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A SIMPLIFIED APPROACH FOR THE SEISMIC ASSESSMENT OF HOSPITAL COMPLEX NETWORKS

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Abstract.
Modern cities are complex organisms, very difficult to control and represent through comprehensive models. Their safety and their resilience cannot be tackled without a full comprehension of their systems, networks and infrastructures. Health care systems are one of the most crucial assets of complex communities. The network of Hospitals, indeed, is assumed to be effective and supportive in case of emergency, such as at the occurrence of strong earthquakes. In this work the reliability of a Hospital network is verified. The analysis is aimed at evaluating the relative efficiency of each Hospital Complex inside the network, taking into account its size, performance and accessibility. Interdependencies between the Hospitals and the transportation networks has been taken in account in the analysis. The research has been applied on a case-study, i.e. a real network of Hospital buildings, including 41 complexes. The effectiveness of each complex has been measured using a reduced number of meaningful parameters appositely selected. A further evaluation, concerning a simplified rating of the seismic vulnerability of the Hospital buildings have been made for all considered cases. Furthermore, the capacity of each Hospital complex has been evaluated in terms of extension of the reference area and amount of the covered population. Finally, the accessibility to each complex has been checked, by analyzing the mutual connectivity of the entire network using graph theory, which has been applied by considering the effective position of each Hospital complex inside the area, and the real connection infrastructure. As a result of the study, an effective description of the examined network has been achieved, and a simplified rating of each Hospital complex has been found.

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1 INTRODUCTION

The health care networks are one of the critical infrastructures in communities [1]. At the occurring of emergencies, indeed, the Hospital buildings are expected to provide the first rescues, becoming the core of the post-emergency organization [3-5]. This work is aimed at proposing a synthetic method to evaluate the reliability of the Health network in case of seismic emergency, by including the transportation network.

The study refers to a real Health network, located in Italy, consisting of a total volume of 5128000 m^3, and organized in 3 regional companies, 12 district organizations and 533 structural units.

In the past years the considered Hospital network of Tuscany has been the object of jointed agreement between the Regional Government and three Tuscan Universities, which accomplished a wide survey, aimed at evaluating the seismic vulnerability of the Hospital buildings. As a results of such research, a qualitative vulnerability mapping of a large percentage of the Hospital building population has been made [6], by following a qualitative approach based of the 2nd Level GNDT forms [7].

In this work the Hospital buildings population of the Tuscan Health system is assumed as case-study to set a simplified method for network risk evaluation and Resilience analysis [1]. The Hospital Complex have been ordered after their administrative organization. The Hospital buildings have been classified after three different criteria, i.e. the strategic role, found according to the criteria adopted by the Tuscan Health Organization [8], the seismic vulnerability, which has been arranged on the basis of the information provided by De Stefano *et al*. [6], and the seismic hazard, i.e. the site PGA, as provided by the Italian hazard classification [9,10]. Each of these classifications comprehends three classes, indicating, respectively, good, moderate and low performance level.

The classification of the Hospital population has been combined to the analysis of the transportation network to achieve a more comprehensive evaluation of the adequacy of the Health system to face the seismic emergency. The checked road accesses have been classified after their length, capability (highways vs local roads) and redundancy, in order to evaluate the reliability of each Hospital Complex as potential emergency headquarter. Even if the reliability of the Hospital complexes has been evaluated with special attention to the seismic risk, the criteria adopted for the selection of buildings as emergency center intends to be general and adoptable for all emergency situation. To this purpose the research, still in progress, needs to be integrated with additional information.

2 THE HOSPITAL NETWORK OF TUSCANY

2.1 The administrative organization

The Tuscan administration is articulated in 10 provinces. The health system follows such organization; indeed, there are 10 provincial companies, with the addition of three further ones, introduced to better cover the needs of specific areas, for a total number of 12 companies. They are organized in three main districts, which have as much main headquarters [8], consisting of University Hospital Companies. To this organizational scenario, briefly described in Table 1, a further Hospital must be added, which offer pediatric care for the entire Region. Each provincial company is made of some Hospital complexes, distributed in the area, having different dimension and number of offered care services. In Table 1 each Hospital complex has been named after Regional (R) and Provincial (P) organization.

Table 1. Administrative organization of the Tuscan Health System.

Regional Companies	Provincial Companies	Hospital Complexes
R1	R1_P1	H1.1.1, H1.1.2, H1.1.3, H1.1.4, H1.1.5, H1.1.6, H1.1.7
	R1_P2	H1.2.1, H1.2.2, H1.2.3
	R1_P3	H1.3.1, H1.3.2,
	R1_P4	H1.4.1, H1.4.2, H1.4.3, H1.4.4
R2	R2_P5	H2.5.1, H2.5.2, H2.5.3, H2.5.4
	R2_P6	H2.6.1, H2.6.2, H2.6.3
	R2_P7	H2.7.1, H2.7.2, H2.7.3
	R2_P8	H2.8.1, H2.8.2, H2.8.3, H2.8.4
	R2_P9	H2.9.1
R3	R3_P10	H3.10.1, H3.10.2, H3.10.3, H3.10.4
	R3_P11	H3.11.1, H3.11.2, H3.11.3, H3.11.4, H3.11.5
	R3_P12	H3.12.1, H3.12.2, H3.12.3, H3.12.4, H3.12.5

2.2 The performed classifications

Each provincial company is made of some Hospital complexes, distributed in the area, having different dimension and offered care services. Therefore, they are classified by the Regional Health Service after their strategic role, defined as a function of the number of covered inhabitants, available beds and offered services. In Figure 1 the strategic classification (*SC*) of all Hospital buildings has been represented, while in the Tables 2 and 3 the criteria adopted for the classification and the obtained results have been listed.

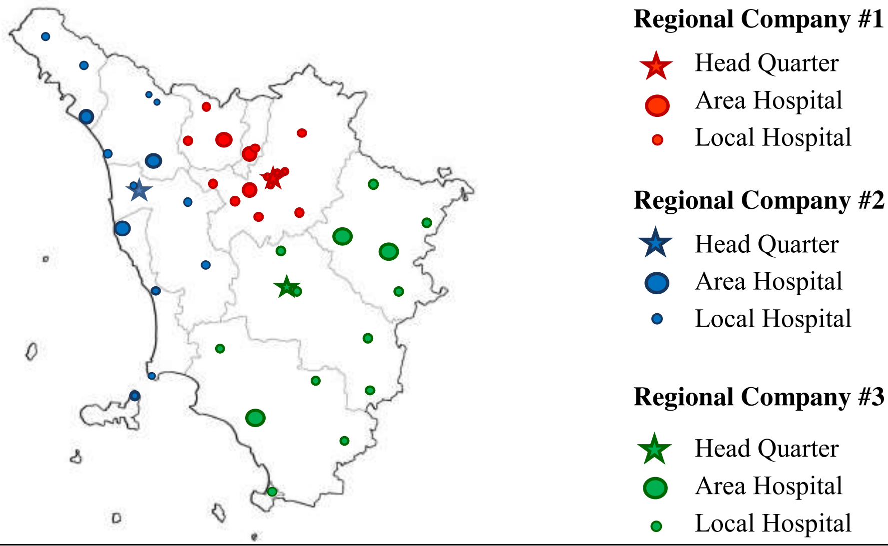


Figure 1. Strategic classification (*SC*) of the Hospital complexes.

The evaluation of the seismic vulnerability of the Hospital Complexes has been made on the basis of the results obtained through by the joint research program between three Departments of the University of Florence and the Regional Government of Tuscany [6]. The research was developed through the 2nd Level GNDT forms [7], which provide an evaluation of the buildings vulnerability in the basis of qualitative judgements made on 11 parameters.

The parameters concern: type and organization of the seismic resistant system, quality of the resistant system, conventional resistance, building location and type of foundation, storey, configuration in plan, configuration in elevation, maximum distance between the masonry walls (connections and critical elements for RC buildings), coverage (elements with low ductility for RC buildings), non-structural elements, state of maintenance. The forms, shown in

Figure2, are opportunely modulated for RC, steel and masonry buildings, in order to provide comparable values of grades for different types of buildings.

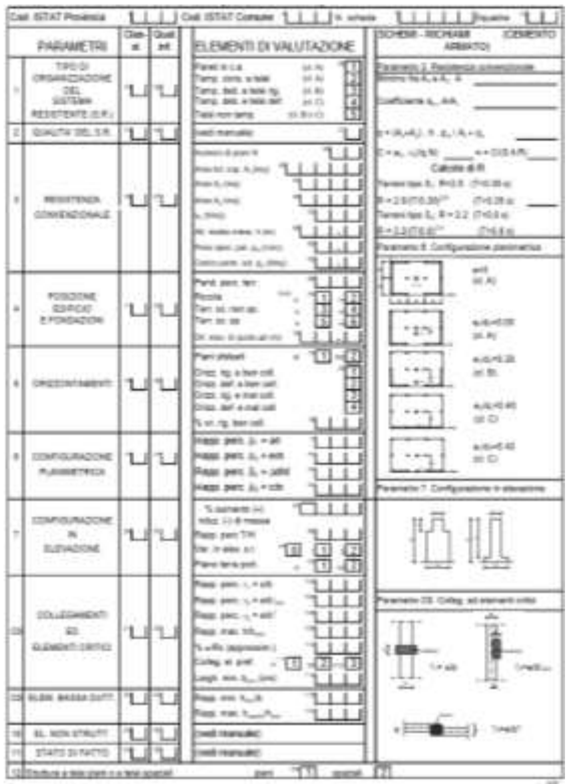
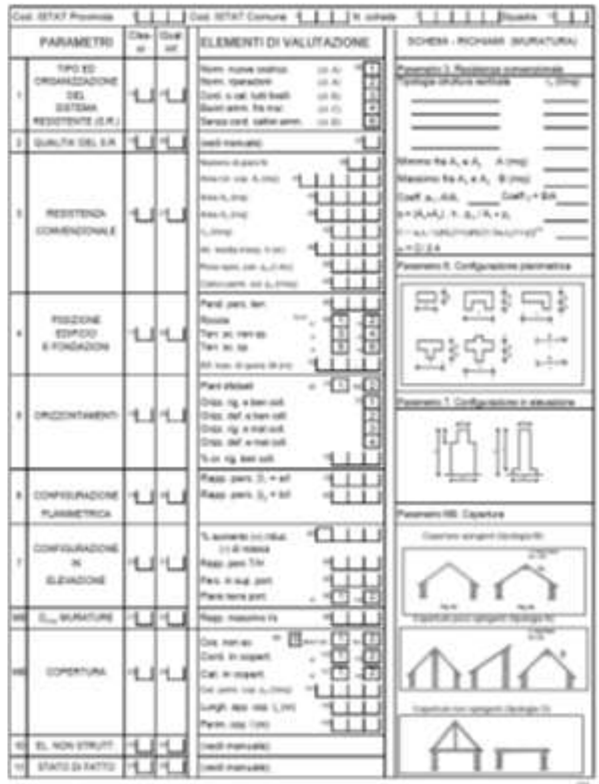
Form for RC buildings	Form for masonry buildings
	

Figure 2. GNDT forms for evaluating the vulnerability index of RC and masonry buildings.

Each parameter is measured through qualitative grades, ranging between *A* (good performance) and *D* (bad performance), according to the detailed GNDT instructions [11,12]. The final grade of the building is opportunely modified through corrective factors, introduced to calibrate the importance of the considered issues. As a results, a numerical evaluation of the vulnerability index (I_v) of the building is achieved, expressed in one hundreds. Such grade has to be assumed as a qualitative evaluation, which cannot represent a scientific judge on seismic performance of each Hospital building. A more accurate evaluation of the seismic vulnerability of the Hospital buildings, anyway, would have required extensive and complex analyses [13-15] which are beyond the scope of this study.

In the following a simplified vulnerability classification has been adopted, consisting of a three-scores rating system. Furthermore, the I_v found in [6] have been integrated though additional information regarding the Hospital Complexes which were not included in the former research activity, of which have been renovated in the last years. Table 3 shows the assumed correspondence between I_v and the adopted Vulnerability Classes (*VC*), while in Table 4 the vulnerability rating of the Hospital Complexes is presented.

The Hazard classification of the Hospital Complex has been made on the basis of the National Hazard map, as provided by the National Technical Code [9]. The seismic hazard of the Region is moderate, with a PGA ranging between 0.05g and 0.29g. Even the seismic hazard has been represented through a qualitative approach, with three classes defined after the PGA ranges listed in Table 3. The obtained Hazard Classification (*HC*) has been shown in Table 4.

Table 3. Assumed criteria for the Hospital Complexes classification

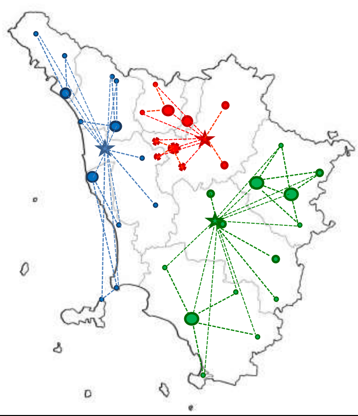
Strategic Classification (*SC*)				Vulnerability Classification (*VC*)			Hazard Classification (*HC*)		
SC	Relevance	Beds	Inhabitants (thousand)	VC	Vulnerability	VI range (1/100)	HC	Hazard	PGA range
A	District	> 100	> 150	A	Low	0- 30	A	Low	< 0.15g
B	Area	> 100	70-150	B	Moderate	30- 60	B	Moderate	0.15g - 0.25g
C	Local	< 100	< 70	C	High	60-100	C	High	> 0.25g

Table 4. Rating provided by the performed classification.

Regional Company #1				Regional Company #2				Regional Company #3			
CODE	*SC*	*VC*	*HC*	CODE	*SC*	*VC*	*HC*	CODE	*SC*	*VC*	*HC*
H1.1.1	A	B	B	H2.5.1	A	A	B	H3.10.1	A	A	B
H1.1.2	C	B	B	H2.5.2	A	A	B	H3.10.2	C	B	B
H1.1.3	A	B	B	H2.5.3	B	B	B	H3.10.3	B	A	B
H1.1.4	A	C	B	H2.5.4	C	A	B	H3.10.4	B	B	B
H1.1.5	A	B	B	H2.6.1	A	A	B	H3.11.1	A	B	B
H1.1.6	B	C	B	H2.6.2	C	A	C	H3.11.2	A	A	B
H1.1.7	C	B	B	H2.6.3	C	A	C	H3.11.3	C	A	B
H1.2.1	A	A	B	H2.7.1	A	A	B	H3.11.4	C	B	C
H1.2.2	B	B	B	H2.7.2	C	B	C	H3.11.5	C	A	B
H1.2.3	C	B	C	H2.7.3	C	B	C	H3.12.1	A	B	A
H1.3.1	C	B	B	H2.8.1	A	B	B	H3.12.2	B	A	A
H1.3.2	A	A	B	H2.8.2	C	A	A	H3.12.3	B	C	B
H1.4.1	A	A	B	H2.8.3	C	A	A	H3.12.4	C	B	B
H1.4.2	C	B	B	H2.8.4	C	B	A	H3.12.5	C	B	B
H1.4.3	C	B	B	H2.9.1	B	A	B				
H1.4.4	C	B	B								

3 TRANSPORTATION SYSTEM REFERRED TO THE CARE-NETWORK

The transportation network has been checked by evaluating the amount and the reliability of the connections between each Hospital complex and the corresponding area and Head Quarter Hospitals The quality of the connection has been checked in terms of *i)* distance *ii)* flow capacity and reliability and *iii)* redundancy. In Figure 3 the investigated connections have been shown, together with the main criteria assumed in the classification. The distances found for the interconnections among the considered Hospital Complexes have been taken after the https://www.google.it/maps/dir/ indications.



Distance classification (*DC*):

A-class: distance below 30 km
B-class: distance ranging between 30 km and 100 km
C-class: distance over 100 km

Flow classification (*FC*):

A-class: almost highway only
B-class: highway combined to local transportation
C-class: prevalence of local transportation

Redundancy classification (*RC*):

A-class: two or more alternative ways for the entire itinerary
B-class: alternative ways for part of the itinerary
C-class: no alternative ways

Figure 3. Transportation system of the Tuscan Health network.

In this classification, if there is more than one complex in the same town, their mutual distance has not been read, and the distance to the other Complex are taken form the main complex. In the schemes shown in Figures 4-6, three different circles have been represented, according to the assumed administrative representation of the Hospital Complex. The distances have been checked between each Hospital Complex and the corresponding Area Complexes and the Regional Head Quarter, respectively. Furthermore, the Area Complexes have been connected each other and to the corresponding Head Quarters. The Region taken as case-study for the analysis (Tuscany) has not a vast area; the surface covered by each of the three Regional Companies, therefore, is quite limited. The maximum distances between each Hospital Complex and the corresponding Head Quarter is equal to 65 km, 144 km and 146 km for the three Regional Districts respectively. The assumed classification, therefore, relates the class A to mutual distances below 30 km, the class B to distances between 30 km and 100 km and the class C to distances over 100 km.

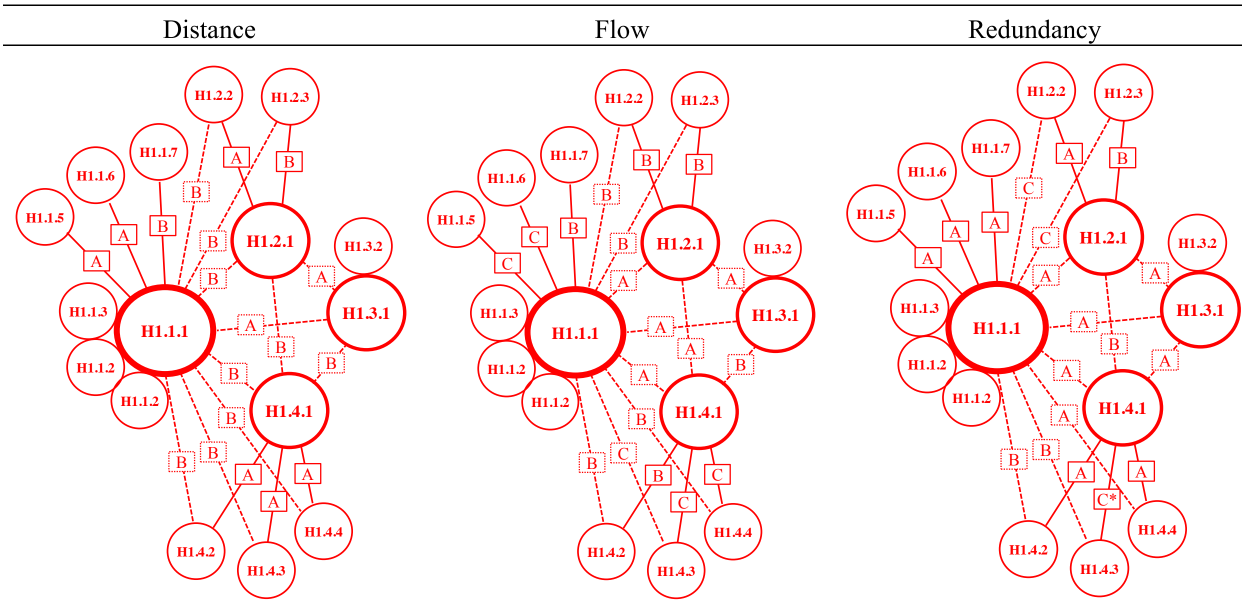


Figure 4. Health Company #1: classification of the connection network.

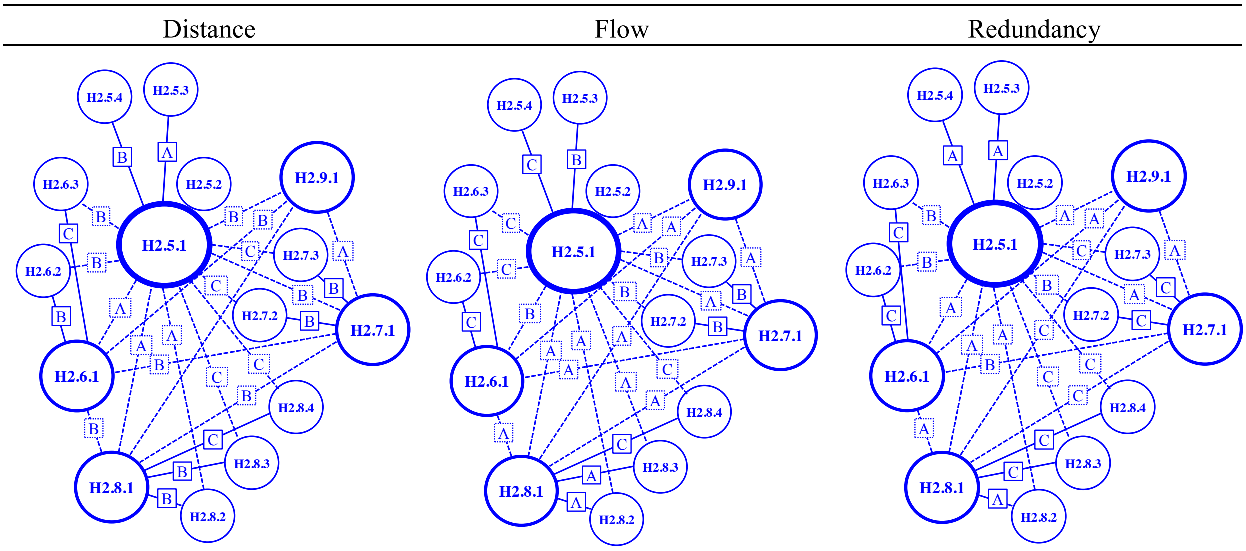


Figure 5. Health Company #2: classification of the connection network.

The flow capacity has been assumed to be a relevant parameter to check the accessibility of the Hospital complexes. Indeed, at the occurring of flow peaks, the dimension and the quality of the access reads largely affects the real accessibility of the emergency centers. In this work three classes of capacity-classes have been considered, depending on the type of the itinerary, as explained in Figure 3. The flow capacity has been evaluated by distinguishing the "high flow" (class A) itineraries from the local ones (class C). The "high flow" itineraries include both highways and roads with at least two lines for each direction of travel. In this analysis the class B refers to itineraries made only partially by high-flow streets.

Another important evaluation concerns the possibility to achieve an Hospital complex through alternative ways. The redundancy, indeed, is one of the crucial issues for resilient systems. In case of occurrence of landslides, floods or other collapses, the transportation system could fail, preventing the accessibility of the Hospitals. Even in this case, three different redundancy classes have been considered, as indicated in Figure 3. The class "A" indicates the possibility to completely replace the main connection without substantial differences in terms of travel time. The class "B" comprehends connections partially replaceable; in this case if the interruption would occur in one of the not replaceable tracts, the ordinary travel time could substantially increase. The class "C", finally, indicates itinerary not easily replaceable in their entire length. The obtained Redundancy classification obtained for the three considered Health Companies is shown in Figures 4-6.

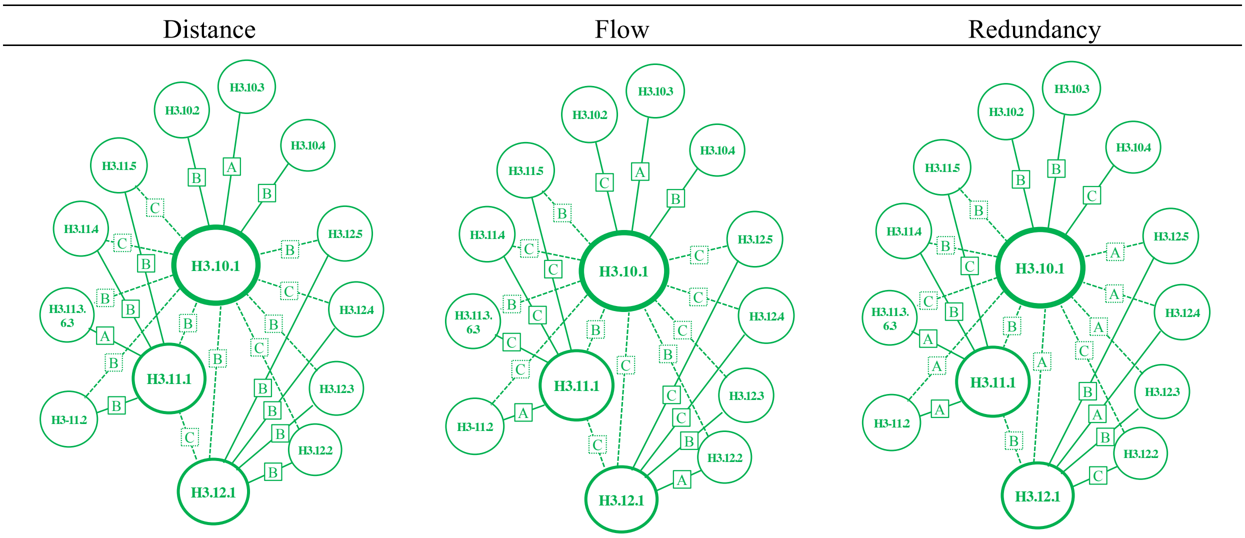


Figure 6. Health Company #3: classification of the connection network.

4 COMBINED ANALYSIS OF THE HEALTH AND THE TRANSPORTATION NETWORKS

The analyses made on the Health network and on the transportation one have been combined, in order to have a comprehensive lecture of the reliability of each Hospital complex. The combined lecture, still in progress, can provide useful information regarding the possible choice of emergency locations, or the hierarchy to follow in the network upgrading.

In Figure 7 the layout of the analysis has been shown. Depending on the applicative purpose of the analysis, further classes of information could be added, regarding the availability of suitable spaces for temporary camp or medical equipment support, or the adequacy of the logistic network. Some of these information could be collected by adopting the forms arranged by Protezione Civile (http://www.serviziemergenzaintegrati.org/) for the COM buildings.

As regards the connection network, the reliability of the main access roads should be checked in detail, in order to pinpoint the possible weaknesses and vulnerabilities.

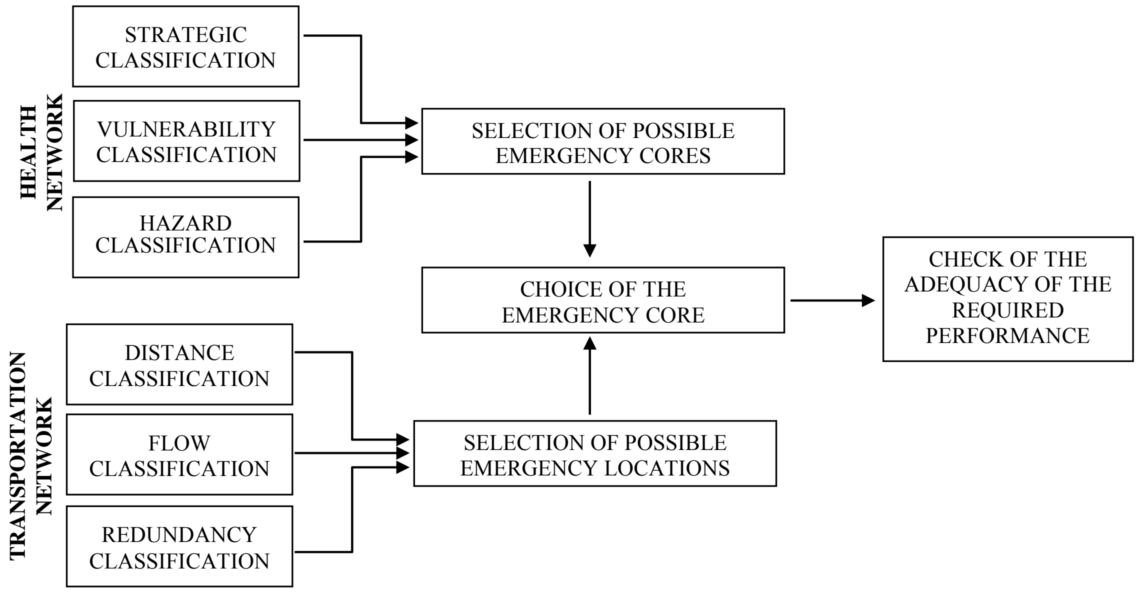


Figure 7. Layout of the network analysis.

5 CONCLUDING REMARKS

In this work, still in progress, a simplified approach to evaluate the reliability of a complex Health network is proposed and applied to a case-study, the Tuscan Health network in Italy. The method of analysis consists of a systemic, simplified and qualitative classification of the considered network after a number of meaningful parameters. Namely, the Hospital complexes of the Health network have been classified after their strategic role, seismic vulnerability and seismic hazard. The transportation network, in turn, has been classified by considering the possible connections between each Hospital complex and the most strategic ones belonging to the same district. The classification included the distance, the flow quality and the redundancy, i.e. the availability of alternative connections.

The combination of the two analysis provided a simplified but comprehensive representation of the reliability of the considered Health system, with regards to the seismic risk.

Further analysis should be developed to include in the evaluation additional information, regarding the logistic network of the Hospital complexes, the possibility to set temporary camps in their vicinity, or the presence of specific fragility factors in the transportation network.

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