Car-Following Parameters by Means of Cellular Automata in the Case of Evacuation

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Abstract

This study is attention to the car-following model, an important part in the micro traffic flow. Different from Nagel–Schreckenberg's studies in which car-following model without agent drivers and diligent ones, agent drivers and diligent ones are proposed in the car-following part in this work and lane-changing is also presented in the model. The impact of agent drivers and diligent ones under certain circumstances such as in the case of evacuation is considered. Based on simulation results, the relations between evacuation time and diligent drivers are obtained by using different amounts of agent drivers; comparison between previous (Nagel–Schreckenberg) and proposed model is also found in order to find the evacuation time. Besides, the effectiveness of reduction the evacuation time is presented for various agent drivers and diligent ones.

Keywords: Car-Following, Agent Drivers, Diligent Drivers, Evacuation Time, Effectiveness

1. INTRODUCTION

Car-following model has an important role in the micro traffic flow. Maerivoet et al. [1] have expressed that car-following behavior influences the activities of traffic on the roadway. The smoothness of traffic activities on the roadway is determined by the speed of vehicles on the aforementioned road. The flexibility of vehicles speed in the sense that they can adjust the acceleration and deceleration has been considered by Brilon et al. [2] with insert a parameter based on the temporal variables into the car-following model. Besides, the smoothness of traffic activities is also determined by the cooperation model between the drivers and it is associated by car-following model such as presented by [3-5]. Car-following model is also very influential in creating the stability of traffic flow such as investigated by [2-7].

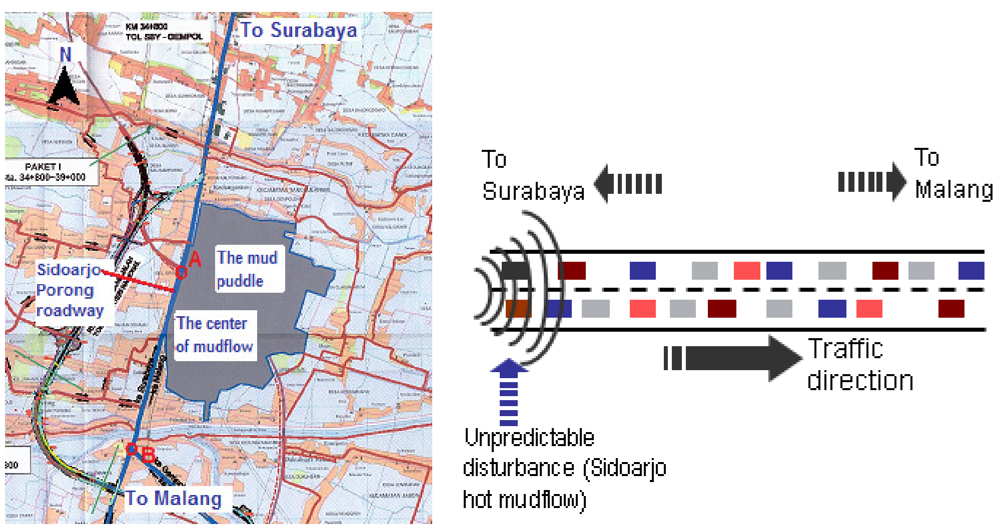
In this work, in the case of evacuation, car-following model has the proposed parameters, they are agent drivers and diligent ones. They have a good response to the surrounding environment and also recognize speed changes so that allowing traffic to be controlled by the best way to minimize the evacuation time. Agent drivers have capability to lead the other cars and they also have information that can be derived from the evacuation control centre and transferred to the other drivers through wireless network connection. Besides, agent drivers can lead the other cars to the safe area in a fastest way. Not only agent drivers but also diligent ones have a concern to the distance between their vehicle and the vehicle ahead.

Car-following model used in this study is reflected in the case of vehicles evacuation on Sidoarjo Porong roadway. The location of this road is in Sidoarjo, East Java, Indonesia. The structure of Sidoarjo Porong roadway and surrounding areas is shown in Fig. 1. The road is very close to the hot mudflow disaster and as a main artery road connects between Surabaya, the capital city of the province and the cities inside the province. Besides, the mud volcano remains have high flow rates until now [8]. One of the important things when the dike of hot mudflow is damaged and the mud overflows from the damaged dike to the nearby road spontaneously is how to evacuate the vehicles from disaster area to the safe area. At the time of the vehicles evacuation is carried out, the best way to get the minimum evacuation time is a condition that is highly desirable.

This study presents the impact of agent drivers and diligent ones toward the evacuation time and also describes the effectiveness of reduction the evacuation time for various agent drivers and diligent ones.

2. THE ROAD STRUCTURE AND ITS CONDITIONS

The map of Sidoarjo Porong roadway and surrounding areas is shown in Fig. 1(a). Sidoarjo Porong roadway is located in the middle part of this map (the blue color, straight line). There is center of hot mudflow (the gray color) very close to this road. The road has two directional, from Surabaya to Malang and from Malang to Surabaya. In this work, we investigate one directional, i.e. from Surabaya to Malang, this part is adjacent to the center of mudflow. The visualization of this part is shown in Fig. 1(b) in which there are two lanes formally.



(a) (b)

FIGURE 1: (a) Sidoarjo Porong roadway and surrounding areas; (b) Structure of Sidoarjo Porong roadway, direction: from Surabaya to Malang.

In the context that mud overflows into the road, we assume that it comes from one end of the road and has the same direction as the vehicles direction. In another sense, when we see in Fig. 1(b), we can say that mud will flows from left to right in accordance with the vehicles movement. The speed of the mudflow is assumed to be constant. It is set as smaller than maximum speed of vehicle. The other condition on this road is that there is no traffic light at all.

3. THE PROPOSED MODEL IN THE CASE OF EVACUATION

There are two major methods of car-following in the micro traffic flow models, continuous models and discrete ones. Several kinds of the continuous models are Optimal Velocity Model (OVM), Generalized Force Model (GFM), Full Velocity Difference Model (FVDM), and Two Velocity Difference Model (TVDM) explained in [9]; [10]; [11]; and [5], respectively. In the continuous models, a driver is stimulated by his own velocity v_n, n is the position of his car; the distance between the car and the car ahead s_n; and the velocity of the vehicle in front v_{n+1}. The equation of the vehicles motion is characterized by the acceleration function $\ddot{s}_n(t) = \dot{v}_n(t)$ in which depends on the input stimuli. The equation of the acceleration function is $\ddot{s}_n(t) = \dot{v}_n(t) = F\big(v_n(t), s_n(t), v_{n+1}(t)\big)$, t is the time variable.

The discrete model of car-following has been developed by using Cellular Automata (CA). CA is model that has discrete in space, time and state variables. Due to the discreteness, CA is extremely efficient in implementations on a computer. CA for traffic has been called by Traffic Cellular Automata (TCA) [1]. Maerivoet et al. [1] have also expressed that there are some kinds of stochastic models of CA for micro traffic flow, one of them is Nagel-Schreckenberg model. They stated that 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. Their model has been called the Nagel-Schreckenberg TCA and it has been explained in the [12]. Hereinafter, the Nagel-Schreckenberg TCA is referred as the NaSch. Maerivoet et al. [1] have also stated that the NaSch model has been called as a minimal model, in the sense that all the rules are a necessity for mimicking the basic features of real-life traffic flows.

In this study, we propose the driver behavior parameters and inserted into the car-following part of micro traffic flow. They are agent drivers and diligent ones. The characteristics of agent drivers and diligent ones are explained in the section one. We can summarize that agent drivers and diligent ones have the ability to expand their chance increasing their speed in accordance with the information they get from the surrounding environment. Their ability can be reflected by the addition of the speed parameter on those, for each agent driver is $c' = [0 : v_{\max}]$ while for each diligent one is $c = [0 : \min(\bar{v}, v)]$. These parameters have the sense that for agent drivers can expand the chance to increase the speed start from zero to maximum speed $v_{\max}$, while for diligent drivers start from zero to minimum value between mean speed $\bar{v}$ and current speed v. With regard to the addition of the speed parameters, the velocity of agent drivers and diligent ones are respectively defined by the equations $v'_{i,j,t} = v_{i,j}(t) + [0 : v_{\max}]$ and $v_{i,j,t} = v_{i,j}(t) + [0 : \min(\bar{v}, v)]$. $v_{i,j}(t)$ is the velocity of the *ith* lane-*jth* site car by the time *t*. $v'_{i,j,t}$ and $v_{i,j,t}$ are consecutive the velocity of an agent driver and a diligent one by the time *t* in the position *ith* lane-*jth* site.

In the model, the road consists of two lanes (as be mentioned in section two) and each lane is comprised of *L* sites of equal size. Each site can either be occupied by a vehicle or it can be empty. The amounts of agent drivers *A* are determined by the integer number, while diligent drivers are determined by using probability *dd*. The velocity for each vehicle is an integer value between zero and $v_{\max}$. The initial velocity for each vehicle is determined by using normal random in which mean speed $\bar{v}$ and standard deviation *sd* as parameters inserted in the system. The total number of vehicles on the road is determined by the initial conditions using probability of vehicle density *k*, and with open boundary conditions. Due to the fact that the vehicles evacuation must be performed in the best way to minimize evacuation time *T*, the specific rules of the Nagel-Schreckenberg traffic cellular automata (NaSch) [12] is modified in the following for the car-following model. At each discrete time step $t \to t+1$, all the vehicles simultaneously update their states according to four consecutive steps:

1) Acceleration: if $v_{i,j}(t) < v_{\max}$ and $gs_{i,j}(t) > v_{i,j}(t)+1$, $v_{i,j}(t+1) \rightarrow v_{i,j}(t)+1$. $gs_{(i,j)}(t)$ is the distance between the *ith* lane-*jth* site car and the next car ahead.
2) Braking: if $gs_{i,j}(t) \leq v_{i,j}(t)$, $v_{i,j}(t+1) \rightarrow gs_{i,j}(t)-1$
3) Randomization: with probability *h* and random number $\xi(t)$, if $\xi(t) < h$; $v_{i,j}(t+1) \rightarrow v_{i,j}(t)-1$
4) Vehicle movement: in accordance with the proposed parameters in the car-following part, agent drivers and diligent ones; vehicle movement is divided into three kinds,
   (*a*) $x_{i,j}(t+1) \rightarrow x_{i,j}(t)+v_{i,j}(t+1)+[0:v_{\max}]$ for an agent driver,
   (*b*) $x_{i,j}(t+1) \rightarrow x_{i,j}(t)+v_{i,j}(t+1)+[0:\min(\bar{v},v)]$ for a diligent driver,
   (*c*) $x_{i,j}(t+1) \rightarrow x_{i,j}(t)+v_{i,j}(t+1)$ for an usual driver.
   $x_{i,j}(t)$ is the position of the *ith* lane-*jth* site vehicle by the time *t*.

By referring [1], the modified implementation of lane-changing model is conducted by the following two rules consecutively executed at each time step: (*i*) the lane-changing model, exchanging vehicles between laterally adjacent lanes. By using two lanes; probability of lane-changing *lc*; and integer value $a=[0:v]$, the rules are: if $gs_{i=1,j}(t) < v_{i=1,j}(t)$ and $x_{i=2,j,j+v}(t)=0$, $x_{i=2,j+a}(t+1) \rightarrow x_{i=1,j}(t)$; and if $gs_{i=2,j}(t) < v_{i=2,j}(t)$ and $x_{i=1,j,j+v}(t)=0$, $x_{i=1,j+a}(t+1) \rightarrow x_{i=2,j}(t)$. (*ii*) vehicle movement, all the vehicles are moved forward by applying three kinds of the vehicle movement in the step 4.

The lane-changing model describes that if in a lane, a driver is not possible to move his car forward (there is a car ahead) and he sees the empty sites in other lane with the number of sites up to the speed *v* then he drives his car into the aforementioned lane. When a car is on a new lane, it has a speed less than or equal to the current speed *v*. It implies a deceleration that experienced by a car when it is moving to the other lane.

4. SIMULATION RESULTS

Regarding with the real situation on Sidoarjo Porong roadway, the start position of the evacuation is point A and the destination area (safe area) is point B (Fig. 1a), the distance is 3500 m, it is as a road length *L*. In this work, *L* is assumed to be 500, so that the length of one site is set to 7 m. By referring to [12], one time step approximately corresponds to 1 second in real time. The initial velocity for each vehicle is determined by using normal random with the value of parameters ($\bar{v}$ and *sd*) is depends on the vehicle density (probability of vehicle density *k*). In the term of the low vehicle density, we use $\bar{v}$ and *sd* is 4 and 1, respectively; in the intermediate one, $\bar{v}$ and *sd* is consecutively set by 3 and 1; while in the high one, we use $\bar{v}$ and *sd* is 2 and 1, respectively.

The following section, we show relations between *T* and *dd* using different amounts of agent drivers *A*, after that comparison between previous (NaSch) and proposed model is performed in order to find the evacuation time, and followed by description of the effectiveness of reduction the evacuation time for various *A* and *dd*.

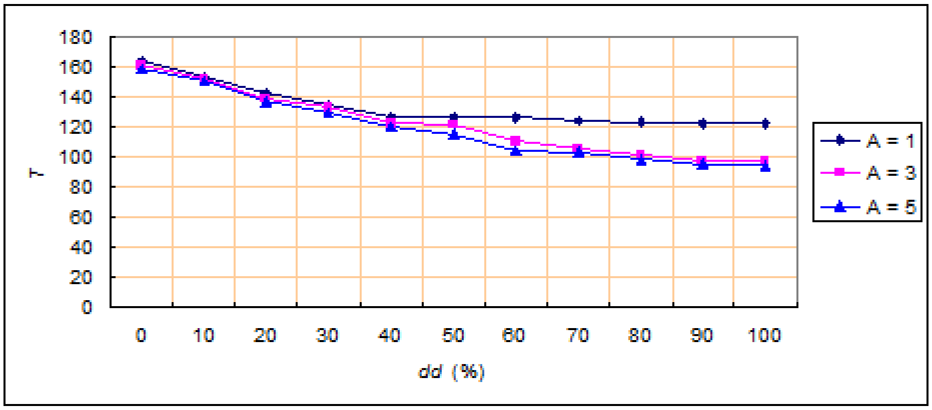
4.1 Relations between the Evacuation Time *T* and Diligent Driver *dd*

In these relations, we present the evacuation time *T* for unequal vehicle densities *k*. For each of the selected *k*, the evacuation time *T* is obtained in various *A*.

A. The Case of the Low Vehicle Density

For the low vehicle density *k* = 0.2; parameters $\bar{v}$ and *sd* for the initial velocity of each vehicle are 4 and 1, respectively. In Fig. 2(a), for *lc* = 0.3; and successively *A* = 1, 3, and 5; we obtain that by the increase of *dd* from 0% to 100%, *T* decreases either for *A* = 1, 3 or 5. By the value of

A = 1, *T* decreases significantly from *dd* = 0% to 40%, but the decrease of *T* gradually occurred from *dd* = 40% to 100%. While, *T* decreases significantly for *A* = 3 and 5 start from *dd* = 0% to 100%.



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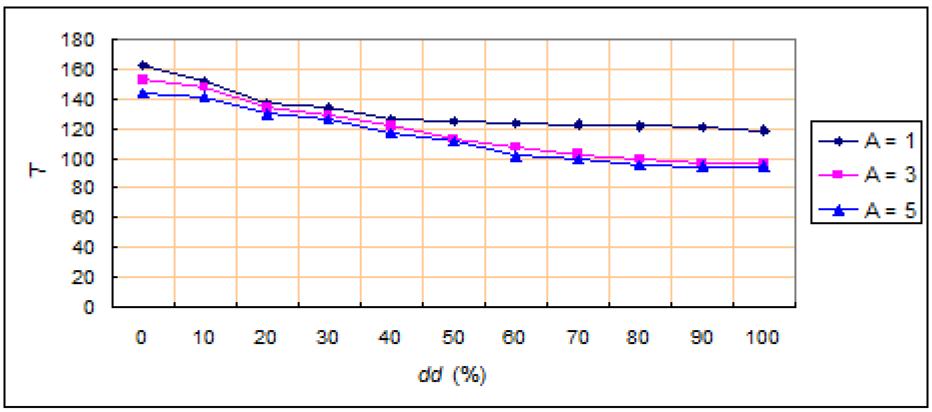

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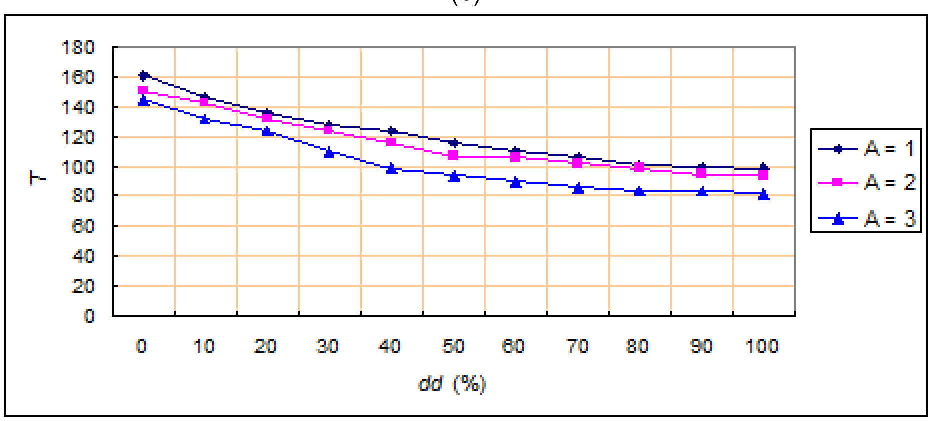
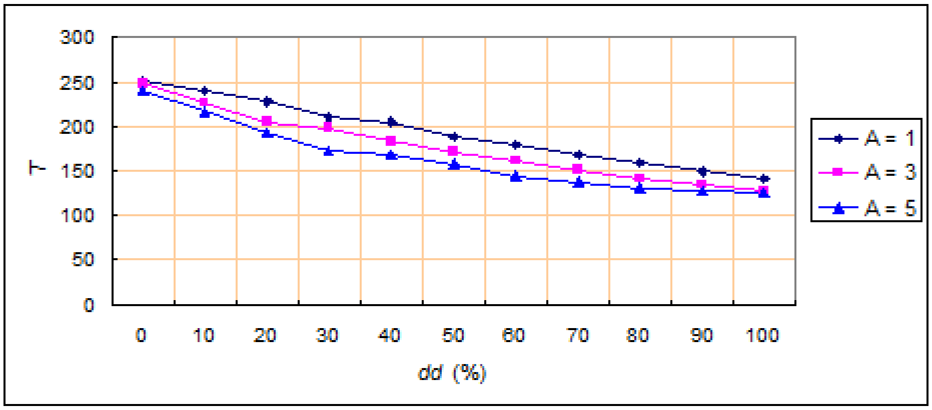


(c)

FIGURE 2: *T* vs. *dd* for different *lc* at (a) *lc* = 0.3, (b) *lc* = 0.5, (c) *lc* = 0.8; *k* = 0.2.

The condition is also experienced for *lc* = 0.5 and successively *A* = 1, 3, and 5; when *dd* increases, we find *T* decreases either for *A* = 1, 3, or 5 (Fig. 2(b)). When *A* = 1, the decrease of *T* significantly occurred from *dd* = 0% to 40%, while *T* gradually decreases from *dd* = 40% to 100%. The decrease of the evacuation time *T* also significantly occurs when we use *A* = 3 or 5, it happens for each *dd* that increases from 0% to 100%.

In Fig. 2(c), for *lc* = 0.8 and successively *A* = 1, 3, and 5; the decrease of the evacuation time *T* is obtained as *dd* increases. By using the value of *A* = 1, 3, or 5; all of the evacuation time *T* significantly decrease. Those conditions happen on the value of *dd* from 0% to 100%. We also find that for all the value of *lc* (0.3, 0.5, and 0.8); by the increase of *A*, the evacuation time *T* decreases as *dd* increases from 0% to 100%.



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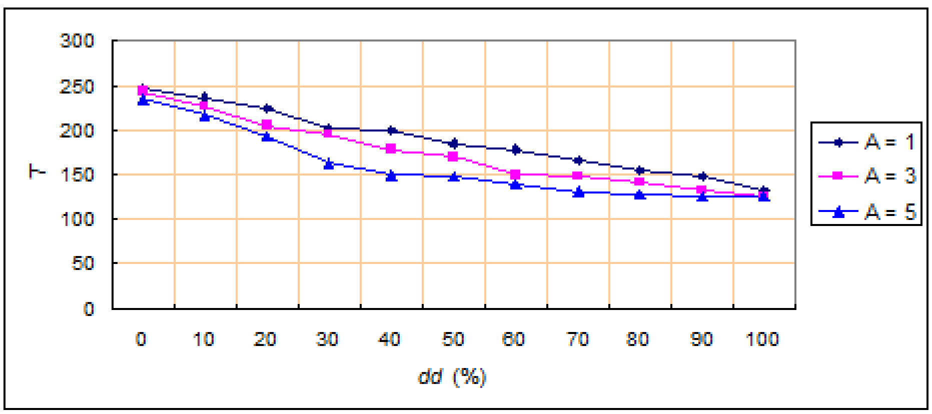

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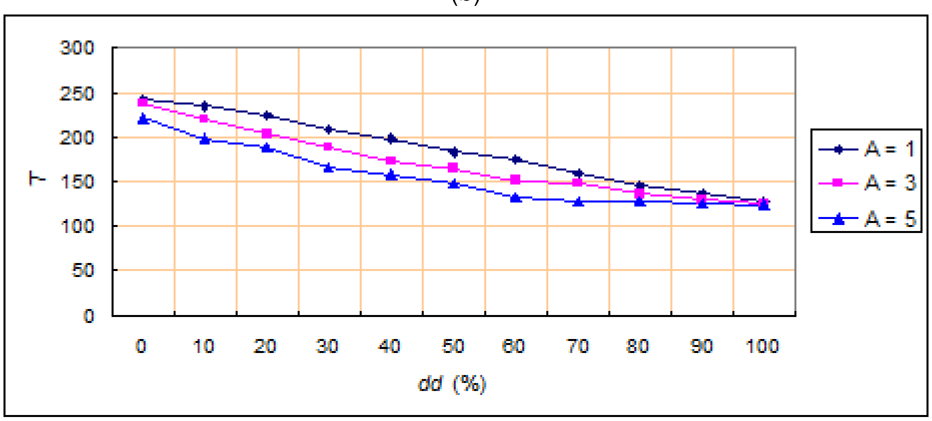


(c)

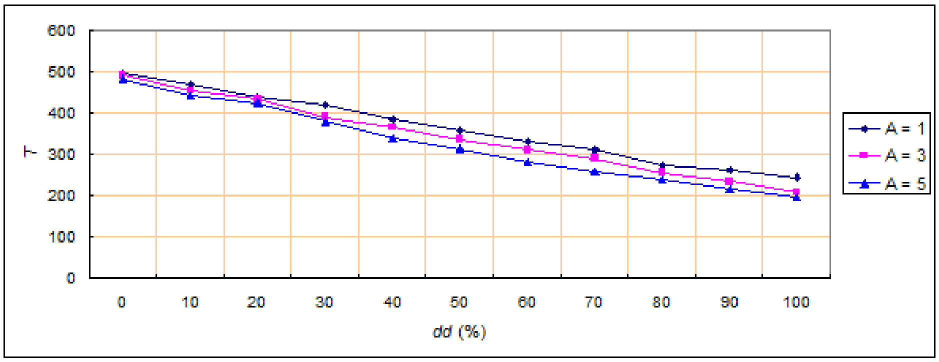
FIGURE 3: *T* vs. *dd* for different *lc* at (a) *lc* = 0.3, (b) *lc* = 0.5, (c) *lc* = 0.8; *k* = 0.5.

B. The Case of the Intermediate Vehicle Density

For the intermediate vehicle density *k* = 0.5; parameters $\bar{v}$ and *sd* for the initial velocity of each vehicle are 3 and 1, respectively. In Fig. 3(a), by using *lc* = 0.3 and successively *A* = 1, 3, and 5;

we obtain that with the increase of *dd* from 0% to 100%, *T* significantly decreases, it happens either for *A* = 1, 3 or 5.

The condition is also experienced for *lc* = 0.5, and successively *A* = 1, 3, and 5; the evacuation time *T* significantly decreases as *dd* increases from 0% to 100% (Fig. 3(b)). While, for *lc* = 0.8, and successively *A* = 1, 3, and 5; the decrease of evacuation time *T* is obtained from *dd* = 0% to 100% (Fig. 3(c)). We also find that for all the value of *lc* (0.3, 0.5, and 0.8); by the increase of *A*, the evacuation time *T* decreases as *dd* increases from 0% to 100%.



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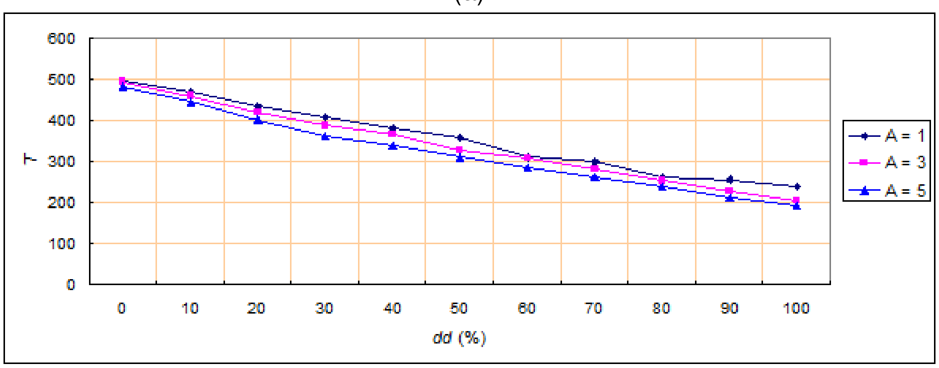

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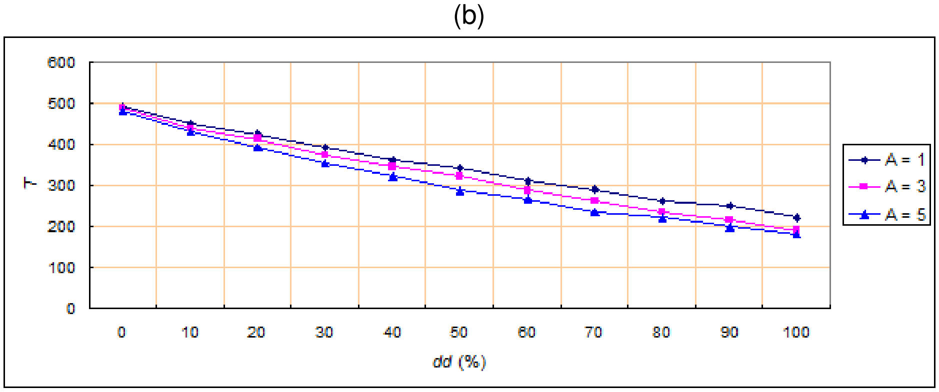

(c)

FIGURE 4: *T* vs. *dd* for different *lc* at (a) *lc* = 0.3, (b) *lc* = 0.5, (c) *lc* = 0.8; *k* = 0.8.

C. The Case of the High Vehicle Density

For the high vehicle density *k* = 0.8; parameters $\overline{v}$ and *sd* for the initial velocity of each vehicle are 2 and 1, respectively. In Fig. 4(a), by using *lc* = 0.3 and successively *A* = 1, 3, and 5; we obtain that with the increase of *dd* from 0% to 100%, *T* significantly decreases, it happens either for *A* = 1, 3 or 5.

The condition is also experienced for *lc* = 0.5, and successively *A* = 1, 3, and 5; the evacuation time *T* significantly decreases as *dd* increases from 0% to 100% (Fig. 4(b)). While, for *lc* = 0.8, and successively *A* = 1, 3, and 5; the decrease of evacuation time *T* is obtained from *dd* = 0% to 100% (Fig. 4(c)). We also find that for all the value of *lc* (0.3, 0.5, and 0.8); by the increase of *A*, the evacuation time *T* decreases as *dd* increases from 0% to 100%.

4.2 Comparative Evaluation Between Proposed and Previous (NaSch) Model

The comparative evaluation between the proposed model and the previous one (NaSch) is performed by referring to *k* = 0.2; 0.5; and 0.8, respectively. For the proposed model, we use *dd* = 0.8; the value of *A* is in sequence 1, 3, and 5. Using the same value of *lc* = 0.8, the evaluation both of those is conducted for each *k*.

For the low density *k* = 0.2, we get *T* for the previous model is bigger than that the proposed one. The extreme comparison result occurs between *T* in the previous model and *T* in the proposed one using *A* = 5. We find *T* in the previous model is 164 and *T* in the proposed one is 83, thus the proposed model gets *T* almost double faster than that *T* in the previous one (there is the decrease of *T* for the proposed model around 49.4%).

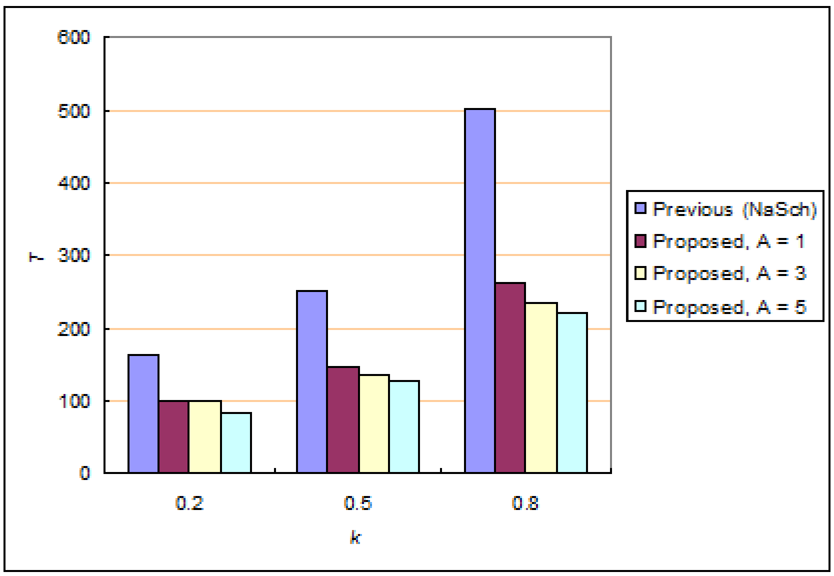

FIGURE 5: Comparative evaluation between the previous model (NaSch) and the proposed one for *lc* = 0.8 and *k* = 0.2; 0.5; 0.8, respectively. The proposed model uses *dd* = 0.8 and successively *A* = 1, 3, and 5.

For the intermediate density *k* = 0.5, we also get *T* for the previous model is bigger than that the proposed one. There is also the extreme comparison result between *T* in the previous model and *T* in the proposed one using *A* = 5. We find *T* in the previous model is 250 and *T* in the proposed one is 127, thus the proposed model gets *T* almost double faster than that *T* in the previous one (there is the decrease of *T* for the proposed model around 49.2%).

For the high density *k* = 0.8, we get *T* for the previous model is bigger than that the proposed one. We have the extreme comparison results between *T* in the previous model and *T* in the proposed one using either *A* = 1, 3, or 5. We find *T* in the previous model is 501, while *T* in the proposed one is 262; 236; and 221, respectively for *A* = 1; 3; and 5. Thus the proposed model gets *T* almost double faster than that *T* in the previous one for *A* = 1, and the proposed model gets *T* more than double faster than that *T* in the previous one for *A* = 3 and 5. It means that there is the decrease of *T* for the proposed model around 47.7%, 52.9%, and 55.9% for successively *A* = 1, 3, and 5.

4.3 The Effectiveness of Reduction the Evacuation Time

In this section, we present the effectiveness of reduction of *T* for unequal vehicle densities *k*. The effectiveness of the proposed model is measured by the comparative evaluation of the evacuation time *T* between the proposed model and the previous one (NaSch model). For the proposed model, we use the several of *dd* and *A*. Either the proposed model or the previous one, the value of *lc* used is 0.8.

	Evacuation time *T*						
	***A* = 1**	**Effectivenes (%)**	***A* = 3**	**Effectivenes (%)**	***A* = 5**	**Effectivenes (%)**	**Previous (NaSch)**
Proposed: *dd* = 0.2	136	17	132	20	124	24	164
Proposed: *dd* = 0.5	116	29	107	35	94	43	
Proposed: *dd* = 0.8	101	38	99	40	83	49	
Proposed: *dd* = 1	99	40	94	43	81	51	

TABLE 1: The effectiveness of *T* for *k* = 0.2, *lc* = 0.8.

A. For the Low Vehicle Density

In Table 1, for the low density *k* = 0.2; *lc* = 0.8; parameters $\bar{v}$ and *sd* used are 4 and 1, respectively; *dd* are consecutively set to 0.2, 0.5, 0.8, and 1; and using A = 1, 3, and 5; we find the effectiveness of reduction of *T*. We provide the effectiveness of *T* for the proposed model is almost double when the percentage ratio of *dd* = 0.8 and *A* = 5, it is 49%. While by using the percentage ratio of *dd* = 1 and *A* = 5, the effectiveness of *T* for the proposed model is more than double, it is 51%.

	Evacuation time *T*						
	***A* = 1**	**Effectivenes (%)**	***A* = 3**	**Effectivenes (%)**	***A* = 5**	**Effectivenes (%)**	**Previous (NaSch)**
Proposed: *dd* = 0.2	224	10	202	19	187	25	250
Proposed: *dd* = 0.5	183	27	164	34	147	41	
Proposed: *dd* = 0.8	146	42	136	46	127	49	
Proposed: *dd* = 1	128	49	125	50	124	50	

TABLE 2: The effectiveness of *T* for *k* = 0.5, *lc* = 0.8.

B. For the Intermediate Vehicle Density

In Table 2, for the intermediate density *k* = 0.5; *lc* = 0.8; parameters $\bar{v}$ and *sd* used are 3 and 1, respectively; *dd* are consecutively set to 0.2, 0.5, 0.8, and 1; and using A = 1, 3, and 5; we find the effectiveness of reduction of *T*. We provide the effectiveness of *T* for the proposed model is almost double when the percentage ratio of *dd* = 1 and *A* = 1, and also occurs for the percentage ratio of *dd* = 0.8 and *A* = 5, those are 49%. While by using the percentage ratio of *dd* = 1 and *A* =

3; and also using *dd* = 1 and *A* = 5, the effectiveness of *T* for the proposed model are double, those are 50%.

	Evacuation time *T*						
	***A* = 1**	**Effectivenes (%)**	***A* = 3**	**Effectivenes (%)**	***A* = 5**	**Effectivenes (%)**	**Previous (NaSch)**
Proposed: *dd* = 0.2	425	15	413	18	393	22	501
Proposed: *dd* = 0.5	341	32	321	36	286	43	
Proposed: *dd* = 0.8	262	48	236	53	221	56	
Proposed: *dd* = 1	220	56	190	62	180	64	

TABLE 3: The effectiveness of *T* for *k* = 0.8, *lc* = 0.8.

C. For the High Vehicle Density

In Table 3, for the high density *k* = 0.8; *lc* = 0.8; parameters $\bar{v}$ and *sd* used are 2 and 1, respectively; *dd* are consecutively set to 0.2, 0.5, 0.8, and 1; and using A = 1, 3, and 5; we find the effectiveness of reduction of *T*. We provide the effectiveness of *T* for the proposed model is almost double when the percentage ratio of *dd* = 0.8 and *A* = 1, it is 48%. While by using the percentage ratio of *dd* = 1 and *A* = 1; *dd* = 0.8 and *A* = 3; *dd* = 1 and *A* = 3; *dd* = 0.8 and *A* = 5; *dd* = 1 and *A* = 5, we get the effectiveness of *T* for the proposed model are more than double, those are 56%; 53%; 62%; 56%; and 64%, respectively.

5. CONCLUSION

Agent drivers and diligent ones are incorporated into the car-following NaSch model. The modified car-following NaSch model is proposed. The relations between the evacuation time and diligent drivers, comparison between the previous model (NaSch) and the proposed one, and the effectiveness of reduction the evacuation time are investigated.

The simulation results find the impact of agent drivers and diligent ones with respect to the evacuation time. Regarding the relations between evacuation time and diligent drivers are obtained that with the increase of diligent drivers, evacuation time decreases either in the low vehicle density, in the intermediate one, or in the high one. In these relations are also shown that with the increase of the number of agent drivers, the evacuation time decreases for each the value of diligent drivers in the same number of agent drivers. Based on the comparative simulation study, this work shows that the proposed model has the faster way than that the previous one in the case of evacuation. The proposed model gets the evacuation time at least almost double faster than that the evacuation time in the previous one for the number of agent drivers is five with a certain value of diligent drivers, it occurs either in the low vehicle density; in the intermediate one; or in the high one. The impact of diligent drivers is depends on the percentage ratio of diligent drivers and is double when the percentage ratio of diligent driver is 100% in the low vehicle density and in the intermediate one, and is more than double when the percentage ratio of diligent driver is 80% or 100% in the high vehicle density. It is also found that the impact of agent drivers is depends of the number of agent drivers and is approximately double when the number of agent drivers is five in the low vehicle density and in the intermediate one (with any certain value of diligent drivers); or is more than double when the number of agent drivers is five in the high vehicle density (with any certain value of diligent drivers), in comparison to the existing simulation results without any agent (NaSch model).

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