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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Indirect flood impacts and cascade risk across interdependent linear infrastructures" *by* Chiara Arrighi et al.

Anonymous Referee #2

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In this paper, the authors developed a risk analysis of the water distribution system (WSS) and the road network system under flooding events. The case study is the metropolitan area of Florence, which is in a flood-prone area. The paper aims to study the interdependence between the WSS and the road system by evaluating the accessibility to critical components of the WSS. Network models and topological metrics (e.g. the length of the disrupted edges, network service areas) are used to measure the vulnerability of the systems.

Overall, I found this paper interesting and relevant to the field of infrastructure resilience. In particular, the paper tries to analyse interconnections between two infrastructure systems by looking at a real-world case study. Anyway, the paper still needs

some work to be ready for publication. Therefore, I hope my comments will help in the revision process.

- The syntax of the whole text should be revised. In particular, I found sections 2 and 3.1 difficult to read. Moreover, I found many typo errors in the text (for example, line 234: (2-3"), line 388: "be be").

- In line 37, you presented previously published works and you wrote "Among these works, indirect impacts and cascade effects are mostly addressed with complex conceptual frameworks (Fekete, 2019; Emanuelsson et al., 2014), . . ." How do you define a "complex conceptual framework"? Please, be more precise when reporting other works.

- Line 50: "Modern cities are currently defined as "systems of systems", where the "systems" are Critical Infrastructure (CI) systems (Gardner, 2016)." I do not agree with this definition. For me, a city is made also of people, cultures, the environment, the ecosystem, etc. Falco published a paper about this (Falco (2015) "City Resilience through Data Analytics: A Human-Centric Approach).

- In the text, you wrote often about the "impedance time". For example, in line 372: "Service Areas (SAs) are applied to understand which portions of the city are accessible within a given time, i.e. the impedance time." I have never heard about it. I checked on a vocabulary and it says it is related to electronic measures. Therefore, I am not sure if it is the most correct terminology.

- I found often "silo-based" in the text, but there is not a clear definition of it. I think it is important to add a definition because "silo-based" is a relevant concept for your work.

- Line 58: "Therefore, CIs cannot be considered independently, and silo-based analyses are completely inadequate to understand the behaviour of a given infrastructure operating in its environment (Dueñas-Osorio et al., 2007; Rinaldi et al., 2001)." This statement sounds a bit strong. I checked the two papers. Duenas-Osorio et al. (2007)

wrote in their abstract that “Effective mitigation actions could take advantage of the same network interconnectedness that facilitates cascading failures”, while Rinaldi et al. (2001) wrote “When examining the more general case of multiple infrastructures connected as a “system of systems,” we must consider interdependencies.” You wrote in line 83: “Silo-infrastructure studies are limited in their scope since they ignore cascade effects and thus underestimate impact (De Bruijn et al. 2019).” I think that analyses of a single network system can advance our understanding of specific systems or they can help to find metrics to use for other analyses. In section 3.1, you also analysed the WSS and the road network separately. Based on those results you could measure the Annual Average Loss (AAL) on page 12. Overall, I think that the introduction should be revised from this perspective.

- In this paper, you used network models embedded in space for your analyses. Anyway, the paper did not report enough literature about this topic. Moreover, other papers studied the impact of floodings on road networks. For example, Casali and Heinimann (2019) “A topological characterization of flooding impacts on the Zurich road network. PLoS ONE 14(7)”; Kermanshah and Derrible (2017) “Robustness of road systems to extreme flooding: using elements of GIS, travel demand, and network science.” Natural Hazards, 86.

- Line 120: “Very few studies (Pant et al., 2018; Dong et al., 2019) developed a truly holistic application to analyse interdependency effects; however, indirect consequences are not investigated, especially regarding the WSS-roads interaction.” I found this sentence too strong. I would rephrase it because there are many published works that analyzed cascading effects on networks. Moreover, you reported the work of Dong et al. (2019), who developed percolation analyses on the road networks of different cities, not of interconnected networks. Therefore, why is a percolation analysis a truly holistic application for interdependency? I think that even the study of a single network system can represent a holistic approach since it looks at the network system as a whole. Casali and Heinimann developed a thesis from this concept (Casali

(2020), “Topological Assessment of Changes in Road Network Systems in Time, under Discrete Flooding Events, and under Classes of Unexpected Disruptions”).

- Why do you use to measure indirect impacts: (i) the length of the disrupted network; and (ii) the population which experiences loss of service? Maybe in section 2.2 you can add more text about the motivations. Moreover, why is the total length of edges a better metric to analyse network vulnerability than other metrics (for example, the number of disrupted edges)?

- In the methodology section, I found that not all the information is reported fully. I do not find a definition for the Annual Average Loss (AAL) and details about how you calculated the PPH. Moreover, you introduced the Pressure Driven Demand (PDD), and it can be useful if you will add more information about it.

- In the methodology section, I did not find precise information about how you modelled the networks. For example, what are exactly a node and an edge in the WSS and the road networks? Which software did you use to model them? I understood that the road network extended to a larger area than the WSS network, is that correct? Did the road network add some weights to the edges? For example, in line 217, you wrote that “for the flooded scenarios, the network properties of a link (i.e. travelling speed) are modified according to the functions, and traffic parameters recalculated for the perturbed state.” This means that you used the travelling speed in the analyses of the road network. Therefore, how did you calculate the travelling speed?

- You used the SA (network service area) to look at accessible areas. Did you consider also directions of roads when you analyse the shortest paths?

- Line 226: “ The widely accepted definition of resilience is the ability to overcome an impactful event and return to normal condition through a quick recovery;” There are many authors that defined resilience in recent years. You can add a reference to a published work on infrastructure resilience.

- Figure 4: you can improve the resolution of the figure. Moreover, I cannot see the edges of the urban network in figure a.

- Section 3.1 “Silo base analyses”: you can add a topic sentence to introduce the “silo-based analyses”.

- Figure 5: I cannot read legend of figure b. The description of figure c is missing. You can improve the resolution of this figure. Moreover, what does it mean "low", "medium" and "high" in legend of figure c?

- Caption Table 2: I would repeat here that the WSS is not affected for 30 and 100 years events.

- Figure 6: it is not clear how did you choose the interval limits for this figure because it is not reported in the method section.

- Table 3: why there is not Florence in this table? Then, I would order the municipalities as in table 2.

- Lifting stations are important for the analyses of this paper. You can describe more the geography of lifting stations, for example, how many and where are lifting stations? Therefore, I ask the authors to provide more description of the topology of the WSS in the result section.

- In Line 389 you wrote, “The first recommendation is then to develop ad-hoc emergency plans by identifying potential critical hotspots (e.g. WSS lifting stations), and to analyse the accessibility to these sites.” Therefore, you concluded that identifying critical components in a single network can help to improve emergency plans. Is my interpretation correct?

- Line 393: “The third recommendation is to enhance the system redundancy for those municipalities totally reliant on a single main system, with e.g. emergency water storage tanks.” I agree but by adding new infrastructures maybe we add new externalities to the urban area? What are the immaterial costs of building new water storage tanks

in Florence? This paper might be interesting Chelleri and Baravikovab (2021) “Understandings of urban resilience meanings and principles across Europe”.

- Conclusion part, line 444: “Results showed that the impact of flooding to the two systems differs in both spatial (up to 5 affected municipalities per WSS, 37 for the road system) and temporal scale (60 minutes before first pressure drop, 30 minutes to reach critical depths on roads).” I cannot find in the result part where you reported or discussed the 30 minutes to reach the critical depths on roads. Please, write this result in the main result section.

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