Sistema di supporto alle decisioni finalizzato al miglioramento della "protezione fisica" di infrastrutture critiche in caso di calamità naturali

La fornitura dei servizi essenziali dipende dall'integrità ed efficienza di numerose reti tecnologiche "critiche", quali, ad esempio, le reti elettriche, le reti di telecomunicazioni, acquedotti e gasdotti, reti viarie e ferroviarie. È responsabilità di ciascuna nazione proteggerle con cura e, in collaborazione con gli operatori pubblici e privati che le possiedono e le controllano, realizzare gli strumenti appropriati per aumentarne la resilienza in situazioni di crisi, indotte da eventi meteo avversi, da catastrofi naturali. Quest'articolo descrive i lavori attualmente in corso nell'ambito di progetti nazionali ed europei per la realizzazione di un Sistema di Supporto alle Decisioni (DSS, Decision Support System) in grado di analizzare e prevedere costantemente il livello di rischio al quale sono sottoposte le infrastrutture, valutando in anticipo gli impatti e le conseguenze della loro perdita di funzionalità. Questo consentirà a operatori pubblici e privati di prevenire situazioni avverse e approntare le opportune misure di emergenza e di mitigazione per ridurre o evitare le conseguenze di un pericoloso blackout dei servizi.

Decision Support System aimed at improving the "physical protection" of critical infrastructures against natural events

Nowadays, the delivery of essential services depend on the integrity and efficiency of a set of critical technological networks as for example, electrical grids, telecommunication networks, gas and water pipelines, roads and railways. It is the responsibility of each nation to protect them carefully and, in collaboration with the operators (public and private) that own and control them, realize appropriate tools to increase their resilience against crisis scenarios which might be opened by adverse natural hazards and seismic events. This work describes the ongoing work within the framework of national and European projects for the construction of an operating Decision Support System (DSS) able to continuously evaluate and predict the level of risk to which infrastructures are subjected, by assessing in advance the impacts and consequences of their loss. This allows public and private operators to prepare themselves and set up appropriate emergency and mitigation plans to reduce or remove the consequences of a dangerous blackout of services.

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Introduction

Critical Infrastructures (CI) are technological systems (e.g., gas and water pipelines, telecommunication networks, electrical grids, roads and railways) the correct functioning of which impacts on the life quality of citizens. CI protection is needed to guarantee their physical integrity and the continuity of the services they deliver. Critical Infrastructure Protection (CIP) is thus a major issue of nations, also due to its trans-national relevance. EU has thus issued directives to Member States (MS) in favor of an increased level of protection, thus recognizing the fact that they constitute a unique, large system covering all the EU area (EU Directive, 2008/114/CE).

Resilience (i.e., the ability of a system to recover its equilibrium state after a perturbation) is thus becoming a keyword in this domain. Wherever vulnerability could be decreased down to a certain extent - risks related to the occurrence of common cause failures could be appropriately mitigated, as well as those resulting from human causes - there are natural threats resulting from adverse meteorological and geo-physical events which can be hardly mitigated although they could be, in many cases, at least reliably predicted. The focus has thus been diverted from vulnerability to resilience. The goal will be thus reducing the systems' vulnerability and increasing their resilience.

This task has been attempted, at a federal level, in the U.S. by the creation of a National Infrastructures Simulation and Analysis Centre (NISAC) [1], which plays the role of connecting all national-wide CI operators and systems in a unique site able to analysing and forecasting high-impact natural hazards and the consequent faults on CI and the environment. This should, in principle, favour risk prediction (mainly due to natural hazards) and the set-up of appropriate mitigation and healing strategies in advance. This has been proven to produce some enhancement of the systems' resilience, a better control of dependency phenomena (i.e., those related to the physical and functional dependencies between one infrastructure and the others) and, thus, to prevent cascading effects. Much in the same spirit, the EU-funded Network of Excellence CIPRNet (Critical Infrastructures Preparedness and Resilience Research Network) [2] aims at proposing the NISAC experience in Europe by sustaining the technological and institutional growth of European Infrastructures Simulation and Analysis Centres (EISAC), a constellation of connected national centres enabling a 24/7 risk analysis of the CI elements, providing these data to the appropriate national authorities appointed for CIP. The realization of EISAC national nodes has been demanded to local partners of the CIPRNet network. To this aim, ENEA has inserted the realization of the first seed of the Italian EISAC node into the project "RoMA" (Resilience enhancement of a Metropolitan Area), which has been recently approved and funded by MIUR (the Italian Ministry of Research) in the frame of the Call "Smart Cities and Communities".

From the technical side, the CIPRNet project aims at designing and developing a number of technological tools which will boost the EISAC nodes, by allowing them to operationally sustaining the task of assessing the state of risks of the CI. Among others, there is a Decision Support System (DSS hereafter), the structure and design of which will be the object of the present report.

A major role in the construction of such a tool is played by the GIS (Geographical Information Systems) technologies. In the last few years, the geo-scientific community has been focusing on the use of GIS technologies and techniques for supporting natural disaster early warning and emergency management tasks [3]. The need for related standards and effective spatial DSS, based on a GUI (Graphical User Interface) with geo-visual analytic tools, has been recognized by numerous researchers, as shown by several on-going research activities. Multi-source data and GIS-integrated analysis can contribute to a better emergency planning, providing fundamental information for immediate response [4].

Risk assessment of CI

At the bases of a DSS loop, there is the need of estimating a number of factors which determine the "risk" that the occurrence of a given event might cause in the technological systems. Then, at the end of a thorough estimate of the risk, the system is also called to provide operators and emergency managers with insights usable for supporting decision-making. The DSS workflow shown in this report fulfils just the first task, i.e., estimating the risk and presenting the more complete and consequence-based risk evaluation. The technological activities of the CIPRNet project also encompass the creation of a "What-if" support tool, enabling operators to estimate the impacts that possible mitigation and healing procedures might produce in the critical scenario, thus completing the set of tools supporting operators.

Let us thus define $R(T_i, CI_j^x)$the Risk associated with the loss (or the functionality reduction) of the element CI_j^x (x-th element of the j-th infrastructure) due to a natural threat T_i

$$R(T_i, CI_j^x) = Pr(T_i)\ V(CI_j^x, T_i) I(CI_j^x) \qquad (1)$$

where:

- $Pr(T_i)$ is the probability of occurrence of the threat T_i
- $V(CI_j^x, T_i)$ is the vulnerability, w.r.t the threat T_i, of the x-th element of the j-th infrastructure
- $I(CI_j^x)$ is the sum of impacts and consequences that the absence of the x-th element of j-th CI produces upon failure:
  - in its network and in the other CI networks functionally related to it;
  - on the environment and the population affected by the failure.

The Risk equation (1)

- depends on the composition of 3 factors, which determine the value of the Risk.
- makes reference to a specific threat *manifestation*. A natural hazard (say a tropical typhoon) constitutes a threat for the CI systems as it is associated to several "physical manifestations" (like, e.g., abundant rainfalls, strong wind, lightening, etc.) which may impact on the infrastructures producing harm (i.e., winds could highly stress mechanical structures, flooding could strike on physical CI elements located in flooded areas, lightning could damage electrical systems, etc.). In this respect, we will use T_i to indicate a specific *manifestation* of a given natural hazard; for a given predicted natural hazard, we will specify which of its manifestations will be used to evaluate the Risk of eq.(1).

Impacts indicate the reduction (or loss) of services. They will thus be estimated by using the metrics of Quality of Service (QoS): upon specific physical damage produced by threat manifestations on CI elements, the struck CI and the other ones (where services depend on that delivered by the injured one), will presumably reduce (or even completely lose) their QoS with respect to their standard operating levels. Impacts, moreover, could be "weighted" in terms of the consequences they will produce on:

1. population (in terms of people affected by outages, to be "profiled" in terms of vulnerability area which they belong to)
2. primary services (reduction of functionality in hospitals, schools, public transportations, etc.)
3. the environment (if the impacts are associated to environmental damages, such as pollution, land contamination, etc.)
4. industrial sectors (in terms of reduction of productivity, loss of GDP, etc.)

Eventually, the estimate of Risk through eq.(1) will provide CI operators, emergency responders, public authorities with a comprehensive assessment of the amplitude of the crisis they will be presumably going to face. The awareness of these data will allow a knowledge-based set-up of mitigation and healing plans.

DSS workflow and function

The DSS designed in the CIPRNet project to evaluate the state of Risk of the CI elements in a given area will make a thorough evaluation of eq. (1) by using existing and ad-hoc developed technological tools (databases, simulation models), integrated with existing technologies (now-casting and remote sensing, with High Resolution and SAR data). The DSS can leverage on proprietary Databases and external repositories, containing different typologies of data: Territorial and Environmental, Socio-economical (e.g., Census data), Technological Infrastructures data, Natural hazards/ events (e.g., earthquakes catalogue, landslides, flood risk, etc.).

Figure 1 reports a schematic layout of the different tasks that the designed workflow should accomplish in order to produce a "CI Risk Daily Report", which will

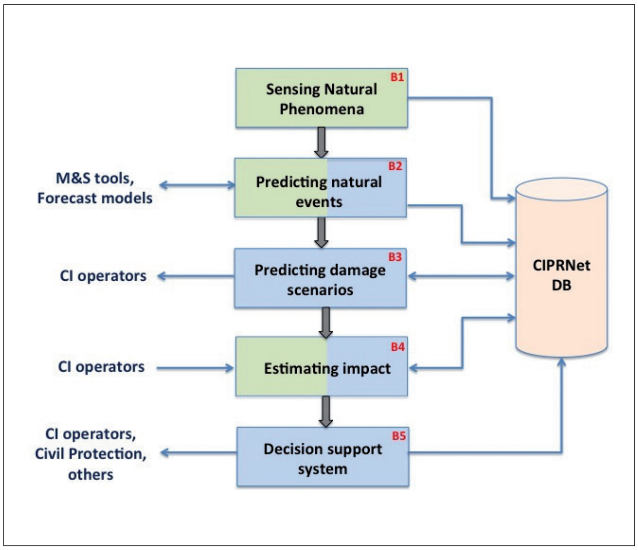

FIGURE 1 DSS Workflow. Different colours shading action boxes indicate technologies directly produced in the CIPRNet project (blue) and data/technologies taken from third parties or externally provided data (green)

constitute the specific outcome of the EISAC nodes in favour of their main end users: Civil Protection Depts. and/or other Public Authorities committed to CIP.

In the following, we will describe the DSS workflow, which is composed of five action boxes (see Fig. 1). Each of them contributes to evaluate the Risk as expressed in eq.(1). It is worth stressing that this is a workflow in collaboration with CI operators, who will be called to comply with and contribute to the risk assessment, as shown in the following.

In the first action (the first term on the right-hand side of eq. (1)), the system collects information from the field (through proximal or remote sensors) and from weather forecast (medium-long term as weather forecast, and short-term by now-casting systems [5]). High resolution downscaling of weather forecast will be performed in areas where a higher forecast resolution would be significant for increasing prediction reliability (e.g., Fig. 2 and Fig. 3). According to these data it is possible to make estimated maps

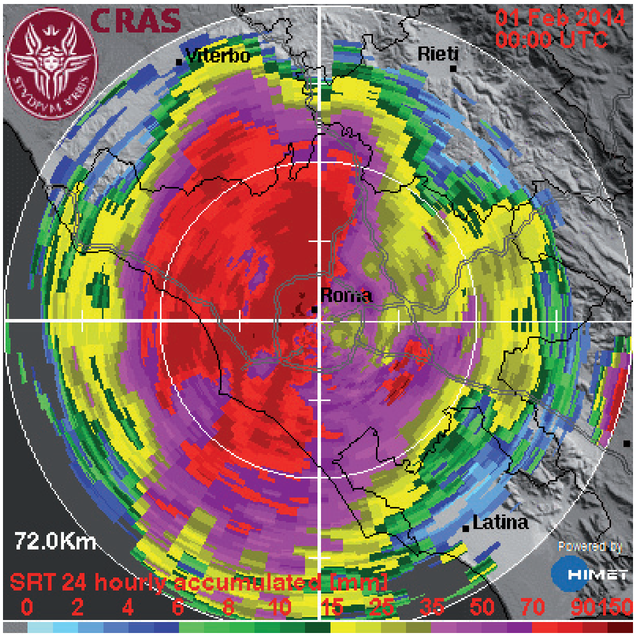

FIGURE 2 The cumulate 24h prediction from a now-casting radar showing the rain abundance on the city of Rome (data taken on January 31, 2014, when a strong precipitation hit the city of Rome). Courtesy of Himet Srl

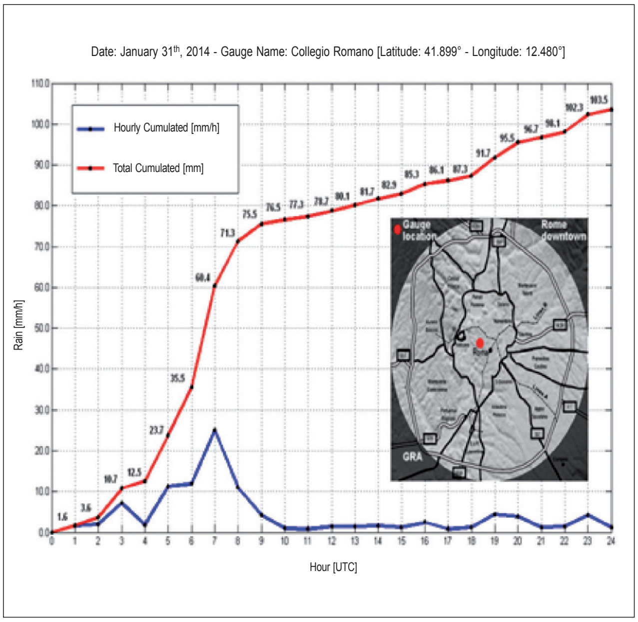

FIGURE 3 The hourly and the cumulated amount of rainfall in Rome on January 31, 2014. The red spot represents the location of the now-casting radar. The red line is the cumulated rainfall, the blue one is the hourly value. Data in mm/hour. Courtesy of Himet Srl

of hourly precipitations, which could then be used to assess the potential impact on CI.

In the second action (the second term on the right hand side of eq. (1)), starting from the event prediction, the system analyses its database to establish the probability that a given infrastructural element is hit by the threat and damaged. Intrinsic vulnerabilities of elements are correlated with the event probability and with its predicted strength in order to provide a damage probability. This information will be integrated, in the third action, into a "Harm Scenario" (i.e., the set of all CI elements possibly hit by one or more of the predicted threats). In this framework, one of the main aims of the DSS is to make geographic data, thematic maps and probable "Damage Scenarios" available to specific end users (and, potentially, to the public). To this end, the system allows end users to view spatial data (Fig. 4) within a suitable web-interface, by means of a WebGIS application (e.g., a customizable and totally user-specific geospatial platform). Such a tool provides interactive query capabilities and integrates the GIS-based solutions with other technologies.

At this stage, the workflow envisages the communication of the expected Damage Scenarios to CI operators; these latter will be called to evaluate, with their own simulation tools, the impact (in terms of reduction of functionality) on their networks should the predicted outages of the elements reported in the Harm Scenario effectively occur. In turn, CI operators will reply by identifying the Impacts on their services that the different types of damage would produce - e.g., in terms of reduction of QoS in specific points of their networks.

The fourth action of the workflow will then start. The DSS system will gather the information from the CI operators and, by using specific tools accounting for the system's functional dependences (or interdependencies), will evaluate the overall impact of the predicted harm on

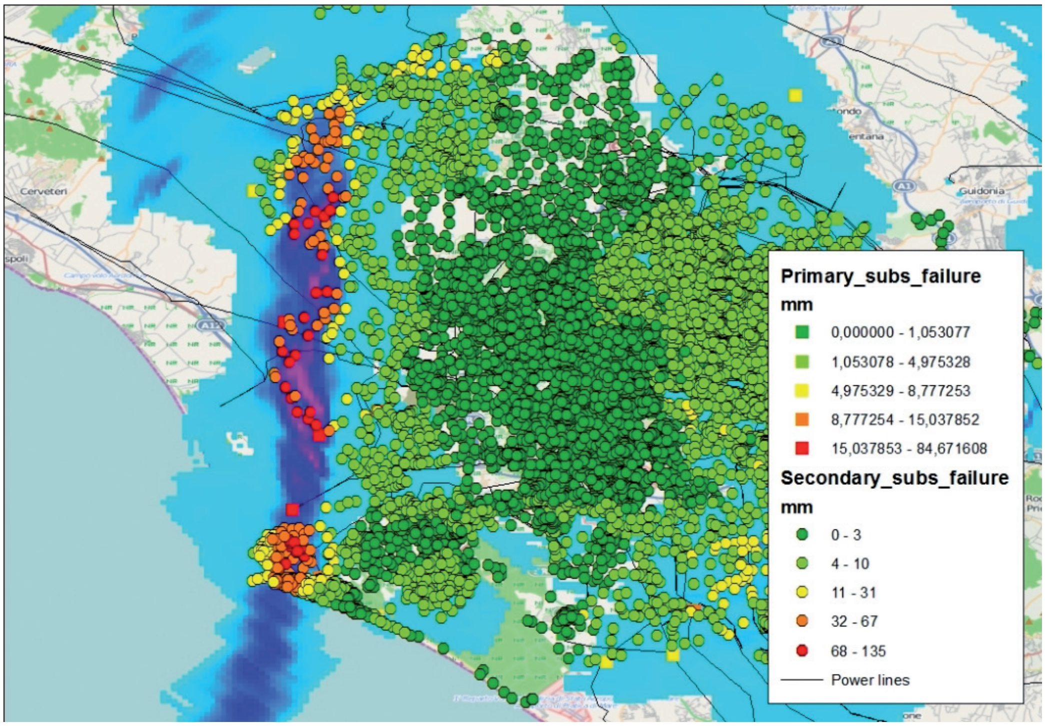

FIGURE 4 Damage scenario with the area of predicted over-threshold precipitations (blue shaded area) and the prediction of potentially affected CI elements (red dots)

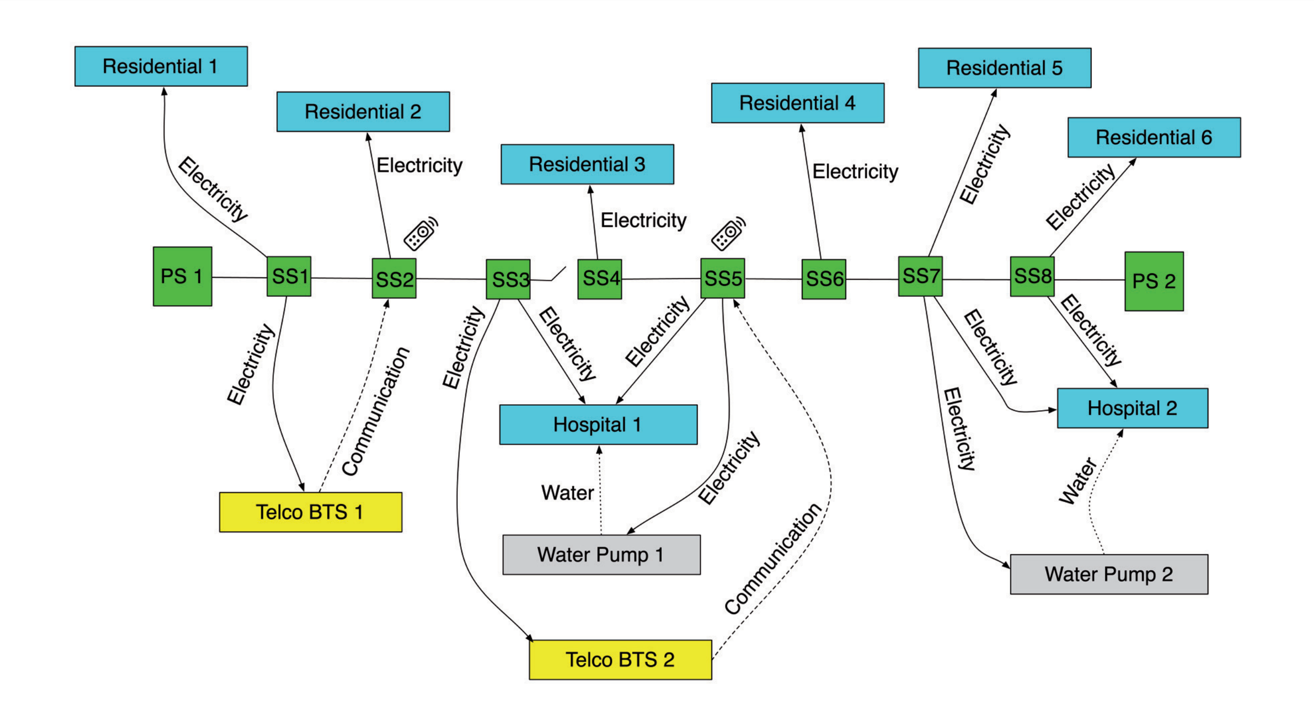

FIGURE 5 An example of an abstract interdependency model that represents the interactions existing among different systems providing services to one another. Green boxes represent electrical substations

the whole CI system (at a level of "system of systems"). In particular, this task will be performed by using appropriate modelling tools (e.g., I2SIM [6]) which, at specific granularity level for the description of the CI present in a given area, will contain their functional dependence useful for estimating the probability of possible cascading effects and feedback loops present among the CIs (Fig. 5). Negative feedback loops, in fact, could amplify and increase the impacts on the infrastructures and add to the overall effects of the outages.

In the fifth layer, the overall scenario description (in terms of functionality reduction or loss of one or more CI) will be "weighted" by estimating the consequences that those complete or partial outages in services might produce in the 4 sectors recalled above. This analysis is carried out by leveraging on "specific vulnerability" indices (i.e., the loss of "well-being" of a specific sector, estimated with some metrics, with respect to the loss of a unitary decrease in a given service, such as electricity, water, gas, telecommunications, etc.). This information will be useful to CI operators and emergency managers to perceive in depth the consequences of the crisis that they will be called to face.

Conclusions

Following the theoretical framework of eq. (1), the DSS workflow evaluates on a 24/7 basis the state of "Risk" of the CI elements in a given area, due to natural threats (as for example flooding, strong wind, heavy rain, heavy snow and hot wave). The various information achieved at the end of the DSS workflow, both quantitative (CI elements risk maps) and qualitative (daily reports concerning impacts and consequences of predicted natural extreme events on different sectors), represent a significant advancement with respect to the current capabilities: (a) the scenario is "predicted", thus it will be delivered to decision-makers prior to the event occurrence; (b) the workflow will also evaluate possible cascading effects due to the more or less evident system's dependencies, thus increasing the impact predictions based on single-infrastructure evaluations; (c) other than impacts at the physical and service levels, the DSS will correlate impacts data with different types of information layers (physical, environmental, territorial, industrial, economic, social), and will be able to establish further types of impacts: on the population, on the different industrial sectors, on the environment. Moreover, the webGIS advanced interface allows the DSS end users to visualize CI elements risk maps and overlay this information with other kinds of information as, for example, impact and consequence analysis results. In particular, on the environmental side, the system could also be used for predicting the course of events in the cases where the CI damage scenario would imply some event (such as oil spill, toxic or radioactive releases from plants, etc.). In such a case, the DSS could interact with specific simulation models (ocean dynamics, gas transport in the atmosphere, etc...) for the prediction of environmental impacts.

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