Specification, estimation and validation of a pedestrian walking behavior model

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Thomas Robin

13th December 2007
Objectives

- Model the pedestrian behavior at operational level
- Develop a specification with ‘constrained’ and ‘unconstrained’ parameters
- Estimate the model
- Validate the model
Outline

- Introduction

- Model specification:
  - The space discretization
  - The choice set
  - Cross nested structure
  - Utility specification

- Model estimation:
  - The Japanese data set
    - General diagnosis
    - Parameters values

- Model validation:
  - Methodology
    - Validation of the specification
    - The Dutch data set
    - Validation of the model

- Conclusion
Introduction

- **Microscopic** model: capture the behavior of each pedestrian

- **Operational** level: short range behavior, instantaneous decisions
  - Exogenous destination

- Concept of **personal space**: interactions with other pedestrians
  - Leader follower
  - Collision avoidance
**Model specification** : the space discretization

- **Discrete choice model** : at each step, the pedestrian has to choose the next step in the choice set.

  - **Pedestrian visual space**
  - **Choice set** : discretization of the visual space

  At each step the **choice set** depends on the pedestrian speed and direction.
Model specification: the choice set

3 speed regimes

11 directions

33 alternatives
Model specification: cross nested structure

- **Hypothesis**: alternatives correlated along speed regimes and directions

  Cross Nested Logit model

- **Cross Nested structure**: each alternative belongs to 2 nests

  Nesting based on direction

  Nesting based on speed regime
Model specification: cross nested structure

- Probability of choosing the alternative $i$:

$$P(i|C) = \sum_{m=1}^{M} \frac{\left( \sum_{j \in C} \alpha_{jm}^{\mu_m/\mu} y_j^{\mu} \right)^{\mu/\mu_m}}{\sum_{n=1}^{M} \left( \sum_{j \in C} \alpha_{jn}^{\mu_n/\mu} y_j^{\mu} \right)^{\mu/\mu_n}} \frac{\alpha_{im}^{\mu_m/\mu} y_i^{\mu}}{\sum_{j \in C} \alpha_{jm}^{\mu_m/\mu} y_j^{\mu}}$$

$C$: choice set
$M$: number of nests
$\mathcal{V}_i$: utility of alternative $i$
$\alpha_{jm}$: membership degree of alternative $j$ in the nest $n$
$\mu_m$: parameter of the nest $m$
$y_i = e^{\mathcal{V}_i}$
Model specification: utility specification

Pedestrian walking behavior

Unconstrained
- Keep direction
- Toward destination
- Free flow acc/dec

Constrained
- Collision avoidance
- Leader follower
Model specification: utility specification

\[ V_{vdn} = \beta_{dir\_central} dir_{dn} I_{central} + \left\{ \begin{array}{l}
\beta_{dir\_side} dir_{dn} I_{side} + \\
\beta_{dir\_extreme} dir_{dn} I_{extreme} + \\
\beta_{ddist} ddist_{vdn} + \\
\beta_{ddir} ddir_{dn} + 
\end{array} \right\} \]

*keep direction*

\[ \beta_{dec} I_{v,dec} \left( \frac{v_n}{v_{max}} \right)^{\lambda_{dec}} + \]

*free flow acceleration*

\[ \beta_{acc\_LS} I_{LS} I_{v,acc} \left( \frac{v_n}{v_{max\_LS}} \right)^{\lambda_{acc\_LS}} + \]

\[ \beta_{acc\_HS} I_{HS} I_{v,acc} \left( \frac{v_n}{v_{max\_HS}} \right)^{\lambda_{acc\_HS}} + \]

*leader-follower*

\[ I_{v,acc} I_{acc} \alpha_{acc} D_{acc}^L \Delta v_{acc} \Delta \theta_{acc}^L + \]

\[ I_{v,dec} I_{dec} \alpha_{dec} D_{dec}^L \Delta v_{dec} \Delta \theta_{dec}^L + \]

*collision avoidance*

\[ I_{d,dn} I_C \alpha_C e^{-\rho_C D_C} \Delta v_C^C \Delta \theta_C^C \]
Model specification: utility specification

- Keep direction (unconstrained):

\[
\begin{align*}
\beta_{dir\_central} \cdot dir_{dn} \cdot I_{central} &< 0 \\
\beta_{dir\_side} \cdot dir_{dn} \cdot I_{side} &< 0 \\
\beta_{dir\_extreme} \cdot dir_{dn} \cdot I_{extreme} &< 0
\end{align*}
\]
Model specification : utility specification

- Toward destination (unconstrained): \( \beta_{ddist}ddist_{vdn} + \beta_{ddir}ddir_{dn} < 0 \)
Model specification: utility specification

- Free flow acceleration (*unconstrained*):

  - Acceleration:
    \[
    \beta_{accLS} I_{LS} I_{v,acc} \left( \frac{v_n}{v_{maxLS}} \right)^{\lambda_{accLS}} + \beta_{accHS} I_{HS} I_{v,acc} \left( \frac{v_n}{v_{max}} \right)^{\lambda_{accHS}}
    \]

    \(\beta_{accLS}\) and \(\beta_{accHS}\) determine the significance of acceleration at low and high speeds, respectively.

    \(I_{LS}\) and \(I_{HS}\) are indicators of low and high speed, respectively.

    \(\beta_{accLS} I_{LS} I_{v,acc} \left( \frac{v_n}{v_{maxLS}} \right)^{\lambda_{accLS}}\) and \(\beta_{accHS} I_{HS} I_{v,acc} \left( \frac{v_n}{v_{max}} \right)^{\lambda_{accHS}}\) represent the acceleration utilities at low and high speeds, respectively.

  - Deceleration:
    \[
    \beta_{dec} I_{v,dec} \left( \frac{v_n}{v_{max}} \right)^{\lambda_{dec}}
    \]

    \(\beta_{dec}\) and \(\lambda_{dec}\) determine the significance of deceleration at any speed.
Model specification: utility specification

- Leader follower (constrained):

\[ I_{v,acc} I_{acc}^L \alpha_{acc}^L D_{acc}^L \Delta v_{acc}^L \Delta \theta_{acc}^L + I_{v,dec} I_{dec}^L \alpha_{dec}^L D_{dec}^L \Delta v_{dec}^L \]

\[ \text{sensitivity} \quad \text{stimulus} \quad \text{sensitivity} \quad \text{stimulus} \]
Model specification: utility specification

- Collision avoidance (constrained): $I_{d_n} I_C \alpha_C e^{-\rho_C D_C} \Delta \nu_C \Delta \theta_C$

sensitivity stimulus

Diagram showing potential colliders and a collider with distances $D_d$, $D_k$, and $\theta_d$. The diagram also includes an equation involving $I_{d_n} I_C \alpha_C e^{-\rho_C D_C} \Delta \nu_C \Delta \theta_C$.
The Japanese data set: video sequence

- Collected in Sendaï, Japan, on August 2000, large pedestrian crossing road
The Japanese data set: data processing

- Tracking from video sequence: **2 observations per second**
- Pedestrians trajectories extracted using 3D-calibration (DLT algorithm)
- For each pedestrian trajectory:
The Japanese data set: pedestrian trajectory

- 4 alternatives are never chosen: 1, 12, 23, 33
Model estimation: general diagnosis

- Estimation made using the free Biogeme package (biogeme.epfl.ch)
- Estimation results:

  Number of estimated parameters: 24
  Null log-likelihood: -32451
  Final log-likelihood: -13997.27
  Likelihood ratio test: 36907
  $\bar{\rho}^2 = 0.568$

- Parameters values consistent with hypothesis
Model estimation: parameters values

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Coefficient estimate</th>
<th>t test 0</th>
<th>t test 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_{ddir}$</td>
<td>-0.0790</td>
<td>-21.91</td>
<td></td>
</tr>
<tr>
<td>$\beta_{ddist}$</td>
<td>-1.55</td>
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</tr>
<tr>
<td>$\beta_{dir_{1,2}}$</td>
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<td>$\beta_{dir_{3,4}}$</td>
<td>-0.0521</td>
<td>-19.74</td>
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</tr>
<tr>
<td>$\beta_{dir_{2,6}}$</td>
<td>-0.0252</td>
<td>-9.75</td>
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</tr>
<tr>
<td>$\beta_{acc_LOW_speed}$</td>
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<td>-24.28</td>
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<tr>
<td>$\beta_{acc_HIGH_speed}$</td>
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<td>-4.94</td>
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</tr>
<tr>
<td>$\beta_{dec}$</td>
<td>-0.0630</td>
<td>-3.17</td>
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</tr>
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<td>4.16</td>
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<tr>
<td>$\lambda_{acc_HIGH_speed}$</td>
<td>0.358</td>
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<tr>
<td>$\lambda_{dec}$</td>
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<td>-11.99</td>
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<tr>
<td>$\rho_{\alpha_{acc}}$</td>
<td>0.942</td>
<td>1.89</td>
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<tr>
<td>$\rho_{\alpha_{dec}}$</td>
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<td>$\gamma_{\alpha_{acc}}$</td>
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<tr>
<td>$\rho_{\alpha_{dec}}$</td>
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<td>-6.44</td>
<td></td>
</tr>
<tr>
<td>$\gamma_{\beta_{acc}}$</td>
<td>0.652</td>
<td>6.12</td>
<td></td>
</tr>
<tr>
<td>$\gamma_{\beta_{dec}}$</td>
<td>-0.171</td>
<td>-1.97</td>
<td></td>
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<tr>
<td>$\alpha_C$</td>
<td>-0.00639</td>
<td>-10.04</td>
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<tr>
<td>$\rho_{C}$</td>
<td>-0.239</td>
<td>-8.82</td>
<td></td>
</tr>
<tr>
<td>$\mu_{acc}$</td>
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<td>10.10</td>
<td>4.03</td>
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<td>$\mu_{const}$</td>
<td>1.50</td>
<td>12.20</td>
<td>4.06</td>
</tr>
<tr>
<td>$\mu_{central}$</td>
<td>2.35</td>
<td>3.29</td>
<td>1.89</td>
</tr>
<tr>
<td>$\mu_{not_central}$</td>
<td>1.75</td>
<td>11.41</td>
<td>4.87</td>
</tr>
</tbody>
</table>
Model estimation: parameters values

- **Keep direction** (unconstrained):
  \[
  \beta_{\text{dir}_\text{central}} d_{\text{dir}_\text{dn}} I_{\text{central}} + \beta_{\text{dir}_\text{side}} d_{\text{dir}_\text{dn}} I_{\text{side}} + \beta_{\text{dir}_\text{extreme}} d_{\text{dir}_\text{dn}} I_{\text{extreme}}
  \]

- **Toward destination** (unconstrained):
  \[
  \beta_{\text{d}_\text{dist}} d_{\text{dist}_\text{vdn}} + \beta_{\text{d}_\text{dir}} d_{\text{dir}_\text{dn}}
  \]
Model estimation: parameters values

- Free flow acceleration (unconstrained):
  - Deceleration: $-0.0630 \quad -2.41$

$$\beta_{\text{dec}} I_{v,\text{dec}} \left( \frac{v_n}{v_{\text{max}}} \right) \lambda_{\text{dec}}$$

![Graph showing contribution to the utility vs. speed of the pedestrian.](image)
Model estimation: parameters values

- **Free flow acceleration** (unconstrained):
  - Acceleration:
    - Low speed:
      - \( \beta_{\text{accLS}} I_{LS} I_{v,\text{acc}} (\nu_n / \nu_{\text{maxLS}})^{\lambda_{\text{accLS}}} \) + \( \beta_{\text{accHS}} I_{HS} I_{v,\text{acc}} (\nu_n / \nu_{\text{max}})^{\lambda_{\text{accHS}}} \)
      - \( \beta_{\text{accLS}} = -4.97 \)
      - \( \lambda_{\text{accLS}} = 4.16 \)
      - \( \beta_{\text{accHS}} = -7.47 \)
      - \( \lambda_{\text{accHS}} = 0.358 \)

![Graph showing the contribution to the utility vs. speed of the pedestrian](image)
Model estimation: parameters values

- **Leader-Follower** (constrained):

\[
I_{v,\text{acc}} I^{L}_{\text{acc}} \alpha^{L}_{\text{acc}} D^{L}_{\text{acc}} \Delta v^{L}_{\text{acc}} \Delta \theta^{\delta L}_{\text{acc}} + I_{v,\text{dec}} I^{L}_{\text{dec}} \alpha^{L}_{\text{dec}} D^{L}_{\text{dec}} \Delta v^{L}_{\text{dec}}
\]

- **Collision avoidance** (constrained):

\[
I_{d,\text{dn}} I_{C} \alpha_{C} e^{-\rho_{C} D_{C}} \Delta v^{\gamma C} \Delta \theta^{\delta C}
\]
Model validation: methodology

- Validation of the specification:
  - Development of a model with constants only (ASC model)
  - Simulation on the Japanese data set
  - Cross validation on the Japanese data set

- Validation of the model:
  - Simulation on an experimental Dutch data set, not used for model estimation
  - Comparison of the proposed model with the ASC model
Model validation: model constants-only

- The simplest model: utility of each alternative represented only by an alternative specific constant (ASC)

- This model with only constants (ASC model) estimated on the Japanese data set.

  28 parameters (33, minus 4 never chosen, minus 1 for normalization)

- It reproduces the aggregated observations proportions of the Japanese data set

- The ASC model used for comparison (for example the number of outliers)
Model validation: simulation on the Japanese data set (Aggregate level)

- The proposed model is applied to the Japanese data set (used for estimation)

<table>
<thead>
<tr>
<th>Cone</th>
<th>$\Gamma$</th>
<th>$M_\Gamma$</th>
<th>$R_\Gamma$</th>
<th>$(M_\Gamma - R_\Gamma)/R_\Gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front</td>
<td>5, 7, 16, 18, 27, 29</td>
<td>8489.27</td>
<td>8481</td>
<td>0.10%</td>
</tr>
<tr>
<td>Left</td>
<td>3, 4, 14, 15, 25, 26</td>
<td>349.67</td>
<td>367</td>
<td>-4.72%</td>
</tr>
<tr>
<td>Right</td>
<td>8, 9, 19, 20, 30, 31</td>
<td>415.41</td>
<td>407</td>
<td>2.08%</td>
</tr>
<tr>
<td>Extreme left</td>
<td>1, 2, 12, 13, 23, 24</td>
<td>12.29</td>
<td>10</td>
<td>22.96%</td>
</tr>
<tr>
<td>Extreme right</td>
<td>10, 11, 21, 22, 32, 33</td>
<td>14.30</td>
<td>16</td>
<td>-10.59%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Area</th>
<th>$\Gamma$</th>
<th>$M_\Gamma$</th>
<th>$R_\Gamma$</th>
<th>$(M_\Gamma - R_\Gamma)/R_\Gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>acceleration</td>
<td>1, 11</td>
<td>1041.50</td>
<td>1065</td>
<td>-2.21%</td>
</tr>
<tr>
<td>constant speed</td>
<td>12, 22</td>
<td>7606.49</td>
<td>7565</td>
<td>0.55%</td>
</tr>
<tr>
<td>deceleration</td>
<td>23, 33</td>
<td>633.02</td>
<td>651</td>
<td>-2.76%</td>
</tr>
</tbody>
</table>
Model validation: simulation on the Japanese data set (Disaggregate level)

- **Outlier**: Observation with predicted probability less than 1/33 (hazard)

Number of outliers:
- 7.13% for proposed model
- 19.90% for ASC model
Model validation : Cross-validation on the Japanese data set

- Japanese data split into 5 subsets, each containing 20% of the observations

5 experiments:

1 subset saved for validation
estimation of the model on the 4 remaining

- Number of outliers (compared with the ASC model cross validation)

<table>
<thead>
<tr>
<th>Model</th>
<th>Exp. 1</th>
<th>Exp. 2</th>
<th>Exp. 3</th>
<th>Exp. 4</th>
<th>Exp. 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed spec.</td>
<td>8.78%</td>
<td>6.36%</td>
<td>7.60%</td>
<td>7.87%</td>
<td>5.87%</td>
</tr>
<tr>
<td>Constant only</td>
<td>20.79%</td>
<td>20.70%</td>
<td>17.13%</td>
<td>19.88%</td>
<td>18.64%</td>
</tr>
</tbody>
</table>

Robust specification
The Dutch data set: video sequence

- Collected at Delft university, in 2000-2001, 2 pedestrians crossing flows
The Dutch data set: general information

- **Experimental** data set
- Video sequence recorded at **10 frames per second**
- Pedestrians trajectories extracted from the video sequence
- For each pedestrian trajectory:
  - 724 pedestrians, 47481 observations
The Dutch data set: comparison with the Japanese data set

- Normalized observations distribution among alternatives

- Observations repartitions inside the nest (Japanese / Dutch)

<table>
<thead>
<tr>
<th>Nest</th>
<th># steps</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>acceleration</td>
<td>1065</td>
<td>11.48%</td>
</tr>
<tr>
<td>constant speed</td>
<td>7565</td>
<td>81.51%</td>
</tr>
<tr>
<td>deceleration</td>
<td>651</td>
<td>7.01%</td>
</tr>
<tr>
<td>central</td>
<td>4297</td>
<td>46.30%</td>
</tr>
<tr>
<td>not central</td>
<td>4984</td>
<td>53.70%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nest</th>
<th># steps</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>acceleration</td>
<td>1273</td>
<td>2.68%</td>
</tr>
<tr>
<td>constant speed</td>
<td>45869</td>
<td>96.61%</td>
</tr>
<tr>
<td>deceleration</td>
<td>339</td>
<td>0.71%</td>
</tr>
<tr>
<td>central</td>
<td>20950</td>
<td>44.12%</td>
</tr>
<tr>
<td>not central</td>
<td>26531</td>
<td>55.88%</td>
</tr>
</tbody>
</table>
The Dutch data set: comparison with the Japanese data set

- Quite similar observations proportions in the direction's cones (not for speed regime)

<table>
<thead>
<tr>
<th>Dataset</th>
<th>extremeleft</th>
<th>left</th>
<th>front</th>
<th>right</th>
<th>extremeright</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japanese</td>
<td>0.11%</td>
<td>3.95%</td>
<td>91.38%</td>
<td>4.39%</td>
<td>0.17%</td>
</tr>
<tr>
<td>Dutch</td>
<td>0.06%</td>
<td>4.40%</td>
<td>91.35%</td>
<td>4.15%</td>
<td>0.04%</td>
</tr>
</tbody>
</table>

- Speed distribution have different shapes (experimental design of Dutch data set)
Model validation: simulation on the Dutch data set (Aggregate level)

- The proposed model is applied to the Dutch data set (NOT used for estimation)

<table>
<thead>
<tr>
<th>Cone</th>
<th>( \Gamma )</th>
<th>( M_\Gamma )</th>
<th>( R_\Gamma )</th>
<th>( (M_\Gamma - R_\Gamma)/R_\Gamma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front</td>
<td>5 – 7, 16 – 18, 27 – 29</td>
<td>43619.98</td>
<td>43374</td>
<td>0.57%</td>
</tr>
<tr>
<td>Left</td>
<td>3, 4, 14, 15, 25, 26</td>
<td>1968.79</td>
<td>2089</td>
<td>−5.75%</td>
</tr>
<tr>
<td>Right</td>
<td>8, 9, 19, 20, 30, 31</td>
<td>1764.39</td>
<td>1972</td>
<td>−10.53%</td>
</tr>
<tr>
<td>Extreme left</td>
<td>1, 2, 12, 13, 23, 24</td>
<td>45.86</td>
<td>27</td>
<td>69.85%</td>
</tr>
<tr>
<td>Extreme right</td>
<td>10, 11, 21, 22, 32, 33</td>
<td>81.97</td>
<td>19</td>
<td>331.44%</td>
</tr>
</tbody>
</table>

- Overprediction of acceleration and deceleration
Model validation: simulation on the Dutch data set (Disaggregate level)

- **Outlier**: Observation with predicted probability less than 1/33 (hazard)

![Graph showing predicted probabilities for Dutch data](image)

Number of outliers: 2.48%
Model validation: Comparison with the ASC model on the Dutch data set (Aggregate level)

- The ASC model is applied to the Dutch data set and compared to the proposed model.

### ASC model

<table>
<thead>
<tr>
<th>Cone</th>
<th>$\Gamma$</th>
<th>$M_\Gamma$</th>
<th>$R_\Gamma$</th>
<th>$(M_\Gamma - R_\Gamma) / R_\Gamma$</th>
</tr>
</thead>
<tbody>
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<td>1877.47</td>
<td>2089</td>
<td>−10.13%</td>
</tr>
<tr>
<td>Right</td>
<td>8, 9, 19, 20, 30, 31</td>
<td>2082.10</td>
<td>1972</td>
<td>5.58%</td>
</tr>
<tr>
<td>Extreme left</td>
<td>1, 2, 12, 13, 23, 24</td>
<td>51.16</td>
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<td>89.47%</td>
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<tr>
<td>Extreme right</td>
<td>10, 11, 21, 22, 32, 33</td>
<td>81.85</td>
<td>19</td>
<td>330.80%</td>
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</table>

### Proposed model

<table>
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<th>$R_\Gamma$</th>
<th>$(M_\Gamma - R_\Gamma) / R_\Gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front</td>
<td>5, 7, 16, 18, 27, 29</td>
<td>43619.98</td>
<td>43374</td>
<td>0.57%</td>
</tr>
<tr>
<td>Left</td>
<td>3, 4, 14, 15, 25, 26</td>
<td>1968.79</td>
<td>2089</td>
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<td>1972</td>
<td>−10.53%</td>
</tr>
<tr>
<td>Extreme left</td>
<td>1, 2, 12, 13, 23, 24</td>
<td>45.86</td>
<td>27</td>
<td>69.85%</td>
</tr>
<tr>
<td>Extreme right</td>
<td>10, 11, 21, 22, 32, 33</td>
<td>81.97</td>
<td>19</td>
<td>331.44%</td>
</tr>
</tbody>
</table>

### Area

<table>
<thead>
<tr>
<th>Type</th>
<th>$\Gamma$</th>
<th>$M_\Gamma$</th>
<th>$R_\Gamma$</th>
<th>$(M_\Gamma - R_\Gamma) / R_\Gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>acceleration</td>
<td>1 − 11</td>
<td>5448.24</td>
<td>1273</td>
<td>327.98%</td>
</tr>
<tr>
<td>constant speed</td>
<td>12 − 22</td>
<td>38700.42</td>
<td>45869</td>
<td>−15.63%</td>
</tr>
<tr>
<td>deceleration</td>
<td>23 − 33</td>
<td>3330.34</td>
<td>339</td>
<td>882.40%</td>
</tr>
</tbody>
</table>

### Equivalent for direction (logical, due to proportions)
Model validation: simulation on the Japanese data set (Disaggregate level)

- **Outlier**: Observation with predicted probability less than 1/33 (hazard)

Number of outliers:
- 2.48% for proposed model
- 10.31% for ASC model

Superiority of the proposed model
Conclusions and Perspectives

**Conclusions:**
- Discrete choice model for pedestrian walking behavior with ‘unconstrained’ and ‘constrained’ parameters
- Model estimated on a real data set, parameters values consistent with hypotheses
- Model validated on a real data set, not used for estimation

**Perspectives:**
- Improve the acceleration and deceleration patterns
- Incorporate physical characteristics of the pedestrians
Thanks for your attention

http://transp-or2.epfl.ch/publications.php#techrep