A conceptual model for flood disaster risk assessment based on agent-based modeling

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***Abstract*—In this paper, we used agent-based modeling in complex system for flood disaster risk assessment according to the characteristics of flood disaster system. The flood disaster multi agent complex system (FDMACS) had been constructed. The internal structure of different agents and agents' alliance in FDMACS had been designed. The agent communication language (ACL) had been selected as the communication tool using for interaction and collaboration among different agents and agents' alliance in FDMACS. This paper initially built the flood disaster risk assessment conceptual model based on multi agent.**

Keywords-risk assessment; flood disaster; ABM; agent

I. INTRODUCTION

Flood is one of natural disasters with the worst loss in the world. The frequent natural disaster is flood disaster in China whether in the affected area, distribution area, affected people and economic loss caused by natural disasters. So, it needs to assess the risk of the flood disaster. Flood disaster risk assessment is the comprehensive evaluation and analysis between the fatalness of flood hazard factors, the stability of flood hazard environments and the vulnerability of flood hazard effected objects. Flood disaster risk assessment has been widely used in flood insurance [1], flood risk management [2], flood disaster shelter [3], disaster warning [4], economic loss assessment [5] and land use impact assessment [6]. On the other hand, flood risk assessment is an important scientific basis for flood disaster risk management and decision-making. The essentially of flood disaster is a complex three-dimensional concept which has related with no interest, uncertainty and complexity. Flood disaster risk is affected by many factors such as hazard factors, hazard environment, objects of hazard effect and the diversity of evaluation methods. Therefore, flood disaster risk assessment is still a worldwide research topic both in the field of natural science and technical science.

II. THE METHOD OF FLOOD DISASTER RISK ASSESSMENT

Flood disaster risk assessment is an important basic research topic in geography, disaster science, hydrology, hydraulics and other related domains. The risk of flood disaster is the interaction results of different components in flood disaster system. The flood disaster system is a complex disaster system. The flood disaster system is composed with flood hazard factors, flood hazard environments, flood hazard affected objects and flood risk. Flood hazard factors include rainstorm, typhoons, tsunamis, ice-snow melt water and broken-dam. Flood hazard environments include atmospheric environment, hydrological environment, meteorological environment and underlying surface environment. The study results show that the stability of flood hazard has great relativity with affected region topography, the distribution of rivers and lakes, land use, vegetation coverage and soil. Flood hazard affected objects are effective objects of different flood hazard factors. The classifications of hazard affected objects have difference according to different research objectives. However, hazard affected objects can be divided into the population, property, housing, infrastructures and crop planting area.

From the view of complex system theory, flood hazard factors, flood hazard environments and flood hazard affected objects are interactional and interdependent. And they will form a complex system with certain structure, function and characteristics. In others words, the flood disaster risk will be affected by many factors such as flood hazard factors, hazard environments, hazard affected objects and evaluation methods. Therefore, flood disaster risk assessment is still a research hotspot in flood, geography, disaster science, hydrology and hydraulics. Flood disaster risk assessment methods can be divided into flood evolution methods [7]-[9], spatial comprehensive analysis methods [10]-[14], fuzzy comprehensive evaluation methods [15], analytic hierarchy process methods [16][17] and complex systems modeling methods [18][19].

A. Flood evolution method

Flood evolution methods study flood disaster risk from the view of disaster dynamics. These methods will focus on the natural properties of flood. Flood evolution methods can be divided into two categories such as hydraulic model and hydrological model. The hydraulic model is to solve one-dimensional or two-dimensional flow based on Saint-Venant equations. And, which has got many researchers attention with the development of large-scale digital computers. On the other hand, the hydrological models study flood risk from the internal rules and mechanism of flood during preparatory, occurrence and development. The probability theory and mathematical statistics are always employed as mathematical tools in hydrological model so as to analyze and establish the relationship between disaster intensity and flood frequency. Flood disaster risk calculated by hydrological model is the same concept with the flood standard such as "once in 100 years" used in hydraulic engineering design. Many flood disaster risk assessment research results have been got using flood evolution methods [7]-[9]. For example, an integrated hydrological and

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hydraulic approach for the risk assessment of a flood-prone area had been used in Italy [7]. The hydraulic model had been selected to study the flood risk especially regarding recurrence intervals of 200 to 10 000 years in Germany [8].

B. Spatial comprehensive analysis method

With the development of spatial information technology and the stepwise understanding of flood formation process, the flood disaster risk assessment gradually begun to use spatial comprehensive analysis utilizing flood evolution, remote sensing and geographic information system (GIS). The flood risk assessment model has been established based on GIS [10]. On the other hand, GIS and multi-source remote sensing data have been employed to assess different the flood risk and flood disaster loss [11] [12]. Meanwhile, the hydraulic model, GIS and remote sensing data have been used in flood risk mapping [13] [14].

C. Fuzzy comprehensive evaluation method

Utilization the fuzz comprehensive evaluation method can quantify the problem in flood risk assessment because there are fuzzy phenomena, concepts and logic problems in flood disaster system. At present, some researchers have introduced the fuzzy evaluation method into flood risk assessment field and achieve some results [15]. Fuzzy comprehensive evaluation method can quantitatively synthetically process some factors which are not easily quantifiable or some problems with not clear boundary using fuzzy theory. The base of fuzzy comprehensive evaluation method is fuzzy math. The fuzzy comprehensive evaluation methods construct fuzzy subsets (membership) function so as quantitatively process the fuzzy indexes which are used to reflect the things being evaluated. Then, comprehensive analysis various indexes were used to fuzzy transform. The key of fuzzy comprehensive evaluation method is constructing fuzzy subsets (membership) function.

D. Analytic hierarchy process method

With the gradual-depth study of flood disaster complex system, the analytic hierarchy process (AHP) has been used in flood disaster risk assessment [16] [17]. The AHP is a comprehensive integrated approach from qualitative analysis to quantitative analysis. AHP method can decompose complicated problem into several levels and factors. The risk assessment of flood disaster is a complex multilevel problem so AHP can be used to decompose the flood disaster system into different hazard factors and objects of hazard effect according to the actual assessment need.

E. Complex system modeling method

The flood risk is macro emergence result of the flood disaster complex system. In order to better study flood risk, agent-based modeling (ABM) method in complex system can be introduced into natural disasters risk assessment. ABM is one future development directions in flood disaster risk assessment. But, the flood risk assessment methods based on ABM are in the initial stage, such as the framework of natural disaster risk assessment based on agents has preliminary constructed [18] [19].

III. THE FRAMEWORK OF FLOOD DISASTER RISK ASSESSMENT METHOD BASED ON ABM

The flood disaster system is a typical complex system. Flood disaster risk is the interaction result of all elements in flood disaster complex system. So, the flood disaster risk assessment model needs to express the complex relationship between different elements in flood disaster complex system. Under the guidance of the internal rules and mechanism in flood hazard during preparatory, occurrence and development, ABM technology has been employed to establish flood multi agents complex system. Then, the flood disaster risk assessment technology framework based on ABM has been proposed in this paper.

A. Theory of complex system modeling based on ABM

Agent is a physical or abstract entity and the basic unit in multi agents systems (MAS). Agent can act on their own and the environment. Meanwhile, agent will respond to the environment. In general, agent has the knowledge, goal and ability. Knowledge is the description the world which agent lives in or the solution problem. Goal is the aim of all actions of agent. Ability is function such as reasoning, decision-making and control. MAS are more than one alliances composed by many different agents. ABM is an important modeling tool for MAS. MAS emphasize particularly on simulation the behavior of the various components in the system and taking into account their interaction from the microscopic. Meanwhile, MAS consider the interaction of the various components in the system and lets them interact. And thus, the macroscopical complexity of the system can be showed. Compared with the traditional methods, this top-down modeling approach can be more intuitively performance the complexity of flood disaster system. The main contents in flood risk assessment based on MAS include the construction of flood disaster risk assessment and the structural design of agent communication mechanism.

B. The construction of flood disaster risk assessment based on ABM

The flood risk assessment architecture based on ABM and the internal structure in different agents will be focused on in this section.

1) The architecture of the flood risk assessment based on ABM

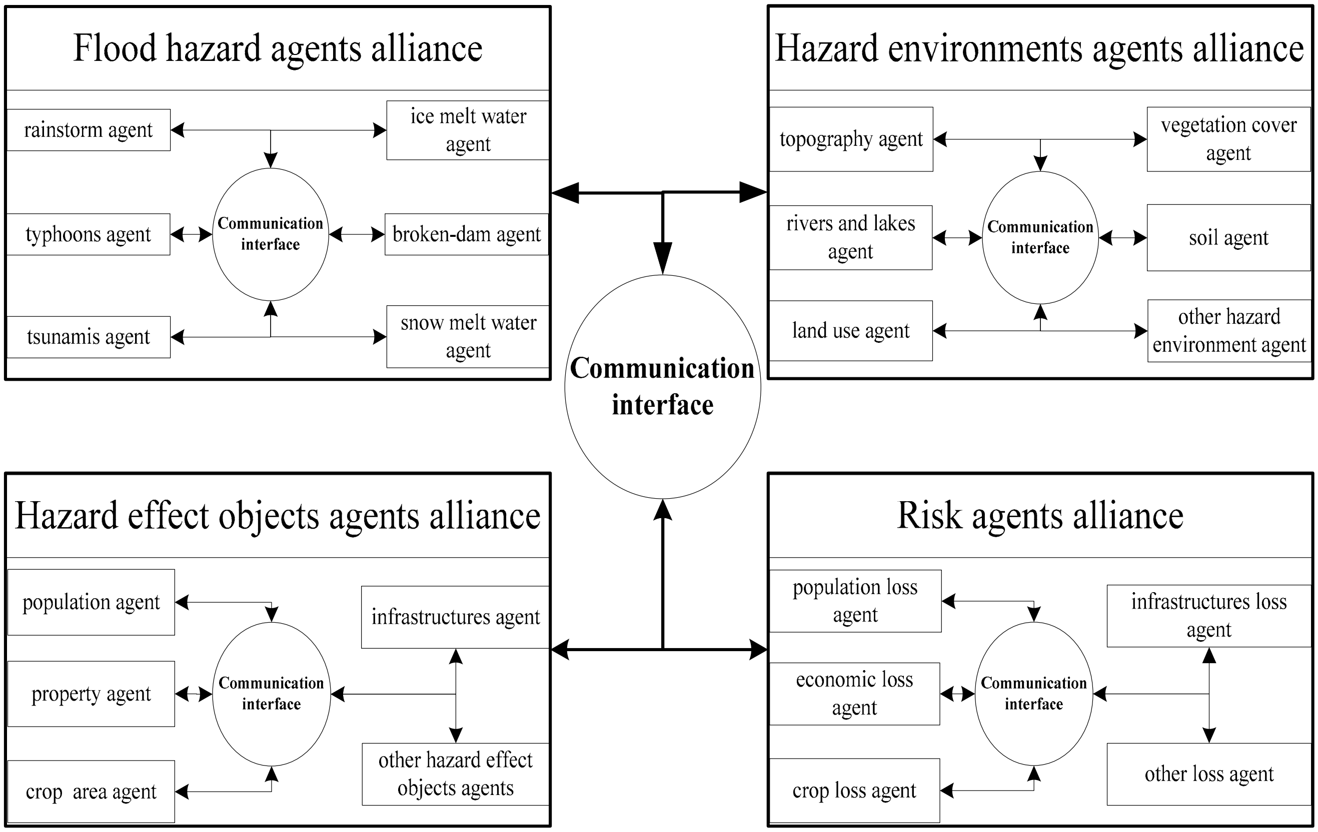

Figure 1. Architecture of flood risk assessment system based on MAS

We used the existing study results of flood risk assessment to construct flood hazard complex system. Then, we selected ABM technology to top-down model the flood hazard complex system. Meanwhile, the state and behavior characteristics of hazard factors, hazard environments and hazard effect objects will be abstracted from the microscopic level. Final, we established the flood disaster multi agent complex system (FDMACS). There are four agents' alliance such as hazard factor agents' alliance, hazard environments agents' alliance, hazard effect objects agents' alliance and risk agents alliance in FDMACS. There are rainstorm agent, typhoons agent, tsunamis agent, ice melt water agent, broken-dam agent, snow melt water agent in flood hazard agents' alliance. The hazard environment agents' alliance includes topography agent, rivers-lakes agent, land use agent, vegetation cover agent, soil agent and other hazard environment agents. The hazard effect objects agents alliance is formed by population agent, property agent, infrastructures agent, crop planting area agent, other hazard effect objects agents. Population loss agent, economic loss agent, crop loss agent, infrastructures loss agent and other loss agents are included in risk agents' alliance. Figure 1 is the architecture of flood risk assessment system based on multi agents.

From figure 1, the different agent alliance including hazard factor agents' alliance, hazard environments agents' alliance, hazard effect objects agents' alliance and risk agents' alliance in FDMACS uses communication interface to interact and coordinate. The different agents in four categories agents alliance, i e, rainstorm agent and typhoons agent, also use communication interface to interact and coordinate. Thus, the communication between different levels agents can achieve the coordination roles among different agents. The several key issues in FDMACS are internal structure design of different agents, communication mechanism design among different agents and coordination mechanism design among different agents.

2) Internal structure in different agents

The internal structural designs in FDMACS main include four categories agent alliance structural design and the structural design of single agent in different agent alliance.

The internal structure of four categories agent alliance in FDMACS adopts reactive structure according to the characteristics of flood hazard complex system and BDI model. Reactive agent is generally based on "perception-action" model. The reactive agent strengthens its synchronous cooperative interaction with environment and other agents. However, reactive structure weakens agent's intelligence. The reactive agents are more suitable for flood risk assessment for they have a faster response rate. The difference of four categories agent alliance is that each category agent alliance has different condition-action rules base and objective functions. Figure 2 shows the internal structure of hazard factors agent alliance.

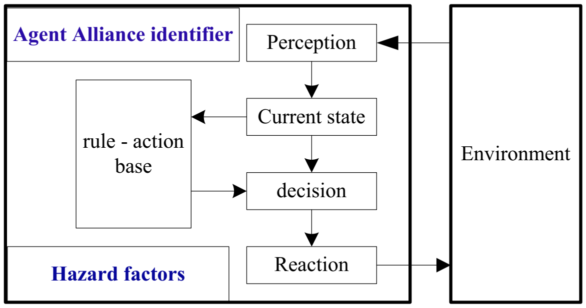

Figure 2. Internal structure of hazard factors agent alliance

The internal structure of single agent in FDMACS, such as rainstorm agent and population loss agent, adopts deliberative structure. Compared with reactive agent, deliberative agent has more learning capability and complex logical reasoning ability. Deliberative agent emphasizes the intelligence of the agent. The reason for single agent using deliberative structure is that the single agent needs to have more learning capability and logical reasoning ability to perform specific tasks in flood disaster risk assessment. Figure 3 shows the internal structure of rainstorm agent.

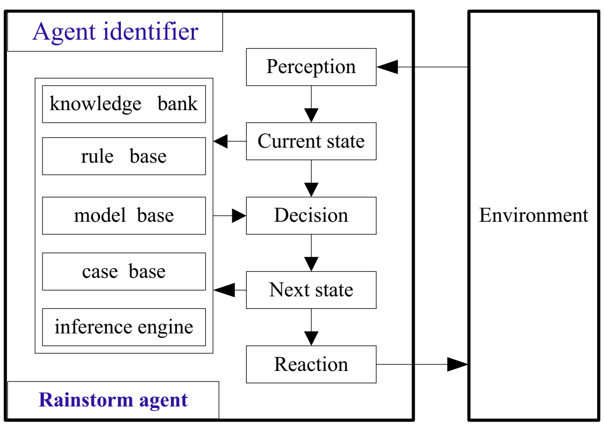

Figure 3. Internal structure of rainstorm agent

C. *Structural design of agent communication mechanism*

The coordination and collaboration among the agents will be focused in this section. The communication is the base of interaction and collaboration among different agents and agents' alliance in FDMACS. The statement method can be used to realize the communication among different agents and agents' alliance for the communication among the agents in FDMACS is bidirectional communication. The statement method achieves communication by exchanging the statement such as definitions, assumptions and other statements sentence. Agent Communication Language (ACL) is one kind of bidirectional communication languages based on statement method. ACL consists of three parts including vocabulary, internal knowledge interchange format, and external knowledge query-manipulation language. The coordination and cooperation of the different agents and agents' alliance in FDMACS can be achieved using the ACL. Then, the interaction and collaboration among different agents and agents' alliance in FDMACS can be realized using the agent's communication mechanism. Final, the flood disaster risks under different scenarios can be assessed using the interaction and collaboration among different agents and agents' alliance.

IV. Discussion and Conclusion

The flood disaster risk assessment model based on ABM has just started. So, there are still many problems need to be resolved. The first one is that flood multi-agent system internal design issue. It is related to the theory of agent construction in artificial intelligence field and the interaction mechanism of the components in flood disaster system. At present, many scholars have researched the interaction mechanism of the flood disaster system research and achieved gratifying results. But, most of these results can't effectively meet the quantitative requirements in multi-agent modeling. The second is that the collaboration and communication problems in FDMACS. There are some difficulties to research the mechanism of the coordination-cooperation and communication for agents in FDMACS because the interaction mechanism between different factors in flood disaster system is not full clear.

The solution to the abovementioned problem needs to depth joint research of many fields, such as artificial intelligence, hydraulics, disaster and computer science. Thus we can really play the ABM advantages, which is modeling the flood disaster system from the micro and assessing the flood risk from the macro, in flood disaster risk assessment.

In this paper, a conceptual model for flood disaster risk assessment based on ABM has been focused. The architecture of flood risk assessment, agent internal structure and agent communication mechanism had been designed. Our future research will focus on solving the several issues mentioned above.

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References

[1] W. K. Hsu, P. C. Huang, C. C. Chang, et al, “An integrated flood risk assessment model for property insurance industry in Taiwan,” Natural Hazards, Vol. 58, No. 3, pp. 1295-1309, 2011.

[2] A. Zerger, and S. Wealands, “Beyond modelling: linking models with GIS for flood risk management,” Natural Hazards, Vol. 33, No. 2, pp. 191-208, 2004.

[3] J. Sanyal, and X. X. Lu, “Remote sensing and GIS - based flood vulnerability assessment of human settlements: a case study of Gangetic West Bengal, India,”. Hydrological Processes, Vol. 19, No. 18, pp. 3699-3716, 2005.

[4] G. Arduino, P. Reggiani and E. Todini, “Recent advances in flood forecasting and flood risk assessment,” Hydrology and Earth System Sciences Discussions, Vol. 9, No. 4, pp. 280-284, 2005.

[5] B. Merz, H. Kreibich, R. Schwarze, et al, "Assessment of economic flood damage," Natural Hazards and Earth System Science, Vol. 10, pp. 1697-1724, 2010.

[6] S. J. Boyle, I. K. Tsanis, and P. S. Kanaroglou, "Developing geographic information systems for land use impact assessment in flooding conditions," Journal of water resources planning and management, Vol. 124, No. 2, pp. 89-98, 1998.

[7] V. Anselmo, G. Galeati, S. Palmirei, et al., "Flood risk assessment using an integrated hydrological and hydraulic modeling approach: a case study," Journal of Hydrology, Vol. 175, No. 1-4, pp. 533-554, 1996.

[8] B. Buchele, H. Kreibich, A. Kron, et al., "Flood risk mapping: contributions towards an enhanced assessment of extreme events and associated risks," Natural Hazards and Earth System Sciences, Vol. 6, No. 4, pp. 485-503, 2006.

[9] H. Apel, A. H. Thieken, B. Merz, et al., "A probabilistic modelling system for assessing flood risks," Natural Hazards, Vol. 38, No. 1-2, pp. 79-100, 2006.

[10] M. Fedeski and J. Gwilliam, "Urban sustainability in the presence of flood and geological hazards: The development of a GIS-based vulnerability and risk assessment methodology," Landscape and Urban Planning, Vol. 83, No. 1, pp. 50-61, 2007.

[11] Z. Sheng, A. Sturdivant, A. Michelsen, et al., "Rapid economic assessment of flood-control failure along the Rio Grande: A case study," International Journal of Water Resources Development, Vol. 21, No.4, pp. 629-649, 2005.

[12] C. Glasser and P. Reinartz, "Multitemporal and multispectral remote sensing approach for flood detection in the Elbe-Mulde region 2002," Acta Hydrochimica et Hydrobiologica, Vol. 33, No. 5, pp. 395-403, 2005.

[13] J. D. Pelletier, L. Mayer, P. A. Pearthree, et al., "An integrated approach to flood hazard assessment on alluvial fans using numerical modeling, field mapping, and remote sensing," Geological Society of America Bulletin, Vol. 117, No. 9-10, pp. 1167-1180, 2005.

[14] V. Meyer, S. Scheuer, D. Haase, "A multicriteria approach for flood risk mapping exemplified at the Mulde river, Germany," Natural Hazards, Vol. 48, No. 1, pp. 17-39, 2009.

[15] D. Mao, L. Wang, "Diagnosis and assessment on vulnerabitity of the urban flood-waterlogged disaster in Hunan province," Resource and Environment in the Yangtze River, Vol. 11, No. 1, pp. 89-93, 2002 (In Chinese).

[16] J. Liu, J. Li, J. Liu, et al., "Integrated GIS/AHP-based flood risk assessment: a case stduy of Huhaihe River basin in China," Journal of natural disasters, Vol. 17, No. 6, pp. 110-114, 2008 (In Chinese).

[17] J. Lian, H. Gong, X. Li Et Al, "Design and development of flood/waterlogging disaster risk model based on Arcobjects," Journal of Geo-information Science, Vol. 11, No. 3, pp.376-381, 2009 (In Chinese).

[18] F. Wang, Z. Yin, J. Wen, et al., "Assessing model for dynamic risk of natural disasters based on multi-agent system," Geography and Geo-information Science,Vol. 25, No. 2, pp. 85-88, 2009 (In Chinese).

[19] R. J. Dawson, R. Peppe, M. Wang, "An agent-based model for risk-based flood incident management," Natural hazards, Vol. 59, No. 1, pp. 167-189, 2011.