Transactions of the Korean Nuclear Society Virtual Autumn Meeting
October 21-22, 2021

Formalism Study for Agent-based Modeling in Nuclear Emergency Evacuation Simulation

Geon Kim, Gibeom Kim, Gyunyoung Heo*
Kyung Hee University, Deogyeong-daero, Giheung-gu, Yongin-si, Gyeonggi-do 17104, Republic of Korea
**Corresponding author: gheo@khu.ac.kr*

1. Introduction

Disaster prevention divided into structural and non-structural measures. [1] Structural measures are made through visible structures. Examples include radiation monitoring facilities, radioactive protective equipment and so on. Non-structural measures are made through invisible structures, computer programming. Examples include emergency planning zone (EPZ), measurement of evacuation time etc.

As a society becomes more complex, research into non-structural measures is important. [2] In this study, we present a method for measuring evacuation time that is, one of the non-structural measures using agent-based model (ABM).

In the ABM, an agent is an element that judges interactions in the program after setting attributes and behavioral rules in the evacuation model. In this study, 'agent' is defined as evacuees and infrastructure.

In the authors' previous study, evacuation model was developed. [3] In this model, the only interaction between evacuee 'agent' was described. However, the performance and behavior of evacuees are obviously affected by the interaction with infrastructure. The interface among various types of agents is not easily understood and implemented in an ABM because of their complexity.

This study focused on how to clearly express interactions within 'agents' through the method, formalism. Furthermore, we developed a simple evacuation model using the results of formalism such that potential improvements for nuclear emergency evacuation can be investigated under dynamic simulation.

2. Methods

2.1 Agent-Based Model (ABM)

An ABM is widely used in system engineering and artificial intelligence field. The biggest feature is that it can be modeled by micro-level. Also, it can explain the agent's unique attributes (key characteristic) and behavior (decision-making).

However, the agent's complex behavior or complex interactions between agents are difficult for users to fully understand. For this reason, there are difficult parts in reviewing, expanding, and experimenting with a published model. This may result in lower fidelity. In this case, a formal specification describing the ABM is of great use. [4]

2.2 Formalism

The formalism was created for a clear expression of the ABM. It is useful for explaining a social system model, and agent's methodical approach is possible. In this study, we used representative formalism, discrete event system specification (DEVS).

The DEVS is based on the notion that any discrete event system can be modelled with discrete states and an underlying event set associated with it. DEVS largely expressed as an "atomic model" and "coupled model". Atomic model is a model that expresses the internal interaction of each agent or environment. Coupled model is a model that expresses the interaction between agents, between environments, or between agents and environments. [2] Fig 1, 2 show examples of atomic model and coupled model.

Evacuees and infrastructure were defined as agents, so we need the atomic models for each agent and the coupled model for combining them.

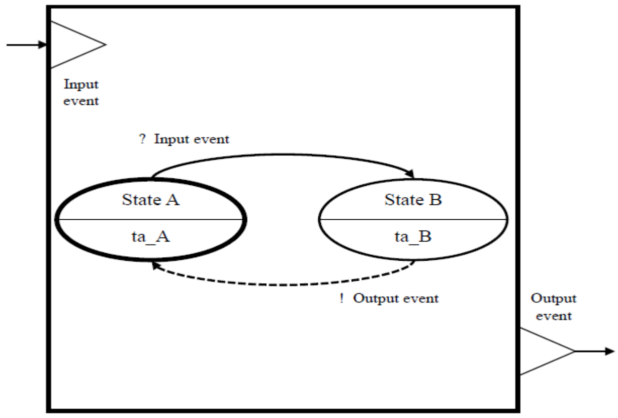

Fig 1. Atomic model (DEVS)

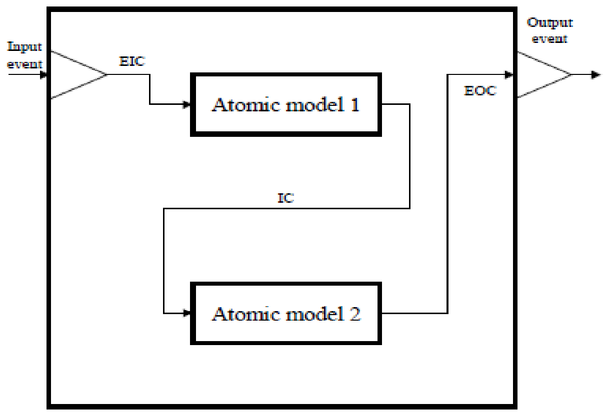

Fig 2. Coupled model (DEVS)

In Fig 1, an ellipse, the upper indicates the agent name which will be defined below, and the lower specifies the time advance function value of the state. The thick solid line(ellipse) represents the initial state of the model. The dotted line between the ellipses is an internal transition function, and the solid line is an external transition function between two states. The annotation with a question mark specifies the triggering event of transition. The annotation with an exclamation mark specifies the output event of the model.

In Fig 2, multiple boxes representing the DEVS models that can be either atomic or coupled. A line links models, a model and an output event, then an input event and a model. "EIC" means the input starting point in the coupled model, called external input coupling. "IC" means interaction between models, called internal coupling. "EOC" signifies the output ending point in the coupled model, called external output coupling. [5]

2.3 Evacuation Time

In this study, the evacuation time was calculated based on the assumption of one-dimensional uniformly accelerated motion. x_0 is the starting point of evacuation and x_{100} is the location of a shelter to be reached. Furthermore, since it was uniformly accelerated motion, acceleration was given as a constant, and velocity was expressed as a change in position at time.

$$Position = x_i \; (i = 0,1, \dots ,100) \quad (1)$$

$$\vec{v_i} = \frac{dx(t)}{dt}, \; \vec{a} = constant \quad (2)$$

The evacuation time is, therefore, defined below:

$$T_{real} = 0.5\vec{a} \times \{\sum_{i=0}^{99}(x_{i+1} - x_i) \times \vec{v_i}\} + I(t) \quad (3)$$

T_{real} is an evacuation time computed in an ABM. I(t) is a time delay affected by the performance of an infrastructure.

Next, it is necessary to compute the time delay by an infrastructure during evacuation.

$$I_0 = 0 \;\; , I(t) = I_0 + \sum T_{infra} \quad (4)$$

$$\sum T_{infra} = \sum(T_f + T_b) \quad (5)$$

T_{infra} indicate time delay due to the performance or availability of infrastructure. In this study, only two infrastructures are demonstrated: T_f is time delay about fire, T_b is time delay about blackout. The value shows how much the agent is disturbed during evacuation.

The evacuation model requires additional assumptions.

1) All agents want to evacuate. The direction of evacuation is uniform. Normal agent's velocity is defined as $\overrightarrow{v_{NORM}}$.
2) Probability of 10% turn the normal agents into an injured agent. At this point, $\overrightarrow{v_{NORM}}$ is reduced to $0.5\,\overrightarrow{v_{NORM}}$ ($\overrightarrow{v_{INJ}}$).
3) Probability of 50% of the injured agents turn into recovery agents. At this point, $\overrightarrow{v_{INJ}}$ is increased to $0.7\,\overrightarrow{v_{NORM}}$ ($\overrightarrow{v_{REC}}$).
4) Recovery agents change to normal agents with probability of 70%.
5) Fire infrastructure occurs with probability of 5% and a 5-second time delay.
6) Blackout infrastructure occurs with probability of 10% and a 10-second time delay.

3. Results

This chapter explain the results of the above assumptions and computational procedures in the framework of formalism.

Fig 3,4 show an atomic model (evacuee, infrastructure). Also, a coupled model (Fig 5) was created through the above two atomic models.

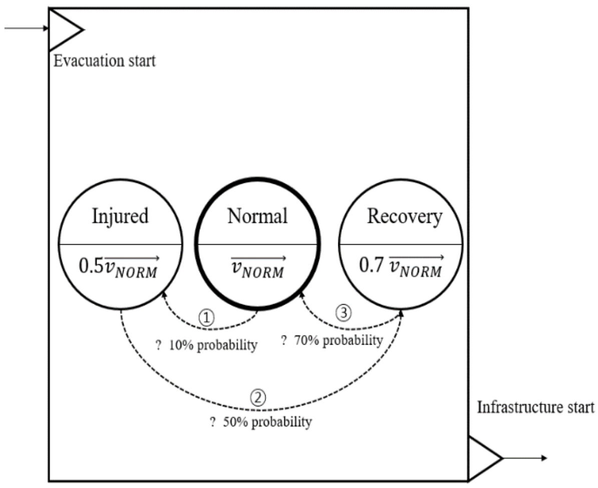

Fig 3. Atomic model (evacuee)

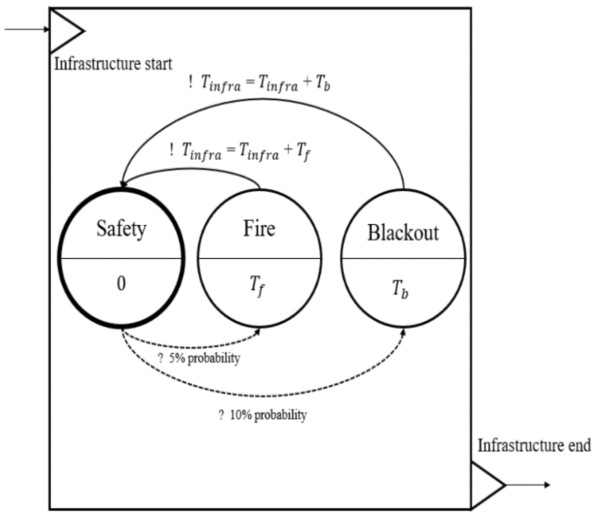

Fig 4. Atomic model (infrastructure)

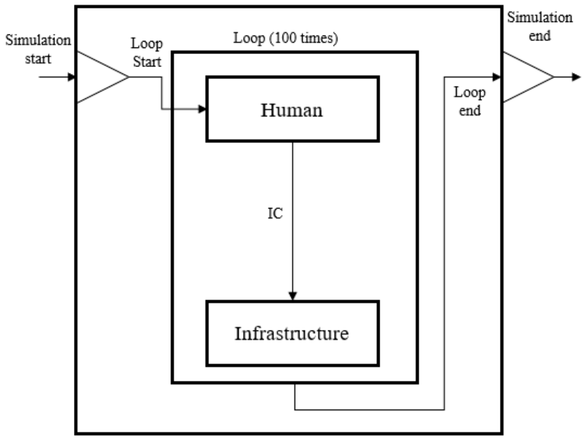

Fig 5. Coupled model

The internal architecture for objected-oriented programming by the following formula. An evacuee model is specified as a 4-tuple in the set-theoretic context, an infrastructure model (called Infra) is specified as a 5-tuple.

$$Evacuee = < X,\ Y,\ (S_1, S_2, S_3),\ \delta_{int} > \quad (6)$$

X: a set of input events (evacuation start)
Y: a set of output events (infrastructure start)
S_n: a set of sequential states
(S_1: normal, S_2: injured, S_3: recovery)
δ_{int}: an internal transition function (velocity)

$$Infra = < Z,\ W,\ (Q_1, Q_2, Q_3),\ \delta_{int},\ \lambda > \quad (7)$$

Z: a set of input events (infrastructure start)
W: a set of output events (infrastructure end)
Q_n: a set of sequential states
(Q_1: safety, Q_2: fire, Q_3: blackout)
δ_{int}: an internal transition function (T_{Infra})
λ : an output function (loop end)

Finally, the algorithm for computing evacuation time was implemented in Netlogo, an ABM tool in Fig 6.

Fig 6. Netlogo (Simple Evacuation Model)

4. Conclusion & Discussion

In this study, an ABM for predicting evacuation time of evacuees under the performance of infrastructures were demonstrated.

Formalism was used to visualize and formularize agents' states which are interacted each other. The advantage of formalism (visualization, formulation) will make it systematically easier to obtain insight.

We created a set of rules and implemented them as Netlogo. In order to make evacuation time a reality in the future, more infrastructure should be established and evacuation dimensions should be increase. In addition, the validity of a set of rules must be verified.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (MSIP: Ministry of Science, ICT and Future Planning) (No. NRF-2021M2D2A1A02044210)

REFERENCES

[1] Yu, S. Y. (2012). GIS and agent-based modeling of emergency evacuation. Journal of Korean Society of Hazard Mitigation, 12(1), 127-132.

[2] Zeigler, BP. (1976). Theory of modeling and simulation. New York: John Wiley & Sons.

[3] Hwang, Y., & Heo, G. (2021). Development of a radiological emergency evacuation model using agent-based modeling. Nuclear Engineering and Technology.

[4] Dawson, R. J., Peppe, R., & Wang, M. (2011). An agent-based model for risk-based flood incident management. Natural hazards, 59(1), 167-189.

[5] Song, H. S., & Kim, T. G. (2010, October). DEVS diagram revised: a structured approach for DEVS modeling. In Proc. European Simulation Conference (Eurosis, Belgium, 2010) (pp. 94-101).