Interactive comment on "Estimating the risk related to networks: a methodology and an application on a road network" *by* Jürgen Hackl et al.

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Received and published: 12 July 2018

Thank you very much for considering our manuscript for possible publication in the Journal of Natural Hazards and Earth System Sciences. We appreciate your careful review of the manuscript and the well structured constructive feedback received. Please find our response below that includes descriptions of the resulting changes in the manuscript. The revised manuscript, the changes made and the supplementary files can be found in the appendix of this commentary[1]. We trust that these changes have improved the work, making it suitable for publication in your journal. We are

[1]https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2017-446/nhess-2017-446-AC2-supplement.zip

looking forward to your response.

General response to all reviewers' comments

Based on the feedback received, we identified three major areas of concern.

1. *The use of an unconventional paper structure*

   The initial idea was to show readers three times the proposed process, each time at a different level of detail: the generic methodology, the application of the methodology, and the modelling. This approach led to the reuse of section headings in some cases and a scattered literature review. We agree with the reviewers that this presentation can cause confusion. Therefore, to improve its readability, we restructured our manuscript as follows:

   (a) (1. Introduction) – We introduced the problem, and included a cohesive literature review of works focused on estimating transportation network related risk due to natural hazards. Additionally, we highlighted the open research in this field, and clearly pointed out our main contributions.

   (b) (2. Methodology) – We reduced the generic methodology to a minimum, and linked this part to the upcoming example, showing the risk assessment in a single instance. Also, we introduced in this section the most important definitions used in the manuscript (e.g., risk, consequences, events) to facilitate the understanding of the content.

   (c) (3. Application) – We removed all redundant content related to the methodology since a connection between the methodology and the example had already been established in the Section 2 (see point (b)). Furthermore, based on the methodology overview in Section 2 (new Figure 1), we explained the modules and models with greater consistency (i.e., why a model is necessary, how a model depends on other models, which model outputs are the most important). We removed all unnecessary mathematical definitions

from the manuscript since (i) these do not contribute to the understanding of the content and (ii) such definitions make the manuscript very hard to follow. For reasons of completeness, however, we attached the mathematical definitions as supplementary files to the paper (see point (h)).

(d) (4. Results) – We restructured this section by subdividing it into three parts: (i) results of a single scenario, (ii) results of multiple scenarios with the same return period, (iii) and results of multiple scenarios with multiple return periods.

(e) (5. Discussion) – We kept the general discussion about the methodology and the models used.

(f) (6. Conclusions) – We made minor additions to this section to expand on possible future work.

(g) (A. Appendix) – As mentioned in Section 3 (see point (c)), we moved the mathematical definitions to supplementary files for interested readers. The remaining content (mainly tables) was moved to an adequate location in the main text.

(h) (S. Supplementary files) – The mathematical definitions were put into supplementary files, which required adding information on the inputs needed from other models, the outputs produced for other models and the model specific requirements (i.e., which data and data format is needed to run the models; e.g., DTM, land-use data). Additionally, we added multiple images to the supplementary files, which could not be included in the result section (e.g., all time steps of the spatial-temporal system evolution).

2. *Lack of clear focus*

In the original manuscript, we were ambitious by including a large amount of content into the paper. This, combined with the unconventional structure of the

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manuscript, impaired the clear message of the manuscript. To address this, we made the following changes:

(a) In the introduction section, we clearly stated the four main contributions of our work: (i) the modelling of a complete chain of events, from a source event to its corresponding societal event, including the link between natural hazards, transportation networks and society, (ii) the estimation of socio-economic impacts (indirect consequences) due to changes in the traffic flow, (iii) the consideration of uncertainties through a simulation-based approach, and (iv) the introduction of a novel simulation engine, which allows the easy coupling of different models.

(b) The content related to the methodology was linked to the application and the use of the simulation engine. Any redundant and unnecessary content was removed.

(c) The application section was "cleaned-up". Some of the models in the initial manuscript were supported by equations and variables (e.g., direct and indirect costs), which were not necessary, and undermined the value of the simulation engine (i.e., models can be swapped as long as input and output remain the same). Therefore, we removed the all unnecessary mathematical content.

3. *Understated link between natural hazards and network risks*

In the initial manuscript, we did not discuss this point in fine detail. To highlight this link, we added additional paragraphs to our literature review, addressing the question of network vulnerability (in general and in the context of natural hazards) and pointing out the advantages and disadvantages of current methods. We also added several examples that explained why multi-hazard spatial-temporal models need both, hazard and network models.

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Since we made major changes to the manuscript, in some instances, we will address the reviewers' comments by referencing our general response above.

Reviewer 2's comments

The authors address the topic of network infrastructure exposed to natural hazard risk taking the road network around Chur, Switzerland, as an example, and as such, the topic is of relevance for the target journal. Nevertheless, the manuscript shows some weaknesses which are discussed below.

Thank you very much. Please find below a summary of changes made to strengthen our paper in response to your feedback.

Main remarks

1. The manuscript takes a systemic viewpoint by introducing the individual steps of risk analysis for networks (which is not a new task, by the way). Nevertheless, a sound review is missing, which makes it difficult to judge whether or not the authors provide added value to the ongoing discussions of this community (some journals are particularly dedicated to network risk and transportation infrastructure, and it would be good to see the application of the authors in relation to other approaches coming from the hazard community).

   Please refer to the general response. In the initial manuscript, we missed the opportunity to give a detailed discussion about the link between natural hazards and network risks. To overcome this issue, we added additional paragraphs to our literature review, addressing the question of network vulnerability (in general and in context of natural hazards) and pointing out the advantages and disadvantages of current methods. We also added several examples, explaining why multi-hazard spatial-temporal models are in need of network models in addition to hazard models.

2. With respect to the hazard type, the authors are not consistent in what process

type they model (Debris flows? Landslides? Floods?). In one section, the study seems to be limited to one process type only, while the Figures clearly indicate different hazard types ("The purpose of the assessment itself was to quantify the risk of a complete chain of events over space and time, from source events to their consequences, considering: rainfall, runoff, flooding, mudflows, physical damages and functional losses to bridges and roads (road galleries, tunnels and other structures were not of primary concern), traffic changes and restoration works"). Depending on the different hazard characteristics (floods - spatial extent and duration, debris flows and landslides - local occurrence and interruption, maybe damage to the road infrastructure, mudflows - do they really occur in the Chur region?) it remains unclear what exactly the impact will be. Even if they use respective models (and maybe just take the results as an input for network interruption), this should be clarified. The same holds for the determination of direct and indirect effects. It would be better to restrict this study on a clearly named sample of effects so that the potential readers can easily follow the concept.

In our study, we used a multi-hazard approach considering floods and mudflows, both triggered by heavy rainfall. Both are spatio-temporal models, whose variables changed over time, depending on previous time steps. In order to clearly present the relationships between the models, we added a schematic overview of the investigated chain of events (Figure 1.) to the manuscript. Additionally, we restructured the Methodology section (please see general response point 1) to align the methodology with the application, making following the paper easier for readers. Finally, a more detailed description of the models used was added to the supplementary files.

«...*do they really occur in the Chur region?*» Unfortunately, such events occur. In the last decades, four major flood events with infrastructure damages over 5 million CHF occurred in this region. This area is also prone to landslides, including debris flows. In fact, the data obtained for the modelling of the mudflow events

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is for the area of study. To highlight this, we added a comprehensive description to Figure 2., where some of the past hazard events are illustrated.

We trust that the new structure of the manuscript and the schematic overview of the process (Figure 1.) have improved the readability of the manuscript.

3. With respect to the traffic flow model, it remains unclear what exactly the input data is. Moreover, I cannot accept a contributions stating that "The methodology is described in detail in Hackl et al. (2016)" simply because the potential reader should get an overview by reading through the current contributions. So at least the main steps have to be summarized here. As such the entire manuscript reads more like a report than a scientific paper - also because of the repetitions that are presented in multiple sections (Floods are a challenge throughout Europe. . ., just to provide one example).

Thank you for this valuable comment. This comment prompted us to change the structure of our article (please see general response). As stated there, the initial idea was to present the reader three times the same process, each time at a different level of detail (i.e., generic, application, models). This caused a lot of redundancy, and prevented us from presenting the three processes with the necessary depth. The new manuscript was refocused on the application. We removed unnecessary parts of the generic methodology, and moved unnecessary mathematical definitions to the supplementary files. This allowed us to focus the content and give readers a clear idea of how the proposed approach can be followed.

4. Irrespectively of the models used, it would be good to only focus on the network reliability (because a blockage can be of any origin, even road closure due to the WEF in Davos, to give another example).

Due to the unconventional paper structure and the lack of focus, one major contribution of our work may have been lost in the manuscript. Modelling the complete

disaster chain from a source event to its consequences results in a more in-depth analysis than just considering blockage of any origin. For example, we can quantify the severity of the damages and functional losses, leading to the identi-fication of optimal intervention strategies (e.g., if a mudflow blocked an important road with a couple of hundreds m^2, the network manager can estimate how long removing the debris with an excavator would take). Also, since the hazard inten-sities (e.g., flood inundation depths) change over time, road blockage, which is spatially correlated, also changes over time. To summarize, the consideration of blockages of any origin might be a common approach for network reliability, but more information is needed for network resilience. We addressed this issue in the new Introduction section by adding an additional discussion about commonly used approaches to analyze network vulnerability and reliability, their advantages and drawbacks, as well as the contribution of our work on this front.

5. The title of this contribution suggests that the focus is on network reliability, not on the modelling (and more or less proper representation) of hazards affecting the road network This would also sole the issues addressed in the first part ("too many scenarios..."). So methodically, the focus should be placed on the following three items: (a) object-level functional losses leading to network functional loss, considering the topology of the network, (b) object-level physical damages and object-level functional losses leading to restoration works, considering specific restoration criteria, and (c) network functional losses leading to changes in traffic flow, supported by an origin-destination matrix.

As suggested, we placed higher emphasis in the use of fragility and functional loss functions. Therefore, we created dedicated sections explaining the general idea of both functions and how these are used in the application. Additionally, in Figure 6., we illustrated how object-level functional losses lead to network func-tional loss, and in Figure 1., we showed the relationships between object-level physical damages and object-level functional losses leading to restoration works,

and how network functional losses lead to changes in traffic flow.

6. Sentences such as "Simulation-based risk assessments require the coupling of multiple heterogeneous models, where a given model encapsulates the behavior and state of a part of the system" do not provide added value - if the entire manuscript could be re-structured using a classical scheme these statements can go to the introduction and have to be underpinned by appropriate references.

As stated in the general response, we restructured the manuscript and moved such statements to the introduction section.

7. The underlying traffic model is tricky and should be described in more detail. What exactly is the data used, and what are the assumptions? As far as I know, Chur is an economic hub for the entire region; so how did the assumptions made mirror the real behavior of commuters? This is central since when the authors compute risk, these figures define us the exposure.

We agree that traffic modelling is a science in itself. For the sake of illustration, computational costs, and legal issues, we used an in-house solution: a static user equilibrium traffic assignment model, based on the BPR functions to simulate traffic flow conditions. Although this model is mathematically simple, computationally inexpensive and widely used in literature, it has limitations. The model assumes that travelers have full knowledge of the traffic conditions, which is not the case. It does not account for travel pattern changes after a disruptive event either, although studies show that this behaviour is considerably different than before a disruptive event. However, with the proposed modular framework of the simulation engine, such a model can easily be replaced by a VISUM or MATSim model. In further studies, we plan to replace this simplified traffic model with an agent-based model in order to also quantify other socio-economic factors such as business interruptions, rescue missions, fatalities, and education access, among other relevant factors. For this paper, we added additional information on

the used traffic model to the supplementary files.

8. So my suggestion is to re-organise the manuscript in the following way: Introduction: sound review of transport network risk to natural hazards, then categorizing the different approaches in network representation and modelling, then presenting the added value based on a identified gap) of the chosen model. Method description of the model and the main assumptions (data used). Results Discussion: limitations, uncertainties, etc.

As suggested we changed the structure of our manuscript. For details please have a look at the general response section.

9. Additionally, references are outdated, e.g., Eidsvig, U. M. K., Kristensen, K., and Vangelsten, B. V.: Assessing the risk posed by natural hazards to infrastructures, Nat. Hazards Earth Syst. Sci. Discuss., pp. 1-31, doi:10.5194/nhess-2016-89, 2016 has already been finally published.

Thank you, we updated the references.

10. Moreover, references to the transport infrastructure are biased towards the contributions of the authors, here we need a broader review and a clear statement of research gaps and needs, and niches to be filled by the current contribution.

As part of the restructuring, we have added a section with open research in the field and our contributions to the introduction of the manuscript (see general response 1.a).

11. English needs a sound proofread by a native speaker.

This was done.

12. Given the shortcomings of the current version, I kindly would like to suggest a rejection and encourage the authors to re-submit once the storyline is clear and focused on what has been promised in the title. Alternatively, the authors may

wish to choose an alternative journal, presumably from the network modelling community.

We trust that the revised manuscript is now suitable for publication in NHESS.

The authors would like to thank the editor and the reviewers in advance for their careful evaluation of our manuscript.

On behalf of our research team

Jürgen Hackl
(corresponding author)

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2017-446/nhess-2017-446-AC2-supplement.zip

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2017-446, 2018.