Decision Making and Emergency Communication System in Rescue Simulation for People with Disabilities

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***Abstract*—Decision making and emergency communication system play an important role in rescue process when emergency situations happen. The rescue process will be more effective if we have appropriate decision making method and accessible emergency communication system. In this paper, we propose a centralized rescue model for people with disabilities. The decision making method to decide which volunteers should help which disabled persons is proposed by utilizing the auction mechanism. The GIS data are used to present the objects in a large-scale disaster simulation environment such as roads, buildings, and humans. The Gama simulation platform is used to test our proposed rescue simulation model.**

Keywords— Rescue Simulation for people with disablities; GIS Multi Agent-based Rescue Simulation; Auction based Decision Making

I. INTRODUCTION

People with disabilities have been addressed as vulnerable population in emergency situations. Japantimes reported “The death rate among disabled people living in coastal areas of Miyagi Prefecture when the March 2011 earthquake and tsunami struck was 2.5 times higher than the overall average”. The helps for these kind of population are very important for disaster mitigation. The studies on how to help disabled people in emergency situations effectively are getting urgent.

In an emergency situation, a human tends to perform two main activities: the rescue and the evacuation. It is very difficult and costly if we want to do experiments on human rescue and or evacuation behaviors physically in real scale level. It is found that multi agent-based simulation makes it possible to simulate the human activities in rescue and evacuation process [1, 2]. A multi agent-based model is composed of individual units, situated in an explicit space, and provided with their own attributes and rules [3]. This model is particularly suitable for modeling human behaviors, as human characteristics can be presented as agent behaviors. Therefore, the multi agent-based model is widely used for rescue and evacuation simulation [1-5].

Recently, Geographic Information Systems (GIS) is also integrated with a multi agent-based model for emergency simulation. GIS map can be used to solve complex planning and decision making problems. In this study, GIS map is used to model objects such as road, building, human, fire with various properties to describe the objects condition. With the help of GIS data, it enables the disaster space to be closer to a real situation [5-10].

Rescue activities are taken by volunteers to help disabled persons. The decision of choosing the order in which victims should be helped to give first-aid and transportation with the least delay to the shelter is very important. The decision making is based on several criteria such as the health condition of the victims, the location of the victims, and the location of the volunteers.

The rest of the paper is organized as follows. Section 2 reviews related works. Section 3 describes the centralized rescue model and the rescue decision making method. Section 4 provides the experimental results of different evacuation scenarios. Finally, section 5 summarizes the work of this paper.

II. RELATED WORKS

In general, there are three types of simulation model (1) flow based, (2) cellular automata, (3) agent based, which are used for emergency simulation. Kisko et al. (1998) employs a flow based model to simulate the physical environment as a network of nodes. The physical structures, such as rooms, stairs, lobbies, and hallways are represented as nodes which are connected to comprise a evacuation space. This approach allows viewing the movement of evacuees as a continuous flow, not as an aggregate of persons varying in physical abilities, individual dispositions and direction of movement [11]. Gregor et al. (2008) presents a large scale microscopic evacuation simulation. Each evacuee is modeled as an individual agent that optimizes its personal evacuation route. The objective is a Nash equilibrium, where every agent attempts to find a route that is optimal for the agent [12]. Fahy (1996; 1999) proposes an agent based model for evacuation simulation. This model allows taking in account the social interaction and emergent group response. The travel time is a function of density and speed within a constructed network of nodes and arcs [13, 14]. Gobelbecker et al. (2009) presents a method to acquire GIS data to design a large scale disaster simulation environment. The GIS data is retrieved from a public source through the website OpenStreetMap.org. The data is then converted to the Robocup Rescue Simulation system format, enabling a simulation on a real world scenario [15]. Sato et al. (2011) also proposed a method to create realistic maps using the open GIS data. The experiment shows the differences between two types of maps: the map generated from the program and the map created from the real data [2]. Ren et al. (2009) presents an agent-based modeling and simulation using Repast software to construct crowd evacuation for emergency response for an area under a fire. Characteristics of the people are modeled and tested by iterative simulation. The simulation results demonstrate the effect of various parameters of agents [3]. Cole (2005) studied on GIS agent-based technology for emergency simulation. This research discusses about the simulation of crowding, panic and disaster management [6]. Quang et al. (2009) proposes the approach of multi-agent-based simulation based on participatory design and interactive learning with experts' preferences for rescue simulation [9]. Hunsberger et al. (2000), Beatriz et al. (2003) and Chan et al. (2005) apply the auction mechanism to solve the task allocation problem in rescue decision making. Christensen et al. (2008) presents the BUMMPEE model, an agent-based simulation capable of simulating a heterogeneous population according to variation in individual criteria. This method allows simulating the behaviors of people with disabilities in emergency situation [23].

Our study will focus mainly on proposing a rescue model for people with disabilities in large scale environment. This rescue model provides some specific functions to help disabled people effectively when emergency situation occurs.

III. PROPOSED RESCUE MODEL AND DECISION MAKING METHOD

A. *Proposed Rescue Model*

Important components of an evacuation plan are the ability to receive critical information about an emergency, how to respond to an emergency, and where to go to receive assistance. We proposes a wearable device which is attached to body of disabled people. This device measures the condition of the disabled persons such as their heart rate, body temperature and attitude; the device can also be used to trace the location of the disabled persons by GPS. Those information will be sent to emergency center automatically. The emergency center will then collect those information together with information from volunteers to assign which volunteer should help which disabled persons.

The centralized rescue model presented has three types of agents: volunteers, disabled people and route network. The route network is also considered as an agent because the condition of traffic in a certain route can be changed when a disaster occurs. The general rescue model is shown in Figure 1.

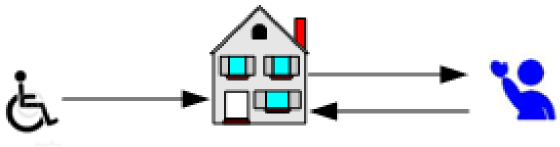


Fig. 1. Centralized Rescue Model

Before starting the simulation, every agent has to be connected to the emergency center in order to send and receive information. The types of data exchanged between agents and emergency center are listed as below.

Message from agent

- A1: To request for connection to the emergency center
- A2: To acknowledge the connection
- A3: Inform the movement to another position
- A4: Inform the rescue action for victim
- A5: Inform the load action for victim
- A6: Inform the unload action for victim
- A7: Inform the inactive status

Message from emergency center

- K1: To confirm the success of the connection
- K2: To confirm the failure of the connection
- K3: To send decisive information

Before starting the simulation, every agent will send the command A1 to request for connection to the emergency center. The emergency center will return the response with a command K1 or K2 corresponding to the success or failure of their connection respectively. If the connection is established, the agent will send the command A2 to acknowledge the connection. The initial process of simulation is shown in Figure 2.

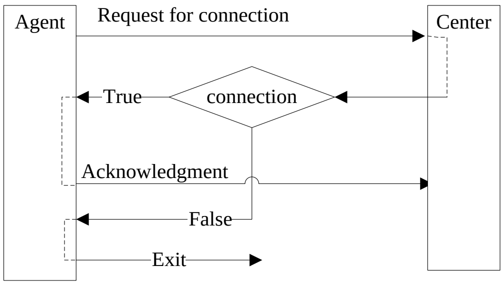


Fig. 2. Initial Process

After the initial process, all the connected agents will receive the decisive information such as the location of agents and health level via command K3; after that the rescue agents will make a decision of action and submit to the center using one of the commands from A3 to A7. At every cycle in the simulation, each rescue agent receives a command K3 as its own decisive information from the center, and then submits back an action command. The status of disaster space is sent to the viewer for visualization of simulation. The repeating steps of simulation are shown in figure 3.

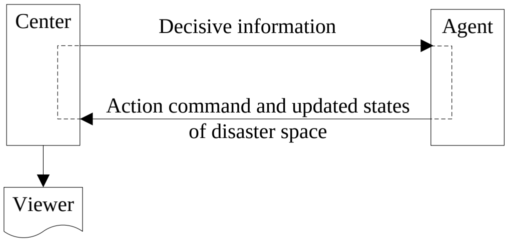


Fig. 3. Simulation Cycles

B. *Disaster Area Model*

The disaster area is modeled as a collection of objects: Nodes, Buildings, Roads, and Humans. Each object has properties such as its positions, shape and is identified by a unique ID. Table 1 to Table 7 presents the properties of Nodes, Buildings, Roads and Humans object respectively. These properties are derived from RoboCup rescue platform with some modifications.

TABLE I. PROPERTIES OF NODE OBJECT

Property	Unit	Description
x,y		The x-y coordinate
Edges	ID	The connected roads and buildings

TABLE II. PROPERTIES OF BUILDING OBJECT

Property	Description
x, y	The x-y coordinate of the representative point
Entrances	Node connecting buildings and roads

TABLE III. PROPERTIES OF ROAD OBJECT

Property	Unit	Description
StartPoint and EndPoint	[ID]	Point to enter the road. It must be the node or a building
Length and Width	[mm]	Length and width of the road
Lane	[Line]	Number of traffic lanes
BlockedLane	[Line]	Number of blocked traffic lanes
ClearCost	[Cycle]	The cost required for clearing the block

TABLE IV. PROPERTIES OF VICTIM AGENT

Property	Unit	Description
Position	ID	An object that the victim is on.
PositionInRoad	[mm]	A length from the StartPoint of road when the victim is on a road, otherwise it is zero
HealthLevel	[health point]	Health level of victim. The victim dies when this becomes zero
DamagePoint	[health point]	Health level dwindles by DamagePoint in every cycle. DamagePoint becomes zero immediately after the victim arrives at a shelter.
DisabilityType	Type[1..7]	Type of disability which is listed in table VII
DisabilityLevel	[low/high]	Victim who has high Disability level, will have higher DamagePoint

TABLE V. PROPERTIES OF VOLUNTEER AGENT

Property	Unit	Description
Position	ID	An object that the volunteer is on.
PositionInRoad	[mm]	A length from the StartPoint of road when the humanoid is on a road, otherwise it is zero
CurrentAction	Type[1..3]	One of action listed in table VII
Energy	Level[1..5]	Amount of gasoline in vehicle
PanicLevel	Level[0..9]	Shows the hesitance level of decision

TABLE VI. ACTION OF VOLUNTEER AGENT

ActionID	Action	Description
1	Stationary	Volunteer stays still
2	MoveToVictim	Volunteer go to location of victims
3	MoveToShelter	Volunteer carry victim to shelter

TABLE VII. TYPE OF DISABILITY

Type	Description
1	Cognitive Impairment
2	Dexterity Impairment (Arms/Hands/Fingers)
3	Mobility Impairment
4	Elderly
5	Hearing Impairment
6	Speech and Language Impairment
7	Visual Impairment

The topographical relations of objects are illustrated from Figure 4 to Figure 7. The representative point is assigned to every object, and the distance between two objects is calculated from their representative points.

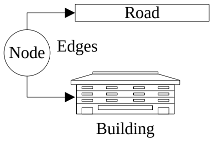


Fig. 4. Node object

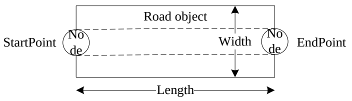


Fig. 5. Road object

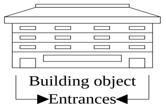


Fig. 6. Building object

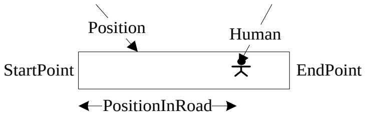


Fig. 7. Human object

C. *Decision Making Method*

The decision making of volunteers to help disabled persons can be treated as a task allocation problem (Nair et al. 2002; Boffo et al. 2007; Hunsberger et al. 2000; Beatriz et al. 2003; Chan et al. 2005). The central agents carry out the task allocation for the rescue scenario. The task of volunteers is to help disabled persons. We utilize the combinatorial auction mechanism to solve this task allocation problem. At this model, the volunteers are the bidders; the disabled persons are the items; and the emergency center is the auctioneer. The distance and health level of each disabled persons are used as the costs for the bids. When the rescue process starts, the emergency center creates a list of victims, sets the initial distance for victims, and broadcasts the information to all the volunteer agents. Only the volunteer agents whose distance to victims is less than the initial distance will help these victims. Each volunteer agent will only help the victims within the initial distance instead of helping all the victims. The initial distance will help volunteers in reducing the number of tasks that they have to do so that the decision making will be faster. The aim of this task allocation model is to minimize the evacuation time or the total cost to accomplish all tasks. In this case, the cost is the total rescue time.

1) *The Criteria to Choose Disabled People*

The volunteer's decision depends on the information of disabled people which receives from emergency center; therefore decisions must follow certain criteria to improve their relief activities.

For example, the volunteers must care about condition of disabled people; the more seriously injured people should have the more priority even if they locate further than the others. There are several criteria that volunteers should take in account before starting rescue process (Quang et al. 2009)

C1: Distance from volunteer to disabled people
C2: Distance from disabled people to nearest other disabled people
C3: Health level of disabled people
C4: Distance from disabled people to nearest other volunteer

Disabled people who have lesser values for criteria of C1, C2, C3 and greater values for criteria of C4 will have higher priority in the volunteer's decision process as shown in Figure 8.

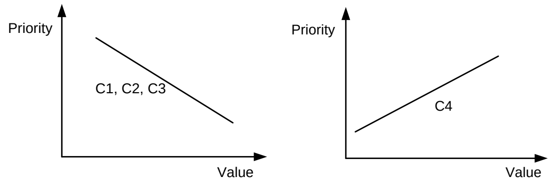


Fig. 8. Priority in the Volunteer's Decision

2) *Determination Important Weight of Criteria*

Referring to the our decision making method which presents at [23], a programming with C# had been created with the following inputs: number of criteria (N = 4); size of population (M = 30); crossover probability ($p_{cross} = 90\%$); mutation probability ($p_{mut} = 10\%$); number of reproduction (L = 100); the pair-wise comparison among criteria is shown in Table 4.8. The solution obtained is w = (0.2882, 0.2219, 0.2738, 0.2161). These values are also considered as input parameters for rescue simulation. It can be changed by adjusting the pair-wise comparison in Table 8.

For each volunteer, the cost to help certain victim is shown in Equation 1.

$$C(v)_k = \sum_{i=1}^{4} w_i * v_i^k \qquad (1)$$

Where: w_i denotes the weight of the c_i criteria while v_i^k denotes the value of the i^{th} criteria for the k^{th} victim. The sign of value of criterion c_4 will be reversed when calculate the cost.

TABLE VIII. PAIR-WISE COMPARISON AMONG CRITERIA

Criterion	Linguistic Preference	Fuzzy Number	Criterion
C1	Good	(0.667, 0.833, 1)	C2
C1	Fair	(0.333, 0.5, 0.667)	C3
C1	Good	(0.667, 0.833, 1)	C4
C2	Poor	(0, 0.167, 0.333)	C3
C2	Fair	(0.333, 0.5, 0.667)	C4
C3	Good	(0.667, 0.833, 1)	C4

3) *Forming Task Allocation Problem*

Given the set of n volunteers as bidders: $V = \{v_1, v_2, \dots, v_n\}$ and set of m disabled persons considered as m tasks: $D = \{d_1, d_2, \dots, d_m\}$. The distances from volunteers to disabled persons; distances among disabled persons and health level of disabled persons and are formulated as follow:

$$M[v_i, d_j]_t = \{m_{ij} \mid m_{ij}: \text{distances from volunteer } v_i \text{ to disable person } d_j \text{ at time step t}\}$$

$$N[d_i, d_j] = \{n_{ij} \mid n_{ij}: \text{distances from disabled person } d_i \text{ to disabled person } d_j\}$$

$$H[d_i]_t = \{h_i \mid h_i : \text{health level of disabled person } d_i \text{ at time step t; } h_{low} \le h_i \le h_{high}\}$$

With the initial distance L. The normalization processes are shown in Equation (2), (3), (4).

Normalize $M[v_i, d_j]_t$:

$$M'[v_i, d_j]_t = \{m'_{ij} \mid m'_{ij} = (\tfrac{1-0}{L-0}(m_{ij} - 0) + 0); 1 \le i \le n;\ 1 \le j \le m\} \qquad (2)$$

Normalize $N[d_i, d_j]$:

$$N'[v_i, d_j]_t = \{n'_{ij} \mid n'_{ij} = (\tfrac{1-0}{L-0}(n_{ij} - 0) + 0); 1 \le i \le n;\ 1 \le j \le m\} \qquad (3)$$

Normalize $H[d_i]_t$:

$$H'[v_i, d_j]_t = \{h'_i \mid h'_{ij} = (\frac{1-0}{h_{high} - h_{low}}(h_i - h_{low}) + 0); 1 \le i \le m\} \qquad (4)$$

The $Bid_{v_i}(\{d_j, d_q \dots d_k, d_l\}, C)$ means that the volunteer v_i will help victims $\{d_j, d_q \dots d_k, d_l\}$ with the total cost C. Total cost C is calculated by Equation 1.

Let I is a collection of subsets of D. Let $x_j = 1$ if the jth set in I is a winning bid and c_j is the cost of that bid. Also, let $a_{ij} = 1$ if the j^{th} set in I contains $i \in D$. The problem can then be stated in equation 5 (Sandholm 2002).

$$(4.1) \qquad \min \sum_{j \in I} c_j x_j$$
$$\text{With constraint} \sum_{j \in I} a_{ij} x_j \le 1\ \forall i \in D \qquad (5)$$

The constraint will make sure that each victim is helped by at most one volunteer at certain time step.

For example, let's assume that volunteer A has the information of 5 victims (d_1, d_2, d_3, d_4, d_5). The initial distance is set to 200 meters. The volunteer estimates the distance from him to each victims and selects only the victims who are not more than 200 meters from his location. Assume that, the victim d_1 and victim d_2 are selected to help with the cost of 1.15. The bid submitted to the center agent is Bid_A= ({(d_1, d_2}, 1.15).

This optimization problem can be solved by Heuristic Search method of Branch-on-items (Sandholm, 2002). This method is based on the question: "Which volunteer should this victim be assigned to?". The nodes in the search tree are the bids. Each path in the search tree consists of a sequence of disjoint bids. Each node in the search tree expands the new node with the smallest index among the items that are still available, not including the items that have already been used on the path. The solution is a path, which has minimum cost in the search tree. Figure 9 shows the procedure of task allocation problem for helping disabled persons in emergency situation.

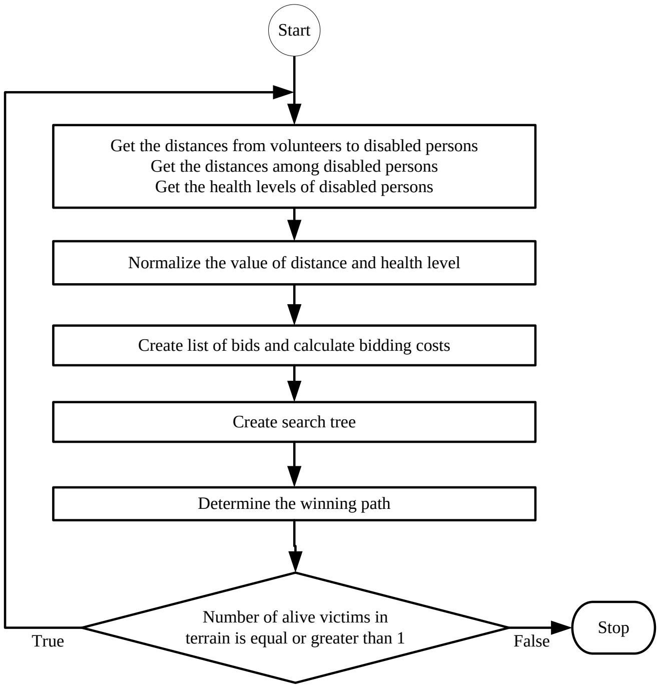


Fig. 9. Procedure of Task Allocation Problem

4) *Example of Task Allocation Problem*

To illustrate an example of a task allocation of volunteers to help disabled persons, let's assume that there are four volunteers and 3 disabled persons;

The initial distance L is set to 200 meters; $h_{\mathrm{low}} = 100$; $h_{\mathrm{high}} = 500$. At certain time of simulation, distances from volunteers to disabled persons, the distances among disabled persons, and the health level of disabled persons are assumed as follows.

$$\text{Before normalization } M[v_i, d_j]_t = \begin{bmatrix} 280 & 260 & 50 \\ 40 & 300 & 100 \\ 250 & 100 & 150 \\ 40 & 70 & 250 \end{bmatrix}$$

$$\text{After normalization } M'[v_i, d_j]_t = \begin{bmatrix} 1.4 & 1.3 & 0.25 \\ 0.2 & 1.5 & 0.5 \\ 1.25 & 0.5 & 0.75 \\ 0.2 & 0.35 & 1.25 \end{bmatrix}$$

$$\text{Before normalization } N[d_i, d_j] = \begin{bmatrix} 0 & 100 & 110 \\ 100 & 0 & 70 \\ 110 & 70 & 0 \end{bmatrix}$$

$$\text{After normalization } N'[d_i, d_j] = \begin{bmatrix} 0 & 0.5 & 0.55 \\ 0.5 & 0 & 0.35 \\ 0.55 & 0.35 & 0 \end{bmatrix}$$

$$\text{Before normalization } H[d_i]_t = \{400,200,300\}$$

$$\text{After normalization } H'[d_i]_t = \{0.75, 0.25, 0.5\}$$

With initial distance 200, the volunteer v_1 can help only victim d_3. The bid is formed as $B_{v_1}(\{d_3\}, C)$. There are four criteria with important weigh: w = (0.2882, 0.2219, 0.2738, 0.2161) [refer to section ii].

The cost C is calculated as below [refer to equation 1]:

Distance from volunteer v_1 to disabled people $d_3 = 0.25$

Distance from disabled people d_3 to nearest other disabled people $d_2 = 0.35$

Health condition of disabled people $d_3 = 0.5$

Distance from disabled people d_3 to nearest other volunteer $v_2 = 0.5$

$$C(v_1, d_3) = \sum_{i=1}^{4} w_i * v_i^3 = 0.2882 * 0.25 + 0.2219 * 0.35 + 0.2738 * 0.5 - 0.2161 * 0.5 = 0.18$$

Possible bids are listed as below.

$$B_{v_1}(\{d_3\}, 0.2882 * 0.25 + 0.2219 * 0.35 + 0.2738 * 0.5 - 0.2161 * 0.5) = B_{v_1}(\{d_3\}, 0.18)$$

$$B_{v_2}(\{d_1\}, 0.2882 * 0.2 + 0.2219 * 0.5 + 0.2738 * 0.75 - 0.2161 * 0.2) = B_{v_2}(\{d_1\}, 0.33)$$

$$B_{v_2}(\{d_3\}, 0.2882 * 0.5 + 0.2219 * 0.35 + 0.2738 * 0.5 - 0.2161 * 0.25 = B_{v_2}(\{d_3\}, 0.3)$$

$$B_{v_2}(\{d_1, d_3\}, 0.2882 * (0.5 + 0.55) + 0.2219 * (0.5 + 0.35) + 0.2738 * (0.75 + 0.5) - 0.216 * (0.2 + 0.25) = B_{v_2}(\{d_1, d_3\}, 0.74)$$

$$B_{v_3}(\{d_2\}, 0.2882 * 0.5 + 0.2219 * 0.35 + 0.2738 * 0.25 - 0.2161 * 0.35\ ) = B_{v_3}(\{d_2\}, 0.21)$$

$$B_{v_3}(\{d_3\}, 0.2882 * 0.75 + 0.2219 * 0.35 + 0.2738 * 0.5 - 0.2161 * 0.25 = B_{v_3}(\{d_3\}, 0.38)$$

$$B_{v_4}(\{d_1\}, 0.2882 * 0.2 + 0.2219 * 0.5 + 0.2738 * 0.75 - 0.2161 * 0.2 = B_{v_4}(\{d_1\}, 0.21)$$

$$B_{v_4}(\{d_2\}, 0.2882 * 0.35 + 0.2219 * 0.35 + 0.2738 * 0.2 - 0.216 * 0.5) = B_{v_4}(\{d_2\}, 0.14)$$

$$B_{v_4}(\{d_1, d_2\}, 0.2882 * (0.2 + 0.5) + 0.2219 * (0.5 + 0.35) + 0.2738 * (0.75 + 0.25) - 0.21 * (0. + 0.35)) = B_{v_4}(\{d_1, d_2\}, 0.55)$$

The possible bids with costs are shown in Table 9.

TABLE IX. POSSIBLE BIDS WITH COSTS

Bid	**Volunteer**	**Disabled person**	**Cost**
$\mathbf{b_1}$	$\mathbf{v_1}$	$\{\mathbf{d_3}\}$	0.18
$\mathbf{b_2}$	$\mathbf{v_2}$	$\{\mathbf{d_1}\}$	0.33
$\mathbf{b_3}$	$\mathbf{v_2}$	$\{\mathbf{d_3}\}$	0.30
$\mathbf{b_4}$	$\mathbf{v_2}$	$\{\mathbf{d_1}, \mathbf{d_3}\}$	0.74
$\mathbf{b_5}$	$\mathbf{v_3}$	$\{\mathbf{d_2}\}$	0.21
$\mathbf{b_6}$	$\mathbf{v_3}$	$\{\mathbf{d_3}\}$	0.38
$\mathbf{b_7}$	$\mathbf{v_4}$	$\{\mathbf{d_1}\}$	0.33
$\mathbf{b_8}$	$\mathbf{v_4}$	$\{\mathbf{d_2}\}$	0.14
$\mathbf{b_9}$	$\mathbf{v_4}$	$\{\mathbf{d_1}, \mathbf{d_2}\}$	0.55

The bid b_2 and b_7 have the same task $\{d_1\}$; b_5 and b_8 have the same task $\{d_2\}$; $b_1, b_3,$ and b_6 have the same task $\{d_3\}$. The more expensive bids will be removed as shown in table 10.

TABLE X. TASKS ALLOCATION AND COST AFTER REMOVAL OF MORE EXPENSIVE BIDS

Bid	Volunteer	Disabled person	Cost
$\mathbf{b_1}$	$\mathbf{v_1}$	$\{\mathbf{d_3}\}$	0.18
$\mathbf{b_2}$	$\mathbf{v_2}$	$\{\mathbf{d_1}\}$	0.33
$\mathbf{b_4}$	$\mathbf{v_2}$	$\{\mathbf{d_1}, \mathbf{d_3}\}$	0.74
$\mathbf{b_8}$	$\mathbf{v_4}$	$\{\mathbf{d_2}\}$	0.14
$\mathbf{b_9}$	$\mathbf{v_4}$	$\{\mathbf{d_1}, \mathbf{d_2}\}$	0.55

Then, the search tree is formed as shown in Figure 10. The winner path is b_2, b_8, b_1 which has the most minimum cost of 0.65. The task allocation solution: volunteer v_2 will help disabled persons d_1 ; volunteer v_4 will help disabled person d_2.volunteer v_1 will help disabled person d_3.

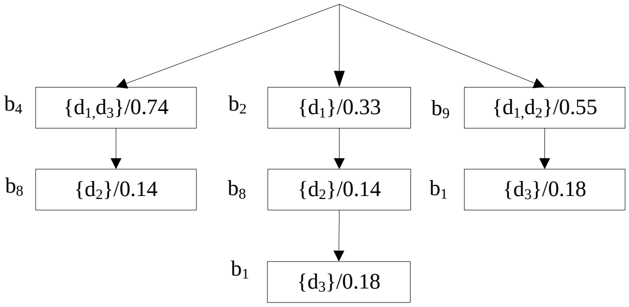


Fig. 10. Branch on Items Based Search Tree

D. Path finding in Gama Simulation Platform

After a volunteer makes the decision to help a certain victim, the path finding algorithm is used to find the route from volunteer agent to victim agent. The GIS data presents roads as a line network in graph type. Figure 11 shows an example of graph computation. The Dijkstra algorithm is implemented for the shortest path computation [8].

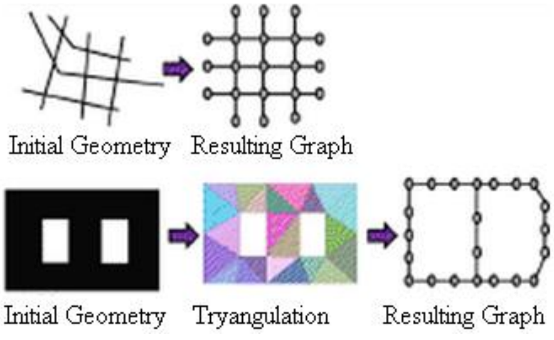


Fig. 11. Example of Graph Computation [8]

IV. EXPERIMENTAL RESULTS

In this section, we present experimental studies on different scenarios. We show the experimental results with traditional rescue model which not considering the updated information of victims and volunteers such as health conditions, locations, traffic conditions.

The traditional rescue model provides fixed mission for which volunteers should help which victims. Whereas, our rescue model provides flexible mission for which volunteers should help which victims. The targets of volunteers can be changed dynamically according to current situation. The experimental results of our proposed rescue model are also presented to show the advantages comparing to traditional model.

The evacuation time is evaluated from the time at which the first volunteer started moving till the time at which all saved victims arrive at the shelters. The simulation model is tested using the Gama simulation platform [8, 10].

A. Experimental Setting

We consider the number of volunteers, number of disabled persons, panic level of volunteer, disability level of victim and the complexity of traffic as parameters to examine the correlation between these parameters with rescue time. The traffic complexity is function of the number of nodes and links in a road network.

Figure 12 presents the sample GIS map consisting of 4 layers: road, volunteer, disabled person and shelter. The initial health levels of disabled persons are generated randomly between 100 point and 500 point. If the health level is equal or less than zero, the corresponding agent is considered as dead.

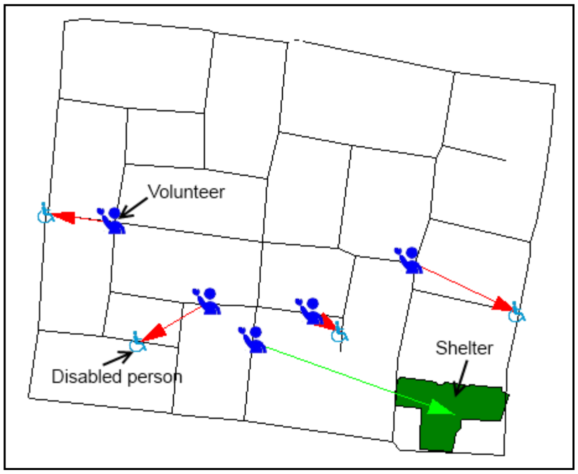


Fig. 12. Sample Gis Map of Disaster Space

B. Experimental results

1) Comparison with traditional model

The traditional model proposes the rescue process without knowing the updated information of victims and volunteers. In disaster space, the traffic condition is changed dynamically. Some road links can be inaccessible.

Our proposed method provides the updated traffic condition so that the path finding method can work effectively. The road map with 50 links is used to conduct the test with traditional model and our proposed model. The result is shown in Table 11 and Figure 13, 14.

TABLE XI. COMPARISON WITH TRADITIONAL MODEL

	Volunteer	**Victim**	**Link**	**Rescue Time**	**Dead Victim**
Proposed Model	10	10	50	880	0
Traditional Model	10	10	50	1300	1

Fig. 13. Rescue Time with Proposed Model

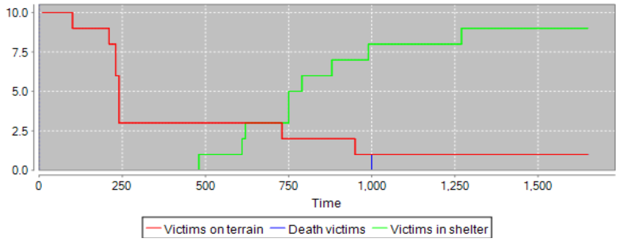


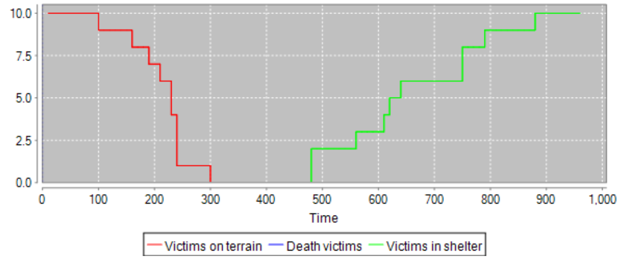
Fig. 14. Rescue Time with Traditional Model

2) Simulation result with consideration of complexity of road network

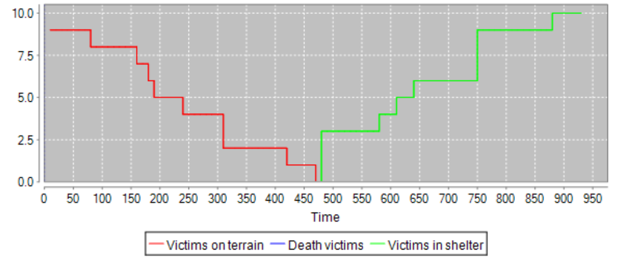
In this concern, we observe the correlation between the complexity of road network and the rescue time. The area of disaster space, the number of victims and volunteers, locations of victims and volunteer are not changed. The complexity of road network presents as the number of road links. The result is shown in Table 12 and Figure 15.

TABLE XII. RESCUE TIME AND NUMBER OF LINKS

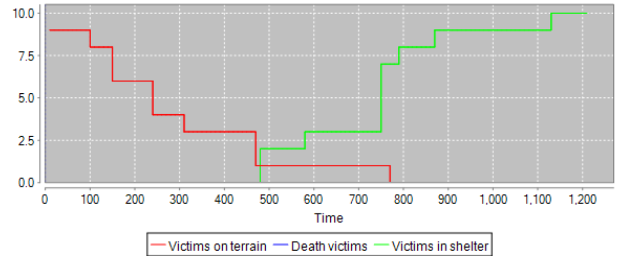
Volunteer	Victim	Link	Rescue Time	Dead Victim
10	10	50	880	0
		40	880	0
		30	1150	0
		20	1150	0



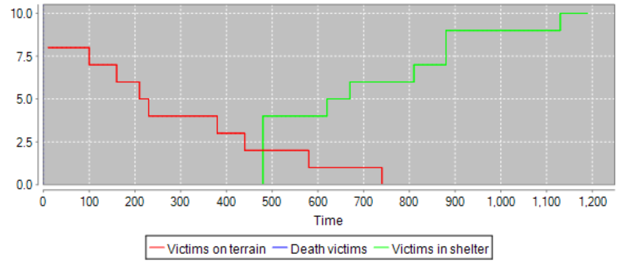
Link: 50 Rescue time: 880



Link: 40 Rescue time: 880



Link: 30 Rescue time: 1150



Link: 20 Rescue time: 1150

Fig. 15. Correlation between Rescue Time and Number of Link

The rescue time increase if number of link decrease at the same area of disaster space.

3) Simulation result with consideration of panic level of volunteer

When emergency situation occurs, the volunteers are also getting panic. The panic probability of volunteers can be presented as the hesitance of volunteers in making decision to help disabled persons. In the simulation, we assume that there are 10 levels of hesitance: 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9. The hesitance level 0 means that there is no hesitance of making decision. These hesitance levels will be assigned to every volunteer agent. At each time step of simulation, a random value x ($0<x<1$) will be generated. If x is equal or greater than hesitance level of volunteers, the corresponding volunteers will make decision to help disabled person; otherwise the volunteers will postpone the decision at this time step.

We applied our method to a sample GIS road map with 50 links (Figure 12). The correlation between panic probability of volunteer and rescue time is shown in Table 13 and Figure 16.

TABLE XIII. SIMULATION RESULTS WITH CONSIDERATION OF PANIC PROBABILITY OF VOLUNTEER

Volunteer	Victim	Link	Panic Level	Rescue Time	Dead Victim
10	10	50	0	880	0
			0.1	900	0
			0.2	1150	0
			0.3	1150	0
			0.4	1500	1
			0.5	1750	1
			0.6	1760	1
			0.7	2200	1
			0.8	2600	2
			0.9	3250	3

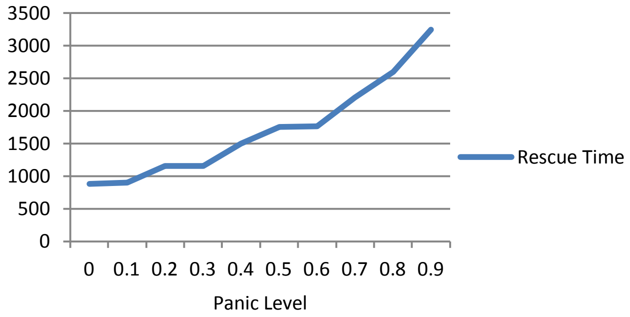


Fig. 16. Simulation Results with Consideration of Panic Level of Volunteer

4) Simulation result with consideration of block lane percentage of road network

When emergency situation occurs, the road lane may block. The road is set as inaccessible condition if its number of block lanes is equal to the number of lanes. In the simulation, we assume that there are 10 levels of block road: 0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9. The correlation between the percentage of block road link, the rescue time and the number of dead victim is shown in Table 14 and Figure 17.

TABLE XIV. SIMULATION RESULT WITH CONSIDERATION OF BLOCK LANE PERCENTAGE OF ROAD NETWORK

Volunteer	**Victim**	**Link**	**Percentage of block road**	**Rescue Time**	**Dead Victim**
10	10	50	0.1	950	0
			0.2	1000	0
			0.3	1050	0
			0.4	1200	0
			0.5	1325	1
			0.6	1700	1
			0.7	2300	1
			0.8	2700	3
			0.9	3450	4

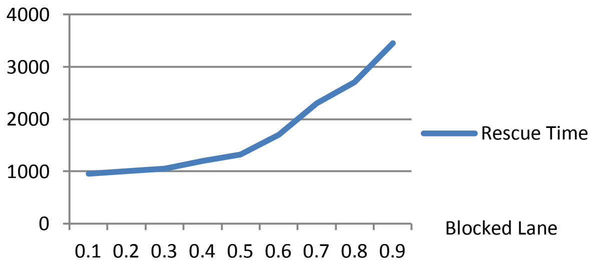


Fig. 17. Simulation Results Result with Consideration of Block Lane Percentage of Road Network

5) Simulation result with consideration of disability level of victim

The disability level of victim may affect to the rescue process. In order to facilitate the simulation, we assume that there are two level of disability: low and high. The victims, who have higher level of disability, will reduce the health level faster than victims, who have lower disability level. The correlation between the percentage of disability level of victim, the rescue time and number of dead victim is shown in Table 15 and Figure 18.

TABLE XV. SIMULATION RESULT WITH CONSIDERATION OF PERCENTAGE OF HIGH DISABILITY LEVEL

Volunteer	**Victim**	**Link**	**Percentage of High Disability Level**	**Rescue Time**	**Dead Victim**
10	10	50	0.1	880	0
			0.2	890	0
			0.3	1050	0
			0.4	1050	1
			0.5	1125	1
			0.6	1250	2
			0.7	1325	3
			0.8	1450	4
			0.9	1550	5

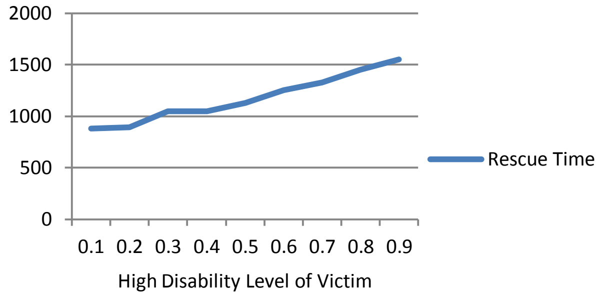


Fig. 18. Simulation Result with Consideration of Percentage of High Disability Level

6) Simulation result with consideration of disconnectivity between agent and emergency center

In reality, when emergency situation occurs, the communication among objects may have problem. This problem of communication will affect to the rescue process. In simulation, we simulate the disconnectivity by postponing the decision of volunteer for certain number of time steps. The result is shown in Table 16 and Figure 19.

TABLE XVI. SIMULATION RESULT WITH CONSIDERATION OF DISCONNECTIVITY BETWEEN AGENT AND EMERGENCY CENTER

Volunteer	**Victim**	**Link**	**Disconnectivity**	**Rescue Time**	**Dead Victim**
10	10	50	10	960	0
			20	980	0
			30	1000	0
			40	1020	0
			50	1050	0
			60	1060	0
			70	1075	0
			80	1085	0
			90	1115	1

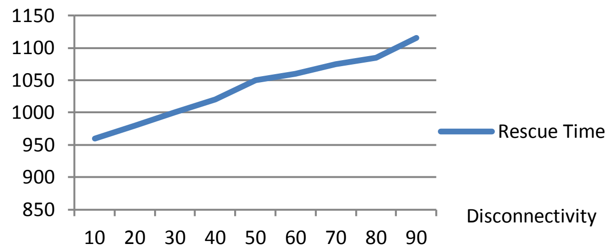


Fig. 19. Simulation Result with Consideration of Disconnectivity between Agent and Emergency Center

V. CONCLUSION

In this paper, we propose a rescue model for people with disabilities. The decisions to help victims are based on updated information from victims and volunteers therefore it can be change to adapt the current emergency situation.We also conduct the rescue simulation with considering the complexity of road network, the panic level of volunteers, the disability level of victims and the disconnectivity between agent and emergency center. The simulation results show that our model has less rescue time than traditional model which applies static decision making method.

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