

Agent-Based Modeling Approach Evaluate Evacuation Scenarios - Human Behavior Pattern Study

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1. Introduction

The Evacuation Time Estimate (ETE) calculates the time that evacuation vehicle (90%, 100%) in the Emergency Response Planning Areas (ERPA) go out of the Urgent Protective Action Planning Zone (UPZ). It is typically performed through traffic simulation modeling. Traffic simulations are generally intended to support transportation planning and are not specific to evacuation. In the case of Korea, it was calculated as PTV-VISUM, which simulates the demand for traffic in the Emergency Planning Zone (EPZ) by adjusting the calculating factors such as the number of people, the number of vehicles and the road capacity. Traffic simulations such as CORSIM and VISSIM are used for ETE [1].

The most effective public protection management in radiological accidents are rapid evacuation to a safe area before radioactive material leaks out. Existing ETE considers staged evacuation for the preferential evacuation of residents in the Precautionary Action Zone (PAZ) and analyzes the time required for evacuation in the following areas after evacuating 90% in the previous phase. Therefore, ETE utilizing traffic simulation were aimed at ensuring the minimum evacuation time [2].

According to a survey of one of the Nuclear Power Plants (NPPs) sites, 99% of households with vehicles answer they would evacuate using private vehicles. Also, the stronger the tendency to move with family members, the longer the Trip Generation Time (TGT) [3]. On the other hand, not only the minimum evacuation time but also the selection of the minimum exposure path considering the moving direction of the radioactive material was considered to be important. Therefore, it is necessary to analyze the human - environment complex system in addition to the traffic demand analysis that considers the traffic flow such as the evacuation speed and the road capacity. One of the methodologies for analyzing human-environment complex systems is the agent-based modeling. It has a tendency to be based on various behavioral patterns that agents can take in a given scenario, and they behave individually by interacting with agents or the environment.

The purpose of this study is to develop an evacuation model considering human characteristics by using agent-based modeling rather than exact ETE. It is important to establish a basis for simulating the human - environment interaction such as the diffusion of radioactive materials along with the evacuation behavior in the future. We

modeled some elements of evacuation trip patterns and evacuation tendencies and compared the normal and adverse scenarios in the evacuation scenarios.

2. Methods

2.1 Agent-Based Modeling

An agent-based modeling is a way to predict the behaviors that human beings can realize in the system by giving the system the attributes that the environment that surrounds them. A representative software tool for the agent-based modeling is NetLogo, which uses the LISP programming language.

In this study, an agent-based modeling was developed in which evacuation behavior patterns can be simulated by receiving agent density and speed as input variables according to the evacuation scenarios set using NetLogo. Figure 1 below is a schematic drawing to explain the components of NetLogo. NetLogo consists of patches in the form of grid, which is the environment of turtle (agent) and agent. Agents can interact with agents, and patches can interact with surrounding patches [4]. There are also node and link, which are basic elements of the network. A node represents a point where a change in agent speed occurs, and an agent may be located on each node. Link represents the road by connecting each node. Agents can also influence the environment through action, and can have an effect on agents depending on the nature of the environment. Utilizing NetLogo's Geographic Information System (GIS) extension module, it is possible to load the Geographic Information of the study area in the system interface.

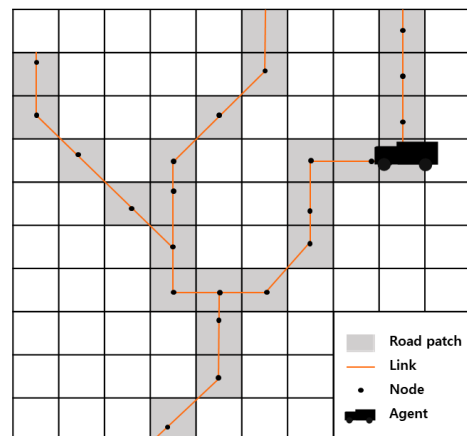


Fig. 1. Schematic for explain the components of NetLogo

2.2 Evacuation Scenarios

U.S. NRC has developed 10 evacuation scenarios with variable combinations to calculate ETE. The variables of this evacuation scenario are Season (Summer / Winter), Day (Midweek / Weekend), Time (Daytime / Evening) and Weather (Normal / Adverse), it affects the position distribution and speed of the agent [2]. Table I below shows the population density and speed of evacuation scenarios provided by the U.S. NRC.

Table I: Evacuation scenarios

Scenarios		Example
Season	Summer	Summer activities
	Winter	Students will evacuate directly from the schools
Day	Midweek	Students will evacuate directly from the schools
	Weekend	At home
Time	Daytime	At home and dispersed within the EPZ
	Evening	At home
Weather	Normal	100% speed
	Rain	85% speed
	Snow/Ice	65% speed

Special events and road impacts outside the scope of this study were excluded. The evacuation scenario combinations used in this study are as follows :

1. Winter, Weekend, Evening, Normal
2. Summer, Midweek, Daytime, Adverse

Scenario 1 assumes that residents are evacuated from their homes and that evacuation speed is not affected by normal weather. Scenario 2 shows an increase in transient populations due to summer activities and congestion on the road because it is a weekday week. Adverse weather also slows the evacuation speed.

2.3 Design Assumption

This study area selected one of the NPPs sites. This study limited the study area to the village because it is a case study of the evacuation model that simulates behavior patterns that evacuees can take. The road and building layers of the study area were extracted from the GIS data produced by the National Geographic Information Institute and modified to fit the evacuation model. One of the building layers was designated as a shelter, and this evacuation model is a simplified model in two dimensions

The existing ETE considers staged evacuation by dividing the ERPA into 16 zones for the preferential evacuation of residents in the PAZ. Staged evacuation analyzes the time required for evacuation in the

following areas after evacuating 90% in the previous phase [2].

According to precedent research, there is no evacuation strategy that can be considered as the best strategy in the road network, and the performance of the evacuation strategy is affected by the road structure and population density. If the road is not congested, simultaneous evacuation is the fastest way to evacuate from the area where the accident occurred. On the other hand, staged evacuation is effective in reducing the evacuation time by alternately evacuating neighbor areas of affected areas when population density is high [5]

According to a survey of one of the Nuclear Power Plants (NPPs) sites, 99% of households with vehicles answer they would evacuate using private vehicles [3]. This study assumes the simultaneous evacuation and the use of private vehicles, which are predicted by behavior patterns that can be taken by residents in real situations, rather than the assumed mobility restrictions and staged evacuation of existing evacuation plans.

2.4 Agent Behavior

In the evacuation scenarios in section 2.2, the most normal scenario 1 and the adverse scenario 2 are set as comparison scenarios. The evacuation scenario varies according to the combination of three variables: Season (Summer / Winter), Day (Midweek / Weekend), and Time (Daytime / Evening). However, since the exact location of the agent can not be predicted, we assume the weightings between population density (Table II) of housing complexes, tourist attractions, and road traffic in the study area.

Table II : Population density

Scenarios		Description	Weight
1	Winter	Tourist attractions	0.1
	Weekend	At home	0.7
	Evening	Reduced road traffic - compared to daytime	0.2
2	Summer	Tourist attractions	0.25
	Midweek	At home	0.3
	Daytime	Road traffic congestion	0.7

When an accident occurs and the siren rings, the agent recognizes the shelter and searches for the location of the shelter. By setting the shelter as a destination, we simulated the behavior of the agent through two algorithms. Figure 2 below shows the procedure of simulating the behavior of moving to the shelter when the initial value of the agent is set from the given evacuation scenario and the accident signal is input.

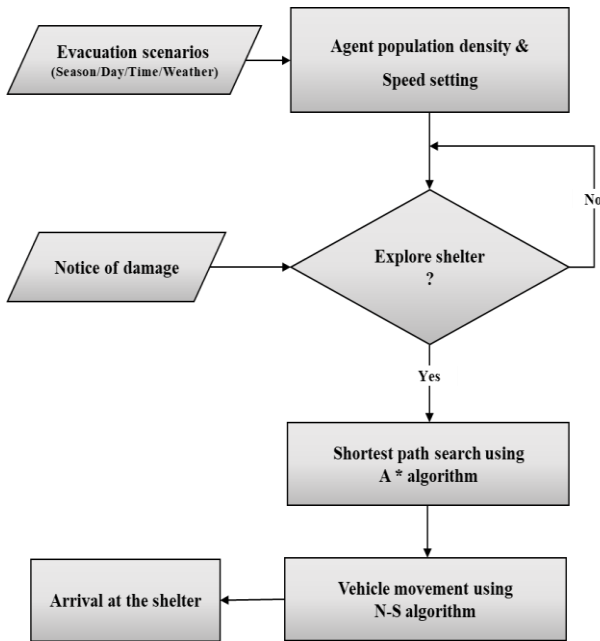


Fig. 2. Procedure of evacuation model using NetLogo

At First, the A* algorithm is used as the method by which the agent searches for the shortest path from the current location to the shelter. The A* algorithm shown in Figure 3 below is an algorithm that finds the shortest link distance from the start node to the end node [6]. In this study, the current node where the agent is located is set as the start node and the shelter location is set as the end node.

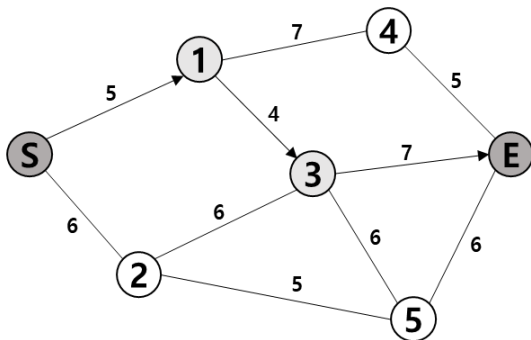


Fig. 3. A* Algorithm

Equation (1) to calculate $f(n)$ as the shortest distance in A* algorithm is as follows :

$$f(n) = g(n) + h(n) \quad (1)$$

Where $g(n)$ is the distance of the shortest path from the start node to the current node, $h(n)$ is the current node to the end and n is the node.

Secondly, the rules that agents use when moving the shortest path are modeled using the Nagel-Schreckenberg cellular automata model (N-S model). The N-S model is a model suitable for modeling traffic flow in urban road networks. It is a moving model that recognizes the distance from the next vehicle within the specified speed range [7]. In the evacuation model using the N-S model, the behavior rules are as follows :

- a) The average speed is 60 km/h
- b) If the current speed is less than the limit speed ($V_{max} = 120$ km/h)
- c) Deceleration to the minimum speed if the current speed is higher than the distance from the preceding vehicle ($V_{min} = 0$)
- d) Randomness of speed

It also reflected the slowing of the evacuation speed due to adverse weather.

3. Results

In this study, the evacuation model was developed as a simultaneous evacuation which is predicted by behavior patterns that can be taken by residents in real situations, rather than staged evacuation. Figure 4 shows the NetLogo interface of the evacuation model developed. The interface was constructed by converting the actual area of the study area to 100 meters per patch. The unit time (tick) is counted when one cycle run in the algorithm. The unit time of the system was converted to 6 sec per tick. In the constructed system, the evacuation scenario was set through the chooser, and the slide was adjusted to set the reference speed to 60 km/h. The number of agents was assumed to be 1,000 in the study area.

Winter, weekend, evening, and normal weather conditions of normal scenario 1 were set. The simulated evacuation time was 21 minutes and 6 seconds. When the route search was performed on a vehicle navigation map of the actual study area under the same conditions, it was found for 21 minutes. As the two results are similar, it is shown that the agent evacuation time of this evacuation model is a reasonable estimation method. Adverse scenario 2 of summer, midweek, daytime, and rain combination was set as 1,250 evacuees with 25% more people than standard 1,000 people considering the increase of tourists. The evacuation time was calculated as 24 minutes and 37 seconds due to the deceleration caused by the rain. In addition, it was calculated as 31 minutes 21 seconds as a result of simulating winter and snow conditions. It shows that the evacuation rate is significantly affected by the weather than the population density because it simulates a situation where population density is not high.

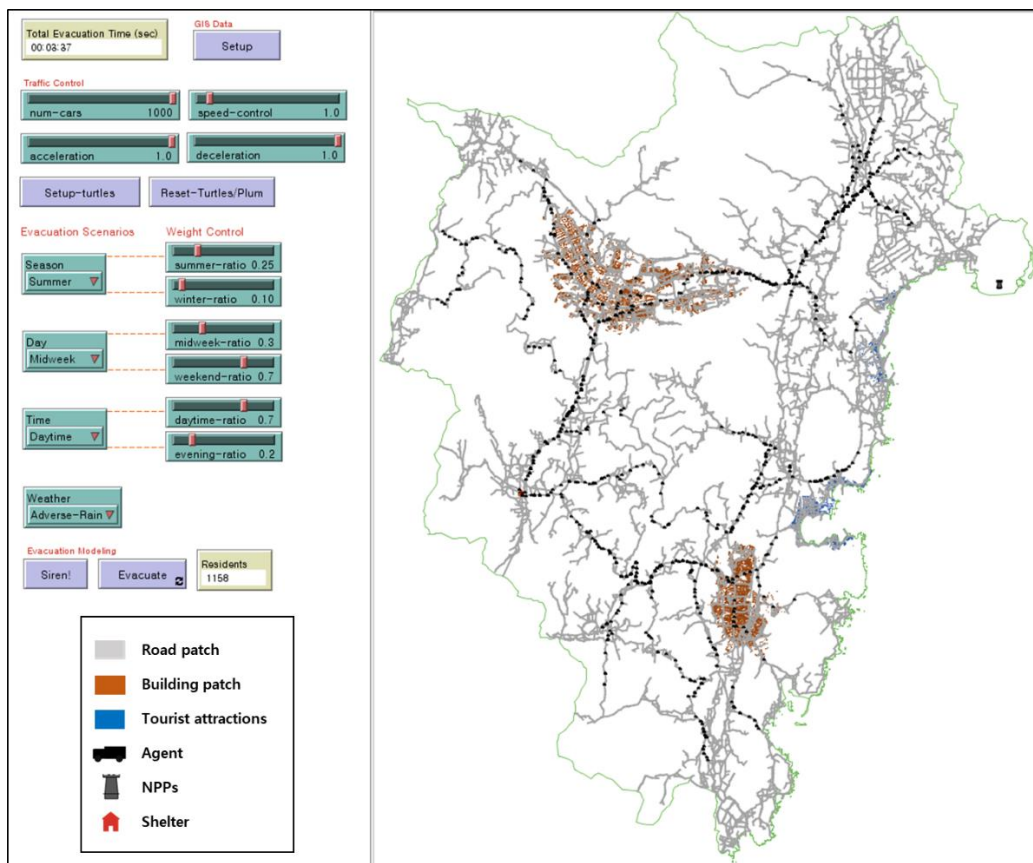


Fig. 4. Interface during simulation in scenario 2

4. Conclusions

The purpose of this paper is to develop an evacuation model for a simultaneous evacuation strategy that combines evacuation trip patterns that residents can take in real situations. Geographical information of the study area, one of the NPPs sites, was used in the evacuation model. This evacuation model was developed by extending GIS module to NetLogo program which is agent-based modeling. We conducted an agent-based modeling of agent behavior patterns and environments and interactions in the study area to study the evacuation patterns of agents in radiological accidents.

This paper suggests the possibility of simulating the interaction with the environment of the agent in the evacuation, unlike the existing traffic simulation. In the future, we expect to be able to develop simulations that approximate the real situation, taking into consideration the characteristics of human behavior patterns and the characteristics of radiological accidents.

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