Dear Editor,
Dr. Paolo Tarolli
Natural Hazards and Earth System Sciences
July 31, 2021
Title: “USAR simulation system: presenting spatial strategies in agents' task allocation under uncertainties"

We are grateful for the opportunity to resubmit our manuscript to the NHESS. We thank the reviewers for providing highly constructive and insightful comments to improve our manuscript. We have responded in detail to each comment and applied significant changes to our manuscript, based on the reviewers’ suggestions. The major changes made are as follows:

1. The role of spatial data and tools in the literature review and background section was described. In this regard, the vital role of accurate and current spatial was expressed in earthquake-affected environments, such as assessing the extent of damage and casualties, surveying vulnerable areas after an earthquake, examining the existing infrastructure in the region, and finally tremendous aid in humanitarian efforts.
2. The history of earthquakes in the study area was studied and the reason for simulating earthquakes with magnitudes of 6.6, 6.9, and 7.2 was explained. In this regard, the existing articles from the study area (District 1 of Tehran) were referenced.
3. We have revised and rewritten the methodology section. We have improved this section with more information about VIKOR and JICA models. The reason for using the VIKOR method and how to use it were written. Also, to make the steps of preparing vulnerability maps more transparent using the JICA model, a figure and a paragraph were added in the methodology section.
4. In order to improve the results section, the discussion regarding the output of the vulnerability of buildings, the number of injured people, and the discussion regarding the output of the proposed task allocation method were added to the manuscript. At this stage, the output of the present study was compared with the output of previous research in each stage.
5. The main limitations of the proposed method were expressed in the conclusion section and based on the existing limitations; several recommendations were provided for future researches.

The next section contains our point-by-point responses to the reviewers’ comments. We believe that our manuscript is substantially improved and is more readable for broader audiences. We look forward to hearing from you. We would be glad to respond to any further questions and comments that you may have.

Yours Sincerely

Reviewer 3

My revision follows two other reviews' reports provided by the other two experts, and following that the authors revised this manuscript accordingly.

1- **About the article content, first I have to recommend the authors to improve the aim and the provided novelty of the present manuscript. Moreover, a brief synthesis of the expected improvements provided by the proposed research would be welcomed. In this latter case, just one or two sentences could be sufficient.**

Response:
We are grateful for the opportunity to explain our manuscript. We thank you for providing highly constructive and insightful comments to improve our manuscript. To improve the purpose of the research and the innovation of the research, the following sentences were inserted in the text. Then, the expected improvements were expressed after applying the method and achieving the goal and innovation of the research.

In the introduction section: "The main purpose of the research is to improve task allocation in crisis-ridden conditions for agent-based groups by considering proper strategies to manage uncertainties."

In the introduction section: "The innovation of the study is the establishment of an approach to improve conditions during reallocations or future allocations when initial allocations encounter problems due either to availability uncertainties or the addition of a new task. In general, spatial strategies are selected in such a manner that the final cost of the system will not increase abnormally if the initial allocations encounter problems."

In the introduction section: "By applying spatial strategies in the assignment of tasks, it is expected that the tasks allocation in conditions of uncertainty will be done optimally and USAR operations will be performed more quickly."

2- **About the literature review, the authors introduced the role of spatial data and tools in this research topic, too briefly. By the way, geoinformation plays a primary role in earthquake-induced urban rubble as well as well as in earthquake simulation on urban areas. Therefore, a more in-depth analysis should be provided.**

Response:
We generally agree with the reviewer's point to add more in-depth role of geoinformation in earthquake simulation. Spatial data and tools play a very important role in earthquake-stricken environments, such as assessing the extent of damage, investigating post-earthquake events (high-risk areas after the earthquake), examining the existing infrastructure in the region, and so on. In the simulation of urban environments, this role becomes more important and sensitive because we are faced with a large volume of important spatial data in decision making. Recommended tools generally have a spatial basis and use spatial data and analysis, even in earthquake engineering. To modify the text and emphasize this issue, the following sentences were added to the text.

In the agent-based USAR simulation section: "In previous studies, a geospatial information system (GIS) platform was used when preparing the environment and creating a simulation base map [1-3]. Spatial analysis and tools are used in most research endeavors in USAR operations [4]. Accurate and current spatial data play a vital role in earthquake-affected environments, such as assessing the extent of damage and casualties, surveying vulnerable areas after an earthquake, examining the existing infrastructure in the region, and finally tremendous aid in humanitarian efforts [5, 6]. Risk assessment of urban areas limits the impact of harmful events by increasing awareness of their potential consequences using spatiotemporal data [7]. Recommended tools in earthquake engineering sciences generally have a spatial basis and use spatial data and analysis [7]. Basic information, maps, and spatial tools in the form of Spatial Decision Support Systems (SDSS) and spatial frameworks such as webGIS have a significant impact on the speed of USAR operations [8]. Earthquake environment simulation is one of the important parts of agent-based modeling which is implemented using spatial analysis. To evaluate the vulnerability of buildings, some models and software based on infrastructures' spatial parameters have been developed [2], such as U.S. Geological Survey (USGS) model [9], HAZUS-MH (Multi-Hazard) [10], JICA[1] model [3], Federal Emergency Management Agency (FEMA) fragility curves [11], PO-ZID[2], and PO-AB[3] parametric methods [12]) and CIPCast-ES (Critical Infrastructure Protection - Earthquake Simulator) simulator [8]."

3- **About the study area analysis, I ask the authors to pay more attention to the analysed bibliography. For example, to refer to a paper of 2009 about the probability of a new earthquake in the future when an earthquake actually occurred in 2017 is very strange to read. Moreover, I ask the authors to provide a reference for this statement about the North Tehran fault: 'It has the potential for a 7.2 magnitude earthquake'.**

Response:

Thank you for your in-depth analysis. According to various references, Iran has been introduced as one of the earthquake-prone areas and in recent years, several earthquakes have occurred in it. The authors themselves have witnessed a 6.2 magnitude earthquake in Tabriz and a 5.7 magnitude earthquake in Tehran. There is no doubt that Iran is seismic and according to previous studies, Iran is among the five seismic countries in the world [2]. In this regard, various studies have been conducted in the country by the International Institute of Earthquake Engineering and Seismology (IIEES) and the Crisis Management Organization of Iran, most of which are in Persian. The history of earthquakes in this region is presented in various articles, the following figures are examples of them [13].

[1] Japan International Cooperative Agency (JICA) model
[2] Potresne Odpornosti Zidanih (Slovenian language)
[3] Potresne Odpornosti armiranobetonskih konstrukcij (Slovenian language)

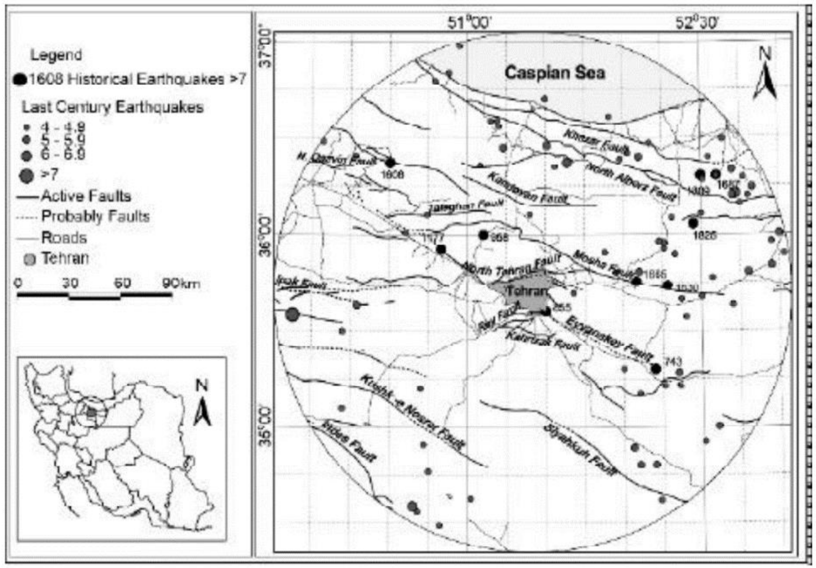


Figure 1- History of earthquakes around Tehran [13]

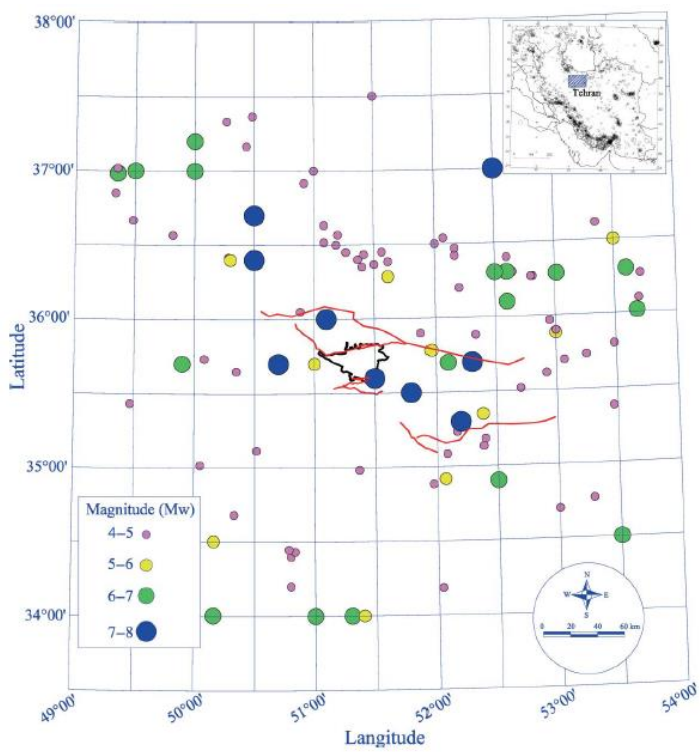


Figure 1- History of earthquakes around Tehran [14]

Alborz region, which is a mountain range located in the northern part of Tehran, witnessed a 7.3 magnitude earthquake in 1990 .In the city of Tehran, earthquakes greater than 7 have occurred throughout its history. The North Fault has also shown earthquakes between 6 and 7.2 in the past [2, 14, 15]. Therefore, a 7.2 magnitude earthquake is not an unlikely scenario. The values of the simulated earthquakes are different in various researches and a single number is not stated for the maximum earthquake potential. It should also be noted that the methodology presented in this research can be implemented for earthquakes with different magnitudes. In order to clarify the issue and remove the existing ambiguities, the paragraph was edited as follows:

In the case study and data section: “The recent Tehran earthquake (5.2 magnitude) in December 2017 attracted the attention of many urban planning organizations. Tehran is a highly seismic area because it is surrounded by the Ray, Masha-Fasham, and North Tehran faults (Figure 1(b)) [14]. Tehran is located in the southern part of the Alborz Mountains, where a magnitude 7.3 earthquake occurred in 1990 [16, 17]. Tehran faults show some M7+ historical earthquake records [2, 14]. Seismologists have reported that Tehran is vulnerable to earthquakes and is expecting a destructive earthquake in the future [3, 13]. The North Tehran fault (NTF) is the city's largest and most prominent active tectonic structure fault, which is approximately 175 km long [2, 18]. The paleoearthquakes study on this fault has revealed seven surface-rupturing events with magnitudes between 6.1 and 7.2 [2, 14, 15]. For this purpose, the North Tehran fault scenario, with the capacity to cause the most destructive potential earthquake in Tehran, was selected in the present study. The method developed in this research can be implemented for any scenario. In accordance with the previous earthquakes and suggestions of seismologist experts, we simulated 6.6, 6.9, and 7.2 magnitude earthquakes. The basic data used in environment simulation were block maps, population, distance from the fault, building material, agent location, year of building construction, and building height.”

Thanks to the attention of the esteemed referee, "It has the potential for a 7.2 magnitude earthquake" sentence was edited as follows according to the history of the North Fault earthquakes:
In the case study and data section: “The paleoearthquakes study on this fault has revealed seven surface-rupturing events with magnitudes between 6.1 and 7.2 [2, 15].”

4- **About the material and methods section, the following issues merit attention. First, what does means this statement: ‘We assume the presence of a disaster environment in which events are uncertain’? Moreover, about the simulation model, I would suggest the authors read the following two publications “Earthquake Simulation on Urban Areas: Improving Contingency Plans by Damage Assessment” and “A comprehensive system for semantic spatiotemporal assessment of risk in urban areas” published in the framework of an FP7 European project. i.e., CIPRNet, and that released a complex earthquake simulator (CIPCast-ES).**

Response:
We appreciate the reviewer’s suggestions. The phrase "We assume the presence of a disaster environment in which events are uncertain" means that data and events in the earthquake environment are not definite and there is uncertainty in them. For example, it is not clear exactly how long it will take if we want to go from point A to point B. To clarify this sentence, the sentence was edited as follows:
In the scenario of the proposed agent-based USAR simulation section: “We assume the presence of a disaster environment in which events are uncertain, for example, the time it takes to go from location A to location B is not exactly known.”

The two articles " Earthquake Simulation on Urban Areas: Improving Contingency Plans by Damage Assessment" and " A comprehensive system for semantic spatiotemporal assessment of risk in urban areas " were carefully studied. These two valuable articles will help us to use spatial data to simulate an earthquake-stricken environment and to provide a supportive decision-making system in the form of a WebGIS, which unfortunately we have not studied before. These two articles will be very useful in the field of environment simulation using the CIPCast-ES simulator and trying to present and implement the proposed method in the form of a webGIS. These two articles were used to improve the text of the article, also based on them ideas for future researches formed in the minds of the authors. Therefore, suggestions were made to readers to use CIPCast-ES to reduce the difficulty and time required to simulate an earthquake-stricken environment. The highlights of these two articles, which helped document our research in different sections of the article, are as follows:

In the agent-based USAR simulation section: "To evaluate the vulnerability of buildings, some models and software based on infrastructures' spatial parameters have been developed [2], such as U.S. Geological Survey (USGS) model [9], HAZUS-MH (Multi-Hazard) [10], JICA[4] model [3], Federal Emergency Management Agency (FEMA) fragility curves [11], PO-ZID[5], and PO-AB[6] parametric methods [12]) and CIPCast-ES (Critical Infrastructure Protection - Earthquake Simulator) simulator [8]."

In the agent-based USAR simulation section: Risk assessment of urban areas limits the impact of harmful events by increasing awareness of their potential consequences using spatiotemporal data [7]. Recommended tools in earthquake engineering sciences generally have a spatial basis and use spatial data and analysis [7]. Basic information, maps, and spatial tools in the form of Spatial Decision Support Systems (SDSS) and spatial frameworks such as webGIS have a significant impact on the speed of USAR operations [8]."

In the conclusion section: "In this study, a simplified environment was considered, for example, it was assumed that the roads were not damaged. It is suggested that environment simulators such as Hazus or CIPCast-ES be used as a deterministic approach to simulate the damaged environment and the vulnerability of roads and. Future studies could also present the output of this study in the form of a spatial decision support system (SDSS) or a webGIS."

5- **The authors proposed the use of the VIKOR method. I could concur with the author that this method fits with the research aims. Indeed, in a research article, the choice of a methodology must be justified. Moreover, some description must be provided on this method. It is not sufficient to simply refer as follows "The interval-based VIKOR method has been previously described (Sayadi et al., 2009). Ordering is performed by the central agent." The authors must provide the required details.**

Response:

We generally agree with the reviewer's point to add detailed information. Some previous research has used formulas to calculate agent scores, including the following formula used by Rasekh and Vafaie Nejad ([14]).

$$\text{Cost} = X + (10 \times Y) + (10 \times Z) + (10 \times K) + T$$

X represents the time it takes for an agent to reach the activity position from his place, Y indicates the difficulty coefficient, Z represents the priority coefficient of activity performed by each agent, T represents the duration of each activity, and K represents the fatigue coefficient. All factors must follow the same unit. The use of such a formula is not very appropriate due to the fact that it strongly affects the results of the tender and is practically not an accepted formula and depends on experts' opinions. In this step, we use multi-criteria decision methods to evaluate the agents' bids. At this stage, all MCDM decision methods such as VIKOR, TOPSIS[7], ELECTRE[8], etc. can be used.

In previous researches, these methods have not been evaluated together in the field discussed in this article, and the predominant method in this field has not been recommended. On the other hand, since we use interval instead of a number in multi-criteria decision making, we could not use complex

---

[4] Japan International Cooperative Agency (JICA) model

[5] Potresne Odpornosti Zidanih (Slovenian language)

[6] Potresne Odpornosti armiranobetonskih konstrukcij (Slovenian language)

[7] Technique for Order of Preference by Similarity to Ideal Solution

[8] ÉLimination et Choix Traduisant la REalité

MCDM methods that could not consider an interval instead of a number. In previous studies, TOPSIS and VIKOR have been used based on interval values. In the article entitled "Developing an Agent-Based Simulation System for Post-Earthquake Operations in Uncertainty Conditions: A Proposed Method for Collaboration Among Agents" we used the interval-based TOPSIS method and in the article entitled " Agent-based task allocation under uncertainties in disaster environments: An approach to interval uncertainty" we used the interval-based VIKOR method to prioritize tasks. A review of the authors' previous research does not show any particular superiority or advantage between these methods. The interval-based VIKOR method is more considered in previous researches when the values are interval and it can be said that it is a more popular method. Therefore, in this study, we used the interval VIKOR method to evaluate and compare the agent's bid. In this research, the VIKOR method is used in two stages: ordering existing tasks and holding an auction. To determine the implementation stages of the VIKOR method, the following two sections were added to the text.

In the ordering existing tasks section: "At this stage, all MCDM decision methods such as VIKOR[9], TOPSIS[10], ELECTRE[11], etc. can be used. In previous researches, the predominant method in this field has not been recommended. On the other hand, since we use interval instead of a number in multi-criteria decision making, we use MCDM methods that can consider an interval instead of a number. In previous studies, TOPSIS and VIKOR have been used based on interval values, but no particular superiority has been observed [19-21]. In this research, the interval VIKOR method is used to sort tasks and compare the agents' bids. The VIKOR method is done in five main steps [21, 22]: First, the decision matrix with interval data is formed so that the rows represent the alternatives (A), the columns represent the criteria (C), and the matrix values (f_{ij}) represent the value of alternatives i relative to criterion j. Matrix values are interval ($f_{ij} \in [f_{ij}^L, f_{ij}^U]$). Then the positive (PIS) and negative ideal solution (NIS) is determined. The positive ideal solution is the highest column value for the profit criterion and the lowest column value for the cost criterion. Then S and R intervals are calculated and based on them, the interval Q is calculated using the following formulas.

$$S_i^L = \sum_{j\in I} w_j \left(\frac{f_j^* - f_{ij}^U}{f_j^* - f_j^-}\right) + \sum_{j\in J} w_j \left(\frac{f_{ij}^L - f_j^*}{f_j^- - f_j^*}\right) \qquad i=1, \dots, m$$

$$S_i^U = \sum_{j\in I} w_j \left(\frac{f_j^* - f_{ij}^L}{f_j^* - f_j^-}\right) + \sum_{j\in J} w_j \left(\frac{f_{ij}^U - f_j^*}{f_j^- - f_j^*}\right) \qquad i=1, \dots, m$$

$$R_i^L = max\left\{ w_j \left(\frac{f_j^* - f_{ij}^U}{f_j^* - f_j^-}\right) \middle| j \in I, \quad w_j \left(\frac{f_{ij}^L - f_j^*}{f_j^- - f_j^*}\right) \middle| j \in J \right\} \qquad i=1, \dots, m$$

$$R_i^U = max\left\{ w_j \left(\frac{f_j^* - f_{ij}^L}{f_j^* - f_j^-}\right) \middle| j \in I, \quad w_j \left(\frac{f_{ij}^U - f_j^*}{f_j^- - f_j^*}\right) \middle| j \in J \right\} \qquad i=1, \dots, m$$

$$Q_i^L = v\frac{S_i^L - S^*}{S^- - S^*} + (1-v)\frac{R_i^L - R^*}{R^- - R^*}$$

$$Q_i^U = v\frac{S_i^U - S^*}{S^- - S^*} + (1-v)\frac{R_i^U - R^*}{R^- - R^*}$$

$$S^* = \min_i S_i^L, \quad S^- = \max_i S_i^U, \quad R^* = \min_i R_i^L, \quad R^- = \max_i R_i^U$$

In the above formula, A* and A^- are PIS and NIS, i is associated with benefit criteria, and J is associated with cost criteria, wj is the weight of criterion Cj and v is introduced as the weight of the strategy of ‘‘the majority of criteria” (or ‘‘the maximum group utility”), here suppose that v = 0.5.

[9] Vlsekriterijumska Optimizacija I Kompromisno Resenje
[10] Technique for Order of Preference by Similarity to Ideal Solution
[11] ÉLimination et Choix Traduisant la REalité

Finally, find an appropriate alternative based on Q Intervals. A better option is to have a smaller Q interval than the others. The following constraints are used to calculate the smaller interval. If a=[a^L a^U] and b=[b^L b^U], the comparison between these two intervals is as follows:

- If the two intervals do not have an intersection, the interval whose values are lower is minimum interval number.
- If the values of the two intervals are $a^L \leq b^L < b^U \leq a^U$, the interval a is minimum if $\alpha(b^L - a^L) \geq (1-\alpha)(a^U - b^U)$.
- If the values of the two intervals are $a^L < b^L < a^U < b^U$, the interval a is minimum if $\alpha(b^L - a^L) \geq (1-\alpha)(b^U - a^U)$.

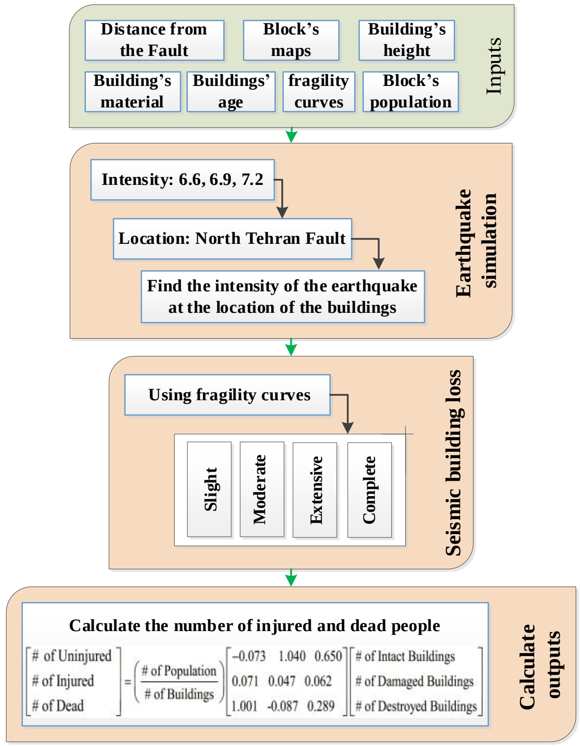
In the holding an auction section: "In some previous researches, special formulas have been used to calculate the agents' scores based on the difficulty of the task, the priority of the task, the duration of each activity, and so on [14]. The use of such a formula is not very appropriate due to the fact that it strongly affects the results of the action and is practically depends on expert opinions. In this step, instead of using the formula to evaluate the agents' bid, the interval VIKOR method is used to find better propose."

6- About the results section, the authors have shown the Vulnerability maps for District 1. By the way, in the manuscript, they did not provide detail on how these maps were obtained. To specify the use of ArcGIS is not sufficient. The same thing about the use of JICA. First, the authors must specify this acronym, and then they must provide some detail about it to help the larger readability of this study.

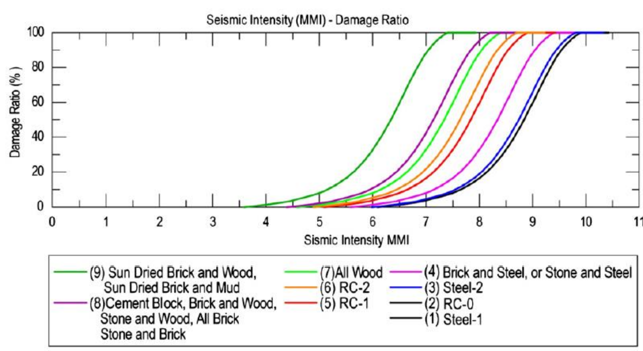
Response:

Thank you for pointing out this misunderstanding to us. To make the steps of preparing vulnerability maps more transparent using the JICA model in this research, the following figure and paragraphs were added in the methodology section. In this section, previous articles that have used this model were also referenced so that those interested can get acquainted with how to implement it by reading those articles in more detail.

In the USAR simulation section: "To simulate an earthquake-damaged environment, an earthquake risk assessment model was developed based upon the Japan International Cooperative Agency (JICA) model. The JICA model is the output of cooperation between the Center for Earthquake and Environmental Studies of Tehran and the JICA. The results of this project and its implementation have been presented previously [23] and used in various studies [3, 17, 19]. This model can calculate the buildings' level of destruction and the number of injured people based on the earthquake intensity, earthquake location, building vulnerability, and the population in these buildings [17]. The steps for creating a vulnerability map and finding casualties based on the JICA model are shown in Figure 2.



(a)



(b)

Figure 2. Building damage assessment: a) Steps for calculating the number of injured people, b) URML pre-code fragility curves [3, 6, 23].

In the results and discussion section, the following paragraph was added to clarify how to prepare a vulnerability map with the JICA model.

In the results and discussion section: "Based on the process presented in Figure 2 for different scenarios, the magnitude of the earthquake was calculated at the location of the buildings. Then, based on the vulnerability curve of buildings and the type of materials used, the amount of destruction of each building is determined."

In the results and discussion section: "After calculating the vulnerability of buildings and based on the formulas expressed in Figure 2, the numbers of injured and deceased people can be calculated using the JICA model."

7- **Moreover, also about the simulation, the authors specified in the results section that the AnyLogic software '… can process geospatial information system data'. Also, in this case, I suggest the authors provide more information about the environmental simulation in the materials and methods section rather than in the results section.**

Response:

Based on the suggestion of the esteemed referee, which is also a very useful opinion, the method of simulating the environment was transferred to the methodology section. Additional explanations on how to simulate the environment were also provided in the methodology section.

In the Materials and Methods section: "AnyLogic software is used to simulate the scenario described in the previous section based on multi-agent systems. In our scenario, we included four types of agents: injured individual, rescuer, coordinator, and central agent. In AnyLogic software, a statechart is designed to suit the tasks of each agent. Statechart determines the work process of the agent. The tasks described in the previous section were implemented for each agent. The simulated agents in the environment are independent, located in a specific place, logical and decision-making, can move to a specific location, and other agents, except the injured agent, communicate with each other. In simulating USAR operations, location and the use of maps and spatial analysis play a key role. AnyLogic software can process geospatial information system data. The initial locations of injured agents were based on building damage and the locations of rescue groups were randomly generated in the environment. The definitions of agents and their characteristics were described in detail in our previous article [19]. The relevant agents move along the central line of the road and use the Dijkstra algorithm to find the shortest path. Dijkstra's algorithm is a well-known algorithm for finding the shortest paths in road networks [4].

There are many injuries in the environment. The rescue of the injuries is possible with the cooperation of the agents. The process of cooperation between agents is simply put as follows: The central agent first sorts the tasks according to their priorities. After the coordinating agent has been determined, the central agent sends the task properties to the coordinating agent. The coordinator holds an auction. Rescue agents bid in accordance with their environmental and working conditions. Rescuers are in a ready state at the start of the operation. Each successful rescue agent moves to the task's location. After reaching the task position, the rescue agent begins rescuing the injured agents. During the execution of their assigned work, the agents may find considerable differences between the real-world information and the information expressed in the auction. In such instances, the agents may stop performing their tasks and report the discrepancies to the central agent. The method of cooperation between the agents is described based on the proposed method in the next section."

8- **From my side, it is a bit strange to read a scientific article without any discussion section. Indeed, some discussion is provided in the results section, but it is not sufficient and must be improved. In doing that, to refer to other research experiences in comparing this one is expected. In other words, it is not acceptable to have a scientific article without proposer discussions.**

Response:

The authors completely agree with the reviewer's comment and have revised the section as follows to make the results understandable. The error occurred in expressing the title of the "Results" section, and the title was changed to "Results and Discussion". In order to improve the article, the discussion regarding the output of the vulnerability of buildings, the number of injured people, and the discussion regarding the output of the proposed task allocation method were added to the text of the article. At this stage, the output of the present study was compared with the output of previous researches in each stage. In this regard, the following paragraphs were added to the text.

In the results and discussion section: "The results of estimating the vulnerability of District 1 for scenario 6.6 show the complete destruction of 18% of the buildings (7,063 buildings of all buildings) in the study area, which is mostly located in the central and northeast part of the region. For this scenario, 27% of the extensive destruction is observed in the buildings, so that these buildings are uninhabitable and there is a possibility of the vulnerability of people in this category of buildings. In the 6.9 magnitude scenario, 29% of complete destruction and 31% of extensive destruction is observed in buildings. It is obvious that with the increase of earthquake intensity, the amount of destruction of buildings increases. Scenario 7.2 shows that with this intensity, 53% of the buildings are severely damaged and these buildings will not be usable. Most of the damaged buildings are located in the central part of the region. A similar result has been obtained in research [2], the main reason being the high structural density and population in this part of District 1. In previous researches, Hashemi and Alesheikh (2011) estimated the number of complete damaged buildings 4% and 32% damage for District 10 of Tehran based on the 6.4 Richter for the Mosha Fault. Hooshagi and Alesheikh (2018) estimated the damage to buildings for the city of Tehran at 16% complete destruction and 24% extensive destruction based on the 6.6 Richter scenario in Niavaran Fault. The degree of degradation of 18%, 29% and 53% according to scenarios 6.6, 6.9 and 7.2 in this study is almost similar to previous researches."

In the results and discussion section: "According to Table 2, as the magnitude of the earthquake increases, the number of people dead and injured increases, so that in the 7.2 magnitude earthquake, 58% of the people were directly involved. Based on the JICA model, Mansouri et al. (2008) estimated the number of deaths and injuries related to the 6.7 magnitude Riches earthquake at 7% and 4%, respectively. The percentage of people who died and were injured in their research is similar to the 6.6 magnitude earthquake scenario in our research."

In the results and discussion section: "Using the proposed strategies, the smallest improvement in results with uncertainty was 2.9 h (13%) for a scenario with 2000 agents and 28,856 tasks (6.6 magnitude earthquake). The maximum improvement was 60.6 h (21%) hours for 1000 agents and 111,463 tasks. In a previous study, task allocation progress was 18% when uncertainty was applied in a laboratory environment regardless of spatial strategies [20]. Previous research has also shown that that taking uncertainty in task allocation into account in District 3 of Tehran improved the duration of the rescue operations by 20%, and decreased the number of fatalities by 15% [19]. Therefore, the proposed approach in this study showed a better performance than the traditional CNP methods."

In the results and discussion section: "The reduction rate ranged from 54% to 60% when the number of agents was doubled. The duration of a USAR operation increased when the number of tasks increased for a given number of agents. Therefore, the duration of the rescue operation was related to the number of rescue agents and the number of available tasks in a scenario. There was an inverse relationship between the duration of the USAR operation and the number of rescue agents, and a direct relationship between the duration of the operation and the number of tasks."

9- In the conclusion section, at least one or two statements on the limits of the proposed methods should be expected.

Response:

Thank you for your in-depth analysis and insightful comments. The main limitations of the proposed method are two cases, which were added as follows to clarify the issue:

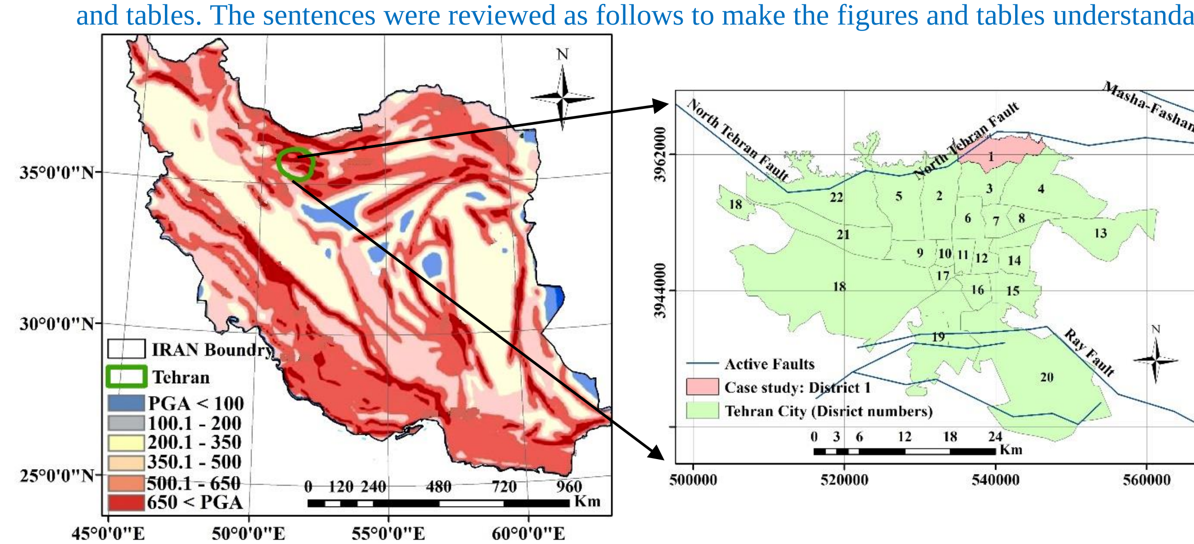
In the conclusion section: "One of the limitations of agent-based simulation is the difficulty of implementation and time-consuming processes that require the availability of powerful processors. Although the proposed method is simple in terms of interval uncertainty and does not perform complex calculations, it is time-consuming due to a large number of calculations to apply spatial strategies for each task and each agent. These processes require the availability of powerful processors. Another limitation of the proposed method is the assumption of communication between agents and the central agent. The proposed method is developed for assistant agents in which groups' information (as agents) is transmitted between groups through tools such as mobile phones. Although the volume of message transfer in this method is less than the traditional CNP method, in severe earthquakes that damage the internet infrastructure, the task allocation method still has problems. Of course, this limitation exists in all communication methods that consider the whole groups."

Technical comments

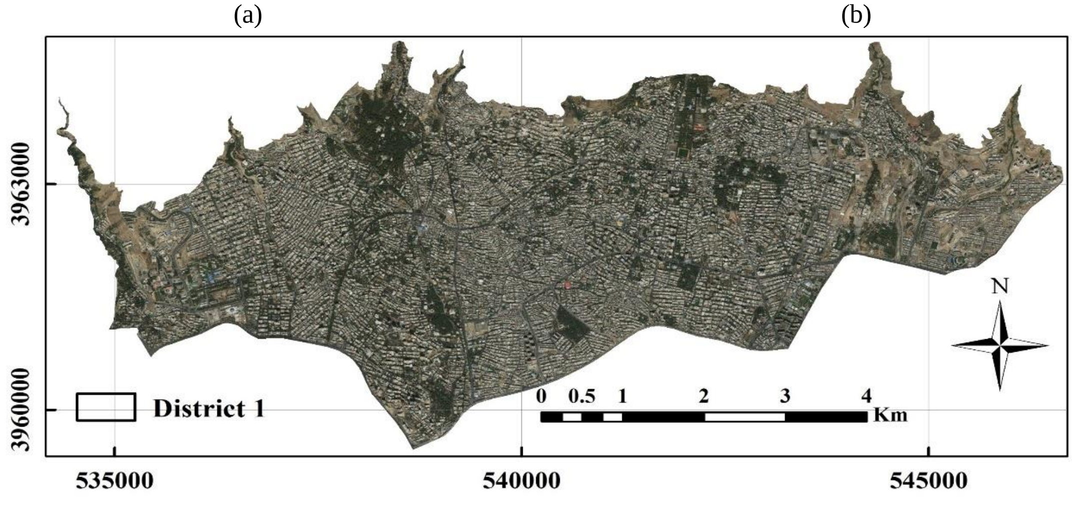
1- Captions of figures and tables must be self-explicative. For example, in figure 1, a map of PGA is reported but this acronym and its significance is not explained in the caption.

Response:

The authors completely agree with the reviewer’s comment and have revised all captions of images and tables. The sentences were reviewed as follows to make the figures and tables understandable.



(a) (b)



(c)

Figure 1 Location of case study: (a) peak ground acceleration (PGA) map of Iran for a return period of 2475 years and approximate location of Tehran, (b) location of District 1 and active faults in Tehran (c) Map of District 1 (study area) and active faults, Tehran.

2- Case study: population of the study area referred to which year?

Response:

Thanks to this statement. The population census in Iran is conducted every 5 years. The statement is related to the last census conducted in 2016, which was mentioned in the text of the article to clarify the issue.

In the case study and data section: "According to the 2016 census, its population is 433,500 people."

We believe that our manuscript is substantially improved and has no similarity to our previous articles. We would be glad to respond to any further questions and comments that you may have.

Yours Sincerely

1. Welch, M.C., P.W. Kwan, and A.S.M. Sajeev, *Applying GIS and high performance agent-based simulation for managing an Old World Screwworm fly invasion of Australia.* Acta Tropica, 2014. 138, Supplement: p. S82-S93.
2. Kamranzad, F., H. Memarian, and M. Zare, *Earthquake Risk Assessment for Tehran, Iran.* ISPRS International Journal of Geo-Information, 2020. 9(7): p. 430.
3. Omidvar, B., S. Tavakoli, and M. Eskandari, *Seismic Risk Analysis of Metropolitan Tehran: A Link Between Hazard Analysis, Vulnerability Assessment and Loss Estimation Studies.* Journal of Seismology and Earthquake Engineering, 2011. 13(2): p. 117-137.
4. Uno, K. and K. Kashiyama, *Development of Simulation System for the Disaster Evacuation Based on Multi-Agent Model Using GIS.* Tsinghua Science & Technology, 2008. 13, Supplement 1: p. 348-353.
5. Crooks, A.T. and S. Wise, *GIS and agent-based models for humanitarian assistance.* Computers, Environment and Urban Systems, 2013. 41: p. 100-111.
6. Hashemi, M. and A.A. Alesheikh, *A GIS-based earthquake damage assessment and settlement methodology.* Soil Dynamics and Earthquake Engineering, 2011. 31(11): p. 1607-1617.
7. De Nicola, A., et al., *A comprehensive system for semantic spatiotemporal assessment of risk in urban areas.* Journal of Contingencies and Crisis Management, 2020. 28: p. 178-193.
8. D'Agostino, G., et al., *Earthquake Simulation on Urban Areas: Improving Contingency Plans by Damage Assessment: 13th International Conference, CRITIS 2018, Kaunas, Lithuania, September 24-26, 2018, Revised Selected Papers*. 2019. p. 72-83.
9. Deyasi, K., A. Chakraborty, and A. Banerjee, *Network similarity and statistical analysis of earthquake seismic data.* Physica A: Statistical Mechanics and its Applications, 2017. 481: p. 224-234.
10. Fallah-Aliabadi, S., et al., *Risk analysis of hospitals using GIS and HAZUS: A case study of Yazd County, Iran.* International Journal of Disaster Risk Reduction, 2020. 47: p. 101552.
11. da Silva, A.H.A., et al., *Damage estimation in reinforced concrete buildings from induced earthquakes in Brazil.* Engineering Structures, 2021. 234: p. 111904.
12. Lutman, M., et al., *Aspects of earthquake risk management in Slovenia.* Procedia Economics and Finance, 2014. 18: p. 659-666.

13. Hosseini, K.A., et al., *Recognition of vulnerable urban fabrics in earthquake zones: a case study of the Tehran metropolitan area.* Journal of Seismology and earthquake Engineering, 2009. 10(4): p. 175.
14. Yazdani, A. and M.S. Abdi, *Stochastic Modeling of Earthquake Scenarios in Greater Tehran.* Journal of Earthquake Engineering, 2011. 15(2): p. 321-337.
15. Ritz, J.-F., et al., *Paleoearthquakes of the past 30,000 years along the North Tehran Fault (Iran).* Journal of Geophysical Research: Solid Earth, 2012. 117(B6).
16. Berberian, M. and R. Yeats, *Tehran: An Earthquake Time Bomb; In Tectonic Evolution, Collision, and Seismicity of Southwest Asia: In Honor of Manuel Berberian's Forty-Five Years of Research Contributions*. 2016. p. 84.
17. Hamzehloo, H., F. Vaccari, and G.F. Panza, *Towards a reliable seismic microzonation in Tehran, Iran.* Engineering Geology, 2007. 93(1): p. 1-16.
18. Kamranzad, F., H. Memarian, and M. Zare, *Earthquake Risk Assessment for Tehran, Iran.* ISPRS International Journal of Geo-Information, 2020. 9(7).
19. Hooshangi, N. and A.A. Alesheikh, *Developing an Agent-Based Simulation System for Post-Earthquake Operations in Uncertainty Conditions: A Proposed Method for Collaboration among Agents.* ISPRS International Journal of Geo-Information, 2018. 7(1): p. 27.
20. Hooshangi, N. and A.A. Alesheikh, *Agent-based task allocation under uncertainties in disaster environments: An approach to interval uncertainty.* International Journal of Disaster Risk Reduction, 2017. 24: p. 160-171.
21. Sayadi, M.K., M. Heydari, and K. Shahanaghi, *Extension of VIKOR method for decision making problem with interval numbers.* Applied Mathematical Modelling, 2009. 33(5): p. 2257-2262.
22. Wang, Z., et al., *Distributed energy system for sustainability transition: A comprehensive assessment under uncertainties based on interval multi-criteria decision making method by coupling interval DEMATEL and interval VIKOR.* Energy, 2019. 169: p. 750-761.
23. Mansouri, B., K. A Hosseini, and R. Nourjou, *SEISMIC HUMAN LOSS ESTIMATION IN TEHRAN USING GIS*. 2008.