A Microscopic Simulation of Evacuation Model Considering Car-Following Behavior under Flood

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Abstract This study developed a microscopic simulation evacuation model considering car-following behavior in flood situation using software AIMSUN. We formulated the relationship between car-following free velocity and the depth of water by information with respect to the accurate representation of vehicle’s dynamics properties under flood. Moreover, a flood prediction model combining traffic analysis is conducted to catch up with the momentarily changed network because of the disaster. We also compare the effectiveness of different departure models of human behavior. They are exponential and simultaneous activities. The results indicate that the flood significantly affects the evacuation and that strategies promoting smooth evacuation activity are very important.

Key Words: microscopic simulation, car-following, flood evacuation, AIMSUN,

1. INTRODUCTION

In recent years, heavy rains, which cause localized flood, often happen in Japan due to the changing of earth environment. For example, in the year 1999, 77mm/hr of rain fell in Fukuoka city; in the year 2003, 99mm/hr of rain fell in Dazaifu city. Furthermore, 2 times’ serious overflows occurred in Mikasagawa and caused severe damage to the main land of Fukuoka city. Figure 1 shows the flood situation in Hakata station located at the center of Fukuoka. Cars were in the state of submersion under water and couldn’t move any more.

Although evacuation on foot is officially recommended if at all possible because of the traffic jam, in practice, for disabled and elderly people, evacuation by automobiles is the only choice. Also, since traveling by car is convenient, comfortable and fast, there are still many people evacuated with car. Moreover, because large amount of car traffic exists before the flood happened in the metropolitan areas, the amount of traffic in flood situation is not little. With the underwater roads increasing for the heavy rain, the network will become more and more congested. The problems mentioned above make the analysis of traffic situation and the finding of suitable policies for a sudden flood become very essential.

In the absence of realistic estimation of vehicle operations under different policy measures,
the conventional evaluation techniques may tend to undervalue/overvalue the measures. To overcome these problems in evaluation, the techniques such as application of microscopic traffic simulation are clearly required. Microscopic simulation, which analyzes each individual vehicle behavior using car-following, lane-change models etc, is proven to be a useful tool for aiding transportation feasibility studies. However, in the previous researches, flood evacuation by car’s microscopic simulation is rarely seen. For example, Takahashi et al. evaluated the refuge system in consideration of the dynamic state of flood by flooding refuge simulation. However, the candidate is only pedestrian. Fukakusa et al. used static assignment method. But static assignment cannot represent the momentarily dynamic changes. Kuwazawa et al. used simple method to express traffic congestion of automobile traffic, etc.

In this research, a microscopic traffic simulation model with a flood prediction module being used to capture the dynamics of the network is built using the software AIMSUN. In order to improve the realism, we formulate a relationship between car-following velocity and the depth of water by information with respect to the accurate representation of vehicle dynamic properties under flood. This relationship is confirmed by the observation data. In addition, evacuee’s departure model is also included in the simulation.

By carrying out the simulation, the car’s movements on the network in the flood and full dynamic time dependent traffic phenomena including congestion are caught visually. In the future, we expect the structure and results of this research can be used in support of flood emergency evacuation and find some useful method to shorten the evacuation time.

Figure 1 Flood situation in Hakata transportation station in Japan (1999)

2. CONCEPTUAL FRAMEWORK OF FLOOD EVACUATION

There are four modules in the conceptual framework for flood evacuation. These modules represent flood hazard, evacuee behavior, agency decisions and transportation modeling. Each of these modules interacts in some way with the other modules. For example, flood hazard can partially or totally block roadways. People act accordingly to the threats they received. Network congestion can cause agency personnel to alter signal timings to relieve bottlenecks. Figure 2 illustrates flood evacuation framework of the identified modules and their proposed interrelationships.

- Flood Prediction Module: predicts the influence of flood harm, such as dike break point, expected duration, area of effect, expanding speed, risk levels, etc.
- Human behavior Module: represents the various behavioral aspects of evacuees. Input parameters include age, gender, economic demographics, departure time and number of the evacuees. Work is ongoing to identify and develop human behavior models as regards emergency evacuation.
• Emergency Management Decision Support Module: takes into account of agency decisions such as resource allocation, road closures, and signal timing plan implementation. This module represents agency level discussions and decision-making.
• Flood Evacuation Traffic Simulation Module: represents the traffic simulation program. It includes the physical data from the traffic network, such as intersection coordinates, link length, speed limits, etc and uses car-following model, lane changing model, etc. to recur the real traffic situation.

In this research, the microscopic simulation evacuation model involves 3 parts: flood prediction model, human behavior module and evacuation traffic simulation module. Emergency management decision support module will be added in the future research.

![Conceptual flood evacuation simulation frameworks](image)

**Figure 2 Conceptual flood evacuation simulation frameworks**

### 3. EVACUATION TRAFFIC SIMULATION MODULE

#### 3.1 Outline of Simulation Model
The basic components and data on various parameters required for development of microscopic traffic simulation model include:

a) Network geometry (nodes, links, segments, zones etc, lane data for each link, link/lane characteristics in terms of capacity etc)

b) Vehicular characteristics (vehicle length, maximum speed, maximum acceleration, maximum deceleration, desired speed, etc.)

c) Driver characteristics and behavior data

d) Travel demand (O-D matrices)

e) Data on traffic control systems (signal phases and cycle length etc.)

f) Traffic flow models such as car-following and lane changing models.

#### 3.2 Car-Following Model in AIMSUN
In this research, traffic modeling package AIMSUN is used for the simulation. AIMSUN is a microscopic simulator that can be used as a tool for traffic analysis to help traffic engineers in
the design and assessment of traffic systems. It has been proven to be very useful for testing new traffic control systems and management policies, either based on traditional technologies or as implementation of Intelligent Transport Systems. The behavior of each vehicle in the network is continuously modeled throughout the simulation time period while it travels through the traffic network, according to several vehicle behavior models (e.g., car-following, lane changing). The system provides highly detailed modeling of the traffic network, it distinguishes between different types of vehicles and drivers. It also enables a wide range of network geometries to be dealt with, and models conflicting maneuvers, etc. The most important model in Aimsun, car-following model, is illustrated in equations (1), (2), and (3).

The car-following model implemented in AIMSUN is based on the Gipps model (Gipps, 1981). It can be considered as an ad hoc development of the empirical model. It basically consists of two components, acceleration and deceleration. The former represents the intention of the vehicle to achieve a certain desired speed, while the latter reproduces the limitations imposed by the preceding vehicle when trying to drive at the desired speed.

This model states that, the maximum speed at which a vehicle (n) can accelerate during a time period (t+T):

$$V_a(n, t+T) = V(n, t) + 2.5 \cdot \alpha(n)T \cdot (1 - \frac{V(n, t)}{V^*(n)}) \cdot \sqrt{0.025 + \frac{V(n, t)}{V^*(n)}}$$

(1)

Where:

- $V(n, t)$ is the speed of vehicle n at time t;
- $V^*(n)$ is the desired speed of the vehicle (n) for current section;
- $T$ is the reaction time;
- $\alpha(n)$ is the maximum acceleration for vehicle n.

The equation of $V^*(n)$ is as function (2)

$$V^*(n) = \text{MIN} \{ s_{lim}(s) \cdot \theta(n), V_{\text{max}}(n) \}$$

(2)

Where:

- $s_{lim}(s)$ is the speed acceptance of the vehicle n;
- $V_{\text{max}}(s)$ is the maximum desired speed of the vehicle n.

On the other hand, the maximum speed that the same vehicle (n) can reach during the same time interval (t+T), according to its own characteristics and the limitations imposed by the presence of the leader vehicle is:

$$V_{\text{p}}(n, t+T) = d(n)T + \sqrt{(d(n)^2T^2 - d(n)\{2[x(n-1, t) - s(n-1) - x(n, t)] - V(n, t)T - \frac{V(n-1, t)^2}{1/2(d(n) + d(n-1))}\}}$$

(3)

where:

- $d(n)$ is the maximum deceleration desired by vehicle n;
- $x(n, t)$ is the position of vehicle n at time t;
- $x(n-1, t)$ is the position of preceding vehicle (n-1) at time t;
- $s(n-1)$ is the effective length of vehicle (n-1);

And $d'(n-1)$ is an estimation of vehicle (n-1)’s desired deceleration as equation (4)

$$d'(n-1) = 1/2 \{ d(n) + d(n-1) \}$$

(4)

Where:

- $d(n-1)$ is the maximum deceleration desired by vehicle n-1.

$$V(n, t+T) = \text{min}(V_{\text{p}}(n, t+T), V_{\text{p}}(n, t+T))$$

Figure 3 shows the simulation execution procedure in an intersection.
3.3. The Car-Following Model Consideration Flooding Situation

In this part, the flood influences will be introduced in AIMSUN’s car-following model, concretely, the free velocity’s average value $\mu$ and standard deviation $\sigma$. The deduction of the new model is from accurate representation of vehicle dynamics properties under flood. And the result is verified by the observation data.

Modeling Free Velocity in the Flood Situation

To improve the realism, we develop a relationship between the depth of water and the car-following free velocity. The model is built on the information of the accurate representation of vehicle dynamics properties. Figure 4 illustrates the forces act on the vehicle in flood situation. The car receives driving force and 3 kinds of resistances. The resistances are 1) water pressure resistance, 2) air pressure resistance, and 3) rolling resistance. The relationship between the resistances and driving force is illuminated in function (5). In the equilibrium situation, driving force is the sum of three resistances.

$$D = \text{Rolling Resistance}(Rr) + \text{Air Pressure Resistance}(Ra) + \text{Water Pressure Resistance}(Rw)$$

$$D = u \ast W + (1/2) \ast \rho \ast CD \ast s \ast (V / 3.6)^2 + K \ast W \ast sw \ast (V / 3.6)^2$$  \hspace{1cm} (5)

Where: $D$ is the driving force (kgf), $\mu$ is the rolling resistance coefficient, $W$ is the weight of the car (kgf), $\rho$ is the air density (kg/m$^3$), $CD$ is the air resistance coefficient (s$^2$/m$^4$), $V$ is the velocity (km/h), $K$ is the water resistance coefficient (kgf*s$^2$/m$^4$), $s$ is the vehicle’s projection area (m$^2$), $sw$ is the tire’s projection area considering water height (m$^2$), in which, $sw=4\ast H\ast TW$, $s=VW\ast VH$, $H$ is the water height (m). $TW$ is the tire width (m). We take the value 0.15 m. $VW$ is the vehicle’s width (m). We take the value 2m, $VH$ is the vehicle’s height (m). We take the value 1m.

The derivation of the relationship between water depth and free velocity illustrated in Figure 5 is from the hypothesis that even at the time of road submersion under water, people steps the engine routinely as usual. That means the power produced is same in the two situations.

$$(Rr+Ra(V))\ast V=(Rr+Ra(V1)+Rw(V1))\ast V1$$

Where $V$ is the free velocity in the dry situation, $V1$ is in the flood situation. It is a cubic function of the velocity and the water height. Solving this function we got:
\[ V_1 = \begin{cases} \sqrt{\frac{C}{2} + \frac{C^2}{4} + \frac{b^3}{27}} + \sqrt{\frac{C^2}{2} - \sqrt{\frac{C^2}{4} + \frac{b^3}{27}}} \times 3.6 & 0 \leq H < 30 \text{ cm} \\ 0 & H \geq 30 \text{ cm} \end{cases} \] (6)

\[ b = u \times W \times \left( \frac{1}{2g} \times CD \times \rho \times s + 4000 \times K \times sw \times H \right) \] (7)

\[ c = \frac{-(u \times W + \frac{1}{2g} \times CD \times \frac{V}{3.6} \times \rho \times s) \times V}{\left( \frac{1}{2g} \times CD \times \rho \times s + 4000 \times K \times sw \times H \right)} \] (8)

Where, \( V_1 \) is the free velocity considering water height (0~30cm)

Figure 5: Speed slowdown by the water assistance with the fixed driving force

The approximation equation of the curve in Figure 5 is shown in Function (6). The \( V_1(i) \) (we take it as vehicle’s free velocity) in function (2) changes with the water height. When the water height (exceeding link height part) ranging from 0 to 30cm, the \( V_1(i) \) changes as Figure 5 shown and drops to 0 when the height is over 30cm. From the observation data, when speed at 40km/h in dry situation produces the fittest engine’s power.

Verification

The data used for the verification is from intermittent press recorder during May to July 2008, which was broadcast in television news when heavy rain attacked Japanese islands. Figure 6 represents one of the examples.

Generally, press recorder information is not suitable for research. To ensure the use of reliable data, only the ones that fulfill the following three conditions were used: 1) Camera was fixed, 2) Water depth can be roughly certified, and 3) No influence of a signal or a pedestrian. Just 5 minutes’ recorders met the above-mentioned conditions and used for the analysis.

Velocity is measured by dividing the length of vehicle’s main body by the elapsed time to cross with the same length on the road, on the condition that it keeps sufficient distance between the front cars. Since a random error cannot be avoided by manual operation, the count repeated many times until reproducibility was obtained and the average value with 0.5-second’s accuracy was used as the result. In addition, since water depth cannot be measured exactly, two classifications into high depth (15cm) and low depth (5cm) were set by observation. The classification boundary is from the rim or rubber height of the tire. For light
car, the value is 10cm and for normal car, it is 12cm. The water below boundary case is low depth and over boundary case is high depth. Average values and standard distributions of velocity of two levels are illustrated in Table 1. In the 5cm condition, the average speed is 18.8km/h and the standard deviation is 8.4. In the 15cm condition, the average speed is 11.4km/h and the standard deviation is 4.7. With the depth of water increasing, average speed decreased, while standard deviation increased. It can be concluded that the decreasing of velocity leads towards reducing on the flexibility of freedom accordingly. The distribution of observation result is shown in Figure 7. But the distribution curve is not so precise because of the limited number of data. We will get more data to detail the tendency in the future research.

The comparison of the observation values with the theoretic value presents in Figure 5. The blue and red observation results were piled up with the theoretic distribution curve (at 40km/h speed). It turns out that the free velocity from observation is in agreement with the result deduced from the assumption function and function (6) can be accepted for simulation.

### Table 1 Distribution of the free velocity

<table>
<thead>
<tr>
<th></th>
<th>Average Velocity (km/h)</th>
<th>Decrease Rate</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low depth</td>
<td>18.8</td>
<td>53%</td>
<td>8.4</td>
</tr>
<tr>
<td>High depth</td>
<td>11.4</td>
<td>71.5%</td>
<td>4.7</td>
</tr>
</tbody>
</table>

![Figure 6: Counting the free velocity](image)

![Figure 7: The distribution of the free velocity](image)

### 4. FLOOD PREDICTION MODULE

A simple flood prediction model is used to derive the dynamic changes of the network. It is assumed that the flood spread from the flood start point with a fixed flow velocity, and at the
reached point it rises at a certain speed. The spreading flow velocity is set to 1m/s, and the rising speed is set to 0.01m/s. There is just one flood dike break point as shown in Figure 9.

5. EXAMPLE NETWORK DESIGN AND SIMULATION APPLICATION

5.1 Vehicle Generations Based on OD Matrix
In this research, two kinds of hourly traffic volume are considered. One is passing traffic whose origin and destinations are not in the object area and it is the traffic just passing through the object area. The other is evacuation traffic that not only origins but also destination shelters are all in the object area and it is the traffic for evacuation. The OD pairs and traffic volumes are illuminated in Table 2.

Based on the OD Matrix mentioned above, two kinds of vehicle generation patterns (scenario A and B) are set.

Scenario A is the activity performed in accordance with the exponential distribution over the simulation period. The reason for setting this kind of pattern is that even the information concerning evacuation and flood threats being provided to the residents living in the object area, the recipients might not carry out the evacuation activity immediately and a staged evacuation activity may be executed. As in Function (9), the interval $T$ between the average arrival times of two continuous vehicles is the function of the mean input flow $\lambda$ and a random value $\mu$.

On the contrary to the staged pattern, scenario B is also performed, assuming that the residents took evacuation simultaneously from the starting time of flood.

\[
T = -1/\lambda \ln(\mu)
\]  

(9)

where, $\mu$ is the random variable within $(0,1)$,

$T$ is the interval between the average arrival times of two continuous vehicles,

$\lambda$ is the mean input flow (vehicles/second).

5.2 Network
A virtual network is made up of 844 links and 388 nodes. It also includes the signals, origination, destination, etc. Evacuation area ranges from 30 unit blocks that located around the river. The departure point of each household in each unit taking refuge is the center of the block. The evacuation destinations located in 5 accommodation shelters, as shown in Figure 9. Link data include the link altitude, number of lanes, speed limit, link types, and the length. Figure 9 also shows 3 link types: (1) national highway, (2) prefectural road, and (3) general way, of which (1) and (2) were regarded as trunk road in red and the general way was in black. The link’s altitude was set per 0.1m units by reference of the hazard map. Red links’ altitude in Figure 8 is 0.1~0.9m, yellow links’ is 1.0~1.9m, green links’ is 2.0~2.4m, blue links’ is 2.5~3m, and grey links’ is above 3.0m.
5.3 Evacuation Activity Settings

a) Limit water depth for car

Limit water depth is the depth that, if exceeded, car cannot move any more. It is set to 0.3m in this research. From the viewpoint of the relations among water depth and height of the links, it is quantitatively estimated whether the inhabitants could take refuge or not by traveling by car to evacuation shelters.

b) Evacuation activity

Table 3 shows the settings of evacuation activity. In addition, since the drivers of passing traffic are not familiar with the local road of the object area, it is assumed that they use only the trunk road.
Table 3 Settings of the evacuation activity

<table>
<thead>
<tr>
<th>Component</th>
<th>Definition and Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evacuee</td>
<td>The residents of an object area</td>
</tr>
<tr>
<td>Means of evacuation</td>
<td>Car</td>
</tr>
<tr>
<td>The rate of evacuation</td>
<td>100% (all residents living in the object area taking refuge)</td>
</tr>
<tr>
<td>Refuge Origin</td>
<td>30 places (center of each unit block)</td>
</tr>
<tr>
<td>Accommodation shelters’ choice</td>
<td>5 places (The nearest shelters from a place of residence)</td>
</tr>
<tr>
<td>The starting time of evacuation</td>
<td>From the dike breaking time</td>
</tr>
<tr>
<td>Simulation duration</td>
<td>60 minutes</td>
</tr>
<tr>
<td>The usage of trunk road</td>
<td>All the cars including passing traffic</td>
</tr>
<tr>
<td>The usage of local road</td>
<td>Just for evacuation</td>
</tr>
</tbody>
</table>

5.4 Simulation Result

Contrary to the road flood case “Flooding”, simulation is also carried out for the no flood damage case “Normal”. Altogether, 4 types of simulation were carried out including the above-introduced scenario A and B. Results are illuminated as below.

Tables 4 and 5 illustrate the evacuated number of the persons who finished the evacuation within simulation by destination shelters in scenarios A and B, respectively.

Table 4 Evacuation result in scenario A

<table>
<thead>
<tr>
<th>Shelter</th>
<th>Total number needs to evacuation</th>
<th>Evacuated Number</th>
<th>Evacuated Rate</th>
<th>Evacuated Number</th>
<th>Evacuated Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shelter 1</td>
<td>1635</td>
<td>1235</td>
<td>75.5%</td>
<td>458</td>
<td>28.01%</td>
</tr>
<tr>
<td>Shelter 2</td>
<td>2551</td>
<td>1458</td>
<td>57.15%</td>
<td>695</td>
<td>27.24%</td>
</tr>
<tr>
<td>Shelter 3</td>
<td>1055</td>
<td>909</td>
<td>86.16%</td>
<td>205</td>
<td>19.43%</td>
</tr>
<tr>
<td>Shelter 4</td>
<td>4531</td>
<td>2857</td>
<td>63.05%</td>
<td>816</td>
<td>18.01%</td>
</tr>
<tr>
<td>Shelter 5</td>
<td>1505</td>
<td>875</td>
<td>58.14%</td>
<td>86</td>
<td>5.71%</td>
</tr>
<tr>
<td>Total</td>
<td>11277</td>
<td>7334</td>
<td>65.04%</td>
<td>2260</td>
<td>20.04%</td>
</tr>
</tbody>
</table>

Table 5 Evacuation result in scenario B

<table>
<thead>
<tr>
<th>Shelter</th>
<th>Total number needs to evacuation</th>
<th>Evacuated Number</th>
<th>Evacuated Rate</th>
<th>Evacuated Number</th>
<th>Evacuated Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shelter 1</td>
<td>1635</td>
<td>1256</td>
<td>76.82%</td>
<td>991</td>
<td>60.61%</td>
</tr>
<tr>
<td>Shelter 2</td>
<td>2551</td>
<td>1223</td>
<td>47.94%</td>
<td>694</td>
<td>27.21%</td>
</tr>
<tr>
<td>Shelter 3</td>
<td>1055</td>
<td>698</td>
<td>66.16%</td>
<td>379</td>
<td>35.92%</td>
</tr>
<tr>
<td>Shelter 4</td>
<td>4531</td>
<td>2789</td>
<td>61.55%</td>
<td>924</td>
<td>20.39%</td>
</tr>
<tr>
<td>Shelter 5</td>
<td>1505</td>
<td>260</td>
<td>17.28%</td>
<td>147</td>
<td>9.77%</td>
</tr>
<tr>
<td>Total</td>
<td>11277</td>
<td>6226</td>
<td>55.21%</td>
<td>3135</td>
<td>27.80%</td>
</tr>
</tbody>
</table>

For scenario A, in the Normal case the evacuated number is 7334, and in the Flooding case it is 2260. For scenario B, in the Normal case the number is 6226, and in the Flooding case the number is 3135. The number decreases sharply in Flooding case in both scenarios. To note,
for Flooding case, the number increased by nearly 38.7% in scenario B as compared to scenario A, suggesting that the effect will become more obvious if the evacuation begins at an earlier time.

Figures 10–13 illustrate the relationships between elapsing time and the cumulative evacuated number. The number increases almost linearly in the Normal case. However the value is fixed at nearly the 20 min in the Flooding case, not only because of the blocked road but also because of the depth of flood.

Figures 14–17 illustrate the evacuated number in every minute. In the Normal case, Fig. 14 illustrates the number in scenario A. Initially evacuated people are few in minutes. As the time increased, the number also increases. However, the number seems a slightly decreases after 20 minutes. Fig.16 shows the distribution in scenario B. It is decreased dramatically as compared to scenario A after 20 minutes, suggesting more serious congestion in this scenario. In the Flooding case, Fig. 15 shows the distribution in scenario A. It increases from the beginning and reaches the maximum value at the time of 10 minutes. Then, it decreases and reaches zero nearly after 25 minutes because of the depth of flooding and the congestion. Fig. 17 illustrates the distribution in scenario B. It shows the same shape as Fig. 15.

Finally, in order to grasp the traffic congestion phenomenon in the road network, the simulation results at the time of 20 minutes when the evacuated number decreases rapidly in both scenarios and both cases illustrate in figures 18 to 21. The traffic density is over 90 vehicles/km for red links, the place where the congestion is most intensive. As can be seen from the figures, it is clear that the congestion situation in scenario B is more serious than that in scenario A for both cases. Nevertheless, the obvious differences between Normal and Flooding cases are not shown. One reason is that the households who cannot hold the evacuation activity increased because the roads near departure place and the reception centers were flooded. Another reason is that in reality, the departure activity is neither simultaneously nor exponential distributed all over the evacuation time. The decision should be made according to the agency-level, which is informed through an effective warning system. This is an important function of the Emergency Management Decision Support Module. But in the present research, this kind of module hasn’t been included.

6. CONCLUSION

In this research, a car-following model consideration of the flood situation is used in the microscopic traffic simulation. Totally 4 types simulation were carried out involving 2 scenarios and 2 cases. From the results, we can conclude that flood has large influence on the evacuation activity. In this research, only the free velocity’s change is considered in the new model. The vehicle’s acceleration and deceleration affected by the flood and the distance between the front cars should also be taken into account. And the Emergency Management Decision Support Module should be added in the model. The future subjects are: (1) to build a highly accurate flood prediction model considering internal water and riverine flood, (2) to build a new car-following model including the changes of speed, acceleration, deceleration and other factors affected by the flood with the depth of water to improve the realism, (3) to apply the simulation to a real network, (4) to realize the three dimension including the
animation of flood, and (5) to add emergency management decision support module to verify the effect of each measure.
Figure 14 Timely completion number of evacuation in scenario A (Normal)

Figure 15 Timely completion number of evacuation in scenario A (Flooding)

Figure 16 Timely completion number of evacuation in scenario B (Normal)

Figure 17 Timely completion number of evacuation in scenario B (Flooding)
Figure 18: The congestion condition for scenario A (normal)

Figure 19: The congestion condition for scenario A (flooding)

Figure 20: The congestion condition for scenario B (normal)

Figure 21: The congestion condition for scenario B (flooding)
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