Journal: NHESS
Title: Kalman-filter based stochastic-multiobjective network optimization and maximal-distance Latin hypercube sampling for uncertain inundation evacuation planning
MS No.: nhess-2017-248
MS Type: Research article
===

Anonymous Referee #2

Received and published: 10 October 2017

GENERAL COMMENT

This manuscript introduces new concepts to develop the evacuation scenarios considering the uncertainty of inundation evacuation planning. For inundation evacuation under uncertainty, a Kalman-filter based stochastic-multiobjective network optimization model is implemented. Moreover, a maximal-distance Latin hypercube sampling method is used to simulate uncertain scenarios of flooding. A case study in Muzha, Taiwan is then used to apply the new frameworks of evacuation scenarios. The results of implementing these new methods are then discussed.

Although the manuscripts have presented new frameworks to improve the quality of evacuation scenarios under uncertainty, in general, several points need to be improved: (1) The flow of writing is not well presented. Some parts need to be connected with a proper story. The writing seems to be inconsistent considering the flow of the story; (2) The main concept of evacuation used in this study has not been addressed in the text; (3) the contribution/novelty of this concept compared to the existing methodologies has not been discussed clearly. Subsequently, further revisions need to be carried out.

[Authors]:

Dear referees and editors,

Thank you for your useful comments on our manuscript. We have prepared a detailed point-by-point reply to all of the comments as follows. The manuscript has been modified accordingly. Yours,

Ming-Che Hu, Yi-Hsuan Shih, Tsang-Jung Chang

(1) The whole manuscript is modified and reorganized. The models, flooding scenarios, assumption, limitation are addressed to improve the flow of writing.

(2) The evacuation concept is addressed and the manuscript is modified as follows.

> ***Evacuation procedures considered here includes authority decision, announcement, community reaction, and evacuation. To simulate flooding scenarios, maximal-distance Latin hypercube method is used to sample***

> ***three uncertain factors, including upstream inflow (upper boundary condition), downstream water level (lower boundary condition), and friction resistance of channel. Then potential flooding scenarios are simulated using the HEC-RAS hydraulic model and uncertain factors. The stochastic evacuation model can be further simplified to be a deterministic model by inputting deterministic inundation scenario. Notice that the proposed model assumes that evacuees have the complete information about shelter capacity status and people would follow authority's evacuation plan. Otherwise, additional time needs to be estimated while people's individual behavior exists under incomplete information cases.***

(3) The contribution and novelty of this research are compared with previous studies and discussed as follows.

> ***This study analyzes stochastic inundation evacuation planning used for flooding events. The KASMNO model was newly established for iterative prediction, measurement, update, and optimization of stochastic inundation simulation and evacuation. Maximal-distance Latin hypercube method has been incorporated with HEC-RAS hydraulic modeling to increase sampling and computational efficiency of uncertain flooding simulation. Accordingly, the tradeoff and uncertainty analysis of evacuation planning was conducted. The flooding scenarios, shelter capacity expansion, and evacuation planning have been presented for decision making.***

SPECIFIC COMMENT

ABSTRACT:

line 12: channel friction resistance uncertainty ==> "uncertainty" can be deleted since you already used UNCERTAIN INUNDATION FACTORS

[Authors]:

The redundant words are deleted and the sentences are modified as follows.

> ***First, this research proposes a maximal-distance Latin hypercube sampling method to seek maximal space-filling sampling in uncertain flooding factor space. Uncertain inundation factors including upstream inflow, downstream water level, and channel friction resistance are considered. Incorporated with the sampling method, HEC-RAS hydraulic model simulates stochastic flooding scenarios.***

Line 15: THE new measurement?

[Authors]:

The sentences are not clear and they are modified as follows.

> ***Kalman-filter method iteratively predicts the flooding state of the next stage. Then prediction and decision are updated according to latest measurements of flooding state. Accordingly, Kalman-filter based stochastic-multiobjective programming determines optimal shelter capacity expansion in the here-and-now stage and the best evacuation planning for each scenario in the wait-and-see stage.***

The story flow of sentences in the last sentence of abstract (line 19-21) is not well connected.

[Authors]:

We reorganized the structure of Abstract. The end of Abstract is modified as follows.

> ***A case study of stochastic inundation evacuation in Muzha, Taiwan, is conducted. Furthermore, tradeoff between shelter expansion and evacuation time are analyzed. The results show decreasing marginal effect of capacity expansion for evacuation time reduction.***

INTRODUCTION

In my opinion, the problem in the second paragraph (starting from line 33) must be moved in the first paragraph. Therefore, the story will be something like this: general problem, specific evacuation problem, issues in the existing evacuation methodologies developed in the current literature, then addressed why your frameworks are necessary.

[Authors]:

We agree with the comments. The first two paragraphs of Introduction are reorganized. The first paragraph begins with introduction of general problem (nature hazards, inundation events, and evacuation planning). The second paragraph addresses the majority of previous evacuation planning studies. The third paragraph discusses our research framework and compares it with previous studies. The first paragraph of Introduction is rearranged as follows. The details of reorganization of Introduction is presented in the revised manuscript.

> ***The first paragraph:***
>
> ***Natural hazards, such as typhoons, hurricanes, and cyclones, lead to heavy rainfall, severe storms, and then possible inundation events. Inundation might result in serious damage to people, property, and facilities (Parker and Fordham, 1996; Rodrigues et al., 2002; Romanowicz and Beven, 2003). Hence, inundation evacuation planning is an important***

consideration for preventing the loss of life (Li et al., 2012; Parker and Priest, 2012; Hegger et al., 2014; Zhang and Pan, 2014; Wang etal., 2015; Wood etal., 2016; Azam et al., 2017). To achieve inundation evacuation planning, locations and capacities of protection refuges should first be designed and constructed. Subsequently, decision support systems of emergency evacuation must be planned (Barbarosoglu and Arda, 2004; Bird et al., 2009; Taubenböck et al., 2009; Marrero et al., 2010; Yeo and Cornell, 2009; Bozorgi-Amiri et al., 2013; Pourrahmani et al., 2015; Xu et al., 2016; Hou et al., 2017; Liu et al., 2017; Muhammad et al., 2017).

Line 48: MANY RELATED STUDIES HAVE DISCUSSED EVACUATION TRANSPORTATION SYSTEM PROBLEMs ==> What is the problem? need to discussed clearly so the contributions of this study can be well presented.

[Authors]:

We add some paragraphs discussing the details of related evacuation transportation issues. We also compare our study with previous studies and address the contribution of our study.

Many related studies have discussed important issues of evacuation transportation systems including uncertain scenarios, dynamic logistics, multi-objective tradeoff (Yi and Ozdamar, 2007; Stepanov and Smith, 2009; Abdelghany et al., 2014). Evacuation planning involves various uncertain factors, including unpredictable impacts, stochastic intensity, random locations of hazard, and uncertain responses of evacuees (Li et al., 2012; Yao et al., 2009). Because stochastic evacuation planning for uncertain flooding scenarios is an important consideration (Romanowicz and Beven, 2003; Barbarosoglu and Arda, 2004; Bozorgi-Amiri et al., 2013), stochastic programming models provide powerful tools for dealing with uncertain disaster and evacuation planning (Yao et al., 2009).

LINE55: WHAT are the two stage of programming models? you then explained in Line 63-64 but the sentences in line55 seem to be unfinished.

[Authors]:

Those sentences are modified as follows.

Stochastic multi-stage programming models determine stochastic optimal decisions at each stage by optimizing expected objective value. Two stage programming models are the most basic multi-stage model; the two stage models select current decisions at the first stage and decide uncertain future choices at the second stage (Romanowicz and Beven,

2003; Barbarosoglu and Arda, 2004; Bozorgi-Amiri et al., 2013). In addition, Li et al. (2012) constructed bi-level programming models to determine the optimal capacity of shelters and evacuation route systems. Kongsomsaksakul et al. (2005) sought optimal locations and investments for shelters.

Our KASMNO model has two optimization stages including evacuation capacity expansion and evacuation routing. In the first stage, authority determines optimal expected solutions for shelter and transportation capacity expansion under flooding uncertainty. In the second stage, optimal evacuation routing is solved for each potential inundation scenario.

METHODOLOGY

First, what type of evacuation that you present in this manuscript? is this self-evacuation process where the people are decided by themselves where they want to evacuate? or is there any pre-existing road/plan that has been developed before? Is there any announcement from the authorities for the evacuation?

[Authors]:

The evacuation procedures of our study includes authority decision, announcement, community reaction, and evacuation. This study proposes a Kalman-filtered based stochastic-multiobjective network optimization model to determine the optimal evacuation plan for community. The community follows the proposed evacuation plan while evacuation decision of the authority is made. The details are addressed and added in the manuscript as follows.

This study establishes a KASMNO model for analyzing both long-term and short-term inundation evacuation planning. This KASMNO model determines (1) long-term shelter and transportation capacity expansion plans for authorities and (2) short-term evacuation routing for evacuees under flooding scenarios. For short-term evacuation procedures, authority decision, announcement, community reaction, and evacuation are considered. To simulate flooding scenarios, maximal-distance Latin hypercube method is used to sample three uncertain factors, including upstream inflow (upper boundary condition), downstream water level (lower boundary condition), and friction resistance of channel. Then potential flooding scenarios are simulated using the HEC-RAS hydraulic model and uncertain factors. The stochastic evacuation model can be further simplified to be a deterministic model by inputting deterministic inundation scenario. Notice that the proposed model assumes that evacuees have the complete information about shelter capacity status and

> ***people would follow authority’s evacuation plan. Otherwise, additional time needs to be estimated while people’s individual behaviour exists under incomplete information cases. The weighting method is used to analyze the tradeoff between the shelter expansion cost and the evacuation time. The uncertain flooding scenarios, the associate evacuation plans, and tradeoff analysis of multiple objectives are conducted and displayed on the GIS platform. The framework of the Kalman-filter based stochastic-multiobjective network programming analysis of inundation evacuation planning is presented in Fig. 1.***

Second, in principle, the evacuation time is calculated by summing initial reaction time (IRT) and evacuation time (ET). Three components are further considered to calculate the initial reaction time (IRT) including institutional decision time (DT), institutional notification time (NT), and reaction time of the community (RT). Do you consider this concept or everything has been included in the multiobjective optimization introduced in this study? If it has been included, please state it clearly.

[Authors]:

Thanks for the comments. The decision time and notification time are not considered in the proposed model. We modify the model to calculate total evacuation time including authority decision time (DT), notification time (NT), reaction time of the community (RT), and evacuation time (ET). The paragraphs and Eq. (1) are modified as follows.

> ***At time t, there are $x(i,k,t,s)$ people to transport from node i to its neighbor shelter k, so the total evacuation time can be calculated as in Eq. (1). Furthermore, the total evacuation in Eq. (1) considers authority decision time (DT), notification time (NT), reaction time of the community (RT), and evacuation transportation time (ET). Eq. (1) determines the optimal evacuation plan by minimizing the expected total time under uncertainty. The total investment cost is computed in Eq. (2). Furthermore, the weighting method multiplies each objective function by a weighting factor and sums up all weighted objective functions. Eqs. (1)-(2) is combined by the weighting method and the weighted multiobjective functions is presented in Eq. (3).***
>
> $$\text{MIN} \ \sum_s\left\{P(s) \times (\sum_t \sum_{i \in nb(k)} \sum_k^m [t \cdot x(i,k,t,s)] + DT + NT + RT)\right\} \quad (1)$$
>
> $$\text{MIN} \ C_s \times \sum_k^m\{y_1(k)\} + C_t \times \sum_{i,j}\{y_2(i,j)\} \quad (2)$$
>
> $$\text{MIN} \ C_r \times \sum_s\left\{P(s) \times \left(\sum_t \sum_{i \in nb(k)} \sum_k^m [t \cdot x(i,k,t,s)] + DT + NT + RT\right)\right\}$$
> $$+C_s \times \sum_k^m\{y_1(k)\} + C_t \times \sum_{i,j}\{y_2(i,j)\} \quad (3)$$

RESULTS AND DISCUSSION

In my opinion, the manuscript needs to discuss the comparison between the results from your study and the other existing frameworks that have been validated and used for another study/region. In this section, the results from this study have not been validated with the other methodologies/data.

Line 180: why 200-m is the radius of potential overflow? please clarify

[Authors]:

The results of this study is compared and validated with previous studies. The detailed comparison of models, data, results, and contribution are addressed in the revised methodology, results, and conclusions sections.

This research determines the potential flooding scenarios based on the simulated overflow and flooding depth. The average flooding area is calculated and 200 m as the radius of potential overflow area.

Line 184: why the simulation is only 425 times?

[Authors]:

To simulate uncertainty, the model considers uncertain upstream flow (0%, ±7%, ±14%), downstream water level (0%, ±6%, ±12%), and channel roughness coefficient (ranging from 0.013 to 0.045 by interval of 0.002). The total simulation time is 425 time. This study applies maximal-distance Latin hypercube sampling for simulation; the results show that increase of simulation numbers presents similar results.

> ***The HEC-RAS hydraulic model is used to simulate uncertain water stage of the Jingmei River in Muzha. Uncertain upstream flow (0%, ±7%, ±14%), downstream water level (0%, ±6%, ±12%), and channel roughness coefficient (ranging from 0.013 to 0.045 by interval of 0.002) are considered in the model. Fig. 3 plots uncertain simulation of water stage of the Jingmei River. In this study, potential inundation overflow locations are determined by comparing the water stage and levee height. Then areas within a 200-meter radius around potential overflow sites are regarded as evacuation zones. Accordingly, Fig. 4 displays the three cases of overflow location and inundation evacuation areas including three cases of Xinhai Road Sec 7, Hengkung Bridge, and Daonan Bridge in Muzha. The probability of each inundation scenario depends on the number of simulation for which the potential water stage exceeds the levee height. Based on the HEC-RAS simulation at each location, the probabilities for three inundation areas (Xinhai Road Sec 7, Hengkung Bridge, and Daonan Bridge) are 0.43, 0.15, and 0.42, respectively.***

Lines 185: Why only three probability scenarios presented in this section? are there only three cases? please clarify. Why are these three probs chosen?

[Authors]:

The HEC-RAS hydraulic model is used to simulate uncertain water stage of the Jingmei River in Muzha. This research simulates and then selects three most severe flooding scenarios as case studies. However, the proposed stochastic model is very flexible and more uncertain scenarios can be analyzed using our models and framework.

> ***The HEC-RAS hydraulic model is used to simulate uncertain water stage of the Jingmei River in Muzha. Potential inundation overflow locations are determined by comparing the water stage and levee height. Fig. 3 plots simulation of water stage and levee heights of the Jingmei River. In this study, areas within a 200-meter radius around potential overflow sites are regarded as evacuation zones. Accordingly, Fig. 4 displays the three cases of overflow location and inundation evacuation areas including three cases of Xinhai Road Sec 7, Hengkung Bridge, and Daonan Bridge in Muzha.***

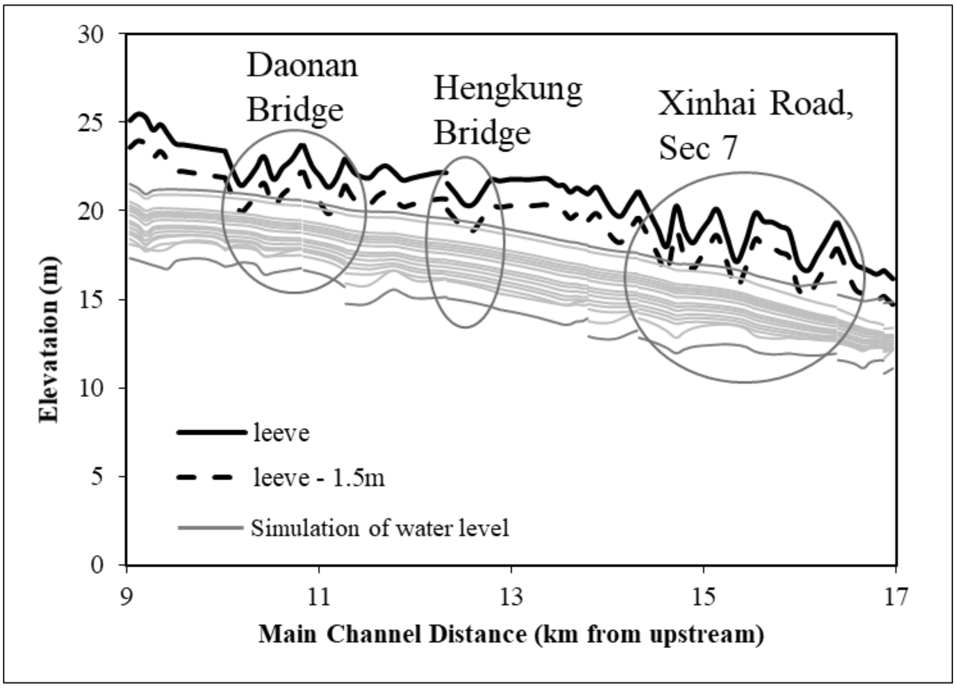

Figure 3. Simulation of water stage, levee height, and potential overflow of Jingmei River.

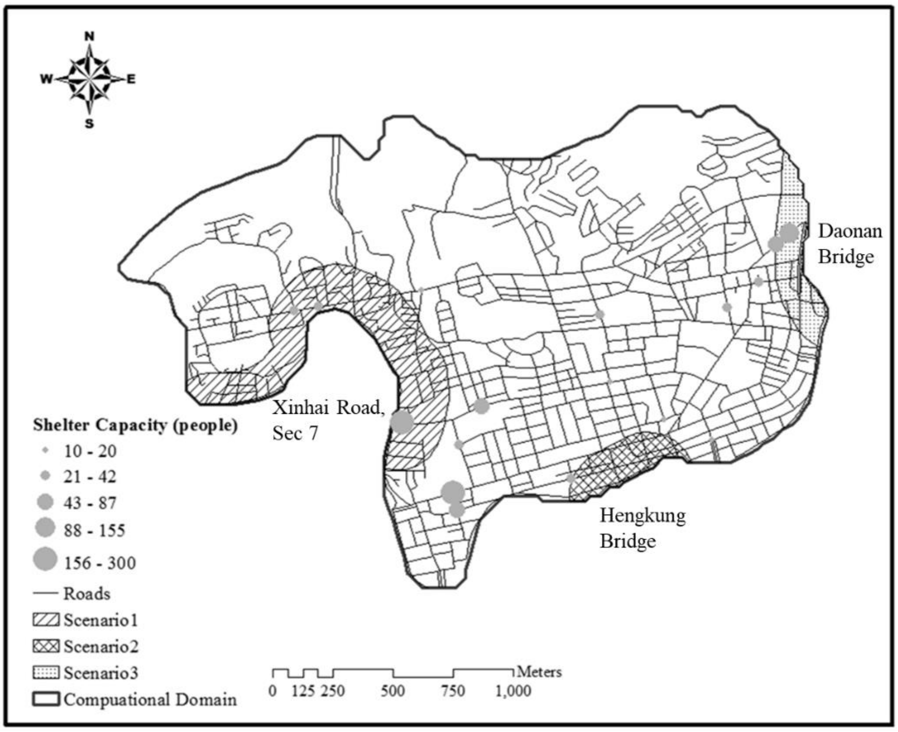

Figure 4. The overflow location and inundation evacuation areas.

Line 188: How to define the people live on higher floors? do you have all the building data in this areas? please explain it clearly.

[Authors]:

People living on lower floors and people living on upper floors are defined as follows. The paragraph is modified accordingly.

> ***People can be evacuated to six shelters located close to the inundation zones. The evacuation area of Xinhai Road Sec 7 area is 0.315 km^2. Hengkung Bridge area is 0.069 km^2, and Daonan Bridge area is 0.089 km^2.*** **Data of people living on each floor are not available. This research assumes the buildings have five floors on average. Then 1/5 of people living on the first floor needs to be evacuated; the rest of people living on upper floors are not evacuated.**

Line 198: HOT ZONE changes to CRITICAL zone?

[Authors]:

We agree with the comments. The sentence is modified as follows.

> ***Since the flooding evacuation area of this scenario contains the highest number of residents, the western area of Muzha is the potential critical zone for evacuation.***

Line 208-209: the sentences are not clear. Suggest to re-write.

[Authors]:

There are some confusing sentences and the paragraph is re-write as follows.

> ***In the stochastic-multiobjective inundation planning, shelter expansions are determined in the first stage before inundations occur. For lower costs of shelter expansion (C_S), Case 1 presents more shelter investment. Since Xinhai Road Sec 7 has the larger inundation area with more people must be evacuated, the results show that largest expansion of a shelter is in the west of Muzha (Shihjian Activity Center) for Xinhai Road Sec 7. The number of extra people to be covered by expansions is 259 for Case 1. For higher costs of shelter expansion, Case 2 is more difficult to increase the shelter capacity. Hence, the capacity expansion of Shihjian Activity Center reduces to 116 people. In Case 2, less capacity expansion leads to the efficient location of the new shelter (in the midpoint of Xinhai Road Sec 7, Hengkung Bridge, and Daonan Bridge areas). Thus, all evacuation scenarios can be benefit from this expansion.***

The comments for Figs 8-9 need to elaborate on the concept of calculating the evacuation time.

[Authors]:

The comments for Figs. 8-9 are modified as follows.

> ***Figs. 8-9 display the evacuation planning on the transportation network system for low and high expansion cost cases. Case 1 with the lower expansion cost builds additional shelter with capacity of 259 people.***
>
> ***Case 2 with higher expansion cost constructs new shelter with less capacity (116 people). In Case 2, the maximal evacuation time for Daonan Bridge area increases to 23 minutes. This is obvious because Case 2 puts higher weighting to expansion cost, and evacuation time would receive less weighting. Hence, in Case 2, evacuees for Daonan Bridge need to travel far away to find shelters while the capacity of closer shelter is not sufficient.***
>
> ***The results indicate that a lower weighting of shelter expansion cost tends to increases shelter capacities, rather than evacuating people to more distant shelters. Conversely, the case with a higher weighting for the expansion cost incurs less shelter expansion. Consequently, an increase in shelter expansion weighting (or cost) reduces the motivation for shelter expansion. Thus, evacuees will be required to travel far away to find shelters, rather than the close shelter being expanded. In addition, comparing flooding areas shows that Xinhai Road Sec 7 area dominates the***

> ***shelter expansion, because it has highest population density and the most people to evacuate.***

CONCLUSIONS

First and second sentences (line 239-240) is not necessary. Suggest to change or delete it.

[Authors]:

The redundant sentences are deleted. The paragraph is modified in the updated manuscript.

The limitations of this study also need to be explained clearly in this section. Only future studies are presented but it can be connected with the limitations of this study.

[Authors]:

The limitation of this research is addressed in the Conclusion section. The paragraph is modified as follows.

> ***Uncertain inundation evacuation planning becomes more critical as the frequency and impacts of disaster events increases. The limitation of this research is that real-time and internet of things (IoT) systems disaster observation/data are not considered. Dynamic disaster response and evacuation with IoT systems would be useful for disaster evacuation planning. Further, this study has not analyzed and simulated uncertain social and economic impact of various disasters. Future studies should include economic, social, and spatial-temporal analysis for disaster simulation and evacuation planning. In addition, real-time optimal control and stochastic evacuation with IoT system under sequential disaster events, climate change, hydrological, and geological uncertainty should be further investigated.***