emergency Support Smart Mobile App *Resolute Project (2015) RESilience management guidelines and Operationalization appLied to Urban Transport Environment. http://www.resolute-eu.org/. Accessed 8 Mar 2021*	It is an application that supports rescue teams in managing evacuation activities in case of emergency and provides citizens with information about dangerous areas.
	GIS Mapping for CI Assets *Trucco P, Petrenj B (2015) MIRACLE-Deliverable 2.2: International Case Studies on Regional CIP-R Programmes and related Good Practices*	It allows visualizing CI assets for a better understanding of physical and logical interdependencies, as well as vulnerabilities of the system.
	Resilience Information and Communication Portal *SMR Project (2015) Smart Mature Resilience. https://smr-project.eu/home/. Accessed 8 Mar 2021*	It is a portal that gathers information of citiesôresilience-building process, with the aim of both sharing knowledge among members and supporting citizens in preparing for an emergency.
	Traffic Scotland Information Service *Transport Scotland (2020) Traffic Scotland. https://trafficscotland.org/media/. Accessed 8 Mar 2021*	It was developed to monitor the road infrastructure network, control the traffic and inform the public about current road works, accidents, journey times and congestions.
Planning cluster	COLAB *The Rockefeller Foundation (2015) 100 Resilient Cities. https://www.rockefellerfoundation.org/100-resilient-cities/. Accessed 8 Mar 2021*	It provides a set of guidelines to bring together partners from different industries and disciplines in order to explore resilience-building opportunities of a city.
	European Resilience Management Guideline *SMR Project (2015) Smart Mature Resilience. https://smr-project.eu/home/. Accessed 8 Mar 2021*	It defines an operational framework for cities, providing guidance about the development and implementation of local resilience planning.
	Partnership Alignment for Enhanced Security *Trucco P, Petrenj B (2015) MIRACLE-Deliverable 2.2: International Case Studies on Regional CIP-R Programmes and related Good Practices*	It ensures an integrated crisis management by providing guidelines that support regions in developing plans and procedures related to emergency situations.
	PRISM Performance and Risk-based Integrated Security Methodology *Harnser Group (2012) The Financial Aspects of the Security of Assets and Infrastructure in the Energy Sector*	It was designed to support the user in the implementation of risk management process related to CIs, providing guidance notes and templates.
	Public Safety Canada *Public Safety Canada (2020) Enhancing Canadaôs Critical Infrastructure Resilience to Insider Risk. https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/nhncng-crtcl-nfrstrctr/index-en.aspx. Accessed 8 Mar 2021*	It provides guidelines to CI operators on how to monitor, respond and mitigate insider risks.

	TTF Thematic Task Forces *Alberto Ceriani (2011) Piano regionale per la protezione delle infrastrutture critiche (PIC)*	They involve experts according to their own background with the aim of developing aligned plans and procedures to manage CI systems.
Training, exercising and simulations cluster	Blue Cascades Exercise Series *Newman D (2018) Blue Cascades VII Cascadia Subduction Zone Earthquake Recovery Tabletop Exercise After Action Report*	It is a program based on exercises that explore CI interdependencies and cascading impacts, while strengthening relationships among participants.
	CATEX Catastrophic Exercise *All Hazards Consortium (2017) CATEX 2017 Exercise. https://www.ahcusa.org/catex-2017-exercise1.html. Accessed 8 Mar 2021*	It is based on a series of exercises conducted by states and private organizations with the aim of testing different capabilities of EM.
	City Resilience Dynamics *SMR Project (2015) Smart Mature Resilience. https://smr-project.eu/home/. Accessed 8 Mar 2021*	It is a simulation platform that allows comparing the impact of different resilience policies, highlighting their contribution to the resilience improvement process.
	GINOM Global Infrastructure Network Optimization Model *EIS Council (2020) GINOM, The Global Infrastructure Nework Optimization Model. https://doi.org/10.2172/1430038*	It is a simulation platform to support decision makers in case of disruptions to resource availability and damage to CI systems.
	MICC Major Incident Control Committee *MICC Partners (2020) MICC Grangemouth. https://www.miccgrangemouth.co.uk/. Accessed 8 Mar 2021*	It is a program in which local businesses train and exercise with public institutions and the community to guarantee an effective implementation of procedures and plans.
	Opportunity Assessment (Tool) Workshop *The Rockefeller Foundation (2015) 100 Resilient Cities. https://www.rockefellerfoundation.org/100-resilient-cities/. Accessed 8 Mar 2021*	It is a series of workshops designed to identify and prioritize resilience-building actions.
	Problem Framing *The Rockefeller Foundation (2015) 100 Resilient Cities. https://www.rockefellerfoundation.org/100-resilient-cities/. Accessed 8 Mar 2021*	It engages stakeholders in workshops to identify problems affecting a CI system and learn new ways to solve them.
	Project Scan (Tool) Workshop *The Rockefeller Foundation (2015) 100 Resilient Cities. https://www.rockefellerfoundation.org/100-resilient-cities/. Accessed 8 Mar 2021*	It is a workshop where participants learn how to assess the contribution of existing projects to the overall resilience of a city and how to improve them.
	Resilience Accelerator *The Rockefeller Foundation (2015) 100 Resilient Cities. https://www.rockefellerfoundation.org/100-resilient-cities/. Accessed 8 Mar 2021*	It gathers multi-disciplinary experts in a workshop to identify urgent problems and learn about new resilience strategies.
	Resilience Garage *The Rockefeller Foundation (2015) 100 Resilient Cities. https://www.rockefellerfoundation.org/100-resilient-cities/. Accessed 8 Mar 2021*	It is a workshop whose aim is to accelerate the application of resilience theory in practice and to refine resilience theory based on practical experience and empirical evidence.
	Resilience Value Realization *The Rockefeller Foundation (2015) 100 Resilient Cities. https://www.rockefellerfoundation.org/100-resilient-cities/. Accessed 8 Mar 2021*	It is a workshop that guides participants in the development of a roadmap to achieve the desired resilience value.
	Serious Games based on Virtual Reality *DARWIN Project (2015) A research project to improve responses to crises arising from natural and man-made disasters. https://h2020darwin.eu/. Accessed 8 Mar 2021*	It is a virtual environment used to train users by testing specific tasks performed during rescue operations.

	SimEnv *DARWIN Project (2015) A research project to improve responses to crises arising from natural and man-made disasters. https://h2020darwin.eu/. Accessed 8 Mar 2021*	It is a simulation tool that provides the means to evaluate different strategies of resource deployment and citizens evacuation.
	Tactical Urban Resilience *The Rockefeller Foundation (2015) 100 Resilient Cities. https://www.rockefellerfoundation.org/100-resilient-cities/. Accessed 8 Mar 2021*	It is a workshop where communities and public institutions collaborate to analyze opportunities and benefits of a resilience program.
	100 RC Systems Studio *The Rockefeller Foundation (2015) 100 Resilient Cities. https://www.rockefellerfoundation.org/100-resilient-cities/. Accessed 8 Mar 2021*	It is a workshop where participants can familiarize with a system thinking approach, by identifying vulnerabilities and interdependences of specific systems and develop solutions to enhance resilience.
Risk and Resilience assessment cluster	Assets and Risk Tool *The Rockefeller Foundation (2015) 100 Resilient Cities. https://www.rockefellerfoundation.org/100-resilient-cities/. Accessed 8 Mar 2021*	It is a tool developed to prioritize shocks and stresses and identify vulnerable physical assets.
	CI System Definition Tool *Resilens Project (2016) Realising European Resilience for Critical Infrastructure. http://resilens.eu/. Accessed 8 Mar 2021*	It is a tool to identify critical assets and CI interdependencies.
	City Resilience Index (The Rockefeller Foundation 2015)*The Rockefeller Foundation (2015) 100 Resilient Cities. https://www.rockefellerfoundation.org/100-resilient-cities/. Accessed 8 Mar 2021*	It is a tool designed to create a resilience baseline and to enable cities to measure and monitor the multiple factors that contribute to their resilience.
	DOMINO Tool *Trucco P, Petrenj B (2015) MIRACLE-Deliverable 2.2: International Case Studies on Regional CIP-R Programmes and related Good Practices*	It is a system, based on a cartography approach, for managing interdependencies, analyzing domino effects and finally assigning a risk level to different areas that could be impacted by an emergency event.
	GIS based Resilience Mapping Tool *Resilens Project (2016) Realising European Resilience for Critical Infrastructure. http://resilens.eu/. Accessed 8 Mar 2021*	It is a visualization tool that, considering the resilience level of each CI components, provides an indication of the resilience scores of the investigated CI systems.
	GRRASP Geospatial Risk and Resilience Assessment Platform *EC (2020) Geospatial Risk and Resilience Assessment Platform. https://ec.europa.eu/jrc/en/grrasp. Accessed 8 Mar 2021*	It is a geographic platform for analyzing CI disruptions, considering the impact of the disservice on the interconnected systems.
	Local Area Risk Assessment *The Rockefeller Foundation (2015) 100 Resilient Cities. https://www.rockefellerfoundation.org/100-resilient-cities/. Accessed 8 Mar 2021*	It is a tool that supports cities in establishing a comprehensive catalog of risks and assessing their impact on specific assets, locations, business sectors and citizens.
	Resilience Actions Inventory and Stakeholder Perceptions Review *The Rockefeller Foundation (2015) 100 Resilient Cities. https://www.rockefellerfoundation.org/100-resilient-cities/. Accessed 8 Mar 2021*	It is a tool designed to support a qualitative diagnosis of resilience by involving different stakeholders to understand their perceptions about the factors that contribute to the enhancement of city resilience.
	Resilience Management Audit Tool *Resilens Project (2016) Realising European Resilience for Critical Infrastructure. http://resilens.eu/. Accessed 8 Mar 2021*	It is a tool developed to guide CI operators in selecting the most suitable policies for enhancing resilience, given the specific characteristics of the CI under investigation.

	Resilience Management Matrix Tool *Resilens Project (2016) Realising European Resilience for Critical Infrastructure. http://resilens.eu/. Accessed 8 Mar 2021*	It is a tool that allows assigning resilience scores to specific CI components, stages and domains which may be of particular interest to the CI operator.
	Resilience Maturity Model *SMR Project (2015) Smart Mature Resilience. https://smr-project.eu/home/. Accessed 8 Mar 2021*	It is a tool developed to identify the resilience maturity stage of a city and provide an optimum path to increase this resilience level.
	Risk Systemicity Questionnaire *SMR Project (2015) Smart Mature Resilience. https://smr-project.eu/home/. Accessed 8 Mar 2021*	It is a tool designed to identify risk scenarios, prioritize them and suggest policies to address the most relevant ones.
	Smart Resilience Indicators *Jovanovic Eu-Vri A (2016) Smart Resilience Indicators for Smart Critical Infrastructure D.2.2-Report on challenges for SCIs*	It is a tool aimed at benchmarking the best resilience solutions and identifying the early warnings to prevent new threats and cascading effects.
	THREVI2 *r2macs (2020) Critical Infrastructure | Risk & Resilience of Complex Systems. https://www.r2macs.com/ci. Accessed 8 Mar 2021*	It provides a systematic and complete identification of CI accident scenarios, covering energy, transport, water and telecommunication sectors, and it evaluates the vulnerabilities of system components.
BCM cluster	Area BCM *Baba H, Watanabe T, Nagaishi M, Matsumoto H (2014) Area Business Continuity Management, a New Opportunity for Building Economic Resilience. Procedia Econ Financ 18:296ï 303. https://doi.org/10.1016/s2212-5671(14)00943-5*	It consists of mitigation measures and recovery actions aimed at maintaining business continuity in an entire area by securing critical external resources.
	BCM for enterprises *Okabe S (2009) Business Continuity Management Plannin: Japanese Approach. Int J Manag Sci Technol*	It consists of strategic management activities aimed at continuing critical business or recovering operations as soon as possible when contingencies arise.