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Discussions

Interactive comment on "USAR simulation system: presenting spatial strategies in agents' task allocation under uncertainties" *by* Navid Hooshangi et al.

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This paper provides an interesting perspective in the use of multi-agent simulation for the rescue in areas submitted to an earthquake. I think that the paper could be shortened and the text should be precised. In its present form, I find difficult to understand what is multi-agent simulation reading this paper.

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. Based on the reviewer's comments, the editor's opinions, and deep thought in the article, it was decided to change the writing structure of the article. Numerous details

were included in the text that made it difficult to understand. For correction, we first explain the whole research in the manuscript and introduce its three phases. We also state that the first and second phases are stated in our previous articles, and in this article, only the intended innovation is described. Interested parties are referred to our previous articles to understand the concepts. As mentioned, this article is the final part of a research project in Iran. This research has been done in three phases: In the first phase, uncertainty in the task allocation among agents is considered and task allocation is done only by considering the proximity (spatial distance) to the tasks. The developed method was evaluated in a square-shaped random environment and no sensitivity analysis was performed. The results were presented in an article entitled "Agent-based task allocation under uncertainties in disaster environments: An approach to interval uncertainty". In the second phase, the feasibility of the developed method in the real environment is investigated. In this paper, the aim was to simulate the operational environment of the crisis and to examine the developed method in the real environment. In the simulated system, the 6.8 Richter earthquake damage was calculated for District 3 of Tehran, and rescue operations were modeled. The results were presented in an article entitled "Developing an agent-based simulation system for post-earthquake operations in uncertainty conditions: a proposed method for collaboration among agents". In the third article (submitted article to NHESS), spatial strategies are included in tasks allocation among agents and simulated with the real environment data. Tasks allocation in crisis environments has spatial nature and the location of the injured and rescue agents play a key role in the assignment of tasks. Therefore, while considering the uncertainty in tasks allocation among agents (the subject of the first article) and simulating the method in the environment with real data (the subject of the second article), different task allocation strategies are examined, and the accuracy of the previous methods increased significantly. The study area in this article is also changed to District 1 of Tehran to evaluate the method capability in different study areas. Our submitted article is a combination of the previous two articles with spatial strategies' innovation in it. In the present article, although there are concepts and practical points of the previous two articles, the main innovation of the research is in terms of spatial strategies and also evaluations are based only on spatial strategies. By applying these corrections, the volume of the article will be reduced and the readers will study the article with a certain intellectual background, and therefore it will be easy to understand the article. The sections that have been fully explained in our previous articles have been summarized and readers have been referred to those articles. Also, new sections and innovations of the article were explained in more detail. The changes are marked by the track and change tool in Word.

In Section 1. Introduction: "The present article is the final part of a research project in Iran. This research project was carried out over three phases. In the first phase, uncertainty in task allocation among agents was considered and task allocation was performed only by considering the proximity (spatial distance) to the tasks. The developed method was evaluated in a square-shaped random environment without a sensitivity analysis [12]. In the second phase, the feasibility of the developed method was investigated in a simulated environment using real regional data. In this phase, the operational environment of a crisis was simulated and the developed method was examined in a real environment. In the simulated system, damage for a 6.8 magnitude earthquake damage was calculated for District 3 of Tehran, and rescue operations were modeled [1]. In the third phase using the concepts of previous articles [1, 12], spatial strategies were included in task allocation among agents and simulated with real-environment data. The present paper is the output of the third phase of the research project, which aimed to improve task allocation in crisis-ridden conditions for agent-based groups by considering proper strategies to manage uncertainties. This paper first develops an agent-based simulation system for USAR operations, then applies uncertainties in agent decision-making by improving an interval VIKOR method to perform task allocation, and defines strategies for conditions under which the initial assignment has encountered a problem and requires reallocation (i.e., managing availability uncertainty during implementation). The main innovation of the study is the establishment of an approach to improve conditions during reallocations or future allo-

cations when initial allocations encounter problems due either to availability uncertainties or the addition of a new task. In general, strategies are selected in such a manner that the final cost of the system will not increase abnormally if the initial allocations encounter problems."

I feel confuse about the scope of the first part (part 2) of the paper. Is it for explaining what is multi agent simulation? If it is the case, I (as reader) am not able to understand what is multi agent simulation. Or Is it dedicated to specialists of multi-agent simulation? if it is the case, the part concerning the general use of multi agent simulation has to be removed and the bibliography of the 2.3 should be developed (from line 156 to 176).

Response: This insightful comment is highly appreciated. In this section, it is assumed that users have prior knowledge of multi-agent systems (MAS) and only the various applications of MAS were mentioned. Based on the comments of the reviewer and the fact that readers of the NHESS article may not know MAS, general applications were omitted and multi-agent systems were briefly described and readers were referred to other articles to study the general use of MAS. This section was edited as follows: Section 2.1. Agent-based USAR simulation: "An agent-based model is a class of computational models for simulating the actions and interactions of autonomous agents. Agent-based simulations have been used in various investigations including crisis/disaster management [1, 16], emergency supply chains [17], tsunamis [18], and collective behavior [19]. These simulations can be effective in both planning and policymaking [20]. Simulation of the operating system involves a simplified real environment, which is used to model a wide range of agents in complex systems. Various researchers have modeled a portion of the behavior of agents in simulated environments [16, 18, 21] and demonstrated collaboration among agents. However, agent cooperation in catastrophic environments has been less extensively studied, such that uncertainty in collaboration among agents has generally not been considered. In previous studies, a geospatial information system platform was used when preparing the environment and creating a simulation base map [19]. Spatial analysis and tools related are used in most research endeavors in USAR operations after an earthquake." Also, the bibliography of the 2.3 Reallocation and reassigning methods developed as follows: "Distinct algorithms have been proposed for scheduling and task reallocation in accordance with the tasks and available conditions within an environment [34]. Some reallocation methods (e.g., data envelopment analysis [35]) and exact algorithms (e.g., a branch-and-bound algorithm with column generation) resolve problems on a smaller scale (e.g., 10 jobs and three vehicles). In such methods, the process is time-consuming and slow for resolving large-scale problems [13]. Therefore, they are not suitable for the allocation of tasks that should be performed dynamically and instantaneously in large-scale problems. In some research, such as the investigation of gate reassignment problems, initial assignment tables have been created using heuristic methods in such a manner that a succession delay is minimized [36]. The incidence of adverse events may disrupt the original table. Notably, this method is not suitable for a large number of tasks. Some other task allocation methods are interdependent with the plan's ongoing tasks, such as in construction operations [14]. In those mathematical calculations, when a task fails, all other tasks that were based on its correct implementation must be replanned. An appropriate reallocation method must be applied with respect to the nature and scale of the problem. In USAR, a rescue process generally occurs independently of any other rescue processes, and only a portion of the workflow is ready to be implemented and assigned. Moreover, because of the large number of rescue groups in USAR operations, as well as the available uncertainties and dynamic nature of multi-agent systems in disaster environments, the concept of general planning is uncommon and appropriate plans should be produced both locally and cross-sectionally. Most available methods to resolve the problem of assigning tasks cannot be developed for uncertain conditions and restrictions such as in critical rescue environments (e.g., USAR after earthquakes). With respect to USAR operations, task allocation methods must include different strategies for all conditions and be dynamically generated in a real-time environment. In contrast to previous studies, we define an approach based

on spatial strategies, such that the results of the initial task allocation are used for future task allocations and are appropriate in the rescue environment. Time limitations constitute another issue in the reallocation and reassignment of rescue teams. Therefore, the present study aims to expand the CNP method for rapid problem resolution."

Part 3 (case study): What data are available for this case study?

Response: We generally agree with the reviewer's point to add a data section. In Iran, integrated data from regions is rarely and hardly found. The following paragraph was added to the text to specify the data used. Section 3. Case study and data: "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."

Line 194 “The proposed methodology is a general approach to various phenomena.” This sentence is empty. Please remove or be clearer.

Response: Thank you for your in-depth analysis. The developed method is suitable for cooperation between agents in different phenomena in which agents are in relation to each other. For example, this method is suitable for cooperation between agents in rescue operations during floods, terrorist attacks, and other operations in which several agents must cooperate. Since this case has not been studied in our research, this sentence is removed from the manuscript.

Line 195: What are the characteristics of the environment which are known? What are the unknowns?

Response: Thank you for pointing out this misunderstanding to us. By this, we mean simply to say that there is uncertainty in the environment and that environmental information is not entirely clear. For example, the travel time from point A to B is uncertain or, for example, the exact number of casualties in urban blocks is not certain. Items in which uncertainty was considered to include the number of injuries, the severity of the victims' injuries, duration of the operation, infrastructure priorities, agent energy, route status, task runtime by an agent, and risk level for the agent. Therefore, the sentence is edited as follows. Section the scenario of proposed agent-based USAR simulation: "We assume the presence of a disaster environment in which events are uncertain." Also, "Given the results of previous studies [12, 33, 39, 40] and in accordance with expert opinion on USAR operations, the uncertainties include the number of injuries, severity of the victims' injuries, duration of the operation, infrastructure priorities, agent energy, route status, task runtime by an agent, and risk level for each agent. These are important uncertainties in task allocation. All parameters are specified as intervals during the task allocation process."

Line 196: what controls the uncertainty for a person to be trapped and injured? How is it decided? Is it spatially controlled?

Response: Thank you for your in-depth analysis. There is a population distribution map of the area as shown below.

(Figure 1)

Based on this map and the JICA model, the number of injured people in each urban block is determined. The JICA methodology has four major stages: namely, seismic hazard assumption as an input, building inventory development, building, and human vulnerability function developments and implementations, and, finally, the production of results in a GIS [17]. The inputs of the model are building material, building height, a building's year of construction, distance from the fault, and parcel maps and fragility curves. To calculate the number of injured people, building population and the following Equation is used [17]:

Figure 2- Equation (1)

This number does not exist exactly in the urban block. For example, part of this population goes to work during the day, some are out of the house at night, so the population

in urban blocks is not always a fixed number. Therefore, according to the formulas, there will be uncertainty in the number of injured in each urban block. References to previous articles were given for how to calculate these values. The sentences were edited as follows to clarify the subject.

Section 4.1. The scenario of proposed agent-based USAR simulation: "The injured individuals are trapped under rubble and the number of such individuals in each building block is uncertain. Rescuing injured people is the main goal. Saving each person is a task that must be performed through the cooperation of rescue agents. After an earthquake, the numbers of injured and deceased people can be estimated by using different formulas by determining the magnitude and location of the earthquake, as well as the urban context data of the buildings [38]. Furthermore, the possible locations of injured individuals can be predicted using building damage assessment models. Therefore, the simulation inputs are the injured individuals' locations and their characteristics, which are available with some uncertainty."

Section 4.2. USAR simulation: "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 [41] and used in various studies [1, 42]. 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."

Line 205: What can be the disruptions? Are there statistically defined?

Response: We appreciate the reviewer's question. In this article, tasks allocation is considered with uncertainty. So any big difference from the initial interval can be considered as disruption (in the last part of Figure 3,4 [which is edited as follows]). For example, the initial evaluations show that the route is safe, while the agent realizes when he is in the area that it is practically impossible to move towards the desired route. Or, for example, the initial estimate of the number of injured people in a house is between 3 and 5 people, and the agent goes to the area and sees that the number of injured people is fifteen. Certainly, their equipment will not be enough and they may not be able to work due to limitations. Therefore, he requests the reallocation of the work.

(Figure 3 Task allocation flowchart in the proposed approach by five steps and environmental simulation)

(Figure 4 Task allocation flowchart in the proposed approach, separated into five steps within an environmental simulation)

The disruptions implementation and application of them in formulas is described in Section 4.2.5 Implementation and observation of real values in the environment, which was edited as follows to be understandable. Section 4.3. 5. Implementation and observation of real values in the environment: "During the implementation phase, tasks are implemented by agents in a dynamic environment where there are always uncertainties during task execution. The rescuer observes the difference between predicted values and the actual environment after the work begins. In this study, a random number in the [X -30%X, X + 30%X] interval was chosen to model the real environment. In the real world, the difference between the predicted environment (through building vulnerability estimation models) and the real environment will determine the agent's performance. If the agent observes a large difference between the auction information and the real environment, the agent abandons that task. In this instance, the agent updates the task's values and uncertainties and returns the work to the central agent. The new uncertainty interval will be 80% smaller than the original interval. There are various conditions under which agents will reallocate a task if the environment differs from the expected scenario. For example, the agent can abandon the task if three of eight decision-making parameters are out of range by 5%. Otherwise, the agent finishes the rescue work by accepting the new conditions. The central agent assigns

newly added tasks within the reallocation framework. When a new task is assigned, the task allocation is combined with that of both new and incomplete tasks."

Line 210: I do not understand how injured agents can communicate with other agents. It is possible that injured agents blocked under the destroyed buildings are conscious and able to make some noise but this is rare.

Response: Of course, the injured person cannot have any interaction. In the proposed model, there is an injured agent without any communication in the environment and only its vital signs are changing with a constant trend. Other agents interact with each other. To make the text clearer, emphasize that the injured person has no activity in the environment. The following sentence was included in the text. Section 4.1. The scenario of proposed agent-based USAR simulation: "This agent exists in the environment and has a critical condition that changes continuously. This agent has no activity or communication with other agents."

Line 260: "these relationships are based on expert opinion". Could you add a reference?

Response: Unfortunately, limited research has been done in this field, and only equivalents are mentioned in Dr. Alireza Vafaeinejad's doctoral dissertation entitled "Spatio-Temporal Modeling and Planning of Working Groups in an Activity-Based GIS (case study: rescue groups)" and the book of rescue operations entitled "Team Forming and Teamwork in Rescue Operations (with emphasis on urban search and rescue team)" in the Persian language. These equations have been after various analyzes with rescue experts. We have also used these formulas in our previous articles [1, 2] , but have not presented them in the text.

In its present form, I do not recommend this paper for publication. Authors have to defined the audience for who they write, they have to be more precise in their description, and they have to shorten the paper.

Response: 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

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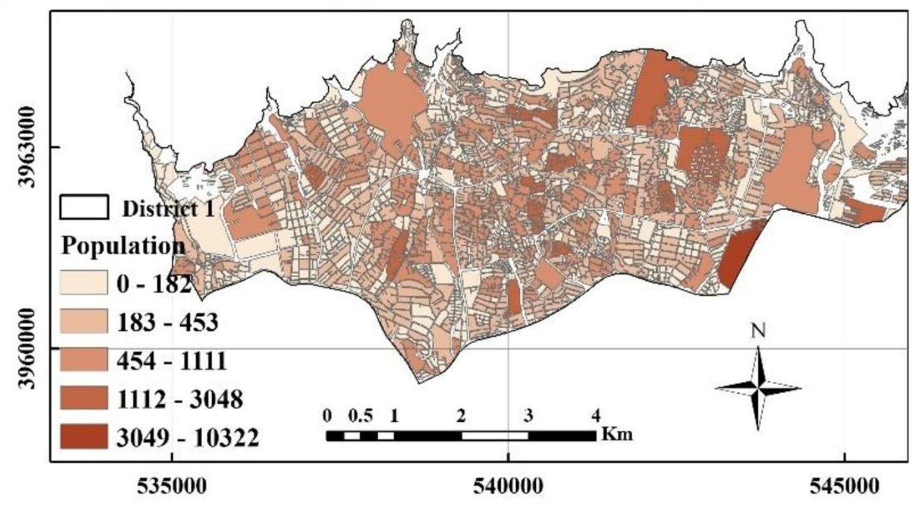

Fig. 1.

$$\begin{bmatrix} Uninjured \\ Injured \\ Dead \end{bmatrix} = \left(\frac{Population}{Buildings}\right) \begin{bmatrix} -0.073 & 1.040 & 0.650 \\ 0.071 & 0.047 & 0.062 \\ 1.001 & -0.087 & 0.289 \end{bmatrix} \begin{bmatrix} Slight \\ Moderate \\ Extensive + Complete \end{bmatrix}$$

Fig. 2.

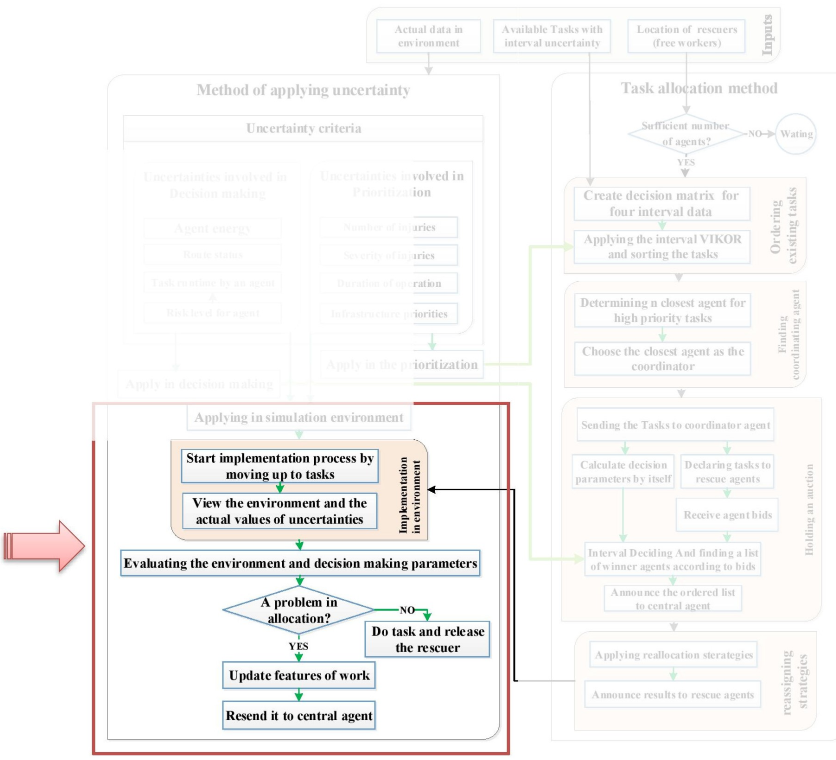

Fig. 3.

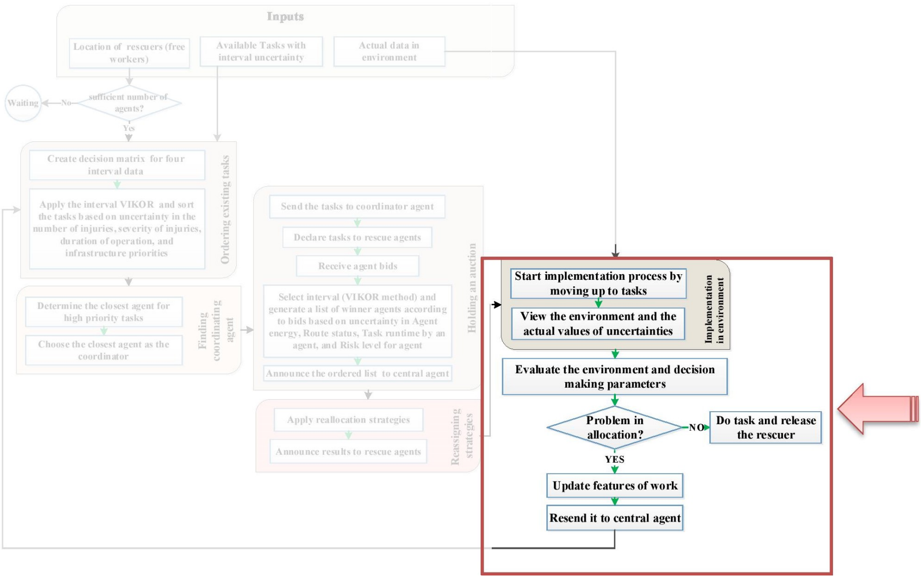
Inputs
Location of rescuers (free workers)
Available Tasks with interval uncertainty
Actual data in environment
sufficient number of agents?
Waiting
No
Yes
Create decision matrix for four interval data
Apply the interval VIKOR and sort the tasks based on uncertainty in the number of injuries, severity of injuries, duration of operation, and infrastructure priorities
Ordering existing tasks
Determine the closest agent for high priority tasks
Choose the closest agent as the coordinator
Finding coordinating agent
Send the tasks to coordinator agent
Declare tasks to rescue agents
Receive agent bids
Select interval (VIKOR method) and generate a list of winner agents according to bids based on uncertainty in Agent energy, Route status, Task runtime by an agent, and Risk level for agent
Announce the ordered list to central agent
Holding an auction
Apply reallocation strategies
Announce results to rescue agents
Reassigning strategies
Start implementation process by moving up to tasks
View the environment and the actual values of uncertainties
Implementation in environment
Evaluate the environment and decision making parameters
Problem in allocation?
NO
Do task and release the rescuer
YES
Update features of work
Resend it to central agent

Fig. 4.