Micro Traffic Simulation with Unpredictable Disturbance Based on Monte Carlo Simulation: Effectiveness of the proposed agent cars for minimizing evacuation time in the case of Sidoarjo hot mudflow disaster

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Abstract—Monte Carlo simulation of micro traffic with unpredictable disturbance is conducted for the realistic situation of evacuation from Sidoarjo hot mudflow disaster. We concern to the main artery road very close to high dike for prevention of spillover the hot mudflow. This road is major traffic connection with surrounding districts and disaster areas and has a heavy traffic. The mud volcano remains with a high flow rates. The important matter when the mud containment walls broken and the mud flows on the road is how does the vehicle can be evacuated from the disaster occurred areas through suffered roads. This study presents evacuation simulation of vehicles in surrounding affected road using an agent-based model. We estimated the time required for evacuation and the number of victim toward the traffic condition (probability of vehicle density) and the driving behavior (probability of lane changing). Both of them are evaluated and compared between with/without agent cars.

Index Term—micro traffic, Monte Carlo simulation, effectiveness, agent car, evacuation time

1 Introduction

THE traffic flow studies using microscopic simulations had been leap occurring with the advancement of computer technology in the last one and half decade [1][2]. The evacuation system in the micro traffic simulation has been studied and reported a couple of years ago. In the early stage, some examples of micro traffic simulation regarding to emergency evacuation are provided by [3][4]. The modeling system of emergency evacuation in the traffic [5][6][7] has chosen to estimate evacuation time from an affected area using static analysis tools at the macroscopic or microscopic level. Another research of emergency evacuation at the micro traffic scale was conducted by Pidd M. et. al.[8]. They developed a prototype of spatial decision support system that can be used for emergency planners to evaluate contingency plans for evacuation from disaster areas. It does not take the interactions between individual vehicles into consideration. Two basic components of agent-based modeling are (1) a model of the agents and (2) a model of their environment provided by Deadmann P.J. [9]. Individual agents make decisions based on interactions with other agents and localized knowledge [10].

How evacuation time can be affected under

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different evacuation scenarios, such as opening an alternative exit, invoking traffic control, changing the number of vehicles leaving a household was observed based on agent-based simulation techniques [11]. Neighborhood evacuation plans in an urbanized wild land interface described by Cova T.J. [12] using agent-based simulation. They were able to assess the spatial effects of a proposed second access road on household evacuation time in a very detailed way. Studies [3]-[8], [11] and [12] enhanced the great benefits of agent-based modeling and simulation in studying emergency evacuation. Study of investigation of the effectiveness of simultaneous and staged evacuation strategies using agent-based simulation was presented [13] with three different road network structures. They measured the effectiveness based on total time of evacuation in affected area.

Aforementioned studies described how to evacuate all residents in affected area whereas this study evacuates vehicles in affected road using agent-based modeling. We conduct micro traffic agent-based modeling and simulation for assessment of evacuation time with and without agents from the suffered area of the Sidoarjo hot mudflow which is situated in the East Java Indonesia called LUSI that occurred on 29th of May, 2006. Even now, the mud volcano remains high flow rates [14]. One of the key elements of evacuation from the mudflow disaster is the road as main traffic connection surrounding disaster area, in particular, dike as well as road traffic [16]. The vehicles density on the road is high [17]. In the micro traffic agent-based modeling and simulation, other than with/without agent, road traffic (probability of vehicle density) and road networks, driving behavior such as probability of lane changing, car-following and unpredictable disturbance due to a difference between disaster speed and vehicle speed are taken into account. Although the proposed simulation is based on the Nagel-Schreckenberg proposed traffic Cellular Automata [1][15], lane changing and car-following parameters are specific to the proposed simulation.

Following section describes the methods used in the proposed micro traffic agent-based modeling and simulation together with the parameter setting for the simulation. Then simulation results are followed by together with some discussions and conclusions.

2 METHODOLOGY

There are some of subsystems in the proposed micro traffic agent-based modeling and simulation. First subsystem is determining of the shape of road structure. It is conducted for the realistic situation in Sidoarjo hot mudflow disaster that the road structure is straight road, one-way direction, and has some of traffic lanes, as well as there is no traffic light over there. With regard to the unpredictable disturbance properties, it has constant speed and same direction with vehicle on the one-way road. With regard to the unpredictable disturbance properties, it has constant speed and same direction with vehicle on the one-way road. Besides that the disaster comes from the one of the ends of the road. These conditions are appropriate with the real condition of Sidoarjo hot mudflow.

The other subsystem is the vehicle generation. It is determined by a random number generation. It provides positions and speeds of all vehicles. Furthermore, we determine the driving behavior. This research uses modified driving behavior of Nagel-Schreckenberg proposed by using traffic Cellular Automata [1][15]. We added two parameters in their model that is lane-changing and car following. All the parameters of driving behavior used in the proposed simulation is acceleration, braking, probability of speed, vehicle movement, lane changing, and car following. We evaluated performance of driving behavior based on Nagel-Schreckenberg in evacuation simulation and compared to the proposed driving behavior. It is evaluation of driving behavior with agent.

As the simulation results, evacuation time and number of victims are evaluated for the vehicle evacuations from the affected disaster area of Sidoarjo. The simulation with and without agent cars is also conducted. The overall simulation flow with the parameters used is shown in Fig. 1.

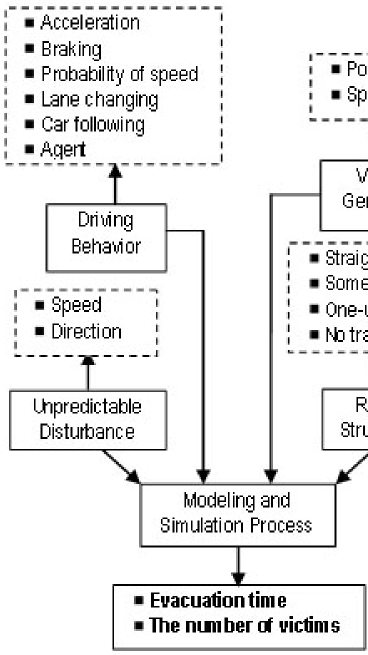

Figure 1. Diagram block of evacuation simulation in the micro traffic

3 Simulation Procedurs

The steps of proposed simulation model are preparation of road structure, vehicle generation, driving behavior, and interpretation of unpredictable disturbance.

3.1 Preparation of Road Structure

The assumed road structure is shown in Figure 2. The realistic situation of main road structure is very close to mud containment walls (dikes) and the road shape is straight line. High hazard will be occurred when the dike of hot mudflow is broken and the mud is spillover from the broken dike to the nearby roads spontaneously.

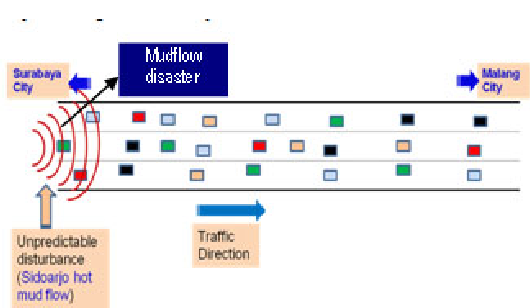

Figure 2. Map of the roadway (Sidoarjo Porong roadway)

The hot mud will flow from behind of vehicles. This implies that the mudflow comes from the one of the ends of the road in the figure. Vehicles and hot mudflow have same direction (in Figure 2, it is from left to right). Although the road is very close to the high dike of the hot mudflow, the transportation density on the road is also very high. This is the real situation that is main artery of traffic. The road has two lanes in one-way direction. The heavy traffic cause many drivers intend to drive their vehicle fast. This situation causes negative impact to the lane traffic. It is often happened the lane becomes more than two lanes illegally because drivers make their own lane on the road. The other actual condition on the road is that there is no traffic light at all.

In the proposed simulation, three traffic lanes are assumed by condition above. Although the density is very high, drivers have a chance to change the lane. We evaluated the evacuation time and the number of victims with respect to the parameters of the probability of density and lane changing.

3.2 Vehicle Generation

The vehicle generation uses random number generator of Merssene Twister. Position and speed of vehicle depend on the probability of vehicle density.

Procedure for the determining of vehicle generation is as follows:

1) Define number of lane ($i = 1...k$);
2) Define number of road length ($j = 1...n$);
3) Determine the probability of vehicle density P_d;
4) Generate the vehicles position $s(i, j)$ and their speed vs randomly toward P_d

$$s(i, j) = [1 : v_{max}] \quad (1)$$

with probability P_d

3.3 Driving Behavior

There are two driving behaviors, with and without agent cars. If an agent car exists, then the following cars recognize speed changes of the agent car so that traffic might be possible to control by the agent car as is shown in Fig.

3. And if the agent car knows the best way to minimize the evacuation time (such information can be derived from the evacuation control center and transferred to the agent cars through wireless network connection), they could lead the following cars to the safe areas in a fastest way.

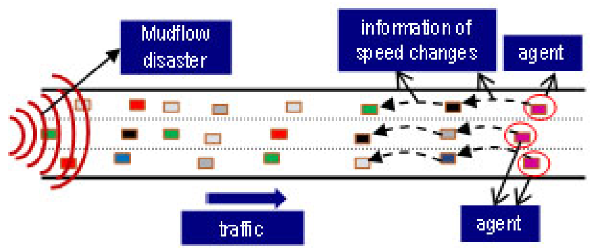

Figure 3. Driving behaviors with agent

3.3.1 Modified Driving Behavior of Nagel-Schreckenberg

A Nagel-Schreckenberg Traffic Cellular Automata is called Stochastic Traffic Cellular Automata (STCA). STCA have four steps of driving behavior rule: acceleration, braking, randomization (slowdown probability), and vehicle movement [1]. Our research modifies it by adding two parameters about lane changing and car following. It is based on [15] that stated the basic implementation of a lane-changing model in traffic cellular automata setting leads to two sub steps that are consecutively executed at each time step of the cellular automata. We called this modification is modified driving behavior of Nagel-Schreckenberg.

The overall rule of the modified driving behavior of Nagel-Schreckenberg is as follows:

1) *acceleration*

$$v < v_{max} \Rightarrow v \leftarrow v + 1 \quad (2)$$

2) *braking*

$$j \leq v \Rightarrow v \leftarrow j - 1 \quad (3)$$

3) *randomization*

$$\zeta < p \Rightarrow v \leftarrow v - 1 \quad (4)$$

4) *vehicle movement*

$$s(i,j) \leftarrow s(i, j + v) \quad (5)$$

5) *lane changing*
Determine probability of lane changing P_{lc},

$$s(i+k, j+m) = 0 \Rightarrow s(i,j) \leftarrow s(j+k, j+m) \quad (6)$$

$k = [-1 : 1], m = [0 : v_{max} - 1]$ with probability of lane changing P_{lc}. Where $s(i+k, j+m) = 0$ has the sense that there is an empty cell in this position.

6) *car following/vehicle movement*

$$v(i, j + v) < v(i,j) \Rightarrow s(i,j) \leftarrow s(i, j + v) \quad (7)$$

where:

v	=	vehicle speed
j	=	a space gap
p	=	slowdown probability
ξ	=	random number
$s(i,j)$	=	vehicle position at (i,j)
P_k	=	probability of lane changing
v_{max}	=	maximum speed of vehicle

3.3.2 Proposed Driving Behavior

There is the related work on the essence of the phenomenological research [18]. It stated that, (1) Concerning irrational behavior: "After five decades studying scores of disasters such as floods, earthquakes and tornadoes, one of the strongest findings is that people rarely lose control.", (2) Concerning cooperation and altruism: "When danger arises, the rule as in normal situations is for people to help those next to them before they help themselves.", (3) Concerning "panic": "Most survivors who were asked about panic said there was none.", and (4) Instead there were stories of people helping their spouses, flight attendants helping passengers, and strangers saving each other's lives.".

Our proposed assumption for building up the agent rule in driving behavior based on the statements above. When disaster occurs, every vehicle on affected road area has to have a good knowledge of driving behavior. One of the important things in this situation is that all vehicles have a good capability of speed control followed by helping each other without any panic. The proposed assumption has the sense of a necessity for mimicking the basic features of real-life traffic flows in affected road area.

Based on the ant behavior [19], we make a technically driving behavior. Agent behavior can be built in some of vehicles. Each agent has appropriate information of speed control and is situated in each. Agent leads other vehicles so that traffic speed can be controlled by the agents. In this situation, the following car-following parameter is getting more important. If the following car does not follow the leading agent car, the traffic condition will not be worth. This condition is consecutively performed to all vehicles in one lane and parallel to the entire lane.

We put the agent behavior in the car-following parameter of driving behavior. The following rule is for an agent:

$$s(i, j + v + c) = 0 \wedge v + c \leq v_{max} \Rightarrow s(i, j) \leftarrow s(i, j + v + c) \tag{8}$$

where $c = 1, 2, ...$

Furthermore, the following rule is for the proposed parameter of driving behaviour:

1) *acceleration*

$$v < v_{max} \Rightarrow v \leftarrow v + 1 \tag{9}$$

2) *braking*

$$j \leq v \Rightarrow v \leftarrow j - 1 \tag{10}$$

3) *randomization*

$$\zeta < p \Rightarrow v \leftarrow v - 1 \tag{11}$$

4) *vehicle movement*

$$s(i, j + v + c) = 0 \wedge v + c \leq v_{max} \Rightarrow s(i, j) \leftarrow s(i, j + v + c) \tag{12}$$

where $c = 1, 2, ...$

5) *lane changing*

Determine probability of lane changing P_{lc},

$$s(i+k, j+m) = 0 \Rightarrow s(i, j) \leftarrow s(i+k, j+m) \tag{13}$$

$k = [-1 : 1], m = [0 : v_{max} - 1]$ with probability of lane changing P_{lc}.

6) *car following/vehicle movement*

$$s(i, j + v + c) = 0 \wedge v + c \leq v_{max} \Rightarrow s(i, j) \leftarrow s(i, j + v + c) \tag{14}$$

where $c = 1, 2, ...$

3.3.3 Observation of The Proposed Parameter in The Driving Behavior

Road traffic is always in a specific state that is characterized by three macroscopic variables: the flow rate q (cars per time step), the density k (cars per site), and the mean speed v (site per time step). Combination of all the possible homogeneous and stationary traffic states in an equilibrium function can be described graphically by three diagrams. The equilibrium relations presented in this way are known under the name of fundamental diagrams. Thus three macroscopic variables above form the basis of the fundamental diagram. The fundamental relation is,

$$q = kv \tag{15}$$

There are only two independent variables density k and speed v.

Related to the fundamental relation of three macroscopic variables, we have conducted the relationship between the parameters proposed in the car-following of driving behavior and the evacuation time T. These proposed parameters are the mean speed v and the density function c. So there are two relationships: mean speed v versus evacuation time T ($v - T$ diagram) and function of density $c(= Q(1/k))$ versus evacuation time $T(c - T$ diagram).

Equation (8) containing the proposed parameter (mean speed v and function of density c). Parameter c in (8) is better known under the name of function of density (= $Q(1/k)$). So that we can be rewritten (8) as,

$$s(i, j+v+Q(1/k)) = 0 \wedge v+Q(1/k) \leq v_{max} \Rightarrow s(i, j) \leftarrow s(i, j + v + Q(1/k)) \tag{16}$$

where $c = Q(1/k)$.

For the position $s(i, j+v+Q(1/k)) = 0$ has the sense that there is an empty cell in this position (it also has the meaning that there is not vehicle in this space).

The previous work [20][21] observed the relation between density k and mean speed v in the fundamental diagram ($k - v$ diagram). There are also some special state points that require extra attention. One of them is about saturated traffic. On saturated roads, flow rate q and speed v are down to zero. The vehicles are queuing and there is a maximum density k_{max} (jam density). We can say on the other hand about the aforementioned special state point generally that by the density k increases (pass through the jam density) then the speed v will be decreases (down to zero). This condition is consistent with the characteristic of $k - v$ diagram.

According to our research subject is about evacuation simulation, we found relationship between car-following parameter (mean speed v) and evacuation time T. Based on $k - v$ diagram [20][21] we can say in accordance with relation between mean speed v and evacuation time T ($v - T$ diagram) that when the mean speed v down to zero (in the time the density k increases/pass the jam density), we found the evacuation time T by the great value. Besides we also observed that by the increase of the mean speed v, we found the evacuation time T decreases. It has occurred either with or without agent in the evacuation simulation (see Fig. 4 and Fig. 5 with/without agent respectively).

Next, we found relationship between function of density c and evacuation time T ($c - T$ diagram). According to $k - v$ diagram and relation between mean speed v versus evacuation time T ($v - T$ diagram), we saw sequentially that by the increase of the density k causes the mean speed v decreases. And then, we also found that the movement of the mean speed v down to smaller value had impact the evacuation time T was going up. On the other words, this condition has the sense that there is relations between the density k and the evacuation time T. Both k and T have linear correlation. When the density k goes up, the evacuation time is also going up.

We know that function of density $c(= Q(1/k))$ is in inverse ratio by k. It has the meaning that by using the density k larger, the density function c has a smaller value. While the density k and the evacuation time T have linear correlation then we can say that by the time c has a small value, the value of the evacuation time T is large. On the contrary, when the value of c is going up, the evacuation time T will down to a smaller value. Our experiment results about the value of c and T found the relation between both of them. Based on linear correlation between the evacuation time T and the density k, we obtain the density function $c = Q(1/k) = (12/10)(1/k)$. By using this value, relation between the density function c and the evacuation time T is found (see Fig. 6). The pattern of their relationship (c and T) is in accordance with the description above.

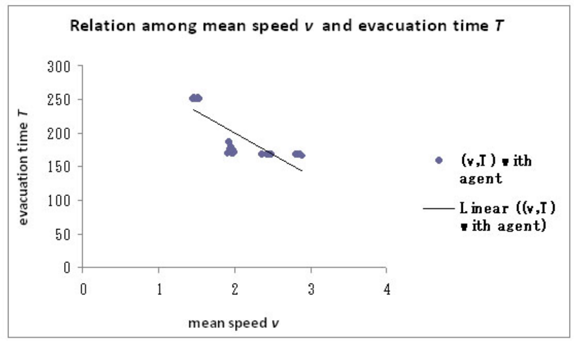

Figure 4. Relationship between mean speed and evacuation time (with agent)

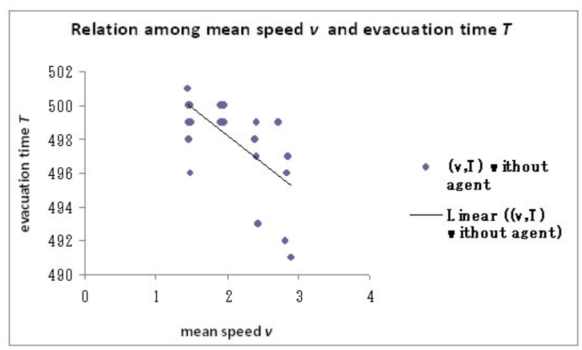

Figure 5. Relationship between mean speed and evacuation time (without agent)

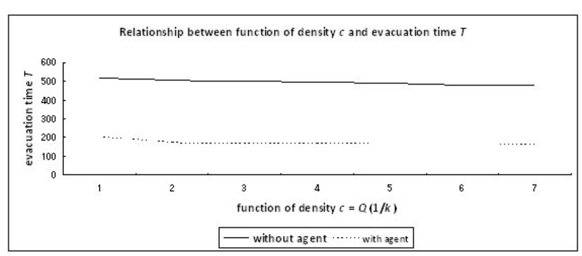

Figure 6. Relationship between function of density c and evacuation time

3.4 Unpredictable Disturbance

Unpredictable disturbance in this study is in the case of Sidoarjo hot mudflow disaster. It has two parameters, speed and direction. We assume that speed of hot mudflow is to be constant. It is set as smaller than maximum speed of vehicle. In the experiments of this study used maximum speed of vehicle 5 cells/time steps and speed of hot mudflow 2 cells/time steps.

Next the second parameter, direction of hot mudflow is the same as the vehicle's direction in the one-way street road. With regard to the direction and speed of hot mudflow in the one-way street road (Sidoarjo Porong roadway) and also the density of the road, we define the victim. It can be described that vehicle and hot mudflow are in one place/location on the same time. By the lattice cell we describe that the victim is as a situation when the hot mudflow disaster with the speed v_d is in the cells $s(i,j)$ and $s(i,j) > 0$ (cell occupied by vehicle). This implication can be expressed by the following rule:

$$s(i, vd * t) > 0 \Rightarrow victim \leftarrow victim + 1 \qquad (17)$$

where t = time.

4 Experiment Results

In general, this experiment investigates the evacuation results obtained with and without agent in the evacuation simulation, after that we compare the results each other. The evacuation without agent, we use the modified driving behavior [1] while in the evacuation with agent using the proposed driving behavior. The effectiveness of evacuation is measured by the total time needed for evacuation. The performance of the evacuation strategies with and without agent on the straight road is evaluated. We evaluate the effectiveness of vehicle evacuation for the proposed driving behavior model (proposed model with agent) based on the modified driving behavior model (modified model without agent). Besides, we also evaluate the number of victims on the affected road. Both these evaluations, based on probability of vehicle density and probability of lane-changing. The evacuation simulation uses the road length of 500 cells, 3 traffic lanes, disaster speed of 2 cells/time steps, and the maximum vehicle speed of 5 cells/time steps.

4.1 Evacuation Time versus Probability of Vehicle Density

We obtain a relation between evacuation time and probability of vehicle density. We use probability of vehicle density from 0.1 to 0.9 with step 0.1. In this evacuation simulation,to find the relation between both of them, there is the other parameter that has to be expressed. It is probability of lane changing. One of the experiment results in this relation by using probability of lane changing of 0.4. Based on the simulation results we found that the proposed model with agent is much faster than that without agent model for all the cases. If the effectiveness of evacuation is defined as an averaged evacuation time, then the proposed model with agent shows 26% improvement in comparison to the modified model (without agent) as is shown in Table 1.

4.2 Evacuation Time versus Probability of Lane Changing

This section expresses relation between evacuation time and probability of lane changing. We set probability of lane changing from 0 to 0.9 by using step 0.1. One parameter has to be included in this simulation is probability of vehicle density. One of experiment results using probability of vehicle density 0.8. This value is set referring to the actual situation on the main artery road that is situated very close to Sidoarjo hot mudflow and the main artery road has a heavy traffic [17]. Based on the simulation results, evacuation time for the proposed model (with agent) is shorter than that of the modified model (without agent) for all the cases. The effectiveness of the proposed model in average is 18%(see Table 2).

4.3 The Number of Victims versus Probability of Vehicle Density

This evacuation simulation also observes the victims on the affected road. We obtain relation between the number of victims and probability of vehicle density. The value of probability of

Table 1
Evacuation time versus probability of vehicle density by using probability of lane changing 0.4

	Evacuation Time		
Probabilty of Vehicle density	Modified Nagel traffic (without agent)	Proposed Model (with Agent)	Effec-tiveness (%)
0,1	250	166	34
0,2	247	168	32
0,3	246	167	32
0,4	250	164	34
0,5	250	169	32
0,6	249	187	25
0,7	249	206	17
0,8	250	213	15
0,9	250	210	16
Average			26

Table 2
Evacuation time versus probability of lane changing by using probability of vehicle density 0.8

	Evacuation Time		
Probabilty of Lane Changing	Modified Nagel traffic (without agent)	Proposed Model (with Agent)	Effec-tiveness (%)
0	250	178	29
0.1	250	199	20
0.2	250	211	16
0.3	250	210	16
0.4	250	210	16
0.5	250	211	16
0.6	246	208	15
0.7	249	201	19
0.8	247	205	17
0.9	246	210	15
Average			18

vehicle density is from 0.1 to 0.9 with step 0.1. One of the experiment results uses the value of probability of lane changing 0.4. We evaluate that the number of victims for both, modified model (without agent) and proposed model (with agent) are proportional to the vehicle density. Although the number of victims for both of the models become great for the high traffic density, the proposed model can reduce the number of victims significantly (see Fig. 7). Fig. 7 also shows that the number of victims increases with the increasing of the probability of vehicle density, in particular, for the value of vehicle density is greater than 0.7.

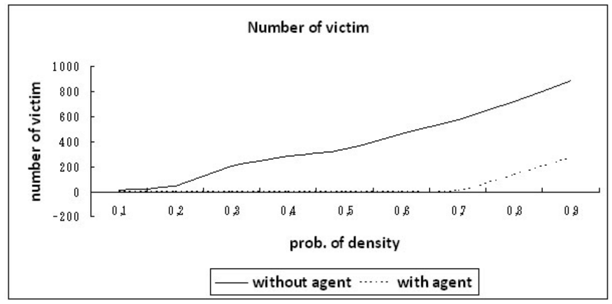

Figure 7. Relationship between number of victims and probability of vehicle density by using probability of lane changing 0.4

4.4 The Number of Victims versus Probability of Lane Changing

The other investigation is about the victims, we want to make relationship between the number of victims and probability of lane changing. The range of probability of lane changing is 0 to 0.9 by using step 0.1, while probability of vehicle density is set at 0.9. We evaluate the number of victims for both modified existing model and the proposed model. Although the number of victims is proportional to the probability of lane changing for both models, the proposed model shows much better results (see Fig. 8).

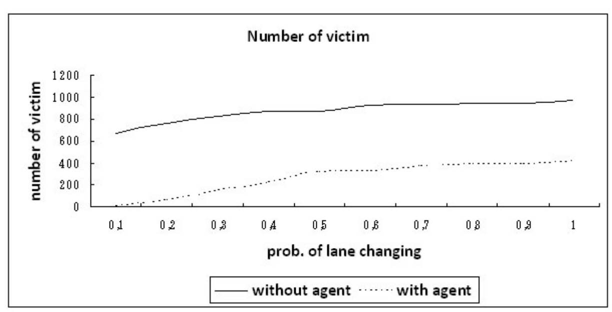

Figure 8. Relationship between number of victims and probability of lane changing by using probability of vehicle density 0.9

5 Conclusion

Modeling and simulation of the vehicle evacuation in our proposed model (with agent) shows that evacuation time obtained is faster than that modified existing model (without agent), either based on probability of vehicle density or probability of lane changing. On the context of panic situations, our proposed model of vehicle evacuation (with agent) is more reliable on the traffic system in disaster areas than that modified existing model (without agent), because the increasing of probability of lane changing in disaster areas is needed the existence of an agent to help speed up the evacuation time. The number of victims on both models, the modified existing model and our proposed model is linear dependent toward the vehicle density and lane changing. Our proposed model (with agent) can reduce the number of victims more significantly than that the modified existing model (without agent).

In addition, many parameters are not considered in the simulations, and a number of issues are subject for further investigation. Future studies along this line of research will need investigation the effects of additional types of road shape in the case of evacuation. There is additional evacuated object associated with realistic situation in Sidoarjo hot mudflow disaster, it is pedestrian, and examine sensitivity of the evacuation strategies when we insert the new parameter about psychological human fact in the evacuation simulation.

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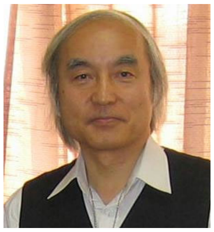

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