We are IntechOpen, the world's leading publisher of Open Access books
Built by scientists, for scientists

6,900
Open access books available

186,000
International authors and editors

200M
Downloads

154
Countries delivered to

Our authors are among the
TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

9

Cellular Automata for Traffic Modelling and Simulations in a Situation of Evacuation from Disaster Areas

Kohei Arai, Tri Harsono and Achmad Basuki
Saga University
Japan

1. Introduction

The traffic flow studies using microscopic simulations (micro traffic model) have leap with the occurrence of the advancement of computer technology in the last one and half decade, as shown in (Nagel, K. & Schreckenberg, M., 1992); (Nagel, K., 1996); (Bando, M., et al., 1995).

The evacuation system in the micro traffic simulation model has been studied and reported a couple of years ago. In the early stage, some examples of micro traffic simulation models related with emergency evacuation are investigated by (Sugiman, T. & Misumi, J., 1988); (Stern, E. & Sinuany-Stem, Z., 1989). The modelling system of emergency evacuation in the traffic stated by (Sheffi, Y., et al., 1982); (Hobeika, A.G. & Jamei, B., 1985); (Cova, T.J. & Church, R.L., 1997) has chosen to estimate evacuation time from an affected area using static analysis tools at macroscopic or microscopic levels.

Another research of emergency evacuation at the micro traffic scale was conducted by (Pidd, M., et al., 1996). 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, i.e. (1) a model of agents and (2) a model of their environment were introduced by (Deadmann, P.J., 1999). An individual agent makes a decision based on the interaction between him and the other agents together with localized knowledge (Teodorovic, D.A., 2003).

How evacuation time can be affected under 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 (Church, R.L. & Sexton, R., 2002). Neighbourhood evacuation plans in an urbanized wild land interface were described by (Cova, T.J. & Johnson, J.P., 2002) using agent-based simulation model. They were able to assess spatial effects of a proposed second access road on household evacuation time in a very detailed way.

The effectiveness of simultaneous and staged evacuation strategies using agent-based simulation for three different road network structures were presented by (Chen, X. & Zhan, F.B., 2008). They measured the effectiveness based on total time of evacuation from affected areas.

Aforementioned studies described how to evacuate all residents in affected area whereas this study evacuates vehicles in affected road using agent-based modelling. We conduct micro traffic agent-based modelling and simulation for assessment of evacuation time with and without agents from the suffered area of the Sidoarjo hot mudflow situated in the East Java Indonesia called LUSI that occurred on 29th of May, 2006. Even now, the mud volcano remains high flow rates (Rifai, R., 2008).

One of the key elements of evacuation from the mudflow disaster is the road as main traffic connection surrounding disaster area and dike of the hot mudflow is very close with the road (Indahnesia.com, 2007). The vehicles density on the road is high (Mediacenter, 2007).

Our micro traffic agent-based modelling and simulation, other than with/without agent; road traffic (vehicle density) and road networks; driving behaviour such as 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 by traffic Cellular Automata (CA) as shown in (Nagel, K. & Schreckenberg, M., 1992) and (Maerivoet, S. & De Moor, B., 2005), lane changing and car-following parameters are specific to the proposed simulation.

The following section describes overview of the traffic models followed by car-following models. Then the introduction of CA model, major topic of the chapter of evacuation simulation will be explained. Agent-based approach of CA traffic model for the case of evacuation is presented. Furthermore, the results of traffic survey are described. The traffic survey is conducted on the specific roadway situated surrounding the hot mudflow disaster area, Sidoarjo, Indonesia. It is found two different types of driver, i.e. usual diver and diligent one. The next section, modified car-following model is investigated by taking the behavior of usual driver and diligent one into account. Finally, concluding remarks and some discussions are described.

2. Overview of the traffic models

One important portion of the micro traffic model is Car-Following (CF). Studies of car-following models have been proposed to describe the interaction between drivers and vehicles. CF became an important evaluation parameter for intelligent transportation system strategies since 1990. CF theories based on the assumption that each driver reacts in some specific way to be stimulated with the vehicles in front. A very attractive microscopic traffic model called the Optimal Velocity Model (OVM) is proposed by (Bando, M., et al., 1995). It was based on the idea that each vehicle has an optimal velocity, which depends on the following distance of the preceding vehicle. Despite its simplicity and its few parameters, the OVM can describe many properties of real traffic flows, such as the instability of traffic flow, the evolution of traffic congestion, and the formation of stop-and-go waves.

OVM used to be calibrated using empirical data provided by (Helbing, D. & Tilch, B., 1998). They stated that when empirical data used in OVM has weaknesses, OVM has a too high acceleration and an unrealistic deceleration. (Helbing, D. & Tilch, B., 1998) have overcome these problems by using a Generalized Force Model (GFM).

(Jiang, R., et al., 2001) stated that GFM cannot describe the delay time δt and the kinematics wave speed at jam density cj properly. They so that proposed the Full Velocity Difference Model (FVDM). FVDM has too high deceleration since empirical deceleration and acceleration are restricted between the following regions, from -3m/s^2 to 4m/s^2.

On the other hand about improving the OVM and considering the Intelligent Transportation System (ITS) application, (Ge, X.H., et al., 2008) proposed a new model taking into account the velocity difference Δv_n and Δv_{n+1}, where $\Delta v_n \equiv v_{n+1} - v_n$. They obtain a more useful model called the Two Velocity Difference model (TVDM). TVDM has shown that unrealistic high deceleration does not appear when they simulate the deceleration progress of two cars.

The CF models (Bando, M., et al., 1995); (Helbing, D. & Tilch, B., 1998); (Jiang, R., et al., 2001) and (Ge, X.H., et al., 2008) are known as time-continuous models. They have in common that they are defined by ordinary differential equations describing the complete dynamics of the vehicle's positions x and velocity v.

Vehicle dynamics system can also be expressed by CA model. The road is divided into sections of a certain length Δx and the time is discretised to steps of Δt. Each road section can either be occupied by a vehicle or empty and the dynamics are given by update rules of the form: $v_n^t = f\left(x_n^{t-1}, v_n^{t-1}, v_{n+1}^{t-1}, \cdots\right)$ and $x_n^t = x_n^{t-1} + v_n^t$, the simulation time t is measured in units of Δt and the vehicle positions x_n is measured in units of Δx.

In this study, we proposed the vehicle dynamics system based on Stochastic Traffic Cellular Automaton (STCA) expressed in (Nagel, K. & Schreckenberg, M., 1992). It has the ability to reproduce a wide range of traffic phenomena. Due to the simplicity of the models, it is numerically very efficient and can be used to simulate large road networks or even faster. A new characteristic of driving behaviour has been proposed, it is about diligent driver.

The proposed evacuation modelling and simulations above (Sugiman, T. & Misumi, J., 1988); (Stern, E. & Sinuany-Stem, Z., 1989); (Sheffi, Y., et al., 1982); (Hobeika, A.G. & Jamei, B., 1985); (Cova, T.J. & Church, R.L., 1997); (Church, R.L. & Sexton, R., 2002); (Cova, T.J. & Johnson, J.P., 2002) and (Chen, X. & Zhan, F.B., 2008) describe how to evacuate all residents from affected areas, the proposed modelling and simulation here is for vehicle evacuation from affected road based on an agent-based modelling. Namely, we conduct micro traffic agent-based modelling and simulation for assessment of evacuation time from the suffered area. In the micro traffic agent-based modelling and simulation, road traffic (probability of vehicle density), driving behaviour such as probability of lane changing, car-following are taken into account. The specific parameter in the proposed modelling and simulation is car-following under a consideration of agents. Diligent driver is also added to the proposed car-following parameter. The number of diligent drivers will be probabilistically determined. Although the proposed simulation is based on the Nagel-Schreckenberg traffic cellular automata, lane changing and new car-following parameters are specific to the proposed modelling and simulation.

3. Overview of the car-following models

There are two major methods of car-following, continuous and discrete models. Some of continuous models are based on the optimal velocity model (OVM), generalized force model (GFM), full velocity difference model (FVDM), and two velocity difference model (TVDM). Meanwhile, cellular automaton model is used for the discrete model.

3.1 Continuous models

In the micro traffic model, the drivers are stimulated their own velocity v_n, the distance between the car and the car ahead x_n, and the velocity of the vehicle in front v_{n-1}. The equation of vehicle motion is characterized by the acceleration function which depends on the input stimuli,

$$\ddot{x}_n(t) = \dot{v}_n(t) = F\left(v_n(t), x_n(t), v_{n-1}(t)\right) \tag{1}$$

3.1.1 Optimal Velocity Model (OVM)

The OVM is a dynamic model of traffic congestion based on a vehicle motion equation. In this model, the optimal velocity function of the headway of the preceding vehicle is introduced. Congestion may occur due to induce by a small perturbation without any specific origin such as a traffic accident or a traffic signal. The OVM can regard to this congestion phenomenon as the instability and the phase transition of a dynamical system (Bando, M., et al., 1995).

The vehicle motion equation is expressed with the assumption that each vehicle driver responds to a stimulus from other vehicles in some specific fashion. The response is followed by acceleration. The sensitivity of acceleration to stimulus is a function of the vehicle position, his time derivatives (or the distance), and so on. This function is determined by the drivers' characteristics, whether or not the vehicle drivers obey postulated traffic regulations at all times in order to avoid traffic accidents.

There are two major types of drivers. The first type is based on the idea that each vehicle must maintain the legal safe distance of the preceding vehicle, which depends on the relative velocity of these two successive vehicles. The second type is that each vehicle has the optimal velocity, which depends on the following distance of the preceding vehicle. In the OVM, the traffic dynamics equation is proposed based on the latter assumption results in a realistic traffic flow model. In this proposed model, the stimulus is assumed to be a function of a following distance and the sensitivity is a constant. The OVM ignores the vehicle length and assumes that all the drivers have common sensitivities. Then each vehicle has the optimal velocity V and that each vehicle driver responds to a stimulus from the vehicle ahead. Driver has to control their speed for maintaining the legal safe velocity in accordance with the motion of the preceding vehicle.

The dynamical equation of the system is obtained (based on the acceleration equation) as,

$$\frac{d^2 x_n(t)}{dt^2} = a\left[V\left(\Delta x_n(t)\right) - \frac{dx_n(t)}{dt}\right] \tag{2}$$

where

$$\Delta x_n(t) = x_{n+1}(t) - x_n(t) \tag{3}$$

n denotes vehicle number (n = 1, 2, …, N). N is the total number of vehicles, a is a constant representing the driver's sensitivity (which has been assumed to be independent of n), and x_n is the location of the nth vehicle. The OVM assumes that the optimal velocity $V(\Delta x_n)$ of n^{th} vehicle depends on the distance between the n^{th} vehicle and the $(n\text{-}1)^{\text{th}}$ vehicle (preceding vehicle) (a distance-dependent optimal velocity). When the headway becomes short the velocity must be reduced and become small enough to avoid crash. On the other hand, when the headway becomes longer the driver accelerates under the speed limit, the maximum velocity. Thus, V is represented as to have the following properties,

i. a monotonically increasing function, and
ii. $\left|V(\Delta x)\right|$ has an upper bound.

$$V^{\max} \equiv V\left(\Delta x \to \infty\right).$$

The OVM takes the optimal velocity function $V\left(\Delta x_n\right)$ as,

$$V\left(\Delta x_n\right) = \tanh\left(\Delta x_n\right) \tag{4a}$$

$$V\left(\Delta x_n\right) = \tanh\left(\Delta x_n - 2\right) + \tanh 2 \tag{4b}$$

where Equation (4a) is called as the simple model and also Equation (4b) is called as the realistic model.

3.1.2 Generalized Force Model (GFM)

The driver behaviour is mainly given by the motivation to reach a certain desired velocity v_n (which will be reflected by an acceleration force), and by the motivation to keep a safe distance from other car (n-1) (which will be described by repulsive interaction forces). The GFM is created to improve the OVM which has the problems of too high acceleration and unrealistic deceleration (Helbing, D. & Tilch, B., 1998).
In the GFM, one term is added to the right-hand side of Equation (2). Thus the formula of the GFM is written by the following equation,

$$\frac{d^2 x_n(t)}{dt^2} = a\left[V\left(\Delta x_n(t)\right) - \frac{dx_n(t)}{dt}\right] + \lambda\Theta(-\Delta v)(\Delta v) \tag{5}$$

where Θ denotes the Heaviside function, λ is a sensitivity coefficient different from a. Note that in the GFM, Equation (5) can be rewritten as follows,

$$\frac{d^2 x_n(t)}{dt^2} = a\left[v_m - v_n(t)\right] + a\left[V\left(\Delta x_n(t)\right) - v_m\right] + \lambda\Theta(-\Delta v)(\Delta v) \tag{6}$$

where v_m is the maximum speed. The first term on the right-hand side is the acceleration force, and the last two terms represent the interaction forces.

3.1.3 Full Velocity Difference Model (FVDM)

A full velocity difference mode (FVDM) (Jiang, R., et al., 2001) for a car-following theory is based on the previous models. The FVDM model includes car-following parameter to the previously proposed models. Through numerical simulation, property of the model is investigated using both analytic and numerical methods. It was found that the FVDM model can represent the phase transition of traffic flow and also estimate the evolution of traffic congestion.
On the basis of the GFM formula, taking the positive Δv factor into account, the FVDM is described as the following dynamics equation,

$$\frac{d^2 x_n(t)}{dt^2} = a\left[V\left(\Delta x_n(t)\right) - \frac{dx_n(t)}{dt}\right] + \lambda\Delta v \tag{7}$$

The FVDM takes both positive and negative velocity differences into account. The model equation of the FVDM (7) may be reformulated into the similar form in the Equation (8).

The GFM assumes that the positive Δv does not contribute to the vehicle interaction, while the FVDM suggests that it contributes to vehicle interaction by reducing interaction force because $a\left[V\left(\Delta x_n(t)\right)-v_m\right]$ is always negative and $\lambda\Theta(\Delta v)\Delta v$ is always positive.

$$\begin{aligned}\frac{d^2x_n(t)}{dt^2}&=a\left[v_m-v_n(t)\right]+a\left[V\left(\Delta x_n(t)\right)-v_m\right]\\&+\lambda\Theta(-\Delta v)\Delta v+\lambda\Theta(\Delta v)\Delta v\end{aligned} \tag{8}$$

One of the examples of the application of the FVDM on car motion simulation with traffic signal shows that it can describe the traffic dynamics most exactly so that the FVDM is verified as a reasonable and realistic model. On the other hand real situation exist in between the FVDM and the GFM. In the FVDM, car accelerates more quickly than the car in the GFM. Therefore, the delay time δt in FVDM is smaller than that in GFM as is shown in Table 1. Since the empirical deceleration and acceleration are restricted in between the range from -3 m/s^2 to 4 m/s^2] (Helbing, D. & Tilch, B., 1998), the FVDM has too high deceleration.

Model	Delay time δt (s)
OVM (a = 0.85 s^{-1})	1.6
GFM (a = 0.41 s^{-1})	2.2
FVDM (a = 0.41 s^{-1})	1.4

Table 1. Delay times of car motions from a traffic signal and disturbance propagation speed at jam density in different models (source: [16])

3.1.4 Two Velocity Difference Model (TVDM)

Two velocity different models (TVDM) for a car following theory are then proposed taking navigation in modern traffic into account. The property of the model is investigated using linear and nonlinear analysis (Ge, X.H., et al., 2008).

Intelligent Transportation System (ITS) plays an important role in the rapid development of modern traffic. By using such navigation system, drivers can obtain the information that they need. In accordance with the above concept, on the basis of the OVM, taking both Δv_n and Δv_{n+1} into account, (Ge, X.H., et al., 2008) obtain a more useful model called the two velocity difference model (TVDM), the following dynamics equation is expressed,

$$\frac{d^2x_n(t)}{dt^2}=a\left[V\left(\Delta x_n(t)\right)-\frac{dx_n(t)}{dt}\right]+\lambda G(\Delta v_n,\Delta v_{n+1}) \tag{9}$$

where $G(.)$ is a generic, monotonically increasing function, and is assumed to be a linear form as,

$$G\left(\Delta v_n,\Delta v_{n+1}\right)=p\Delta v_n+(1-p)\Delta v_{n+1} \tag{10}$$

where p is weighting value. The proper value of p could be lead to desirable results.

3.2 Discrete model: cellular automata model

Cellular Automata (CA) is a model that is discrete in space, time and state variables. The latter property distinguishes CA e.g. from discretised differential equations. Due to the discreteness, CA is extremely efficient in implementations on a computer. CA for traffic has been called by traffic cellular automata (TCA). Some of the TCA models, i.e. (1) Deterministic model: Wolfram's rule 184 (CA-184); (2) Stochastic model: Nagel–Schreckenberg TCA (STCA)

In 1992, Nagel and Schreckenberg proposed a TCA model that was able to reproduce several characteristics of real-life traffic flows, e.g., the spontaneous emergence of traffic jams (Nagel, K. & Schreckenberg, M., 1992). Their model is called the *NaSch TCA*, but is more commonly known as the stochastic traffic cellular automaton (STCA). It explicitly includes a stochastic noise term in one of its rules.

The computational model in the STCA is defined on a one-dimensional array of L sites and with open or periodic boundary conditions. Each site may either be occupied by one vehicle or it may be empty. Each vehicle has an integer velocity with values between zero to $v_{\max}$. For an arbitrary configuration, one update of the system consists of the following four consecutive steps, which are performed in parallel for all vehicles,

1. Acceleration

$$\begin{gathered} v_{(i,j)}(t-1) < v_{\max} \wedge gs(i,j)(t-1) > v_{(i,j)}(t-1)+1 \\ v_{(i,j)}(t) \leftarrow v_{(i,j)}(t-1)+1 \end{gathered} \tag{11}$$

($gs_{(i,j)}(t)$ space gap at each time step t or the distance to the next vehicle ahead).

2. Braking

$$gs_{(i,j)}(t-1) \le v_{(i,j)}(t) \Rightarrow v_{(i,j)}(t) \leftarrow gs_{(i,j)}(t-1)-1 \tag{12}$$

3. Randomization

$$\xi(t) < p \Rightarrow v_{(i,j)}(t) \leftarrow \max[0, v_{(i,j)}(t)-1] \tag{13}$$

($\xi(t)$ is random number, p is stochastic noise parameter or slowdown probability).

4. Vehicle movement

$$x_{(i,j)}(t) \leftarrow x_{(i,j)}(t-1) + v_{(i,j)}(t) \tag{14}$$

Through the step one to four very general properties of single lane traffic are modelled on the basis of integer valued probabilistic cellular automaton rules. Already this simple model shows nontrivial and realistic behaviour. Step 3 is essential in simulating realistic traffic flow otherwise the dynamics is completely deterministic. It takes into account natural velocity fluctuations due to human behaviour or due to varying external conditions. Without this randomness, every initial configuration of vehicles and corresponding velocities reaches very quickly at a stationary pattern which is shifted backwards (i.e. opposite the vehicle motion) in one site per time step.

4. Case study on evacuation from disaster occurred area based on agent-based approach

4.1 Situation

There are some of subsystems in the proposed micro traffic agent-based modelling and simulation. First 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 unidirectional road. Besides that the disaster comes from the one of the ends of the road. These conditions are appropriated with the real condition of Sidoarjo hot mudflow.

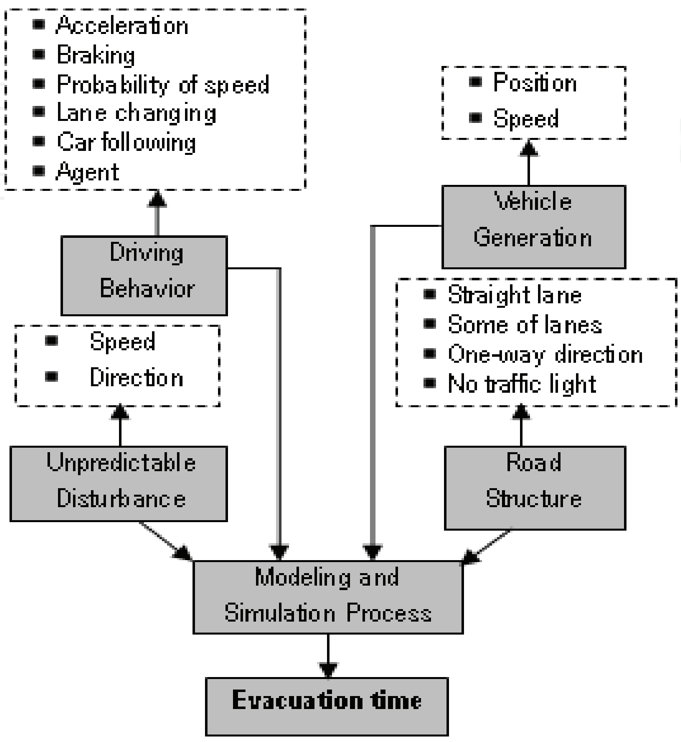


Fig. 1. Diagram block of evacuation simulation in the micro traffic

The other subsystem: vehicle generation, it is determined by a random number generation. It provides positions and speeds of all vehicles. Furthermore, we determine the driving behaviour. This study uses modified driving behaviour of Nagel-Schreckenberg proposed by using traffic Cellular Automata (Nagel, K. & Schreckenberg, M., 1992). We add two parameters in their model those are lane-changing and car-following. All the parameters of driving behaviour used in the proposed simulation are acceleration, braking, probability of speed, lane-changing, car-following, and agent. The overall simulation flow with the parameters used is shown in Fig. 1.

As the simulation results, we evaluated performance of the proposed driving behaviour (driving behaviour with agent) by compare it to the driving behaviour based on Nagel-Schreckenberg (without agent) for vehicle evacuation simulation from the affected disaster area of Sidoarjo. Thus, the simulation with and without agent cars is shown in this section.

4.2 Simulation procedure

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

4.2.1 Preparation of road structure

The assumed road structure is shown in Fig.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 spill over from the broken dike to the nearby roads spontaneously.

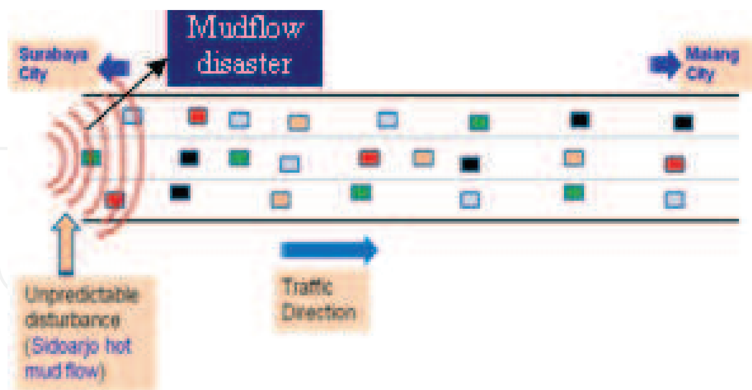


Fig. 2. Map of the roadway (Sidoarjo Porong roadway)

The hot mud will flow from behind of vehicles. It 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 Fig. 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 other actual condition on the road is that there is no traffic light at all.
In the proposed simulation, two lanes of traffic are assumed by condition above. Although the density is very high, drivers have a chance to change the lane.

4.2.2 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 probability of vehicle density P_d; (4) Generate vehicles position $x(i, j)$ and their speed v_s randomly toward P_d

$$x_{(i,j)}(t) = [1 : v_{\max}] \tag{15}$$

with probability P_d.

4.2.3 Unpredictable disturbance

The proposed unpredictable disturbance is in the case of Sidoarjo hot mudflow disaster. It has two parameters, speed and direction. We assumed that speed of hot mudflow is to be constant. It is set as smaller than maximum speed of vehicle. Next the second parameter, direction of hot mudflow is the same as the vehicle's direction in the one-way street road.

4.2.4 Driving behavior

According to the agent, there are two driving behaviours, 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 centre and transferred to the agent cars through wireless network connection), they could lead the following cars to the safe areas in a fastest way.

4.2.4.1 Modified Driving Behaviour of Nagel-Schreckenberg

Regarding to the Equation (11) to Equation (14), STCA have four steps of driving behaviour rule: acceleration, braking, randomization (slowdown probability), and vehicle movement, our study modifies it by adding two parameters about lane changing and car following. It is based on (Maerivoet, S. & De Moor, B., 2005 B) 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 behaviour of Nagel-Schreckenberg.

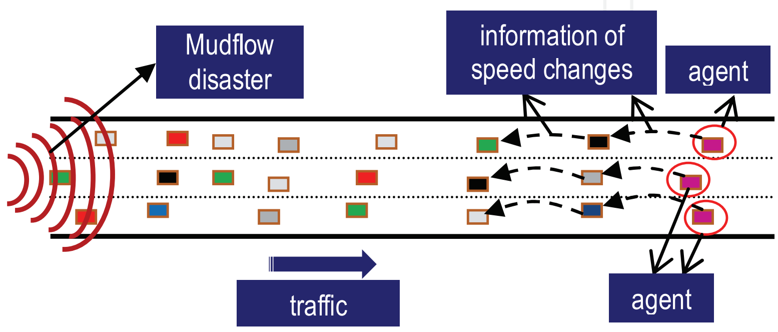


Fig. 3. Driving behaviour with agent

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

1. Acceleration

$$v_{(i,j)}(t-1) < v_{\max} \wedge gs(i,j)(t-1) > v_{(i,j)}(t-1)+1 \\ v_{(i,j)}(t) \leftarrow v_{(i,j)}(t-1)+1 \tag{16}$$

2. Braking

$$gs_{(i,j)}(t-1) \le v_{(i,j)}(t) \Rightarrow v_{(i,j)}(t) \leftarrow gs_{(i,j)}(t-1)-1 \tag{17}$$

3. Randomization

$$\xi(t) < p \Rightarrow v_{(i,j)}(t) \leftarrow \max\left[0, v_{(i,j)}(t)-1\right] \tag{18}$$

4. Vehicle movement

$$x_{(i,j)}(t) \leftarrow x_{(i,j)}(t-1)+v_{(i,j)}(t) \tag{19}$$

5. Lane changing
   Determine probability of lane changing P_{lc} and a = [0 : v] for:

$$gs_{(i=1,j)}(t-1) < v \wedge x_{(i=2,j,j+v)}(t-1) = 0 \\ \Rightarrow x_{(i=2,j+a)}(t) \leftarrow x_{(i=1,j)}(t-1) \tag{20}$$

or

$$gs_{(i=2,j)}(t-1) < v \wedge x_{(i=1,j,j+v)}(t-1) = 0 \\ \Rightarrow x_{(i=1,j+a)}(t) \leftarrow x_{(i=2,j)}(t-1) \tag{21}$$

6. Car following/vehicle movement: Back to step 4).

4.2.4.2 Proposed Driving Behaviour

There is the related work on the essence of the phenomenological research (Kretz, T., 2007). It stated that, (1) Concerning irrational behaviour: "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 behaviour based on the statements above. When disaster occurs, every vehicle on affected road area has to have a good knowledge of driving behaviour. 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.

According to the ant behaviour (Retired Robots, In: http://www.ai.mit.edu/projects/ants/social-behavior), we make a technically driving behaviour. Agent behaviour 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 is worthless. This condition is consecutively performed to all vehicles in one lane and parallel to the entire lane.

We put the agent behaviour in the car-following parameter of driving behaviour. The rule of agent is,

$$\begin{aligned} &x_{(i,j+v+c)}(t-1) = 0 \wedge v_{(i,j)}(t) + c \le v_{\max} \\ &\Rightarrow x_{(i,j)}(t) \leftarrow x_{(i,j)}(t-1) + v_{(i,j)}(t) + c \end{aligned} \tag{22}$$

where c is positive integer.

Furthermore, the rule of proposed driving behaviour as follows:

1. Acceleration

$$\begin{aligned} v_{(i,j)}(t-1) < v_{\max} \wedge gs(i,j)(t-1) > v_{(i,j)}(t-1) + 1 \\ v_{(i,j)}(t) \leftarrow v_{(i,j)}(t-1) + 1 \end{aligned} \tag{23}$$

2. Braking

$$gs_{(i,j)}(t-1) \le v_{(i,j)}(t) \Rightarrow v_{(i,j)}(t) \leftarrow gs_{(i,j)}(t-1) - 1 \tag{24}$$

3. Randomization

$$\xi(t) < p \Rightarrow v_{(i,j)}(t) \leftarrow \max[0, v_{(i,j)}(t) - 1] \tag{25}$$

4. vehicle movement

$$x_{(i,j)}(t) \leftarrow x_{(i,j)}(t-1) + v_{(i,j)}(t) + c \tag{26}$$

5. Lane changing
   Determine probability of lane changing P_{lc} and $a = [0 : v]$ for:

$$gs_{(i=1,j)}(t-1) < v \wedge x_{(i=2,j,j+v)}(t-1) = 0 \\ \Rightarrow x_{(i=2,j+a)}(t) \leftarrow x_{(i=1,j)}(t-1) \tag{27}$$

Or

$$gs_{(i=2,j)}(t-1) < v \wedge x_{(i=1,j,j+v)}(t-1) = 0 \\ \Rightarrow x_{(i=1,j+a)}(t) \leftarrow x_{(i=2,j)}(t-1) \tag{28}$$

6. Car following/vehicle movement: Back to step 4).

4.3 Evaluation of the proposed parameter in the driving behaviour

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. The fundamental relation is,

$$q = kv \tag{29}$$

There are only two independent variables density k and mean 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 behaviour and the evacuation time T. These proposed parameters are the mean speed v and the density function c, which c is defined by $1/k$, completely $c = Q(1/k)$, Q is a function. So there are two relationships: mean speed v versus evacuation time T (v-T diagram) and function of density c versus evacuation time T (c-T diagram).
Function of density c is equivalent to the parameter c in Equation (22), while mean speed v is $v_{(i,j)}(t)$. Thus, parameter c in Equation (22) is better known under the name of function of density (= $Q(1/k)$). So that Equation (22) can be rewritten as,

$$x_{(i,j+v+Q(1/k))}(t-1) = 0 \wedge \left(v_{(i,j)}(t) + Q(1/k)\right) \le v_{\max} \\ \Rightarrow x_{(i,j)}(t) \leftarrow x_{(i,j)}(t-1) + v_{(i,j)}(t) + Q(1/k) \tag{30}$$

where $c = Q(1/k)$.
The previous work (Immers, L.H. & Logghe, S., 2002); (Maerivoet, S. & De Moor, B., 2005 A); (Maerivoet, S. & De Moor, B., 2005 B) and (Tampère, C.M.J., 2004) 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 increase (pass through the jam density), then the speed v will be decrease (down to zero). This condition is consistent with the characteristic of k-v diagram.
Based on k-v diagram, 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 has increased/pass the jam density), we found the evacuation time T by the great value. Besides, we also observe that by the increase of the mean speed v, we find the evacuation time T decreases. It occurs either with or without agent in the evacuation simulation (see Fig.4 and Fig.5 with/without agent respectively).

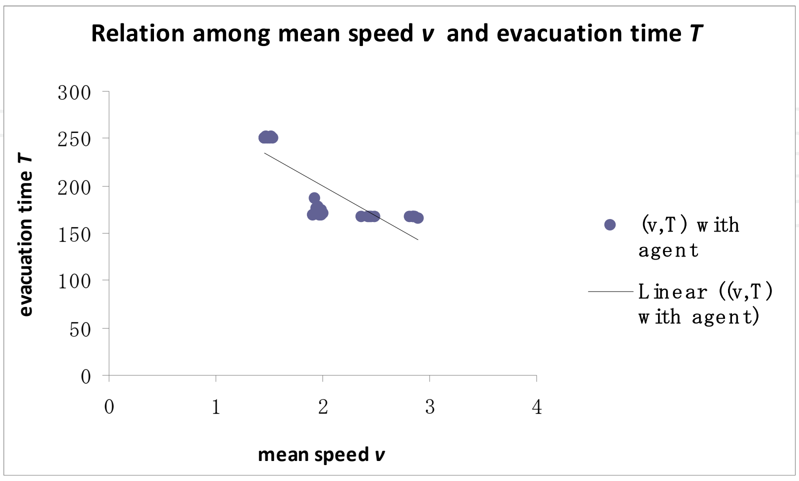


Fig. 4. Relationship between mean speed and evacuation time (with agent)

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 density k, mean speed v will decreases. And then, we also found that the movement of the mean speed v down to smaller value has impact the evacuation time T is going up. On the other hand, we have the sense of relation 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.

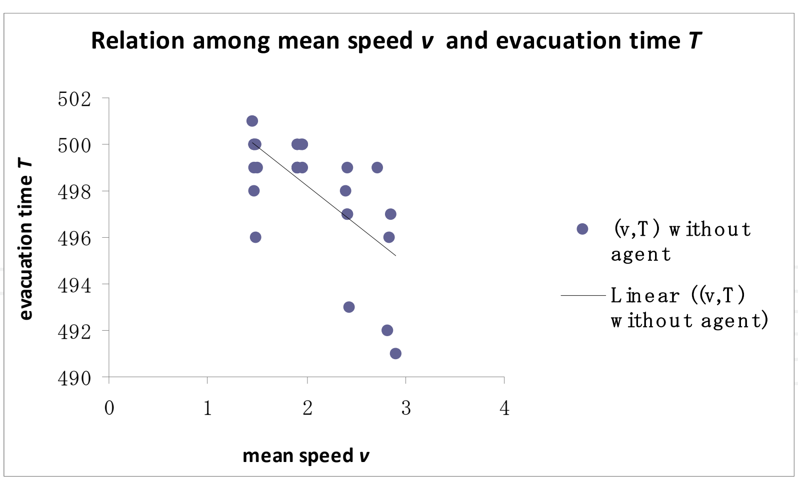


Fig. 5. Relationship between mean speed and evacuation time (without agent)

We knew 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 function of density c has small value. While the density k and the evacuation time T have linear correlation then we say that in the time c has the small value, the value of the evacuation time T is large. The other hand, when the value of c is going up the evacuation time T will down to the smaller value. Our experiment results about value of c and T found relationship between both of them. Based on linear correlation between the evacuation time T and the density k, we looked for function of density c (= $Q(1/k)$). From this correlation we obtained the value of $c = Q(1/k) = (12/10)(1/k)$. By using this value of c, we have the experiment results, relation between function of density c and evacuation time T (see Fig. 6). The pattern of their relationship in accordance with the description above. We showed it with/without agent.

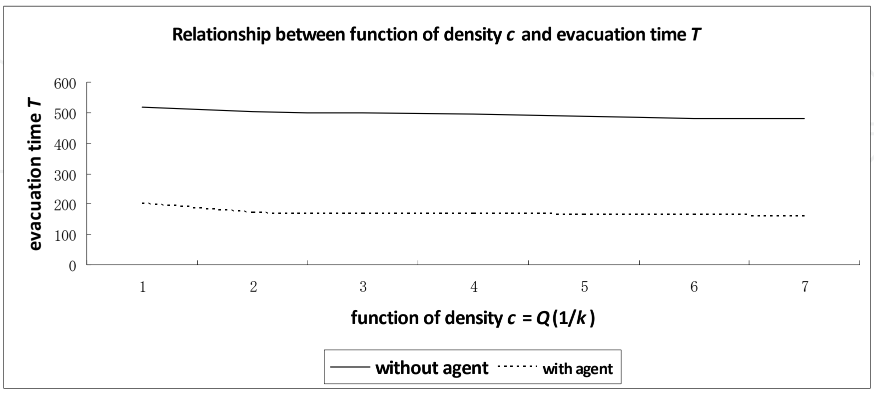


Fig. 6. Relationship between function of density c and evacuation time (with/without agent)

5. Survey results of traffic on the Sudioarjo Porong roadway

5.1 Specification of survey

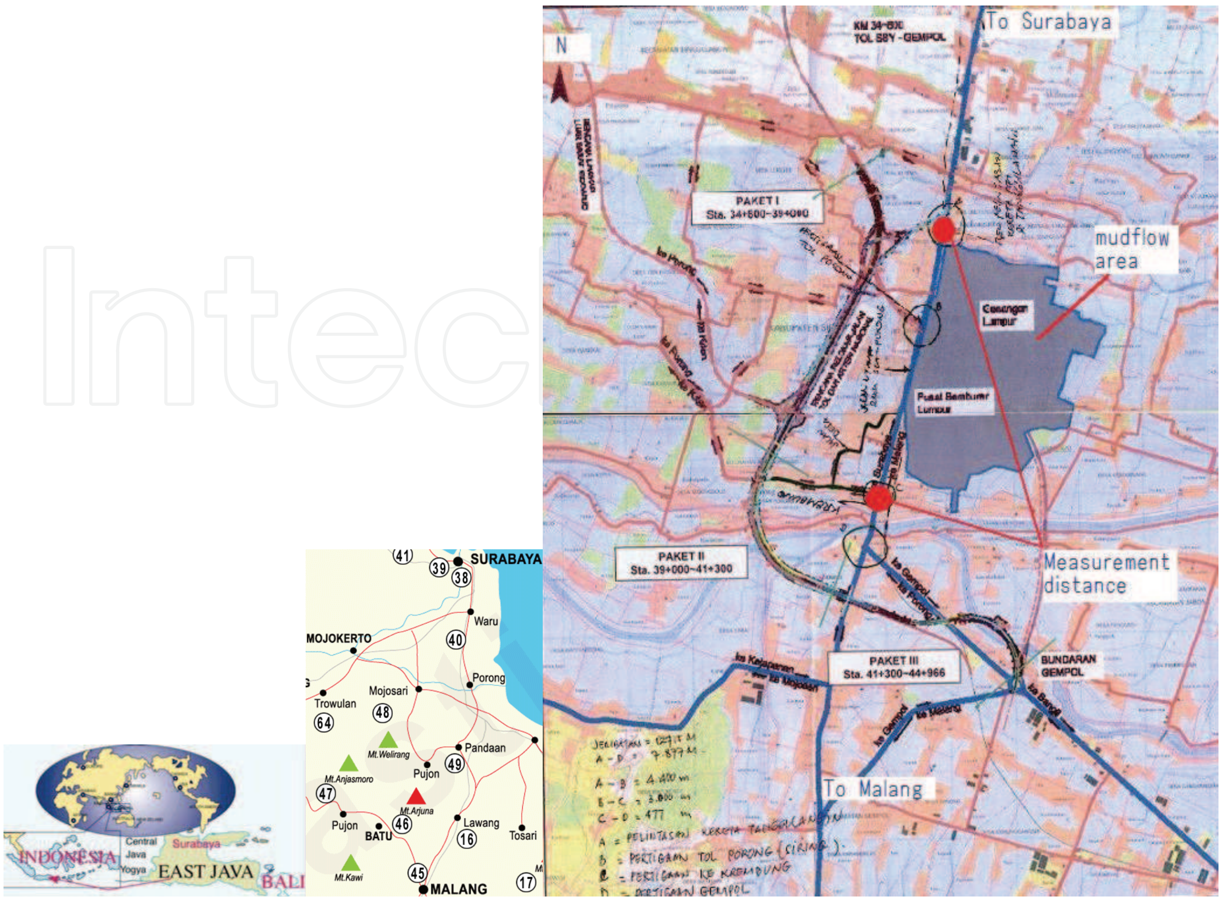
Roadway: Sidoarjo Porong roadway, East Java, Indonesia (Fig.7); direction of traffic: Sidoarjo/Surabaya to Malang/Banyuwangi (unidirectional); parameter was observed in the survey: speed of vehicle; data measurement: speed of vehicles every 15 minutes, during 24 hours, along eight days consecutively. All vehicles passing through the Sidoarjo Porong roadway is classified into four types: bus, truck/trailer, public transport, and private car.

5.2 The influence of cars speed with respect to the driving behavior

During survey the traffic data, we have totally 190 data of speed for each kind of cars (bus, truck/trailer, public transport, and private car). Analysis data is done to get any information related with the driving behavior.

Based on statistical hypothesis testing (t-student distribution), we find the hypothesis results for bus, public transport, and private car are accepted, whereas truck/trailer is rejected. It means that truck/trailer has different speed behaviour if it is compared by the other cars (bus, public transport, and private car). Speed of the truck/trailer is lower than that of the others. Comparison of speed between truck/trailer and all kind of the cars (mean speed of all vehicles) is conducted. Many trucks/trailers have the speed is less than or equal to 40 kilometre per hour (km/hr) when we compare it with all kind of the cars per speed interval, while all kind of the cars have the speed more than 41 km/hr is larger than that of the truck/trailer (see in Table 2 and Fig.8).

We also find distribution of speed for the bus, public transport, and private car. Comparison of their speeds related to the speed of all kind of the cars is conducted. Bus and public transport have the most frequency in the range of speed 36 – 40 km/hr, while for the private cars in the range 41 – 45 km/hr. We also found that all kind of the cars have the most frequency in the range of speed 41 – 45 km/hr (see in Table 3 and Fig.9).



(a) East Java (b) Surabaya to Malang (c) Measured roadway

Fig. 7. The roadway where the traffic survey is conducted

Back to the speed of the trucks/trailers, we show their speeds compared by the speed of all kind of the cars by time to time consecutively in 190 hours (eight days). We find that on the same measurement time, speeds of the trucks/trailers dominantly are lower than that of speed all kind of the cars (see in Fig. 10), number of lower speeds for the truck/trailer is around 81%.

Speed Interval	Truck	All	Speed Interval	Truck	All
1-5	13	11	36-40	52	43
6-10	2	4	41-45	35	51
11-15	1	1	46-50	2	20
16-20	3	2	51-55	0	0
21-25	19	10	56-60	0	0
26-30	27	24	61-65	0	0
31-35	36	24	66-70	0	0
			Total	190	190

Table 2. Distribution of speed for the truck/trailer and all kind of the cars

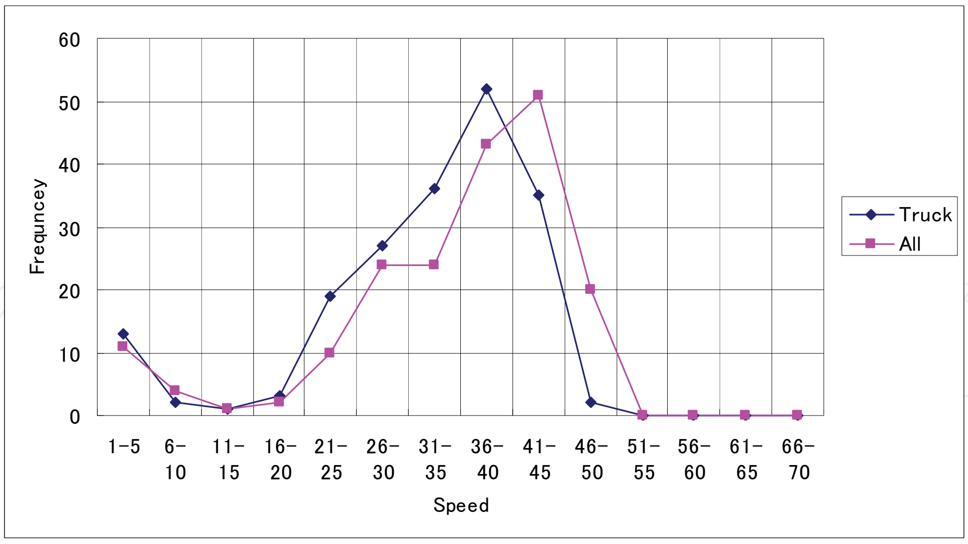


Fig. 8. Distribution of speed for the truck/trailer and all kind of the cars

Speed Interval	Bus	Public	Private	All	Speed Interval	Bus	Public	Private	All
1-5	11	11	12	11	36-40	51	40	30	43
6-10	4	4	3	4	41-45	37	39	36	51
11-15	2	1	1	1	46-50	24	27	31	20
16-20	3	1	2	2	51-55	1	3	21	0
21-25	4	7	11	10	56-60	0	1	3	0
26-30	28	25	20	24	61-65	0	0	0	0
31-35	24	31	19	24	66-70	1	0	1	0
					Total	190	190	190	190

Table 3. Distributions of speed for the bus; public transport; private car; and all kind of the cars

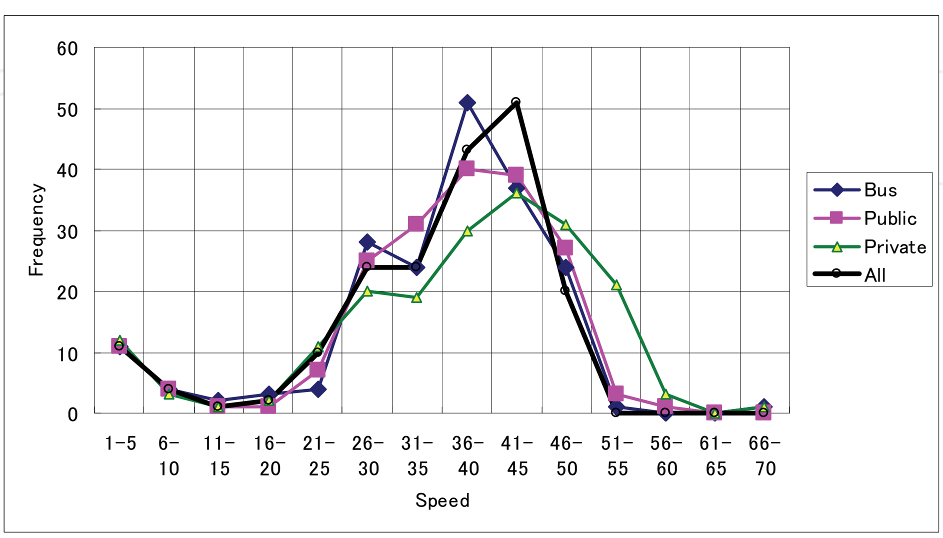


Fig. 9. Distributions of speed for the bus; public transport; private car; and all kind of the cars

Based on data analysis of speed for all vehicles, phenomena of traffics on the Sidoarjo Porong roadway related to the speed of vehicles was observed. We compare the speed each other of all the vehicle types and classify it. In general, number of trucks/trailers have the speed less than or equal to the speed interval (36 – 40 km/hr) is bigger than that the other vehicle types. On the other hand, is founded that the other types (bus, public transport, and private car) have the bigger number of cars available in the speed interval (41 – 45 km/hr) or more than that the trucks/trailers. Finally, according to the driving behaviour, we assume that there are diligent driver and usual driver regarding to their speeds. Dominantly, trucks/trailers become usual driver, while bus; public transport; and private car as diligent drivers.

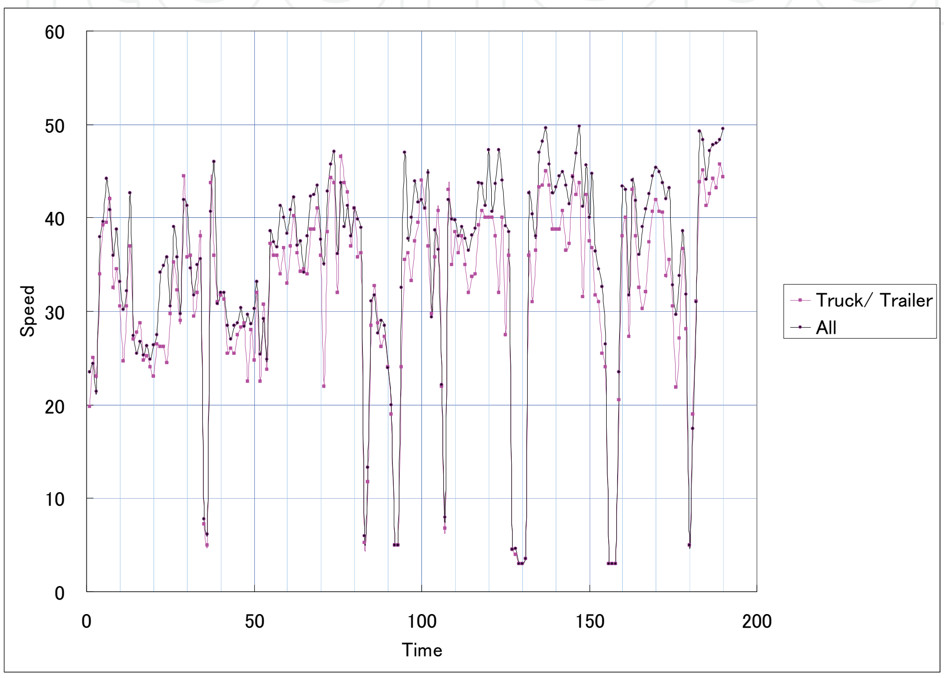


Fig. 10. Speed of the trucks and all kind of the cars in 190 hours (8days) respectively.

6. Modified car-following NaSch model with diligent drivers behaviour

Modified car-following Nagel-Schreckenberg (NaSch) model, is described by means of NaSch model. The rule set of modified car-following NaSch model have the same steps with the rule set of NaSch model for the first to third steps, They are acceleration, braking, and randomization, in Equation (11) to Equation (13). Next step in the NaSch model is vehicle movement shown in Equation (14). The NaSch model is implemented for one lane of traffic (road length is analogized by one-dimensional array L sites). In accordance to the road condition, modified car-following NaSch model uses two lanes of traffic (multi-lane traffic), it has consecutively lane-changing and vehicle movement for next steps. Due to the case of evacuation is reflected on the condition of Sidoarjo Porong roadway, modified car-following NaSch model concerns on the unidirectional road and no looping of traffic, while the NaSch model uses unidirectional road with looping of traffic (periodic boundary conditions).

This section, we propose another driving behavior in the modified car-following NaSch model other than agent driver, it is about diligent driver. Agent driver has been proposed in section 4.2.4.2 inserted into the driving behaviour of NaSch. Based on both of them, agent driver and diligent one, NaSch model is modified and called modified car-following NaSch model. The number of diligent driver is probabilistically determined, while the agent driver is determined by integer. Both diligent driver and agent driver are reflected by the addition of speed in the car-following model. A diligent driver has the additional speed $c' = [0:\min(\overline{v}, v)]$ while an agent has $c = [0:\max(v)]$. We know that velocity v of each car is given by the function of the headway to the vehicle in front. By adding the additional speed to the diligent driver and agent driver then we have the velocity v,

$$v = \begin{cases} v_{(i,j)}(t) + c' = v_{(i,j)}(t) + [0:\min(\overline{v}, v)] \\ \textit{for} \quad \textit{diligent} \quad \textit{driver} \\ \\ v_{(i,j)}(t) + c = v_{(i,j)}(t) + [0:\max(v)] \\ \textit{for} \quad \textit{agent} \quad \textit{driver} \end{cases} \tag{31}$$

By referring (Maerivoet, S. & De Moor, B., 2005 B), we make the implementation of lane-changing model in the modified car-following NaSch model. Implicitly, we have used it in the section 4.2.4.1. There are two sub-steps on the lane-changing section that is consecutively executed at each time step. First, the lane-changing model is executed, exchanging vehicles between laterally adjacent lanes; second, all vehicles are moved forward by applying the modified car-following part of the NaSch model's rules. We make the steps of lane-changing as follows:

1. Lane-changing model

For two lanes of traffic, we proposed as follows:
Determine probability of lane changing P_{lc} and a = [0 : v] for

$$\begin{aligned} gs_{(i=1,j)}(t-1) < v \wedge x_{(i=2,j,j+v)}(t-1) = 0 \\ \Rightarrow x_{(i=2,j+a)}(t) \leftarrow x_{(i=1,j)}(t-1) \end{aligned} \tag{32}$$

and

$$\begin{aligned} gs_{(i=2,j)}(t-1) < v \wedge x_{(i=1,j,j+v)}(t-1) = 0 \\ \Rightarrow x_{(i=1,j+a)}(t) \leftarrow x_{(i=2,j)}(t-1) \end{aligned} \tag{33}$$

The rules in Equation (32) and Equation (33) describe that if in a lane, the driver is not possible to move his car forward (there is car ahead) and he sees that there is any safety space in another lane with the number of space is up to the speed v then he changes the lane. If the car was already stayed in the new lane, then he has the speed less than or equal to the current speed v. It implies any deceleration experienced by the car when moving to the other lane by probability P_{lc}. Adjustment the number of probability P_{lc} obtains how many cars will change their lane when the condition is fulfilled.

2. Vehicle movement

For a diligent driver, his vehicle movement is:

$$x_{(i,j)}(t) \leftarrow x_{(i,j)}(t-1) + v_{(i,j)}(t) + [0:\min(\overline{v}, v)] \tag{34}$$

with $gs(t\text{-}1) > v(t - 1)$.
While an agent driver:

$$x_{(i,j)}(t) \leftarrow x_{(i,j)}(t-1) + v_{(i,j)}(t) + [0:\max(v)] \tag{35}$$

with $gs(t\text{-}1) > v(t - 1)$.

The rule of vehicle movement in the NaSch model is stated in the Equation (14). In this model the current position of the car $x(t)$ is influenced by the previously position $x(t\text{-}1)$ and the current speed $v(t)$. By reflection on the evacuation of vehicle on the suffered road (Sidoarjo Porong roadway), we propose diligent driver into the car-following. He has the speed is shown in Equation (31). Besides he has the current speed $v(t)$, he also has the additional speed between zero to $\min(\overline{v}, v)$ because diligent driver arranges his speed on the temporal average speed. Thus vehicle movement in the modified car-following NaSch model for a diligent driver has equation that is shown in Equation (34), the current position of the car $x(t)$ is not only influenced by the previously position $x(t\text{-}1)$ and the current speed $v(t)$ but also influenced by the diligent driver's additional speed. The other hand, an agent driver into this study has the speed is also expressed in Equation (31), he has the additional speed between zero to $\max(v)$ because agent driver arranges his speed to the maximum speed when the condition is available. Vehicle movement in the modified car-following NaSch model for an agent driver has equation that is expressed in Equation (35), the current position of the car $x(t)$ is influenced by the previously position $x(t\text{-}1)$, the current speed $v(t)$, and the agent driver's additional speed.

Lane changing causes the position of that car move forward in the new lane so that there is difference between the prior positions of the car (there is no moving forward in last lane) and the current position (moving forward by his speed in the new lane). This event provides the time of the car is faster to arrive in any safety areas. The accumulation of lane-changing will support to the effectiveness of vehicle evacuation. Vehicle movement for diligent driver and agent driver also has the important role to find the effectiveness of vehicle evacuation, especially on the suffered road, Sidoarjo Porong roadway.

A modified car-following NaSch model considering agent driver and diligent driver is presented as follows:

1. Acceleration:

$$\begin{gathered} v_{(i,j)}(t-1) < v_{\max} \wedge gs(i,j)(t-1) > v_{(i,j)}(t-1)+1 \\ v_{(i,j)}(t) \leftarrow v_{(i,j)}(t-1)+1 \end{gathered} \tag{36}$$

2. Braking:

$$gs_{(i,j)}(t-1) \le v_{(i,j)}(t) \Rightarrow v_{(i,j)}(t) \leftarrow gs_{(i,j)}(t-1)-1 \tag{37}$$

3. Randomization:

$$\xi(t) < p \Rightarrow v_{(i,j)}(t) \leftarrow \max[0, v_{(i,j)}(t)-1] \tag{38}$$

4. Vehicle movement: If a diligent driver,

$$x_{(i,j)}(t) = x_{(i,j)}(t-1) + v_{(i,j)}(t) + [0:\min(\overline{v}, v)] \tag{39}$$

   Else if an agent driver,

$$x_{(i,j)}(t) = x_{(i,j)}(t-1) + v_{(i,j)}(t) + [0:\max(v)] \tag{40}$$

5. Lane-changing:
   Determine probability of lane changing P_{lc} and $a = [0 : v]$ for:

$$\begin{aligned} & gs_{(i=1,j)}(t-1) < v \wedge x_{(i=2,j,j+v)}(t-1) = 0 \\ & \Rightarrow x_{(i=2,j+a)}(t) \leftarrow x_{(i=1,j)}(t-1) \end{aligned} \tag{41}$$

   or

$$\begin{aligned} & gs_{(i=2,j)}(t-1) < v \wedge x_{(i=1,j,j+v)}(t-1) = 0 \\ & \Rightarrow x_{(i=1,j+a)}(t) \leftarrow x_{(i=2,j)}(t-1) \end{aligned} \tag{42}$$

6. Car-following/vehicle movement: back to step 4).

6.1 Experimental simulation results

The computational simulation of modified car-following NaSch model is carried out and compared with the results of the NaSch model in the case of evacuation. We observe the evacuation time with respect to the diligent driver and also the agent driver. The maximum speed is set to $v_{\max} = 5$ and the system size is $L = 200$.

6.1.1 Fundamental diagram and spatio-temporal structures

Fig.11 shows the fundamental diagram of modified car-following NaSch model. When the density k is lower than the critical density, the flow rate increases with k and the traffic flow is free. When k is larger than the critical density, the flow rate decreases as k increases and the traffic flow is congested. This situation is in accordance with traffic flow stated by (Immers, L.H. & Logghe, S., 2002); (Maerivoet, S. & De Moor, B., 2005 A); (Maerivoet, S. & De Moor, B., 2005 B) and (Tampère, C.M.J., 2004). In those references also state that at saturated roads (large density), the flow rate q is saturated (the vehicles are queuing). The condition is different with fundamental diagram resulted by modified car-following NaSch model (Fig. 11). When density is large, saturation of flow rate q does not happen; it is caused by the role of diligent driver and agent driver.

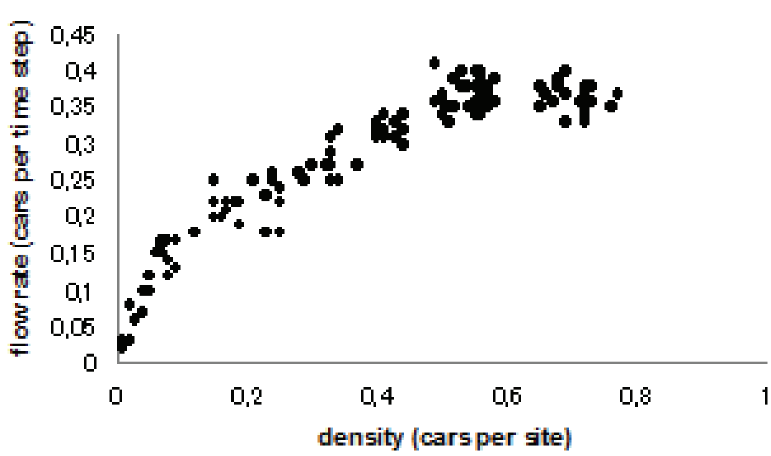


Fig. 11. Fundamental diagram of modified car-following NaSch model

Fig. 12 compares the spatio-temporal structures of the NaSch model and the modified car-following NaSch model. One can see that the evacuation time of the modified car-following

NaSch model is different from those of the NaSch model (previous model). As the number of agent increases in the modified car-following NaSch model, the evacuation time will decreases. Experimental simulation results using diligent driver 0.7; lane-changing 0.4; and density 0.6 (Fig. 12.), provide the evacuation time of the NaSch model T = 107, while the modified car-following NaSch model by using agent = 1 has T = 101; agent = 2, it has T = 95; and using agent = 3, T = 90. The existing of agent driver influenced reduction of the evacuation time T. For these experimental simulation results, by the agent driver three, there is difference of percentage ratio the evacuation time 16% decrease than that in the NaSch model (without agent driver). Traffic jams occur both in the NaSch model and modified car-following NaSch model. The black areas in Fig. 12 show the happening of traffic jams. Either in the modified car-following NaSch model or in the NaSch model, traffic jams emerge in uncertain time.

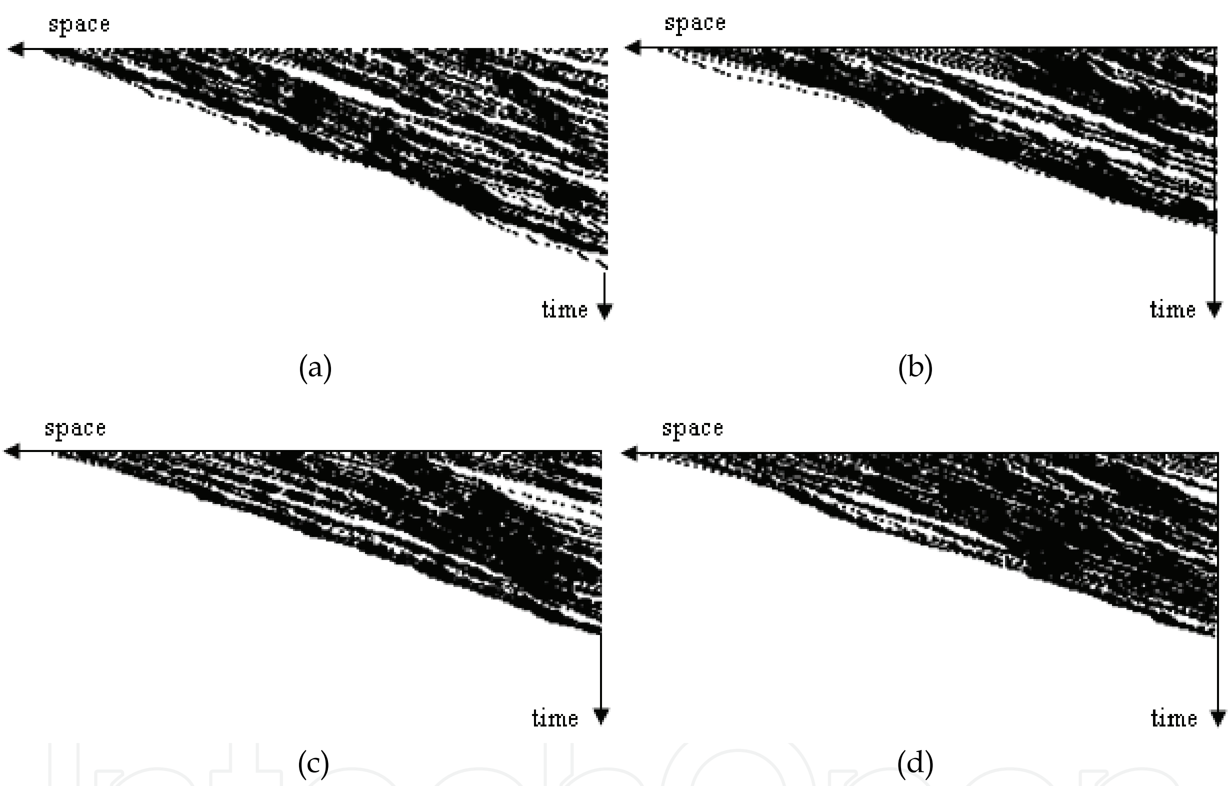


Fig. 12. Spatiotemporal diagrams of the previous model: NaSch model (a) and the modified car-following NaSch model (b) (c) (d) with different the number of agent. The vehicles drive from left to right. The vertical direction (down) is (increasing) evacuation time. (b) agent = 1; (c) agent = 2; (d) agent = 3. The parameters diligent driver = 0.7, lane-changing = 0.4, density k = 0.6.

6.1.2 Effect agent and diligent driver on the evacuation time

We observe the influence of agent and diligent driver with respect to the evacuation time based on lane-changing; mean speed; and diligent driver itself with different number of agent. Fig. 13 compares the effect of lane-changing in the NaSch model and the modified car-following NaSch model. By using lane-changing 0 to 0.6 and diligent driver 0.3; 0.5; 0.7 (for Fig. 13 (a); (b); (c) consecutively) we get the evacuation time in the modified car-following NaSch model is lower than that in the NaSch model. As lane-changing increases, evacuation time will decreases not only in the modified car-following NaSch model but also in the NaSch model (previous model). In Fig. 13, we also note that the evacuation time more decreases when the number of agent is larger. Experimental simulation results in Fig. 13 also show that by the lane-changing increases, it will be found the evacuation time decreases.

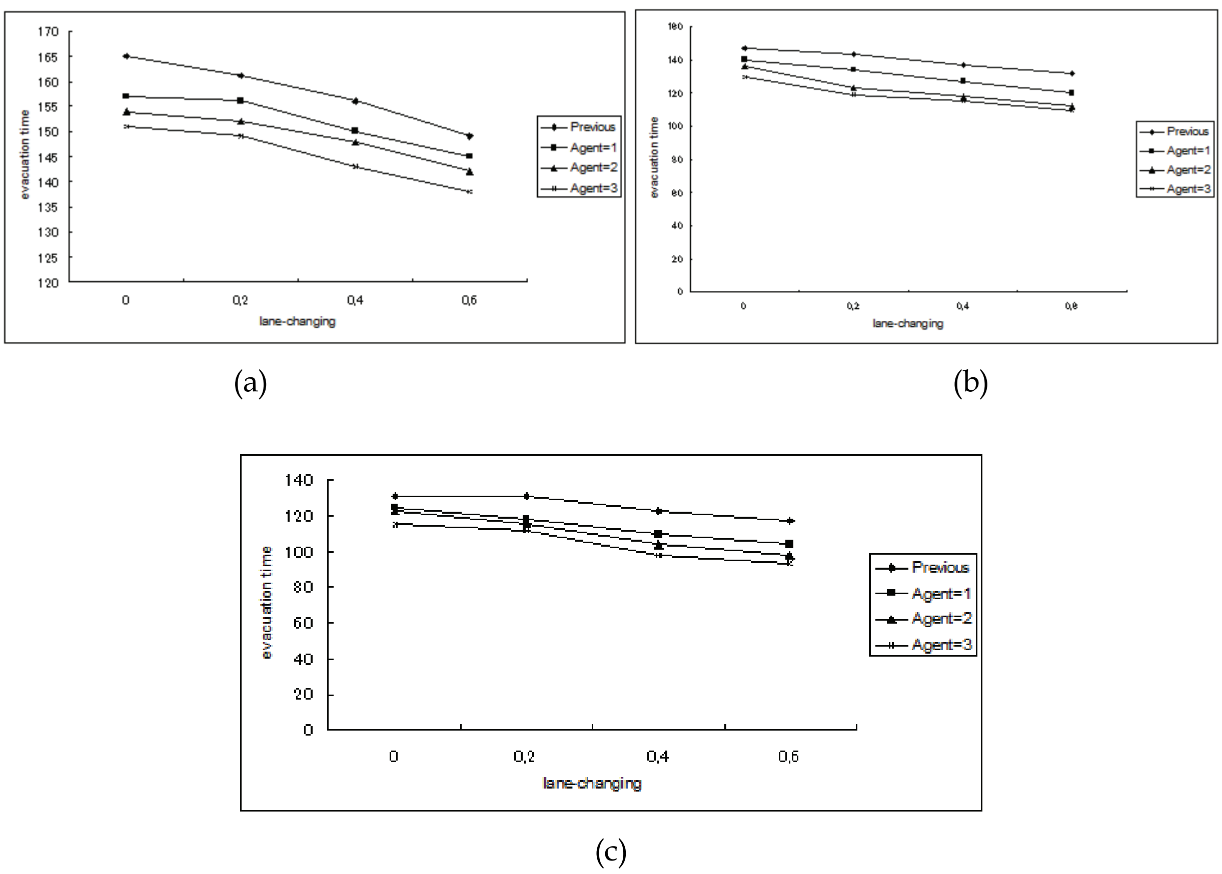
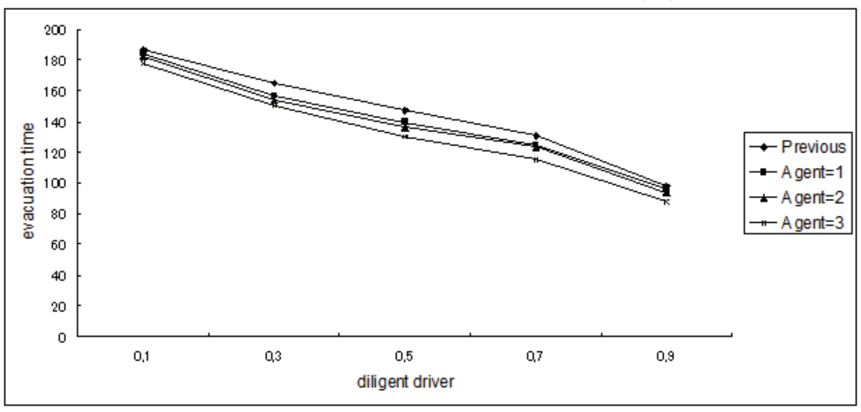


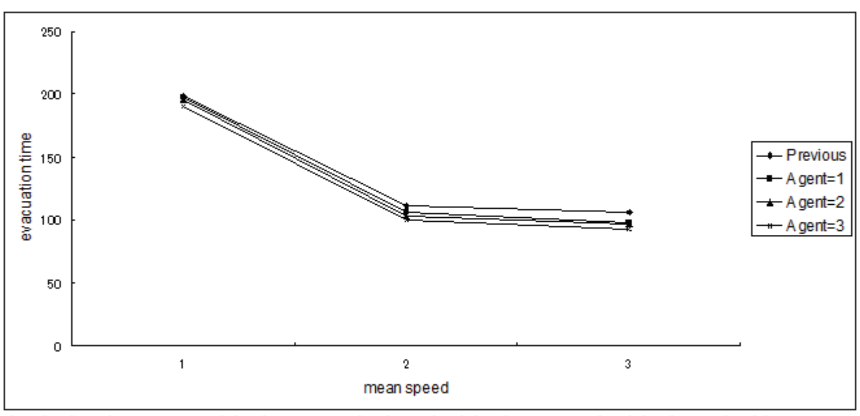
Fig. 13. The lane-changing evacuation time in the previous model: NaSch model and the modified car-following NaSch model. The density k = 0.6. (a) diligent driver = 0.3; (b) diligent driver = 0.5; (c) diligent driver = 0.7.

Furthermore, the effect of diligent driver and mean speed respectively with respect to the evacuation time is conducted. Fig. 14 (a) shows comparison of the effect of diligent driver between previous model (NaSch model) and modified car-following NaSch model. When the diligent driver increases, then either the evacuation time in the modified car-following NaSch model or in the NaSch model decrease. We find that it is lower in the modified car-following NaSch model than that in the NaSch model. These conditions occur not only in the agent = 1 but also in the agent = 2 and 3. Fig. 14 (a) also gives information that as the number of agent increase, the evacuation time will decreases.
The effect of modified car-following NaSch model with respect to the evacuation time based on mean speed is obtained in Fig.14 (b). As the mean speed increases, the evacuation time will decreases not only in the NaSch model but also in the modified car-following NaSch model. We note that the evacuation time in the modified car-following NaSch model is lower than that in the NaSch model when the mean speed increases. For the agent increases, we get the evacuation time in the modified car-following NaSch model decreases. Fig.14 (b)

also shows a leap of evacuation time from mean speed = 1 to mean speed = 2. It has 44% decreasing in the NaSch model and 47% in the modified car-following NaSch model.
We explain above (Fig.14 (a)) the influence of the modified car-following NaSch model with respect to the evacuation time based on diligent driver without lane-changing. Furthermore, we combine the diligent driver and lane-changing to get the evacuation time. Fig.15 expresses that by using lane-changing = 0.2 and diligent driver increases, we get the evacuation time decreases. It occurs both in the NaSch model and the modified car-following NaSch model. Evacuation time in the NaSch model is larger than that in the modified car-following NaSch model. We note that by the increase of agent driver in the modified car-following NaSch model, the evacuation time decreases.



(a)



b)

Fig. 14. Effect of Car-following model in the previous model: NaSch model and the modified car-following NaSch model based on (a) diligent driver, (b) mean speed. The density k = 0.6, lane-changing = 0.

Table 4 shows the effectiveness of the agent and diligent driver in terms of evacuation time. As the diligent driver increases, we have the percentage ratio of the effectiveness also increases in the modified car-following NaSch model (by agent = 1 and 3). We see that by using agent driver is three, the effectiveness is larger than that by using agent driver is one. Table 4 also describes that effect of diligent driver is almost double when the percentage ratio of diligent driver is 100%; i.e. by agent = 1, the effectiveness is 44%; while using agent = 3, it is 50%. Still in the percentage ratio of diligent driver is 100%, we also find the effect of agent driver is also almost double when the number of agent driver is three in comparison to the existing simulation result without any agent (NaSch model) (in the NaSch model, the evacuation time = 183; while for the modified car-following NaSch model = 91).

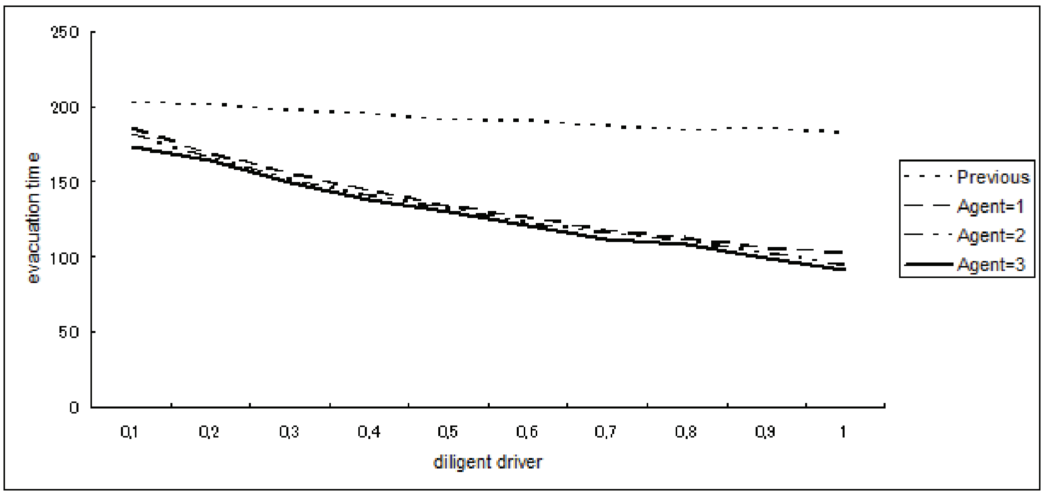


Fig. 15. The diligent driver evacuation time in the previous model: NaSch model and the modified car-following model. The density k = 0.6, lane-changing = 0.2.

dd (%)	Evacuation time				
	Previous model	Modified (*A*=1)	Effectiveness (%)	Modified (*A*=3)	Effectiveness (%)
10	202	186	8	173	14
20	201	169	16	164	18
30	197	156	21	149	24
40	195	144	26	138	29
50	191	134	30	130	32
60	190	126	34	120	37
70	187	118	37	112	40
80	184	113	39	108	41
90	185	106	43	99	46
100	183	102	44	91	50

Table 4. The effectiveness of agent and diligent driver in terms of evacuation time. The density 0.6 and lane-changing 0.2 (*dd*: diligent driver, *A*: the number of agent)

7. Conclusions

Agent and diligent driver are incorporated into the car-following of NaSch model. The modified car-following NaSch model is proposed. Evaluation of the proposed parameter, the fundamental diagram, spatio-temporal patterns, effect of lane-changing and car-following with respect to the evacuation time, combination parameter of diligent and agent driver in the case of evacuation time and the effectiveness are investigated.

The comparative simulation study between with and without agent as well as diligent drivers is conducted based on the NaSch model. In the modified car-following NaSch model, the effect of lane-changing and car-following towards the evacuation time are larger than that in the NaSch model. The simulation results show that the effect of diligent driver depends on the percentage ratio of diligent driver and is almost double when the percentage ratio of diligent driver is 100%. It is found that the effect of agent driver also depends on the number of agent driver and is almost double when the number of agent driver is three in comparison to the existing simulation result without any agent (NaSch model).

8. References

Bando, M., Hasebe, K., Nakayama, A., Shibata, A. & Sugiyama, Y. (1995). Dynamical model of traffic congestion and numerical simulation, *Physical Review E*, Vol. 51, Issue 2, (February 1995) 1035-1042, 1550-2376

Chen, X. & Zhan, F.B. (2008). Agent-based modelling and simulation of urban evacuation: relative effectiveness of simultaneous and staged evacuation strategies. *Journal of the Operational Research Society*, Vol. 59, No. 1, (January 2008) 25–33, 1476-9360

Church, R.L. & Sexton, R. (2002). Modelling small area evacuation: Can existing transportation infrastructure impede public safety?. *Final Report, Vehicle Intelligence & Transportation Analysis Laboratory*, University of California, Santa Barbara

Cova, T.J. & Church, R.L. (1997). Modelling community evacuation vulnerability using GIS. *International Journal of Geographical Information Science*, Vol. 11, No. 8, (December 1997) 763-784, 1365-8824

Cova ,T.J. & Johnson, J.P. (2002). Microsimulation of neighborhood evacuations in the urban-wildland interface. *Environment and Planning A*, Vol. 34, No. 12, 2211–2229, 1472-3409

Deadman, P.J. (1999). Modelling individual behaviour and group performance in an intelligent agent-based simulation of the tragedy of the commons. *Journal of Environmental Management*, Vol. 56, Issue 3, (July 1999) 159–172, 0301-4797

Ge, X.H., Cheng, R.J. & Li, Z.P. (2008). Two velocity difference model for a car following theory. *Physica A: Statistical Mechanics and Its Applications*, Vol. 387, Issue 21, (September 2008) 5239-5245, 0378-4371

Helbing, D. & Tilch, B. (1998). Generalized force model of traffic dynamics. *Physical Review E*, Vol. 58, Issue 1, (July 1998) 133-138, 1550-2376

Hobeika, A.G. & Jamei, B. (1985). Massvac: A model for calculating evacuation times under natural disaster. *Proceedings of the Conference on Emergency Planning*, *Simulation Series*, *Vo. 15*, *No. 1*, pp. 23–28, La Jolla, CA, January 1985, San Diego, CA

Immers, L.H. & Logghe, S. (2002). Traffic Flow Theory. Faculty of Engineering, Department of Civil Engineering, Section Traffic and Infrastructure, Kasteelpark Arenberg 40, B-3001 Heverlee, Belgium

Indahnesia.com (2007). Main toll road near Porong in southern direction closed. In: http://blog.indahnesia.com/entry/200704110832/main_tollroad_near_porong_in_southern_direction_closed.php, posted in Sidoarjo mudflow @ 11 April 2007 08:32 CET by Jeroen

Jiang, R., Wu, Q.S. & Zhu, Z.J. (2001). Full velocity difference model for a car-following theory, *Physical Review E*, Vol. 64, Issue 1, (June 2001) 017101-1 - 017101-4, 1550-2376

Kretz, T. (2007). Pedestrian Traffic, Simulation and Experiment. PhD Thesis, Vom Fachbereich Physik der Duisburg-Essen University

Maerivoet, S. & De Moor, B. (2005A). Traffic Flow Theory. *SISTA Internal Report 05-154*, ESAT-SCD, K.U.Leuven, Belgium, (July 2005)

Maerivoet, S. & De Moor, B. (2005B). Cellular automata models of road traffic. *Physics Reports*, Vol. 419, Issue 1, (November 2005) 1-64, 0370-1573

Mediacenter (2007). Mudflow Sidoarjo Porong East-Java Indonesia. In: http://mudflow-sidoarjo.110mb.com/lumpur23.htm

Nagel, K. & Schreckenberg, M. (1992). A cellular automaton model for freeway traffic. *Journal Physics I France*, Vol. 2, No. 12, (December 1992) 2221-2229, 1155-4304

Nagel, K. (1996). Particle hopping models and traffic flow theory. *Physical Review E*, Vol. 53, No. 5, (May 1996) 4655–4672, 1550-2376

Pidd, M., de Silva, F.N. & Eglese, R.W. (1996). A simulation model for emergency evacuation. *European Journal of Operational Research*, Vol. 90, Issue 3, (May 1996) 413-419, 0377-2217

Retired Robots. The Ants: A Community of Microrobots. Social Behaviour, Clustering Around Food. In: http://www.ai.mit.edu/projects/ants/social-behavior

Rifai, R. (2008). Spatial Modelling and Risk Assessment of Sidoarjo Mud Volcanic Flow. Master Thesis, Academic Output AES MSc theses 2008, Repository ITC publications, Faculty of Geo-Information Science and Earth Observation, University of Twente

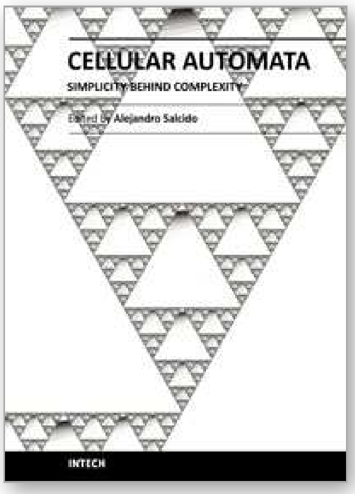
Sheffi, Y., Mahmassani, H. & Powell, W.B. (1982). A transportation network evacuation model. *Transportation Research Part A: General*, Vol. 16, Issue 3, (May 1982) 209–218, 0965-8564

Stern, E. & Sinuany-Stern, Z. (1989). A behavioural-based simulation model for urban evacuation. *Papers in Regional Science*, Vol. 66, No. 1, (December 1989) 87–103, 1435-5957

Sugiman, T. & Misumi, J. (1988). Development of a new evacuation method for emergencies: Control of collective behaviour by emergent small groups. *Journal of Applied Psychology*, Vol. 73, Issue 1, (February 1988) 3–10, 1939-1854

Tampère, C.M.J. (2004). *Human-Kinetic Multiclass Traffic Flow Theory and Modelling: With Application to Advanced Driver Assistance Systems in Congestion*. TRAIL Research School , ISBN 90-5584-060-2, P.O. Box 5017, 2600 GA Delft, The Netherlands, T +31 15 278 60 46, F +31 15 278 43 33, E info@rsTRAIL.nl, I www.rsTRAIL.nl

Teodorovic, D.A. (2003). Transport modelling by multi-agent systems: A swarm intelligence approach. *Transportation Planning and Technology*, Vol. 26, Issue 4, (August 2003) 289–312, 1029-0354



Cellular Automata - Simplicity Behind Complexity
Edited by Dr. Alejandro Salcido

ISBN 978-953-307-230-2
Hard cover, 566 pages
Publisher InTech
Published online 11, April, 2011
Published in print edition April, 2011

Cellular automata make up a class of completely discrete dynamical systems, which have became a core subject in the sciences of complexity due to their conceptual simplicity, easiness of implementation for computer simulation, and their ability to exhibit a wide variety of amazingly complex behavior. The feature of simplicity behind complexity of cellular automata has attracted the researchers' attention from a wide range of divergent fields of study of science, which extend from the exact disciplines of mathematical physics up to the social ones, and beyond. Numerous complex systems containing many discrete elements with local interactions have been and are being conveniently modelled as cellular automata. In this book, the versatility of cellular automata as models for a wide diversity of complex systems is underlined through the study of a number of outstanding problems using these innovative techniques for modelling and simulation.

How to reference
In order to correctly reference this scholarly work, feel free to copy and paste the following:

Kohei Arai, Tri Harsono and Achmad Basuki (2011). Cellular Automata for Traffic Modelling and Simulations in a Situation of Evacuation from Disaster Areas, Cellular Automata - Simplicity Behind Complexity, Dr. Alejandro Salcido (Ed.), ISBN: 978-953-307-230-2, InTech, Available from: http://www.intechopen.com/books/cellular-automata-simplicity-behind-complexity/cellular-automata-for-traffic-modelling-and-simulations-in-a-situation-of-evacuation-from-disaster-a

INTECH
open science | open minds

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

© 2011 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike-3.0 License, which permits use, distribution and reproduction for non-commercial purposes, provided the original is properly cited and derivative works building on this content are distributed under the same license.