Chapter 2

Microscopic validation through sensitivity analysis for the pedestrian’s directional switching behavior model

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2.1 Introduction

For the past four decades, the development of different kinds of model can be seen to simulate complex crowd behavior. Modeling and simulation have become the best choice of methodology to understand and predict certain phenomena in a crowd by its replication. The crucial traits in human crowd behavior and the emergence of several empirically observed collective behavior in a crowd could be reproduced and explained [1, 2, 3, and 4].

In this contribution, the switching action behavior of pedestrian is highlighted and the one-way sensitivity analysis is performed to validate the developed switching action behavior model. Since, in the current state, no available empirical data to be compared with the model's outcomes, the choice of sensitivity analysis is significant.

2.2 Switching action behavior model

A switching action behavior is studied to simulate a scenario of pedestrians change their direction of walking. This scenario is indisputably can happen in any situation. For example, during emergency evacuation, when the designated evacuation area is fully occupied with the preceding evacuees, the trailing evacuees have to change their directions to another evacuation area. Recent literature shows that the change in direction has not been taken into account in any pedestrian modelling.
In this contribution, the CBS-DE, which has been used in the previous studies [5, 6, 7, 8], is employed and extended accordingly in order to study switching action behavior. The mechanism of switching action behavior is proposed by formulating the switching action function through convolution integral of two functions. The change in direction is defined based on the motion of other persons in the perception domain. In reference to the perception domain of a person $i$, if the number of persons in the perception domain of the person $i$ is greater than 9 and the average walking velocity of those persons in the perception domain is less than or equal to 1.0 m/s, the switching action function is activated. Once the switching action function exceeds the critical switching action time $F_{sw,c}$, the person $i$ will change his/her direction.

2.3 Modeling and sensitivity analysis

2.3.1 Mathematical modelling

The following flowchart (Fig. 1) portrays the formulation of switching action behavior. The change in direction of a person $i$ is dependent on the motion of other persons in the perception domain in the defined switching action time. The switching action time is given by the switching action function described by a convolution integral.

To simulate the change in direction, the switching action behavior function is defined for each person $i$. To avoid an artefact of the flow, the change in direction of the person $i$ is determined by reference to the motion of other persons in the perception domain in the defined switching action time. The switching action function is only activated at the time $t$ when a person $i$ satisfies the following conditions:

1. the number density of persons in the perception domain of a person $i$ is more than 9; and
2. the average walking velocity of these persons in the perception domain is less than or equal to 1.0 m/s.
The number of 9 persons is decided by considering the congestion density in the perception domain of a person \( i \) with a radius for switching action model 1.516 m \((= 4d_i)\), as shown in Fig. 2.

![Flow chart of the mechanism of switching action behavior](image)

**Fig.1 Flow chart of the mechanism of switching action behavior**
The switching action function for the person $i$ is calculated by equations 1 and 2.

$$F_{SW}(t) = \int_{t-\alpha_{SW}}^{t} f_{SW}(\tau)g_{SW}(t-\tau)d\tau \quad (1)$$

$$g(t) = e^{-t} \quad (2)$$

where $F_{SW}(t)$ is the switching action function, $f_{SW}$ is the input function, which indicates the number of persons in the perception domain of the person $i$ and $g_{SW}$ is the unit response function. The response function reflects the delay of switching action. For the $g(t)$, a monotonous damping function with respect to time contributes a computational stability. In the present study, the exponentially-decaying function is employed as the $g(t)$.

The change in direction will only takes place once the switching action function exceeds the critical switching action time factor. The critical switching action time factor, $F_{SW,c}$ is introduced in this study, which varies according to the congestion and perception-response time $\alpha_{SW}$. A perception-response time $\alpha_{SW}$ is a model parameter that has to be
calibrated in order to obtain an appropriate switching action behavior. Once $F_{sw}(t)$ of the person $i$ attains the critical switching action time factor $F_{sw,c}$, the person $i$ will change his/her direction to the opposite direction. $F_{sw,c}$ was given by the assumption that 9 persons exist continuously in the perception domain in the perception-response time $\alpha_{sw}$ as follows:

$$F_{sw}(t) = 9\int_{t-\alpha_{sw}}^{t} g_{sw}(t-\tau)d\tau = 9(1-e^{-\alpha_{sw}})$$

(3)

The schematic illustration for the switching action function, $F_{sw}(t)$ and critical switching action time, $F_{sw,c}$ is shown in Fig. 3. Figure 3 indicates that the moving direction is changed at the time $(t)_3$, when $F_{sw}(t)$ is equal to $F_{sw,c}$.

Fig. 3 Example of time series of the switching action function

2.3.2 Validation setting

The sensitivity analysis is performed to assess the impact of the model parameter for perception-response time, $\alpha_{sw}$ on the output of switching action behavior model. The validation is made with a focus on realistic motion of switching action behavior macroscopically. Further from the viewpoint of microscopic, the maximum contact force acting on each person is compared with the experimental results of comfortable loads for people observed by [9].

On the basis of the above circumstances, a range of values of model parameter $\alpha_{sw}$, which gives an appropriate switching action behavior
visually, is calibrated first. This is achieved by conducting trial simulations on the test computational domain by employing CBS-DE with switching action behavior model. The calibrated range of values of model parameter $\alpha_{sw}$ in trial simulations that gives a realistic motion of switching action behavior also be checked for the safe level of contact forces.

Checking for the maximum contact force is performed within macroscopically calibrated range of values of model parameter. The maximum contact force to the recommended values of the parameter must satisfy the benchmark of the safe level of contact force.

2.3 Safe level of contact force

The contact force acting on each person is a significant output from the current trial simulations. The measurement of potential for injury on a human had been reported previously. For instance, an experimental investigation on the level of comfortable loads for people had been conducted by [9]. Twenty-one people with the range of age from 20 to 25 years old had been tested on three barrier types loaded on upper and lower chest and abdomen. In their findings, the comfortable limits of loads were ranged from 175 N to 247 N. Hence, this range of the comfortable loads is used in this work as a benchmark for the safe level of contact forces for each person.

2.3.4 Trial simulations

To examine the change in direction exhibited by the switching action behavior model, a sensitivity analysis through a few trial simulations are conducted on the proposed test computational domain as depicted in Fig. 4. The test computational domain consists of a corridor with a length of 21.0 m and a width of 3.0 m, connected with a rectangular evacuation area on the right-side and an initial position area of persons on the left-side. The designated evacuation area is 4.0 m in length and 3.0 m in width. The test computational domain is delimited by walls with thickness of 0.379 m. The capacity of the designated evacuation area is 35 persons, which gives the density of 2.9 persons/m$^2$. This number is determined based on the
definition of the crowd density by the Department for Culture, Media and Sports (2008).

In the trial simulations, a total of 100 persons are considered and they are positioned randomly with no contacting condition between persons in the initial position area as shown in Fig. 4, with the initial velocities of zero. CBS-DE with switching action behavior model is employed. Persons are moving from the left-side of the test computational domain to the designated evacuation area on the right-side with an inflow rate of 1.9 person/s. The trial simulations associated with the parameter setting in the sensitivity analysis are described in the next subtopic.

![Fig. 4 Test computational domain and initial position of persons for trial simulation](image)

2.4 Results and discussion

2.4.1 Switching action behavior

The calibration is done through sensitivity analysis (trial simulations) for a change in direction by employing CBS-DE with switching action behavior model. In this work, a range of values for the parameter of perception-response time, $\alpha_{sw}$ is checked between 0.100 s to 0.250 s with the interval of 0.025 s. In total there are seven calibrated values and hence seven trial simulations have been conducted (denoted as Sim-1 ~ Sim-7). The results of the trial simulations; the range of values of the perception-response time $\alpha_{sw}$, and the values of critical switching action time factor, $F_{sw,c}$ are summarized in Table 1. The critical switching action time factor, $F_{sw,c}$ is determined from Eq. 3.

Within the range of values for the parameter of perception-response time $\alpha_{sw}$, performances of change in direction are visually realistic and
acceptable. These are depicted in the snapshots shown in Fig. 5 (a) – (g) which illustrated the switching action behavior of persons who were changing their moving direction with different values of \( \alpha_{sw} \) and their respective \( F_{sw,c} \) for every 5 s in the time \( t \) ranging from 45 s to 70 s. The circles in the snapshots represent persons and the arrows show the moving directions of persons. The white circles indicate persons who are moving from the initial position area to an evacuation area. Meanwhile, the black circles indicate persons who have changed their moving directions.

From the snapshots of all simulations (Sim-1 ~ Sim-7), no significant difference can be seen in terms of the switching action behavior, realistic and reasonable switching action behavior can be shown. The person began to change in his/her moving direction around the time \( t = 42 \text{s} \) (Sim-1 and Sim-2) and \( t = 43 \text{s} \) (Sim-3 ~ Sim-7). The time necessary for completion of the switching action behavior was ranged from 21 s to 24 s. The detailed results are concluded in Table 2. To investigate the results microscopically, the maximum contact force acting on each person was checked to a benchmark for the safe level of contact force for each person. It can be seen, Sim-2 and Sim-4 give the low value of contact force which are not exceed the safe level of contact force.

<table>
<thead>
<tr>
<th>Trial simulation</th>
<th>Perception-response time, ( \alpha_{sw} ) (s)</th>
<th>Critical switching action time factor, ( F_{sw,c} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sim-1</td>
<td>0.100</td>
<td>0.856</td>
</tr>
<tr>
<td>Sim-2</td>
<td>0.125</td>
<td>1.058</td>
</tr>
<tr>
<td>Sim-3</td>
<td>0.150</td>
<td>1.254</td>
</tr>
<tr>
<td>Sim-4</td>
<td>0.175</td>
<td>1.445</td>
</tr>
<tr>
<td>Sim-5</td>
<td>0.200</td>
<td>1.631</td>
</tr>
<tr>
<td>Sim-6</td>
<td>0.225</td>
<td>1.813</td>
</tr>
<tr>
<td>Sim-7</td>
<td>0.250</td>
<td>1.991</td>
</tr>
</tbody>
</table>

Table 1 The data for trial simulations
Fig. 5(a) Snapshots of persons changing their moving direction ($\alpha_{sw} = 0.100, F_{sw,c} = 0.856$)

Fig. 5(b) Snapshots of persons changing their moving direction ($\alpha_{sw} = 0.125, F_{sw,c} = 1.058$)
Fig. 5(c) Snapshots of persons changing their moving direction (α_{sw} = 0.150, F_{sw,c} = 1.254)

Fig. 5(d) Snapshots of persons changing their moving direction (α_{sw} = 0.175, F_{sw,c} = 1.445)
Fig. 5(e) Snapshots of persons changing their moving direction ($\alpha_{sw} = 0.200$, $F_{sw,c} = 1.631$)

Fig. 5(f) Snapshots of persons changing their moving direction ($\alpha_{sw} = 0.225$, $F_{sw,c} = 1.813$)
Fig. 5(g) Snapshots of persons changing their moving direction ($\alpha_{sw} = 0.250, F_{sw,c} = 1.991$)

Table 2 The results obtained from trial simulations

<table>
<thead>
<tr>
<th>Trial simulation</th>
<th>Time of 1\textsuperscript{st} person to switch (s) ($T_{sw1}$)</th>
<th>Time of switching action activity completed (s) ($T_{sw2}$)</th>
<th>Duration of switching action (s) ($T_{sw2} - T_{sw1}$)</th>
<th>Max. contact force, $F_{con,max.}$ (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sim-1</td>
<td>42</td>
<td>66</td>
<td>24</td>
<td>725.73</td>
</tr>
<tr>
<td>Sim-2</td>
<td>42</td>
<td>65</td>
<td>23</td>
<td>208.63</td>
</tr>
<tr>
<td>Sim-3</td>
<td>43</td>
<td>65</td>
<td>22</td>
<td>376.98</td>
</tr>
<tr>
<td>Sim-4</td>
<td>43</td>
<td>64</td>
<td>21</td>
<td>166.44</td>
</tr>
<tr>
<td>Sim-5</td>
<td>43</td>
<td>64</td>
<td>21</td>
<td>447.43</td>
</tr>
<tr>
<td>Sim-6</td>
<td>43</td>
<td>65</td>
<td>22</td>
<td>563.89</td>
</tr>
<tr>
<td>Sim-7</td>
<td>43</td>
<td>66</td>
<td>23</td>
<td>309.42</td>
</tr>
</tbody>
</table>

2.4.2 Contact force

As mentioned in the previous subchapter, the maximum contact force is a significant output in this study in order to select the appropriate value of the perception-response time $\alpha_{sw}$. To ascertain the maximum contact force acting on each person within the safe level of contact force, a time series of maximum contact force is plotted. Figure 6 (a) – (g) show the
time series of the maximum contact force acting on the person from the time \( t = 40 \sim 100 \) s for all the simulations (Sim-1 \~ Sim-7). The vertical dashed-lines in the graphs indicate the time range in which the switching action behavior is activated.

By considering the upper and lower limit of the comfortable loads in the range of 175 \~ 247 N, only \( F_{sw,c} = 1.058 \) (Sim-2) and 1.445 (Sim-4), with perception-response time \( \alpha_{sw} = 0.125 \) s (Sim-2) and 0.175 s (Sim-4), respectively, gave good results in terms of the safe level of contact force. The maximum value of the inter-element force with 208.63 N occurs at the time \( t = 59 \) s for the Sim-2 and at time \( t = 53 \) s for the Sim-4 with 166.44 N.

Usually people tend to avoid contact with neighboring persons in the walking process. If we rely on this viewpoint, a parameter value in the Sim-4 should be chosen as the appropriate one rather than that in the Sim-2.

![Fig. 6(a) The time-series of the maximum contact force for Sim-1](image-url)
Fig. 6(b) The time-series of the maximum contact force for Sim-2

Fig. 6(c) The time-series of the maximum contact force for Sim-3
Fig. 6(d) The time-series of the maximum contact force for Sim-4

Fig. 6(e) The time-series of the maximum contact force for Sim-5
2.5 **Summary**

In this contribution, the switching action behavior model has been proposed to simulate the change in direction by formulating the switching action behavior model based on the convolution integral. The validation of the developed model was performed through the sensitivity analysis by calibrating the model parameter, perception-response time $\alpha_{sw}$. The output of the sensitivity analysis was checked both qualitative and
quantitative considerations of switching action behavior and the maximum contact force acting on each person. The choice of sensitivity analysis is significant in this contribution. It is suggested further application of the model can be demonstrated in safety engineering like evacuation during emergency situation.

References