Modeling Networks of Interdependent Infrastructure in Complex Urban Environments Using Open-Data

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Abstract: Dependency effects between Critical Infrastructure (CI) elements represent key information needed to predict and analyze the impact of natural (or man-made) disturbances. The dependency links among CI elements and their associated weight are data whose availability is often complex to determine and are usually not available. Leveraging on several data supporting US and EU Directives for the Resilience and the Protection of CIs, the objective of the present work is to define a dependency network of elements of critical sectors extracted from available open-data. The resulting network is then studied in terms of its basic topological properties. The analysis of the network provides interesting clues about the properties and locations of critical points that can cause cascading failures. In addition, this information can form the basis for planning actions that mitigate the risk of cascading effects.

1 INTRODUCTION

Resilience is a key, systemic, property which is of primary relevance in Smart Cities which are complex environments characterized by the superposition of infrastructure, structural assets, citizens, and host all primary services which citizen must have constantly available. All these components, however, are fully dependent on each other, leading their management and protection a complex task. Whereas repositories of system dependencies already exist, mapping urban dependencies is a challenge hindered by several factors including lack of integration of knowledge held by different critical infrastructure (CI) operators and privacy restrictions. Furthermore, data are constantly changing and are difficult to collect because they are kept by different stakeholders.

One way to analyze CI dependencies is to consider Dependency Risk Graphs (DRGs) (Stergiopoulos et al., 2015) whose nodes represent CI components and directed edges represent the potential risk that the destination node may suffer due to its dependency on the source node in the event of a source node failure. Throughout this work, we will use the acronym POI (Point of Interest) to identify a whatsoever element or installation of a specific technological system belonging to a given network which is ”expression” of a specific Sector. Sectors, in turn, are functional domains which produce goods and/or services to citizens. Sectors are Government functions, Energy production, Water distribution, Finance activities etc. Resulting DRG can be considered for the analysis of possible cascading failures due to infrastructure dependency chains at an urban scale.

The MARIS (Modeling infrAstructuRe dependencIes at an urban Scale) methodology (Di Pietro et al., 2023), previously used for the prediction of dependency cascading outages in CI, can also be implemented by producing DRGs by using open-data (in terms of POI) collected at an urban scale. This paper extends the methodology by considering a broader set of POI types and dependencies. It further propose a strategy to unveal unknown dependencies in order to produce DRGs that can be analyzed to identify possible mitigation actions to cascading failures. This can be achieved by using the results under the form of attachments of new Directives which are proposed, at national or multi-national level, to deal with the task

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of protecting and enhancing resilience of critical assets. They contains the understanding of the complex infrastructure dependencies sedimented by the experience of infrastructure operators, stakeholders and the scientific community than, since at least two decades, have addressed the problem of technogical system's dependencies.

2 DEPENDENCY NETWORKS AND THE MARIS METHODOLOGY

There has been a great deal of effort to identify dependency mechanisms among infrastructure, leading to perturbation flows from one infrastructure to the others, which trigger the onset of the so called "cascading failures". Dependency links represent the functional interaction among infrastructure whose services (or products) supply other infrastructure providing them some necessary input (energy, water, personnel, data etc.) for the infrastructure functioning. The loss of those inputs reduces (or completely inhibits) their functioning. However there is a graduality in the infrastructure dependencies. Some inputs are more relevant than others. In some cases, for instance, products to be received could be appropriately stored and used when missing (like e.g. energy buffer or water reservoirs). Other inputs, when missing, start producing an impact only after a certain time; others can be rapidly supplied if appropriate redundancy strategies have been prepared. Some of these dependencies can also be bi-directional: the fading of one infrastructure's functioning can provide a negative feedback to some feeding infrastructure, which will then further reduce its capability of producing the needed input to the former, thus producing a self-consistent, multi-infrastructure negative feedback and an increasing large functional crisis (inter-dependency effects). This is to say that dependency dynamics is quite complex and establishes along different time and geographical scales.

Related work in this field touches both engineering perspectives for smart city development, network dynamics as well as information modeling. From the engineering perspective, multiple publications delve on the subject of dependencies inside cities. Authors in ((R., 2019) elaborate on dependencies of critical infrastructures by highlighting the "double dimension" of efficiency and susceptibility of elements against disruptions due to their dependencies. A recent work introduces measures to identify critical network components influencing the resilience of interdependent infrastructure networks and their recovery (Almoghathawi, 2019).

From a network dynamics perspective, authors utilize models to analyze the interrelations between infrastructures. From the early work of (Kotzanikolaou, 2013) on n-order cascading effects analysis that laid the foundations on modeling cascading effect Risk, to (Stergiopoulos, 2015) that extended previous work to incorporate time dimensions and centrality metrics, to today's publications, this work emphasizes the need for modeling of information to understand cascading effects. Other authors (such as (Abdelgawad, 2019)) used MATLAB code to identify and quantify the amplification of cascading effects due to interdependencies among CIs, aiming to pinpointing weak points for better preparedness and mitigation. In (Mbanaso, 2021), authors analyze the Nth-order dependency effects between critical infrastructures using Neural Networks and create a model to analyze the criticality and dependency of CI elements, emphasizing on cascading effects. Similarly, authors in (Zhou and Bashan, 2020) explore targeted attack strategies based on dependencies within interdependent networks, finding that dependency-last attacks are more effective than dependency-first or random attacks in triggering cascading failures, while (Aida and Katsikas, 2021) analyze dependencies in large-scale critical infrastructures, offering quantitative assessment parameters for multi-order dependencies between cyber-physical systems.

Major breakthroughs in this domain have been provided by a number of works (like e.g. (Franchina et al., 2011) and (Laugé et al., 2015)) which, by using different approaches, have attempted to produce a qualitative, and in some cases quantitative, estimate of sectorial dependencies, their relevance and the timing during which dependency effects take place.

The net result of these works has been the identification of a fault tree indicating, starting from the failure of an infrastructure belonging to a specific Sector, which other infrastructure of other Sectors would be compromised (after which amount of time) and for each new perturbed infrastructure, the number of other infrastructure attained. Such "dependency" exercise has been realized up to a small number of steps in the hierarchical dependency tree and/or up to a certain time after the occurrence of the main fault event in the cascade-initiating Sector.

After the identification of the dependency tree for each infrastructure Sector, it is possible to build up the inter-sectorial network in a specific area, by appropriately linking elements of different Sectors among them, by using the hierarchical dependency tree as a guide to connect different nodes. Each link connecting different nodes is oriented: it goes from the feeding node to the fed one. Links, in principle, should also be weighted in order to identify, in a ”static” perspective, the relevance of a specific dependence for the fate of the fed node; higher the weight, higher the impact of the loss of the feeding node for the functionalities of the fed one . Lightness, in a ”dynamical” viewpoint, would correspond to a higher latency (i.e. a longer time) for the functional impact of the hit node to the others.

With weighted links, it is possible to ”simulate” dynamic events in cascading failures, as a network model of such type would allow to emulate the behavior of the propagation failure from one node to the others. This is essentially the objectives of the MARIS methodology. An example of such methodology on a synthetic scenario has been given in (Rosato et al., 2021a).

The main objective of the present work is to propose the application of this methodology which, starting from Public Open Data and the availability of appropriate hierarchical dependency trees, is able to construct realistic infrastructure networks which could be useful for further analysis on both their ”static” (i.e. topological, functional) and ”dynamical” (reproduction of fault scenarios) behavior.

The MARIS methodology leverages on three building blocks: (i) the mapping of POI data into the CI sectors (to attribute the dependency of POI to the geographically proximal CI element); (ii) the mapping of CI sector dependencies into POI dependencies (to establish the way in which perturbations flow from one CI to another, thus ultimately affection POI functionality); and (iii) the creation of DRGs of POI facilities.

A significant contribution of MARIS methodology resides on the model's ability to easily incorporate Open Data sources, enhancing scalability and adaptability to different urban contexts.

2.1 POI Facilities Classification

In order to classify data, the first problem is to allot the different elements (POI) to a specific functional class (Sectors). POIs will thus become nodes of a network, where links will represent the unknown dependency of the services exchanged by two different nodes.

POI classification can be dealt with using ”legal” definition of Sectors, by using appropriate national definition of elements belonging to different societal, industrial and economic activities. Links will be then deduced by ”dependency maps” which have been produced for the production of Directive to manage the complex domain of Critical Infrastructure.

2.1.1 The CER and CISR Directives

A clue for identifying the Sectors in which specific POI can be classified is provided by laws (or Directive) issued ad national or federal scale.

The Critical Entities Resilience (CER) Directive (Council of European Union, 2022) 2557/2022 has identified a resilience strategy for the EU Member States (MS) with the aim of realizing a common and homogeneous security space of all CI with respect to natural and anthropic hazards. Such a strategy consists of a number of prescriptions to MS which will be called to set in place specific measures to ensure the resilience of essential services in case of critical situation (essential services, economic and industrial activities). CER Directive follows a similar initiative established in US, the Critical Infrastructure Security and Resilience (CISR) Directive (Presidential Policy Directive, 2013) which manages all Federal Departments and Agencies to identify, prioritize and provide a plan to protect their physical and cyber critical infrastructure. Both Directives provide a list of essential services (and their related ”entities”, such as both infrastructure and their managing organizations): they consist in 11 (for EU) and 16 (for US) sectors, as shown in Table 1.

The CISR Directive inspired the further delivery of 16 Sector-Specific Plan (SSP) documents (within the framework of the National Infrastructure Protection Plan (NIPP)) that provide a detailed description of all CI sectors identified in the CISR directive as well as of their dependencies (NIPP, 2013). Considering the high level of detail of all CI sectors and subsectors and the dependency analysis of all CI sectors, SSP documents were used as input to associate: (i) CISR sectors to POI types and (ii) CISR sector dependencies into POI dependencies.

2.1.2 POI Type Acquisition

The POI data used in this study were acquired from OpenStreetMap (OSM) which is one of the most widely used map services in the world, providing free geospatial information of real world features, with more than 10 million users. Based on the initial 29 primary types or *features* of POI provided by OSM, the data used in the analysis were simplified to 20 different features to address a subset of the CISR sectors and subsectors (Figure 1). Each POI data contains attribute information including geographical entity name, address, affiliation type, longitude, and latitude, administrative region and were stored locally into a geospatial database.

Table 1: Classification of the type of Points of Interests acquired for each CISR sector.

Sector (CISR)	Sector (CER)	POI types
Energy	x	1
Transport	x	4
Finance	x	3
Healthcare	x	9
Water	x	7
Information Technology	x	-
Communications	x	2
Government	x	15
Defense Industrial	x	-
Food and Agriculture	x	27
Nuclear	-	-
Commercial facilities	-	42
Critical Manufacturing	-	-
Dams	-	-
Emergency services	-	6
Chemical	-	-

Table 3 lists a detailed description of each POI considered in the analysis.

Figure 1: List of POI grouped by CISR sector.

2.2 POI Dependency Setup

Based on the sector dependencies defined in the SSP documents (where the type of dependency is expressed as physical, logical or cyber (Marashi et al., 2021), a mapping of the CISR sector dependencies in terms of POIs was implemented. The resulting POI dependency mapping is shown in Figure 2 in terms of *consumer* POIs i.e. elements that are dependent on other elements to work and *producer* POIs i.e. elements that provide resources or services to other elements.

2.2.1 Assumptions

In order to focus the analysis on cascading failures i.e., disruptions occurring in one CI which causes the failure of a component in one or more CIs (CI-Pedia(c), (n.d.)., 2024), intra-dependencies, i.e. the relations among subsystems of the same sector, were not considered. For example, considering the Transport sector, the dependencies existing among the POI facilities *airport* and *motorway* were not considered although an airport may require a motorway to be connected with the nearby territory and to be fed by the needed resources (personnel, supply of different goods etc.).

Regarding the number of dependencies selected for the POIs of each sector, where possible, the same dependencies for multiple POIs were grouped together. In addition, considering that the ultimate goal of this approach is to create an urban level of dependencies, only direct (i.e. first-order) dependencies were considered.

In the following, we analyse the dependency connections which are established among different elements of different sectors which represent the territorial dependency map of CIs. In particular, considering that most POIs depend on the supply of energy, water, communications, transportation, emergency, healthcare and financial services (Figure 2), only dependencies not included in those mentioned above will be discussed.

The proposed method makes use of a multi-step approach for data verification and transposition.

1. Initially, a data quality assessment evaluates the accuracy, timeliness, and relevance of data collected from various open sources using a 70-30 sampling approach per type of POI, including geographical information systems (GIS) and real-time infrastructure performance metrics.
2. We then apply data cleaning and preprocessing techniques to mitigate the impact of incomplete or erroneous data entries.

Since the use of data is not driven by any classifier but rather as input for modeling a wider urban area and the reliability analysis of dependencies that arise in the infrastructure, the notion of a biased dataset is not as relevant. We bridged data gaps by determining the type of data missing and reconstructing the entries from other, identical POIs that include any missing data. This way the methodology ensures a high level of consistency and robustness in modeling the surrounding areas and allowing for optimal analysis of cascading effects.

2.2.2 Energy POIs

A **Substation** represents the main facility of a High or Medium Voltage electrical network that provides electricity to an urban environment. It depends on **communication tower** and **connection point** since these components provide telecommunications services required by SCADA and telecontrol operations.

2.2.3 Transportation POIs

A **Stop position** represents a public transport stop. It receives energy from a **substation** to support critical facility functions, such as lighting and it also relies on a **communication tower**, to enable Internet connection to customers.

A **Motorway** is a main road that requires energy from a **substation** to ensure lighting. Both **Motorway**, **Port** and **airport** facilities also rely on **ambulance station**, **police**, **phone**, **fire station**, **hospital** and **communication tower** to ensure emergency response.

2.2.4 Financial Service POIs

A **Payment terminal** and **atm** are associated to **bank** facilities that require the supply of energy, telecommunication, medical assistance, transportation, wastewater and emergency services to enable ordinary and emergency operations.

2.2.5 Healthcare POIs

Hospital and **clinic** facilites require the supply of energy, telecommunication, water and wastewater to operate. In addition, the dependency on the Transportation sector ensures the efficient shipment of supplies, without which the sector cannot provide healthcare services. The availability of telecommunication is vital to enable routine operations, maintain situational awareness and coordinate healthcare activities during steady state and emergency response. Besides, the dependency on Emergency Services provide life safety and security.

2.2.6 Water POIs

A **fire hydrant** represents an active fire protection measure and a source of water provided whereas a **water well** is a structural facility to access ground water, created by digging or drilling. Both depend on electricity for the functioning of pumps, wells and for treatment operations and on Medical and firefighting responders in emergency scenarios.

A **water works** represents a facility where water is treated to make it suitable for human consumption and whereas a **wastewater** indicates a clarifier or settling basin of a wastewater treatment plant. Both depend on electicity and Emergency services to rescue people and coordinate with public health agencies during emergency and other water quality-related events.

2.2.7 Communications POIs

A **communications tower** is a structure in which a Base Transceiver Station (BTS) and other devices are mounted that enable mobile and Internet connectivity. Communication devices rely on energy to power its backup generators and the Transportation Sector to deliver those fuels. Water sources are also necessary for cooling and other processes.

2.2.8 Government POIs

Government POIs include offices and building complexes (post offices, public buildings), correctional facilities (prison), embassies, courthouses, education facilities (university, school, kindergarten, college).

2.2.9 Food and Agriculture POIs

Food and Agriculture POIs complex production, processing, and delivery systems and has the capacity to feed people and animals. Such facilities are almost entirely under private ownership and operate in highly competitive global markets.

2.2.10 Commercial Facility POIs

Commercial facilities include an extremely diverse range of sites and assets where large numbers of people congregate daily to conduct business, purchase retail products, and enjoy recreational events and accommodations.

2.2.11 Emergency Services POIs

Emergency Services facilities include human (fire, police and ambulance stations) and equipment for daily operations (phones, sirens).

2.3 Creating Dependency Risk Graphs

As above stated, whereas for CI it is possible to get an accurate dependency map (pointing functional dependency and dependency links), other POI data are not accurately specified in terms of their functional dependencies and dependency links. For instance, it might be undefined the dependency of a POI (i.e. an

Government (POI consumer)	**Other sectors** (POI producer)
public building, townhall, prison, social facility, community centre,	substation, water tower, wastewater, police, fire station, connection point, stop position, clinic, atm, general, motorway
nursing home,	substation, water tower, wastewater, ambulance station, fire station, connection point, stop position, clinic, atm, general,
post office,	substation, water tower, wastewater, police, connection point, stop position, hospital, atm, bank, general,
grave yard,	substation, water tower, wastewater, stop position, florist
school, kindergarten, college, university,	substation, water tower, wastewater, fire station, connection point, stop position, hospital, atm, library
telephone,	connection point, substation
diplomatic, courthouse,	substation, water tower, wastewater, police, connection point, stop position, bank, general, airport

Commercial facilities (POI consumer)	**Other sectors** (POI producer)
retail*, accommodation*, sports*, public assembly*, gaming*,	substation, water tower, wastewater, fire station, police, connection point, stop position, motorway, hospital, bank, atm
playground, park,	substation, water tower, wastewater, fire station, police, stop position, motorway, hospital,

Energy (POI consumer)	**Other sectors** (POI producer)
substation,	connection point, communication tower,

Transportation (POI consumer)	**Other sectors** (POI producer)
port, airport,	substation, water tower, wastewater, police, fire station, connection point, hospital, bank, atm,
stop position,	substation, communication tower,
motorway,	substation, wastewater, fire station, connection point, police, hospital, communication tower, ambulance station, phone,

Healthcare (POI consumer)	**Other sectors** (POI producer)
doctors, dentist, physiotherapist, psychotherapist, veterinary, laboratory, pharmacy,	substation, stop position, water tower, wastewater, fire station, connection point, motor way,
hospital, clinic	substation, stop position, motorway, water tower, wastewater, ambulance station, fire station, police, communication tower, connection point,

Emergency services (POI consumer)	**Other sectors** (POI producer)
police, fire station, phone, ambulance station,	substation, stop position, motorway, connection point, water tower, wastewater, hospital,
siren	substation, communication tower,

Communications (POI consumer)	**Other sectors** (POI producer)
communication tower,	substation, stop position, motorway, water tower,
connection point,	substation, stop position, water tower,

Water (POI consumer)	**Other sectors** (POI producer)
water tap, fountain	substation, ambulance station,
fire hydrant, water well,	substation, ambulance station, fire station, connection point, bank, laboratory, motorway,

Food and Agriculture (POI consumer)	**Other sectors** (POI producer)
distribution*, processing & packaging & production*	substation, water tower, wastewater, fire station, police, connection point, stop position, motorway, hospital, bank, atm
barn, silo,	substation, water tower,
supply*,	substation, water tower, wastewater, motorway, airport

Financial services (POI consumer)	**Other sectors** (POI producer)
payment terminal, bank, atm,	substation, wastewater, connection point, police, hospital, communication tower,

Figure 2: POI dependencies grouped by CISR Sector.

hospital) with telecommunication and electrical networks elements. Thus, we should reconstruct the dependency map by using other criteria (for instance, a proximity criteria, that is we decide that the functional elements of other CI which are responsible to provide specific functionality to the Hospital are the geographycally clostest ones). This section will deal with the identification of the different strategies adopted to identify dependencies whereas not explicitly provided. The created DRG can be used as a basis for the use of risk analysis models that allow assessing the criticality of specific dependency chains that can exacerbate the occurrence of cascade effects ((Rosato et al., 2021b)).

3 CASE STUDY: THE MARCHE REGION

As a case study, we created a DRG by using open-data of a specific area of interest and applying the methodology described in the previous paragraphs. In particular, we considered the Marche Region, located in central Italy, with near 1.5 million inhabitants in an area of 9.350 km^2. The resulting regional scenario contains $N = 27.324$ nodes belonging to 10 CISR sectors (as shown in Table 2) where the dependencies among nodes were established by using a proximity strategy. The resulting network of total set of N nodes contains $M = 279.663$ oriented links. In particular, a generic nodes will result to have *incoming* links (coming from producer nodes) and *outgoing* links (going to consumer nodes). At this stage of elaboration, the

Table 2: Major topological properties of POIs for the different CISR sectors: d_{in} is the node degree of incoming links (constant), $d_{out-MAX}$ is the maximum degree of outgoing links.

Sector	POI instances	d_{in}	$d_{out-MAX}$
Energy	281	2	1506
Transp.	426	5,4	1.748
Finance	461	6	2.033
Health.	599	6,8	3.640
Water	493	4,2	3.130
Commun.	9	3,1	12.895
Governm.	840	-	-
Food&A.	5.497	-	-
Commerc.	18.594	0,04	118
Emergen.	201	7	4.642

weight of each link is unitary everywhere. However, this value could be modulated based on the relevance of the connection, or even the latency of its dependency. In fact, a specific link may represent a functional dependency that occurs instantaneously, or that requires a longer latency.

A first analysis can be provided by studying the basic properties of the network: the degree distribution of the nodes and the main centrality properties of the nodes. Table 3 shows that, on average, the number of incoming links is smaller than the number of outgoing ones. In other words, a node, on average, is the provider of a large number of nodes in other sectors that need to be powered by its service. Note that the nodes in the Government and Food and Agriculture sectors are only consumer nodes, since they have no outgoing connections.

Outgoing links count the number of elements of other sectors which are supplied by a specific node, in order to have an appropriate functionality. As stated previously, this counting could be done more appropriately by weighting each link with a specific weight that takes into account the *relevance* of that specific link to ensure the functionality of the provisioned node. Although this may favor a more accurate evaluation of the dependency mechanisms, a simple counting with unit weight of each link (as in our case) already provides a clear identification of the nodes that are critical in guaranteeing the functionality of all the others.

Figure 3 shows the distribution of outgoing links for the nodes belonging to 4 of the most important sectors. Energy nodes consist of electric substations and exhibit a large spread of outgoing degree. Similar results concern the Emergency, Finance and Transport sectors where fire stations, atm and public transport stops respectively are source nodes for many sectors, especially in urban areas. In particular, the POI instances that exhibit the higher outbound degree are: a connection point, a hospital, a water tower, a motorway junction, a department store, a fire station, an ATM and an electric substation.

According to Table 3, there are sector nodes that are providers of a large number of other nodes; some of them are terminal nodes while others are, in turn, providers of other nodes in other sectors. Therefore, nodes with large outbound link degrees concern highly relevant nodes that have *strategic* relevance, since they are central to a large number of subnetworks. A number of highly strategic nodes i.e. nodes with high inbound degree centrality in a DRG, are natural “sinkhole” points of incoming dependency risk. Such nodes appear to be suitable nodes to consider when prioritizing mitigation controls so that multiple cumulative dependency risk chains can be reduced simultaneously. In Figure 5 we represent the network resulting from the connection, according to the adopted methodology, of all POIs of all sectors in Regione Marche. Nodes with different colors represent POI instances of different sectors; their sizes, furthermore, are proportional to their total degree (sum of incoming and outgoing links).

4 CONCLUSIONS

The US CISR and the EU CER Directives have identified a large number of ”critical entities” grouped in different sectors. As a further relevant information, the CISR Directive has also inspired the further delivery of 16 Sector-Specific Plan (SSP) documents that identify a dependency map enabling to link elements of the different different sectors on the bases of their mutual functionalities as producer or consumer nodes. The combination of open-data consisting of the Points of Interest (POI) and the dependency map proposed by the SSP documents has allowed us to build a large regional network connecting elements of different sectors with oriented links, describing the functional dependencies among the different nodes. With the described prescriptions, we have analysed real data with infrastructure elements of Regione Marche taken from publicly available repositories based on OpenStreetMap.

In a first order analysis, the method allows the identification of topological properties of the network and the localization of elements which, according to their degree (outgoing and incoming degree), should be considered as strategic. Aside to that, the MARIS methodology, if implemented with the use of weighted links among the nodes, opens up the possibility of performing network partitioning by recognizing subnetworks slightly coupled with the rest of the networks (i.e. whose all boundary links, if any,

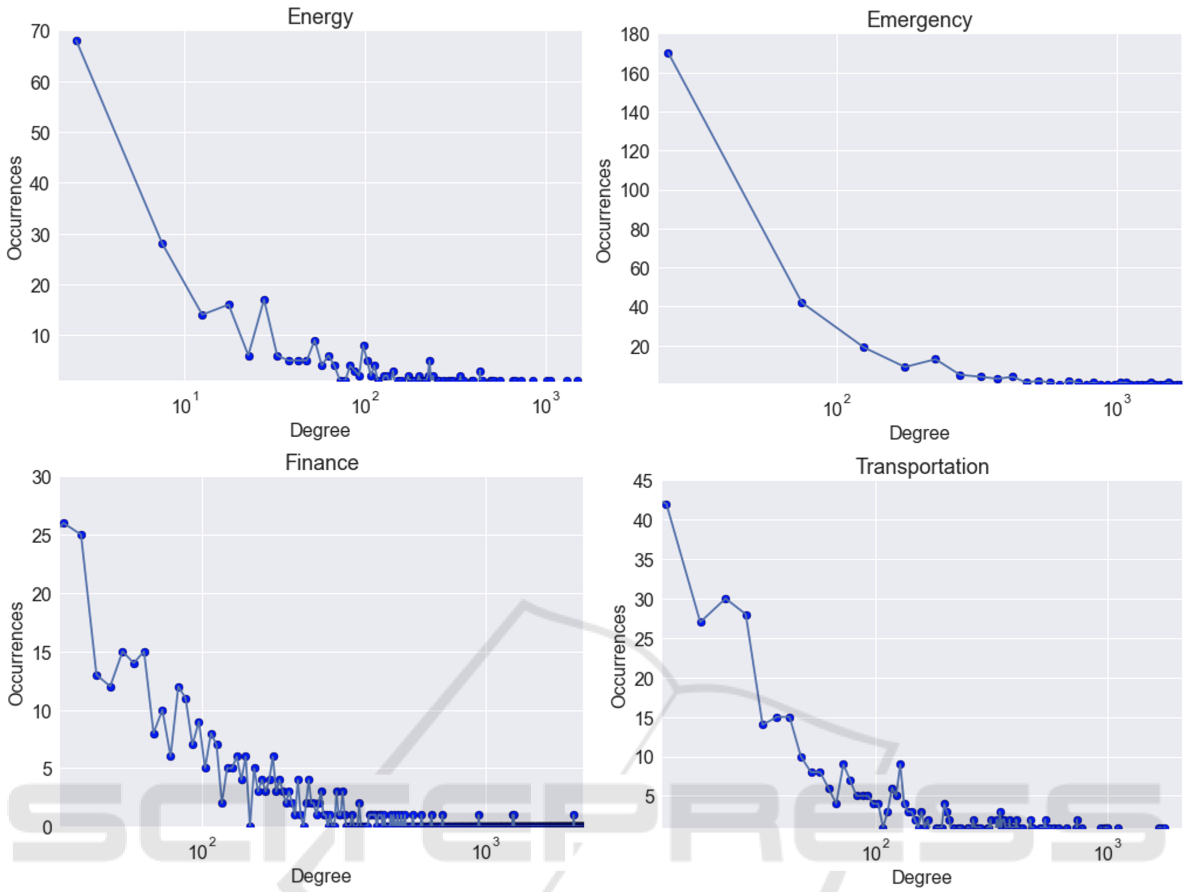

Figure 3: Distribution of the outgoing node's degrees in several sectors (abscissa, in log scale, represents the node degree; in the ordinate the number of nodes with the given outgoing degree. Up-left: nodes of the Energy sector. Up-right: node of the Emergency sector. Bottom-left: nodes of the Financial sector. Bottom-right: nodes of the Transportation sector. Lines are drawn as a guide for the eye.

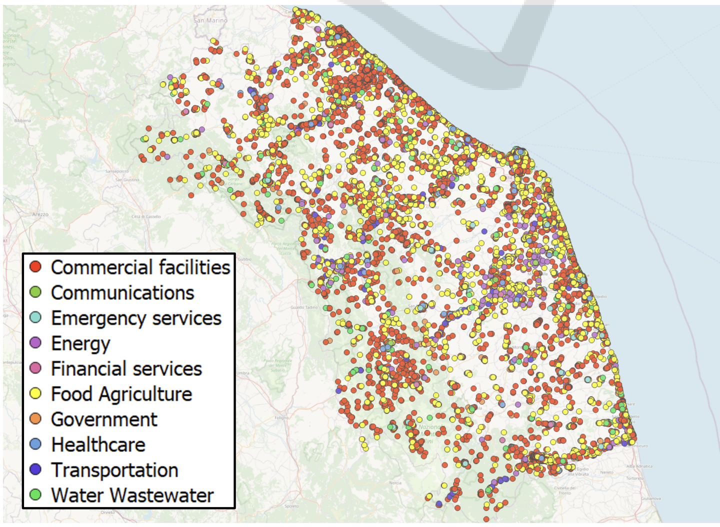

Figure 4: A GIS map of the area under analysis (Regione Marche, Italy) with the different sectors nodes highlighted in different colors, according to the CISR sector to which they belong.

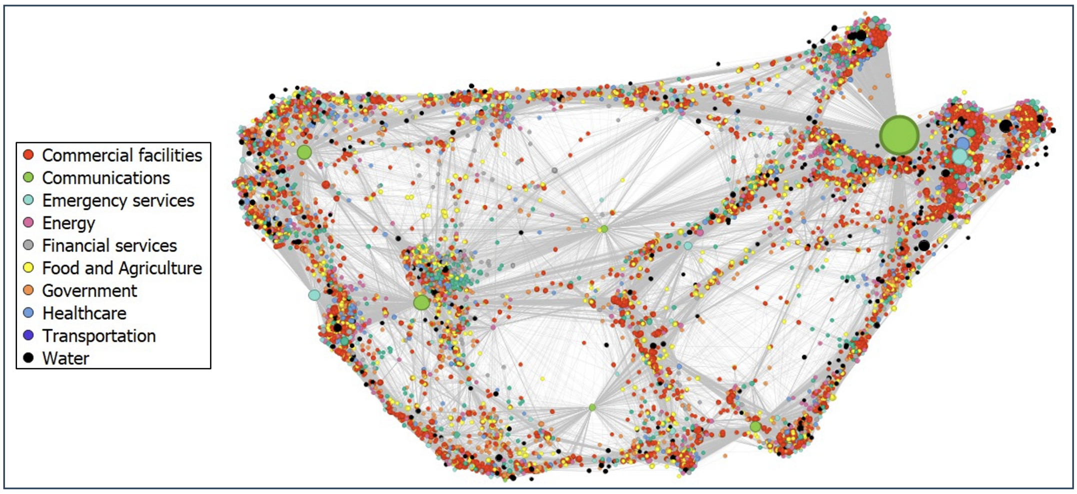

Figure 5: A representation of the graph of the network under analysis (Marche region) where node's size is proportional to the out-degree value.

are weak) and by performing, on those networks, dynamical fault simulations ((Rosato et al., 2021a)) in order to reproduce the cascading failures which issue upon the fault of one (or more) nodes of the networks.

This approach, if appropriately exploited by using the largest and most realistic network of local or regional elements, can be of invaluable support in approaching the realization of "educated" emergency plans aiming at reducing the consequences od cascading failures.

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APPENDIX

Table 3: POI description. Source: (OpenStreetMap, 2024).

Sector	POI type	Description
Government	Post office	Post office building with postal services.
	Public building	An office of a (supra)national, regional or local government entity.
	Townhall	Building where the administration of a village, town or city.
	Prison	A prison or jail where people are incarcerated.
	Diplomatic	An embassy, diplomatic mission, consulate or liaison office.
	Courthouse	A building home to a court of law, where justice is dispensed.
	Telephone	Public telephone.
	Community centre	A place mostly used for local events, festivities and group activities.
	Nursing home	A structure for disabled or elderly persons who need permanent care.
	Social facility	A facility that provides social services e.g. homeless shelters, etc.
	Grave yard	A (smaller) place of burial, often you'll find a church nearby.
	University	An university campus: an institute of higher education.
	School	An university campus: an institute of higher education.
	Nursery school	School and grounds - primary, middle and seconday schools.
	College	Campus or buildings of an institute of Further Education.
Healthcare	Hospital	A hospital providing in-patient medical treatment
	Clinic	A medium-sized medical facility or health centre.
	Doctors	A doctor's practice / surgery.
	Dentist	A dentist practice / surgery.
	Physiotherapist	Someone who practices physical therapy but is not a Physician.
	Psychotherapist	Someone who practices psychotherapy but is not a Physician.
	Veterinary office	A place where a veterinary surgeon practices.
	Medical laboratory	Is a place that analyses body fluids such as blood, urine, faeces etc.
	Pharmacy	A shop where a pharmacist sells medications.
Emergency Services	Police	A police station where police officers patrol from.
	Fire station	A station of a fire brigade.
	Phone	Emergency telephone.
	Siren	A loud noise maker, such as an air raid siren or a tornado siren.
	Ambulance station	Structure set aside for storage of ambulance vehicles, equipment, etc.
Communication	Comm. tower	A huge tower for transmitting radio applications.
	Internet conn. point	Last point of telecom local loops allowing connections to households
Water	Water tap	Publicly usable water tap.
	Fountain	A fountain for cultural / decorational / recreational purposes.
	Fire hydrant	An active fire protection measure.
	Water tower	Structure with a water tank at a high altitude to increase pressure.
	Water well	A structural facility to access ground water.
	Water works	A facility where water is treated to make it suitable for human use.
	Wastewater plant	A wastewater plant is a facility used to treat wastewater.
Commercial facilities	Mall	A shopping mall – multiple stores under one roof.
	Department store	A store – often multiple storeys high – selling a large variety of goods.
	Generic items shop	A store that carries a general line of merchandise.
	Clothes shop	Shop focused on selling clothes and/or underwear.
	Fashion accessories	Shop focused on selling fashion accessories.
	Shoes shop	Shop focused on selling shoes
	Bicycle rental	Shop where to rent a bicycle
	Florist	Shop focused on selling bouquets of flowers
	Sports centre	A building that was built as a sports centre.
	Pitch	An area designed for practising a particular sport.
	Swimming pool	A swimming pool.
	Tennis	A tennis court.
	Hotel	A building with separate rooms available for overnight accommodation.
	Motel	Short term accommodation, particularly for people travelling by car.
	Guest house	Accommodation smaller than a hotel and typically owner-operated.
	Hostel	Cheap accommodation with shared bedrooms.
	Bed and breakfast	A flat with cooking and bathroom facilities that can be rented.
	Chalet	A holiday cottage with self-contained cooking and bathroom facilities.

Continued on next page

Table 3: continued from previous page.

Sector	POI type	Description
	Caravan site	A place where you can stay in a caravan overnight or for longer periods.
	Nightclub	A place to drink and dance (nightclub).
	Park	A park, usually in an urban setting, created for recreation and relaxation.
	Playground	An area designed for children to play.
	Arts centre	A venue where a variety of arts are performed or conducted
	Cinema	A place where films are shown
	Refugee site	A human settlement sheltering refugees or internally displaced persons
	Museum	A building which was designed as a museum.
	Library	A public library to borrow books from.
	Shelter	A small shelter against bad weather conditions.
	Stadium	A building constructed to be a stadium building.
	Theatre	A place where live performances occur, (e.g., musicals, concerts).
	Water park	An amusement park with features like water slides.
	Fairground	A site where a fair takes place.
	Running area	An area for running (jogging) routes.
	Property manag.	Office of a property rental company for commercial or residential use.
	Apartment	A building arranged into individual dwellings, often on separate floors.
	Detached house	A free-standing residential building usually housing a single family.
	House	A dwelling unit inhabited by a single household.
	Residential building	A general tag for a building used primarily for residential purposes.
	Place of worship	A church, mosque, or temple, etc.
	Semidetached house	A residential house that shares a common wall with another on one side.
	Casino	A gambling venue with at least one table game that takes bets
	Gambling	A place for gambling.
Food and Agriculture	Restaurant	A normal restaurant that sells full sit-down meals.
	Fast food	A place for very fast counter-only service and take-away food.
	Cafe	An informal place that offers casual meals and beverages (coffee or tea).
	Pub	A place selling beer and other alcoholic drinks
	Bar	A place that sells alcoholic drinks to be consumed on the premises.
	Biergarten	An open-air area where alcoholic beverages along with food is served.
	Food court	An area with several restaurant food counters and a shared eating area.
	Supermarket	a large store with groceries and other items.
	Bakery	Shop focused on selling bread.
	Kiosk	A small shop sells magazines, tobacco, newspapers, etc.
	Greengrocer	Shop focused on selling vegetables and fruits.
	Agrarian	Shop that sells agrarian products, e.g. seeds, agricultural machinery.
	Barn	An agricultural building that can be used for storage.
	Silo	A storage container for bulk material, often grains e.g. corn, wheat.
	Cowshed	A cow barn is a building for housing cows, usually found on farms.
	Distillery	An establishment for distilling, especially alcoholic liquors.
	Brewery	A dedicated building for the making of beer.
	Winery	A place where wine is produced.
	Stable for horses	A building constructed as a stable for horses.
	Windmill	A traditional windmill, historically used to mill grain with wind power.
	Greenhouse	A greenhouse is a glass or plastic covered building used to grow plants.
	Farm	A residential building on a farm (farmhouse).
	Oil mill	A mill to crush or bruise oil-bearing seeds, e.g. linseed or peanuts.
	Allotments	A piece of land given for growing vegetables and flowers.
	Farmyard	An area of land with farm buildings e.g. farmhouse, dwellings.
	Farmland	An area used for tillage (cereals, vegetables, oil plants, flowers).
Energy	Substation	A power facility with transformers, switchgear or compensators.
Transportation	Public transport stop	The position on the street or rails where a public transport vehicle stops.
	Port	Acoastal industrial area where commercial traffic is handled.
	Motorway junction	A type of road junction linking highway facility to another.
	Aerodrome	An aerodrome, airport or airfield.
Financial Services	Payment terminal	Self-service payment kiosk/terminal.
	Bank	A financial establishment to make finanxial operations.
	ATM	Cash point