Specification, estimation and validation of a pedestrian walking behavior model

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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

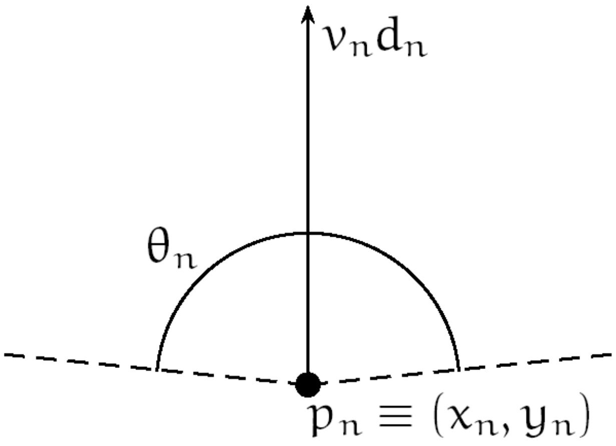
- Concept of **personal space** : interactions with other pedestrians

  → Leader follower

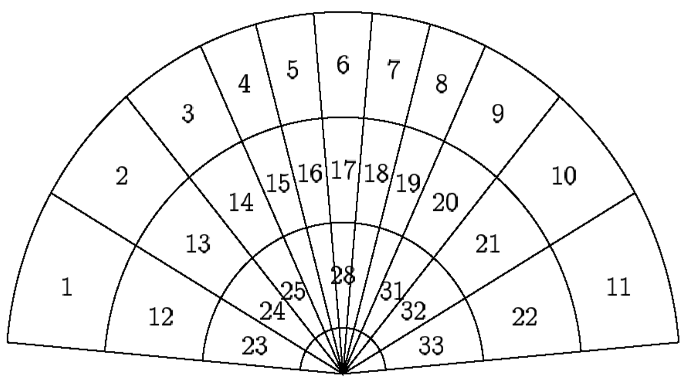
  → Collision avoidance

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

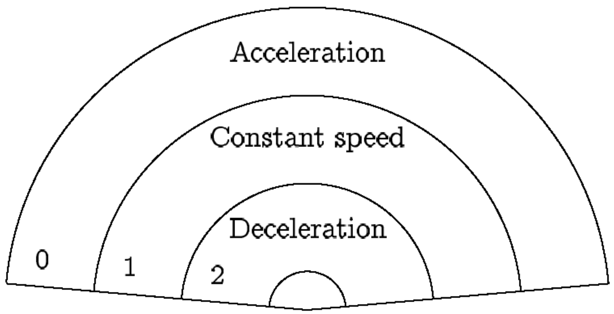


Choice set : discretization of the visual space

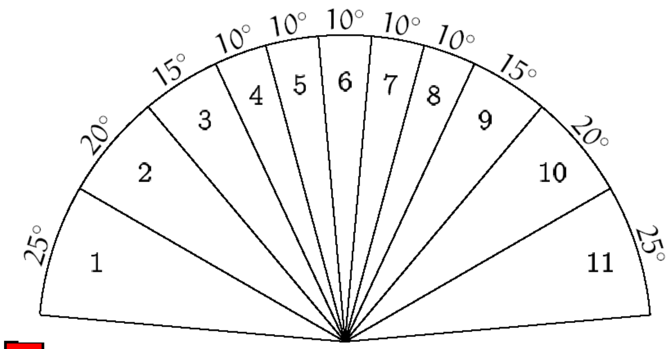
At each step the **choice set** depends on the pedestrian **speed** and **direction**

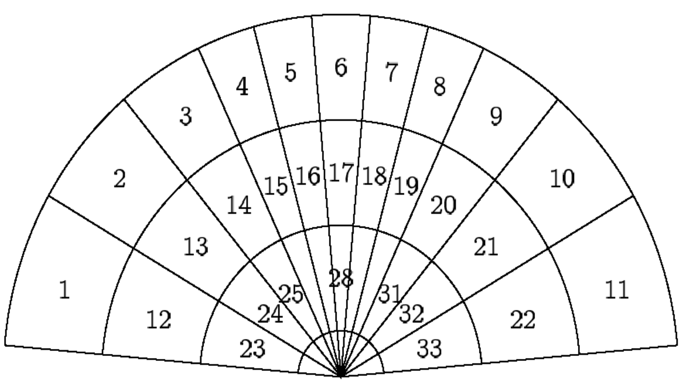
Model specification : the choice set

3 speed regimes



11 directions





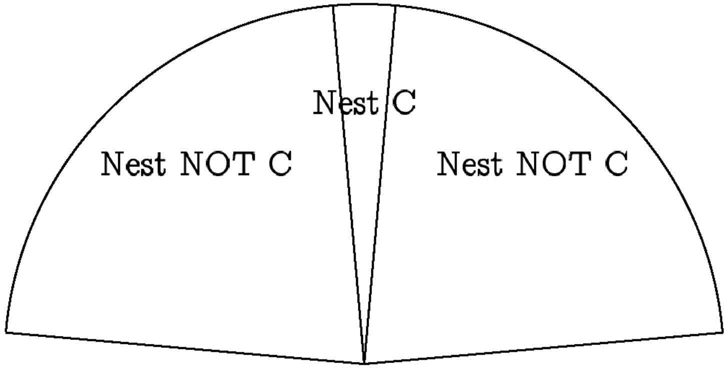
33 alternatives

Model specification : cross nested structure

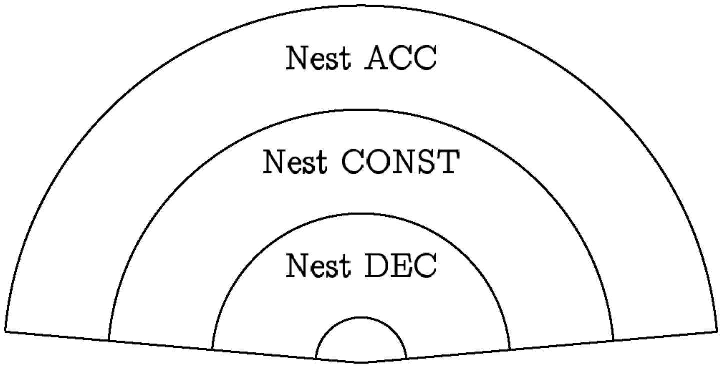
- **Hypothesis** : alternatives correlated along speed regimes and directions

  → **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 :

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

C : choice set

M : number of nests

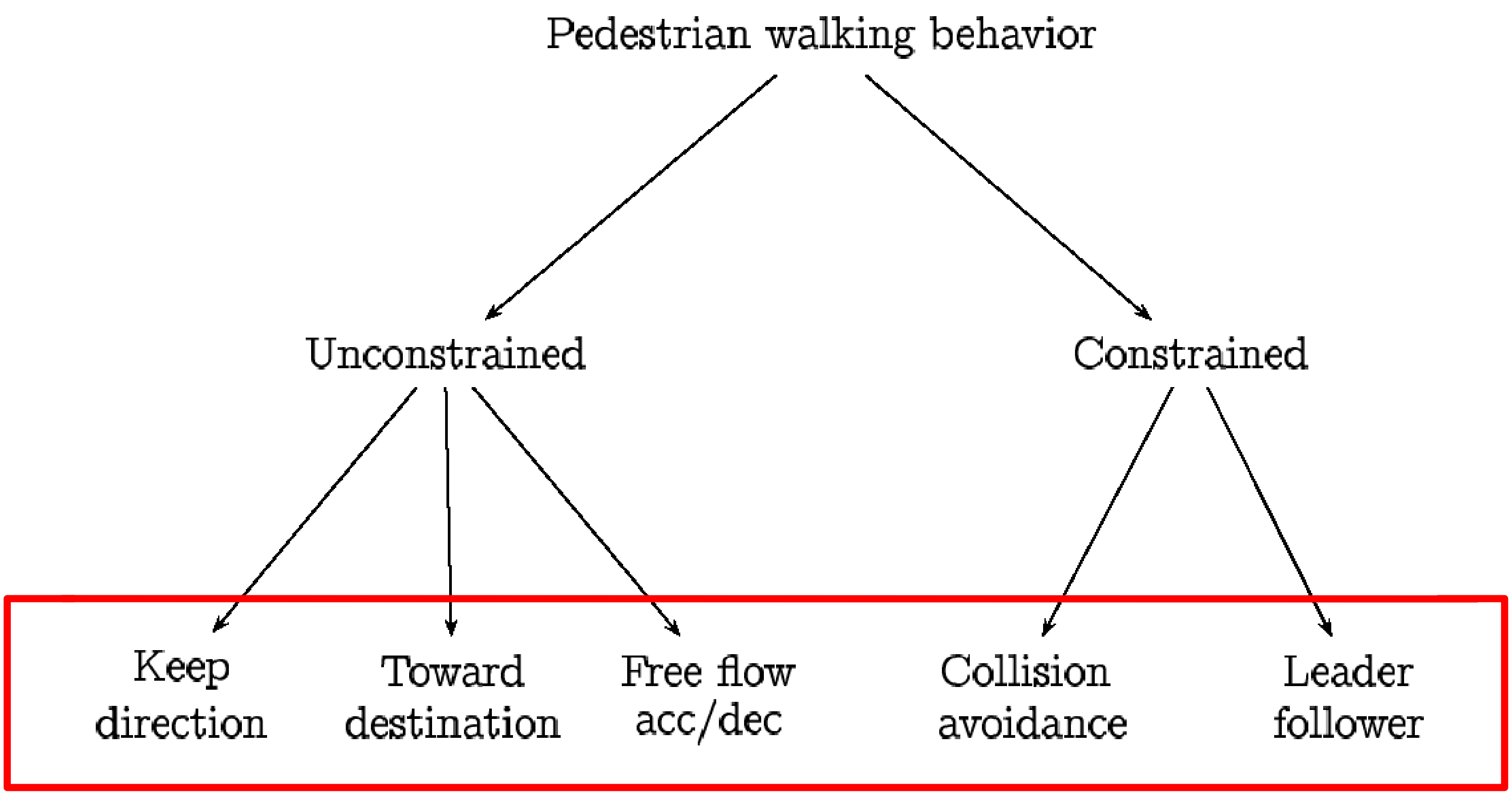
V_i : utility of alternative i

α_{jm} : membership degree of alternative j in the nest n

μ_m : parameter of the nest m

$y_i = e^{V_i}$

Model specification : utility specification



Model specification : utility specification

$$
\left.\begin{aligned}
V_{vdn} = & \beta_{dir\_central} dir_{dn} I_{central} + \\
& \beta_{dir\_side} dir_{dn} I_{side} + \\
& \beta_{dir\_extreme} dir_{dn} I_{extreme} +
\end{aligned}\right\} \quad \textit{keep direction}
$$

$$
\left.\begin{aligned}
& \beta_{ddist} ddist_{vdn} + \\
& \beta_{ddir} ddir_{dn} +
\end{aligned}\right\} \quad \textit{toward destination}
$$

$$
\left.\begin{aligned}
& \beta_{dec} I_{v,dec} (v_n / v_{max})^{\lambda_{dec}} + \\
& \beta_{accLS} I_{LS} I_{v,acc} (v_n / v_{maxLS})^{\lambda_{accLS}} + \\
& \beta_{accHS} I_{HS} I_{v,acc} (v_n / v_{max})^{\lambda_{accHS}} +
\end{aligned}\right\} \quad \textit{free flow acceleration}
$$

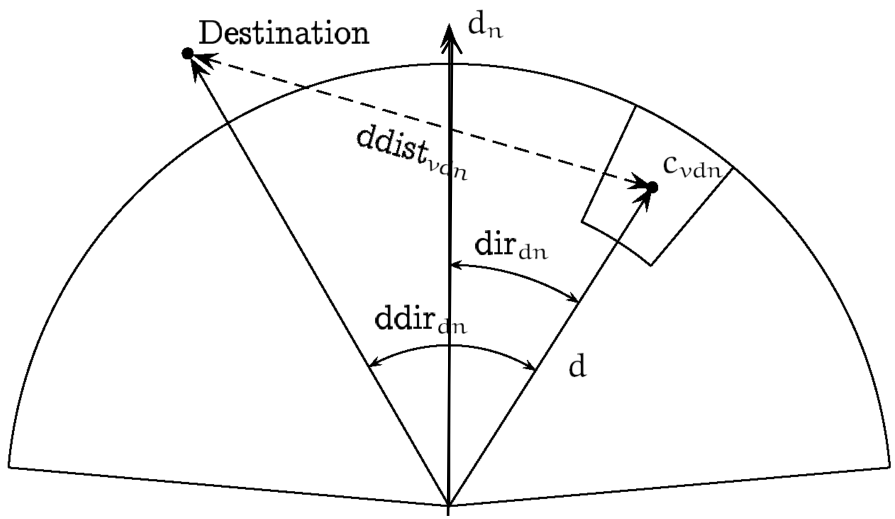
$$
\left.\begin{aligned}
& I_{v,acc} I^L_{acc} \alpha^L_{acc} D_L^{\rho^L_{acc}} \Delta v_L^{\gamma^L_{acc}} \Delta\theta_L^{\delta^L_{acc}} + \\
& I_{v,dec} I^L_{dec} \alpha^L_{dec} D_L^{\rho^L_{dec}} \Delta v_L^{\gamma^L_{dec}} \Delta\theta_L^{\delta^L_{dec}} +
\end{aligned}\right\} \quad \textit{leader-follower}
$$

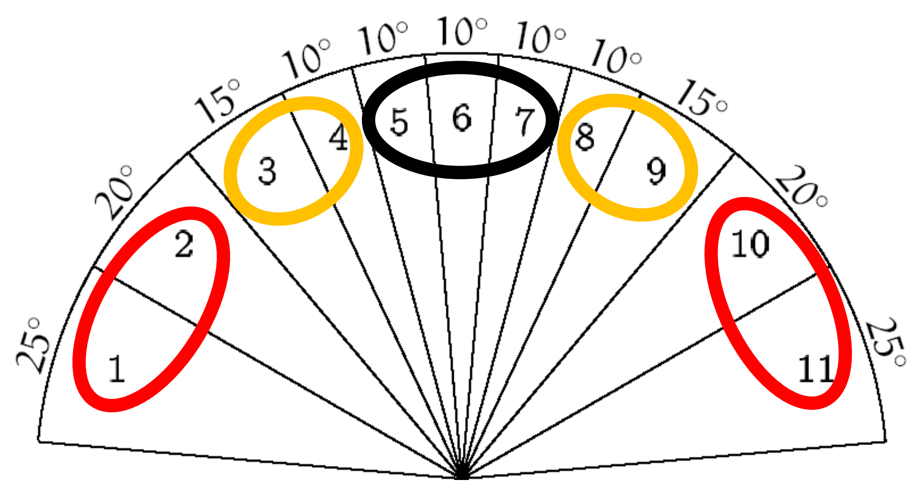
$$
\left. I_{d,d_n} I_C \alpha_C e^{-\rho_C D_C} \Delta v_C^{\gamma_C} \Delta\theta_C^{\delta_C} \right\} \quad \textit{collision avoidance}
$$

Model specification : utility specification

- Keep direction (**unconstrained**) :

$$\underbrace{\overset{<0}{\beta_{\text{dir\_central}}}\,\text{dir}_{dn}I_{\text{central}}}\;+\;\underbrace{\overset{<0}{\beta_{\text{dir\_side}}}\,\text{dir}_{dn}I_{\text{side}}}\;+\;\underbrace{\overset{<0}{\beta_{\text{dir\_extreme}}}\,\text{dir}_{dn}I_{\text{extreme}}}$$





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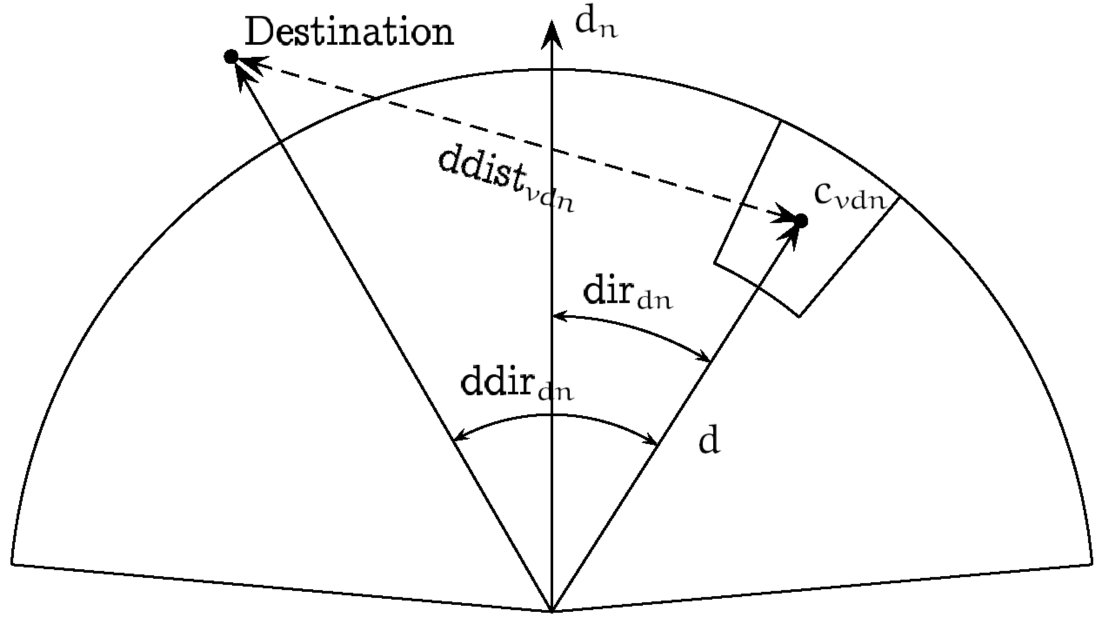
Model specification : utility specification

- Toward destination (**unconstrained**) : $\overset{<0}{\beta_{\mathsf{ddist}}}\underbrace{\mathrm{ddist}_{vdn}}_{\text{distance}} + \overset{<0}{\beta_{\mathsf{ddir}}}\underbrace{\mathrm{ddir}_{dn}}_{\text{direction}}$



Model specification : utility specification

- Free flow acceleration (**unconstrained**) :

  - Acceleration :

$$\underbrace{\overset{<0}{\beta_{\mathrm{accLS}}} I_{\mathrm{LS}} I_{\mathrm{v,acc}} \left(\nu_n / \nu_{\mathrm{maxLS}}\right)^{\overset{>0}{\lambda_{\mathrm{accLS}}}}}_{\textbf{Low speed}} + \underbrace{\overset{<0}{\beta_{\mathrm{accHS}}} I_{\mathrm{HS}} I_{\mathrm{v,acc}} \left(\nu_n / \nu_{\mathrm{max}}\right)^{\overset{>0}{\lambda_{\mathrm{accHS}}}}}_{\textbf{High speed}}$$

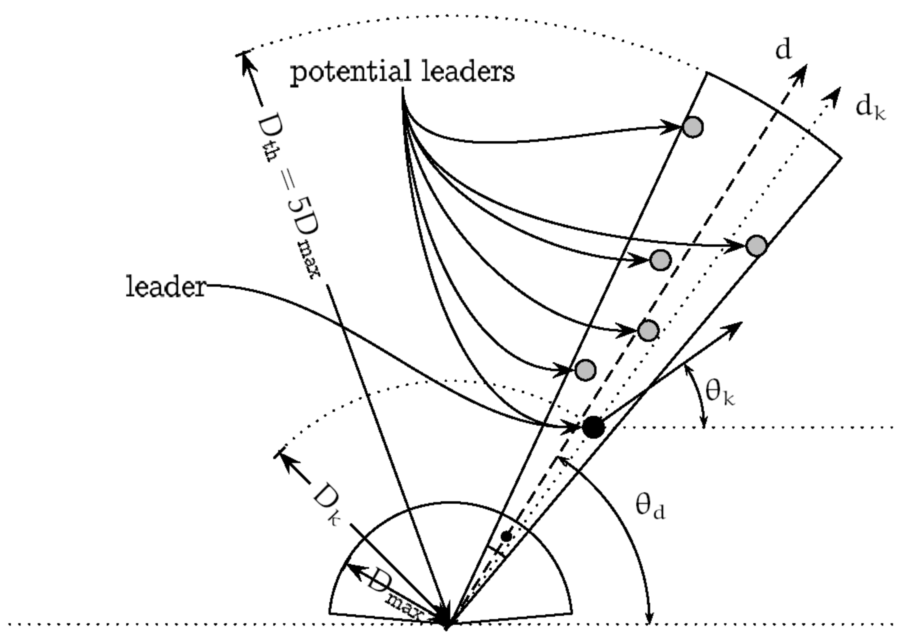
  - Deceleration :

$$\overset{<0}{\beta_{\mathrm{dec}}} I_{\mathrm{v,dec}} \left(\nu_n / \nu_{\mathrm{max}}\right)^{\overset{<0}{\lambda_{\mathrm{dec}}}}$$

Model specification : utility specification

- Leader follower (**constrained**) :

$$I_{v,acc} I^{L}_{acc} \underbrace{\overset{>0}{\alpha^{L}_{acc}} D_{L}^{\overset{<0}{\rho^{L}_{acc}}}}_{\text{sensitivity}} \underbrace{\Delta v_{L}^{\overset{>0}{\gamma^{L}_{acc}}} \Delta\theta_{L}^{\overset{<0}{\delta^{L}_{acc}}}}_{\text{stimulus}} + I_{v,dec} I^{L}_{dec} \underbrace{\overset{>0}{\alpha^{L}_{dec}} D_{L}^{\overset{<0}{\rho^{L}_{dec}}}}_{\text{sensitivity}} \underbrace{\Delta v_{L}^{\overset{>0}{\gamma^{L}_{dec}}}}_{\text{stimulus}}$$



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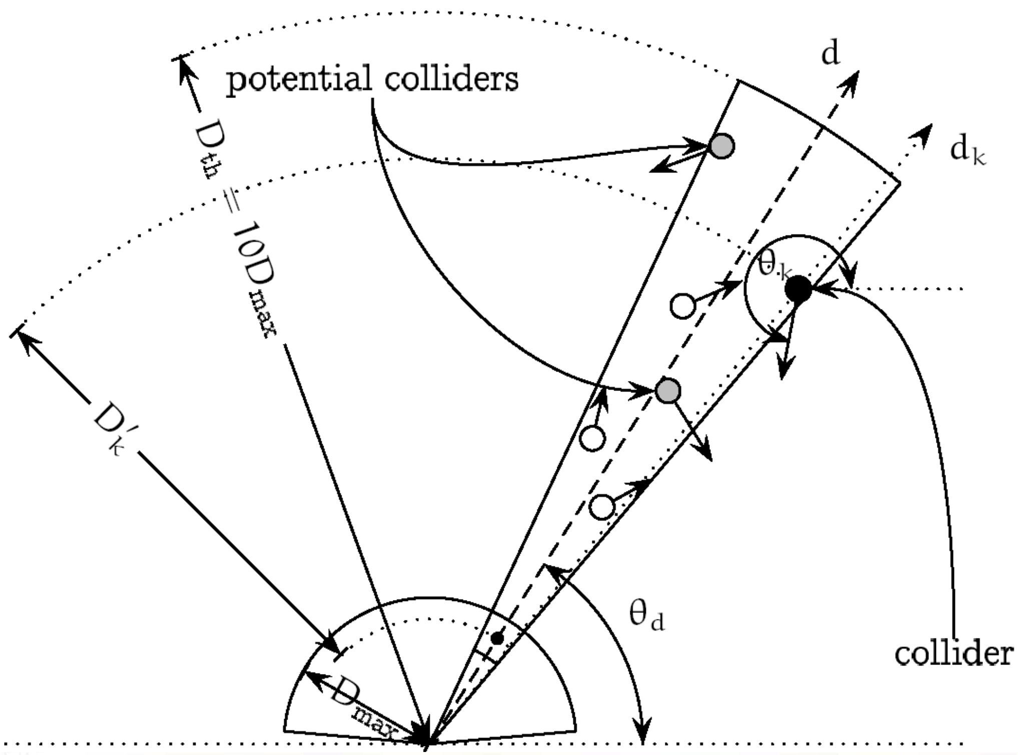
Model specification : utility specification

- Collision avoidance (**constrained**) : $I_{\mathbf{d},d_n} I_C \underbrace{\overset{<0}{\alpha_C} e^{-\overset{>0}{\rho_C} D_C}}_{\text{sensitivity}} \underbrace{\Delta v_C^{\overset{>0}{\gamma_C}} \Delta\theta_C^{\overset{>0}{\delta_C}}}_{\text{stimulus}}$

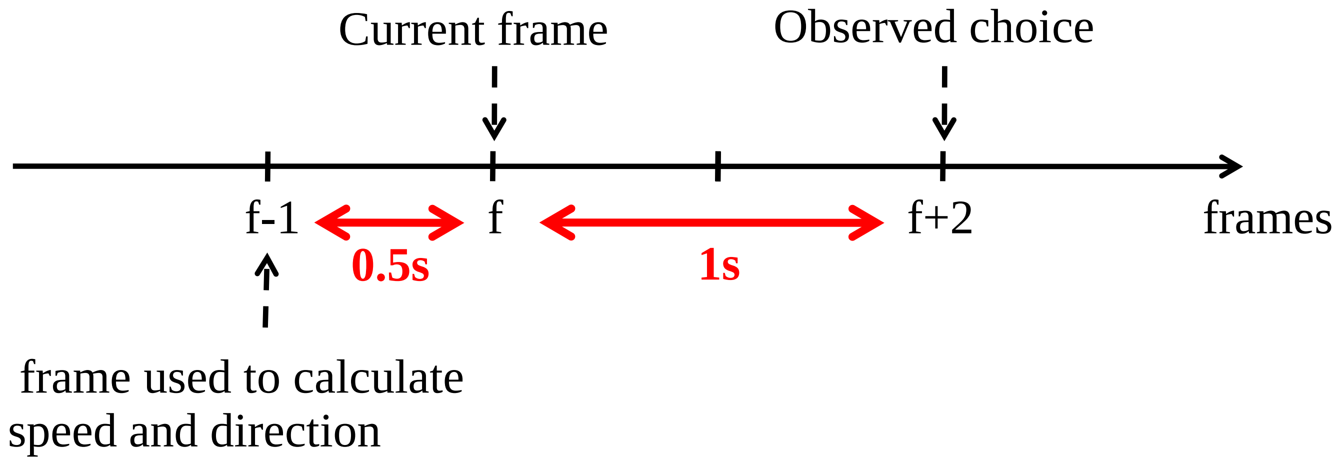


The Japanese data set : video sequence

- Collected in Sendaï, Japan, on August 2000, large pedestrian **crossing road**

The Japanese data set : data processing

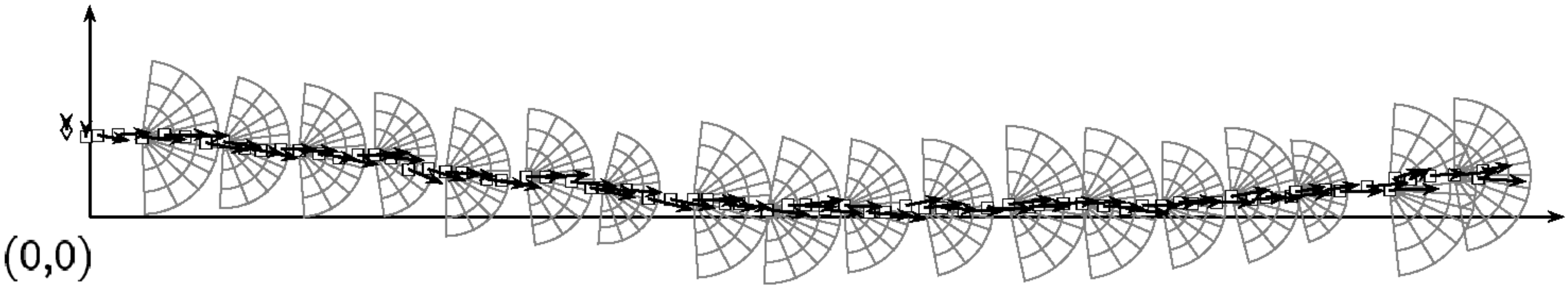
- Tracking from video sequence: **2 observations per second**
- Pedestrians trajectories extracted using 3D-calibration (DLT algorithm)
- For each pedestrian trajectory :



190 pedestrians, 9281 observations

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

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Model estimation : parameters values

Variable name	Coefficient estimate	t test 0	t test 1
β_{ddir}	-0.0790	-21.91	
β_{ddist}	-1.55	-11.16	
$\beta_{\mathrm{dir\_1\_2}}$	-0.0326	-9.44	
$\beta_{\mathrm{dir\_3\_4}}$	-0.0521	-19.74	
$\beta_{\mathrm{dir\_5\_6}}$	-0.0252	-9.75	
$\beta_{\mathrm{acc\_LOW\_speed}}$	-4.97	-24.28	
$\beta_{\mathrm{acc\_HIGH\_speed}}$	-7.47	-4.94	
β_{dec}	-0.0630	-3.17	
$\lambda_{\mathrm{acc\_LOW\_speed}}$	4.16	18.07	
$\lambda_{\mathrm{acc\_HIGH\_speed}}$	0.358	1.98	
λ_{dec}	-2.41	-11.99	
$\alpha^{\mathrm{L}}_{\mathrm{acc}}$	0.942	1.89	
$\rho^{\mathrm{L}}_{\mathrm{acc}}$	-0.489	-1.63	
$\gamma^{\mathrm{L}}_{\mathrm{acc}}$	0.625	2.49	
$\alpha^{\mathrm{L}}_{\mathrm{dec}}$	3.69	6.62	
$\rho^{\mathrm{L}}_{\mathrm{dec}}$	-0.663	-6.44	
$\gamma^{\mathrm{L}}_{\mathrm{dec}}$	0.652	6.12	
$\delta^{\mathrm{L}}_{\mathrm{acc}}$	-0.171	-1.97	
α_{C}	-0.00639	-10.04	
ρ_{C}	-0.239	-8.82	
μ_{acc}	1.66	10.10	4.03
μ_{const}	1.50	12.20	4.06
μ_{central}	2.35	3.29	1.89
$\mu_{\mathrm{not\_central}}$	1.75	11.41	4.87

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Model estimation : parameters values

- **Keep direction** (unconstrained) :

$$\overset{-0.0252}{\beta_{\mathrm{dir\_central}}}\,\mathrm{dir}_{dn} I_{\mathrm{central}} + \overset{-0.0521}{\beta_{\mathrm{dir\_side}}}\,\mathrm{dir}_{dn} I_{\mathrm{side}} + \overset{-0.0326}{\beta_{\mathrm{dir\_extreme}}}\,\mathrm{dir}_{dn} I_{\mathrm{extreme}}$$

- **Toward destination** (unconstrained) :

$$\overset{-1.55}{\beta_{\mathrm{ddist}}}\,\mathrm{ddist}_{vdn} + \overset{-0.0790}{\beta_{\mathrm{ddir}}}\,\mathrm{ddir}_{dn}$$

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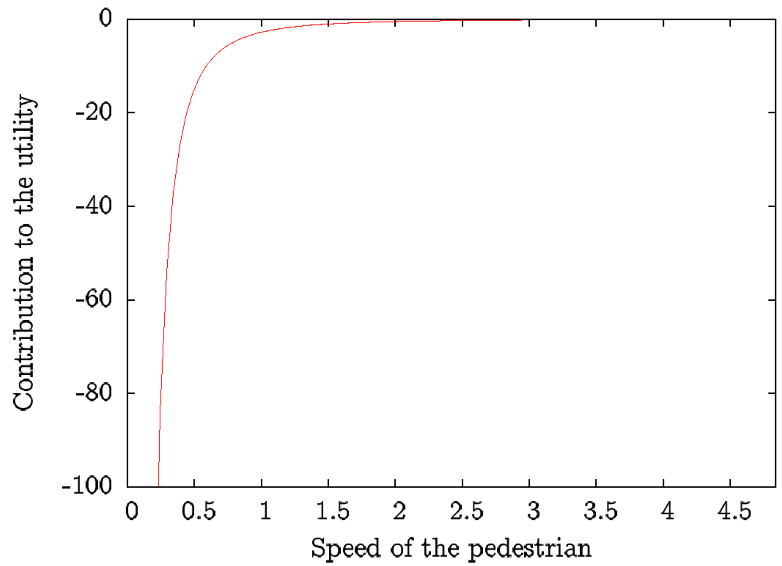
Model estimation : parameters values

- **Free flow acceleration** (unconstrained) :

  - Deceleration :

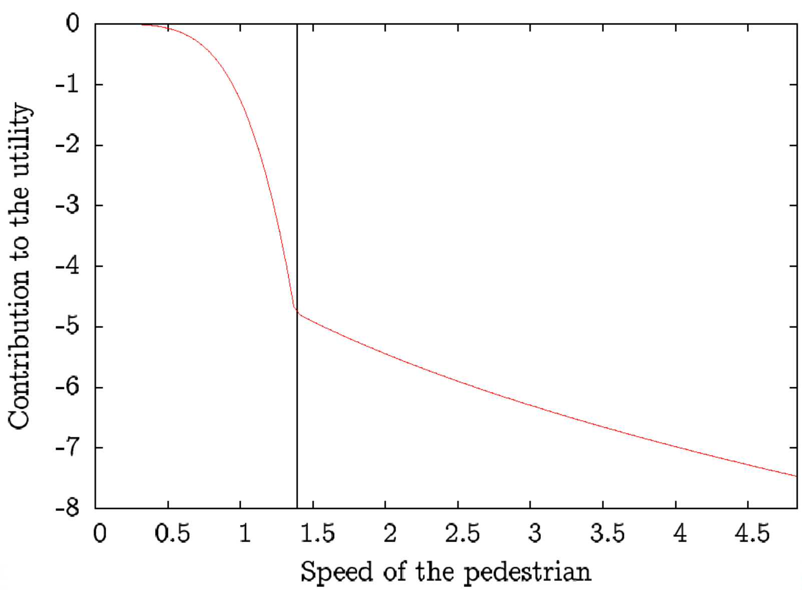
$$\underbrace{\beta_{dec}}_{-0.0630} I_{v,dec} (v_n / v_{max})^{\overbrace{\lambda_{dec}}^{-2.41}}$$



Model estimation : parameters values

- **Free flow acceleration** (unconstrained) :
  - Acceleration :

$$\underbrace{\overset{-4.97}{\beta_{\mathrm{accLS}}} I_{\mathrm{LS}} I_{\mathrm{v,acc}} (v_n / v_{\mathrm{maxLS}})^{\overset{4.16}{\lambda_{\mathrm{accLS}}}}}_{\text{Low speed}} + \underbrace{\overset{-7.47}{\beta_{\mathrm{accHS}}} I_{\mathrm{HS}} I_{\mathrm{v,acc}} (v_n / v_{\mathrm{max}})^{\overset{0.358}{\lambda_{\mathrm{accHS}}}}}_{\text{High speed}}$$



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Model estimation : parameters values

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

$$I_{\mathbf{v,acc}} I^{L}_{\mathrm{acc}} \overset{0.942}{\alpha^{L}_{\mathrm{acc}}} D_{L}^{\overset{-0.489}{\rho^{L}_{\mathrm{acc}}}} \Delta v_{L}^{\overset{0.625}{\gamma^{L}_{\mathrm{acc}}}} \Delta\theta_{L}^{\overset{-0.171}{\delta^{L}_{\mathrm{acc}}}} + I_{\mathbf{v,dec}} I^{L}_{\mathrm{dec}} \overset{3.69}{\alpha^{L}_{\mathrm{dec}}} D_{L}^{\overset{-0.663}{\rho^{L}_{\mathrm{dec}}}} \Delta v_{L}^{\overset{0.652}{\gamma^{L}_{\mathrm{dec}}}}$$

- **Collision avoidance** (constrained) :

$$I_{\mathbf{d},d_n} I_C \overset{-0.00639}{\alpha_C} e^{-\overset{0.239}{\rho_C} D_C} \Delta v_C^{\overset{\text{non significative}}{\gamma_C}} \Delta\theta_C^{\overset{\text{non significative}}{\delta_C}}$$

Model validation : methodology

- Validation of the specification :
  - Developpment 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.

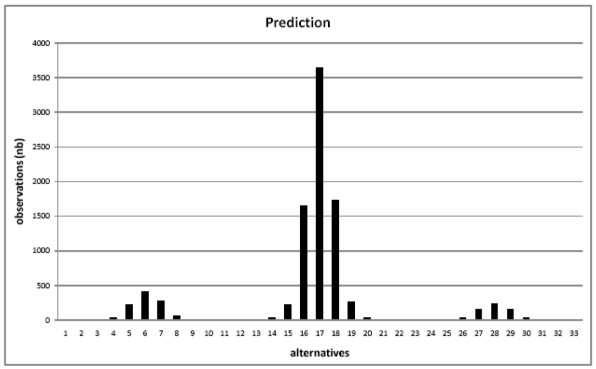
  ⇒ **28 parameters (33, minus 4 never chosen, minus 1 for normalization)**

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

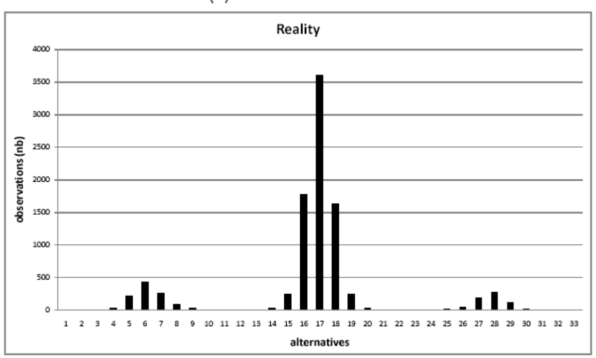
- The ASC model **used for comparison** (for example the number of outliers)

Model validation : simulation on the Japanese data set (Aggregate level)

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



(a) Predicted shares



(b) Observed shares

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

Area	Γ	M_Γ	R_Γ	$(M_\Gamma - R_\Gamma)/R_\Gamma$
acceleration	$1-11$	1041.50	1065	−2.21%
constant speed	$12-22$	7606.49	7565	0.55%
deceleration	$23-33$	633.02	651	−2.76%

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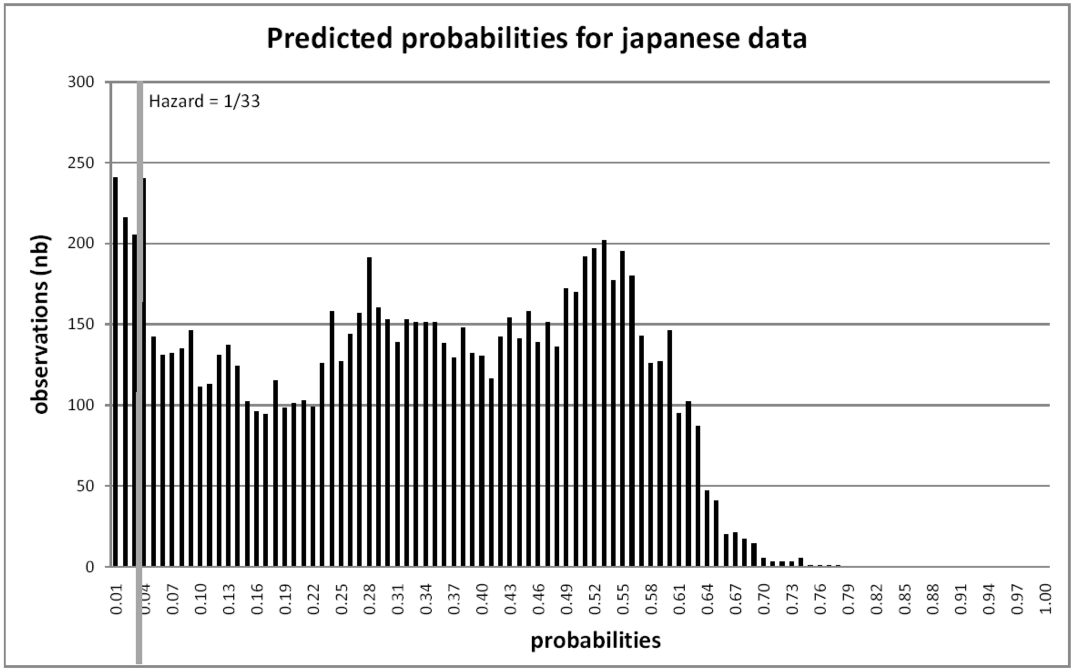
Model validation : simulation on the Japanese data set (Disaggregate level)

- **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 splited 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)

Model	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5
Proposed spec.	8.78%	6.36%	7.60%	7.87%	5.87%
Constant only	20.79%	20.70%	17.13%	19.88%	18.64%

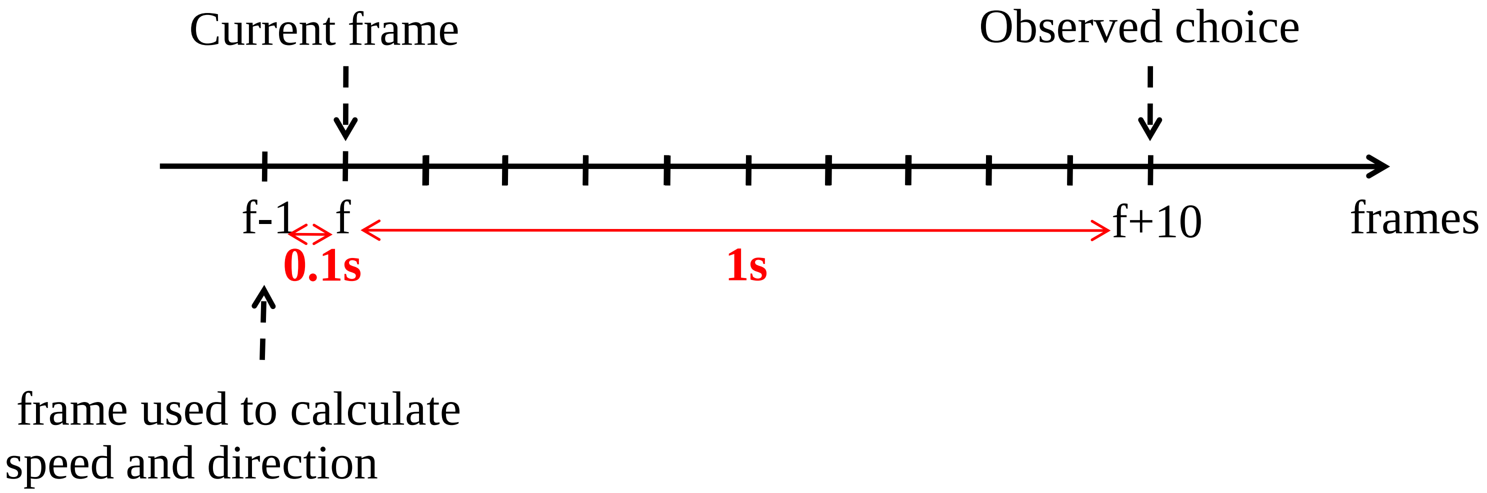
→ **Robust specification**

The Dutch data set : video sequence

- Collected at Delft university, in 2000-2001, 2 pedestrians crossing flows

The Dutch data set : general information

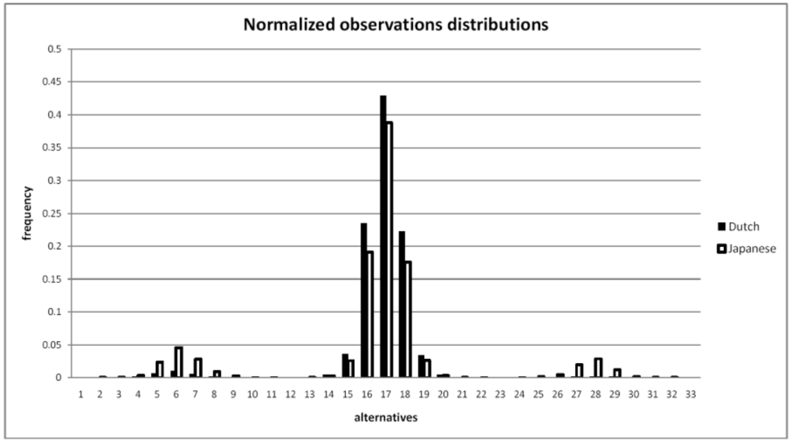
- **Experimental** data set
- Video sequence recorded at **10 frames per second**
- Pedestrians trajectories extracted from the video sequence
- For each pedestrian trajectory :



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)

Nest	# steps	% of total
acceleration	1065	11.48%
constant speed	7565	81.51%
deceleration	651	7.01%
central	4297	46.30%
not central	4984	53.70%

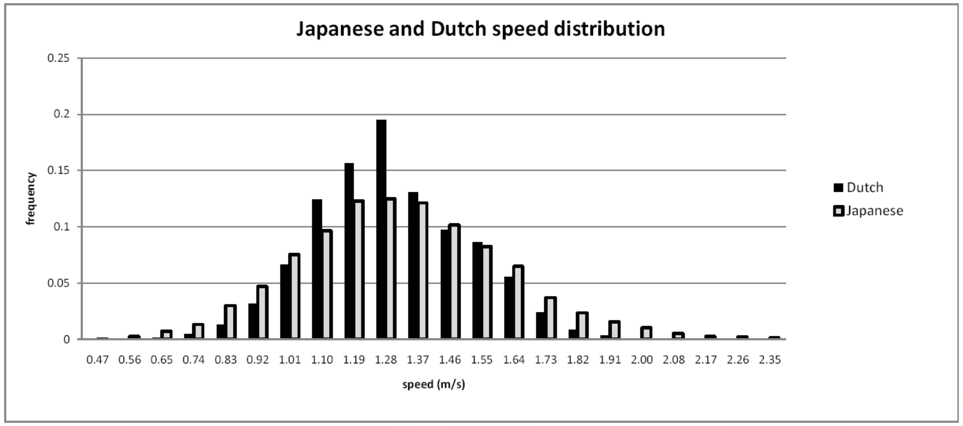
Nest	# steps	% of total
acceleration	1273	2.68%
constant speed	45869	96.61%
deceleration	339	0.71%
central	20950	44.12%
not central	26531	55.88%

The dutch data set : comparison with the Japanese data set

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

Dataset	extremeleft	left	front	right	extremeright
Japanese	0.11%	3.95%	91.38%	4.39%	0.17%
Dutch	0.06%	4.40%	91.35%	4.15%	0.04%

- Speed distribution have different shapes (experimental design of Dutch data set)



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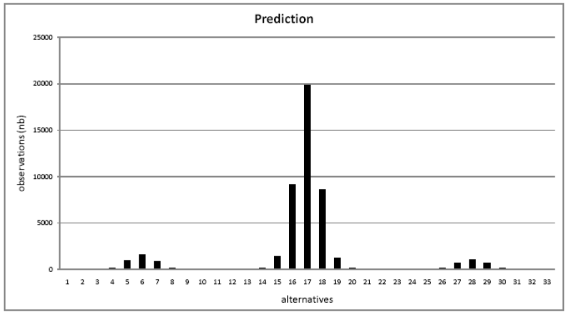
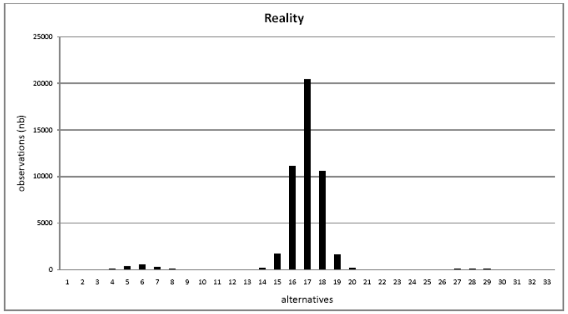
Model validation : simulation on the Dutch data set (Aggregate level)

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



(a) Predicted



(b) Observed

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

Area	Γ	M_Γ	R_Γ	$(M_\Gamma - R_\Gamma)/R_\Gamma$
acceleration	$1-11$	3892.35	1273	205.76%
constant speed	$12-22$	40733.53	45869	−11.20%
deceleration	$23-33$	2855.12	339	742.22%

Overprediction of acceleration and deceleration

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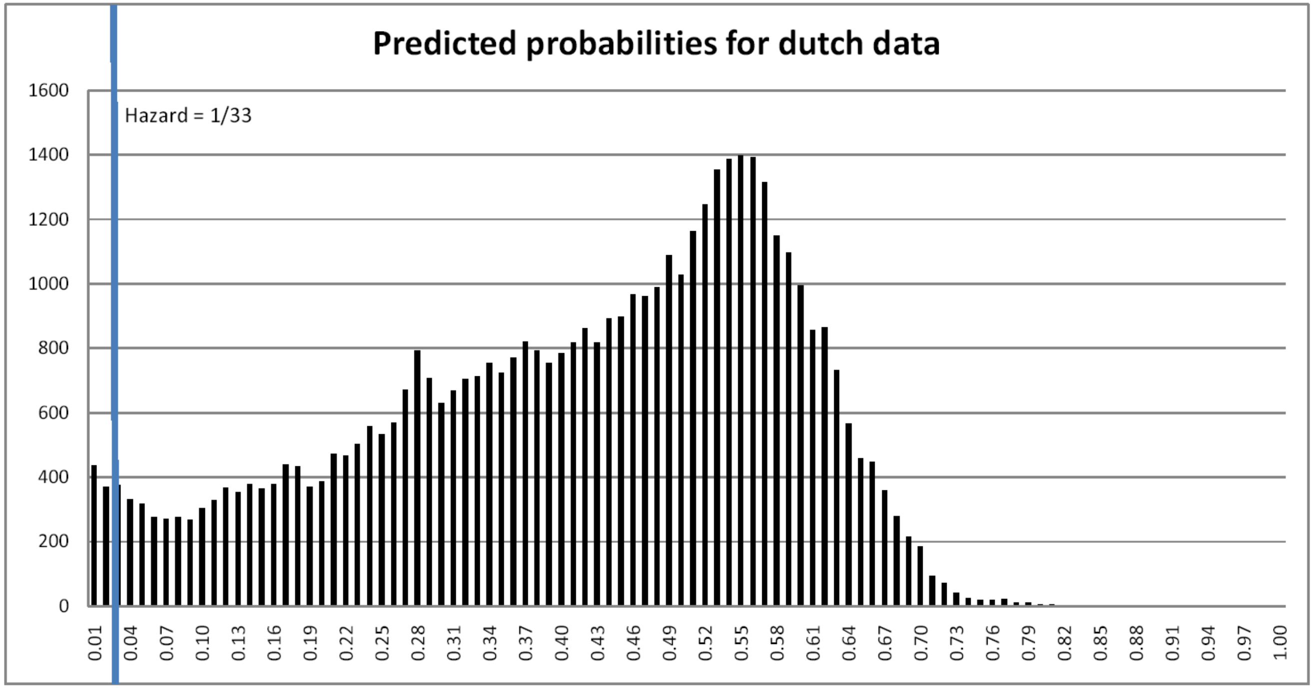
Model validation : simulation on the Dutch data set (Disaggregate level)

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



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)

<u>ASC model</u>

Cone	Γ	M_Γ	R_Γ	$(M_\Gamma - R_\Gamma)/R_\Gamma$
Front	$5-7, 16-18, 27-29$	43386.42	43374	0.03%
Left	$3, 4, 14, 15, 25, 26$	1877.47	2089	−10.13%
Right	$8, 9, 19, 20, 30, 31$	2082.10	1972	5.58%
Extreme left	$1, 2, 12, 13, 23, 24$	51.16	27	89.47%
Extreme right	$10, 11, 21, 22, 32, 33$	81.85	19	330.80%

Area	Γ	M_Γ	R_Γ	$(M_\Gamma - R_\Gamma)/R_\Gamma$
acceleration	$1-11$	5448.24	1273	327.98%
constant speed	$12-22$	38700.42	45869	−15.63%
deceleration	$23-33$	3330.34	339	882.40%

<u>Proposed model</u>

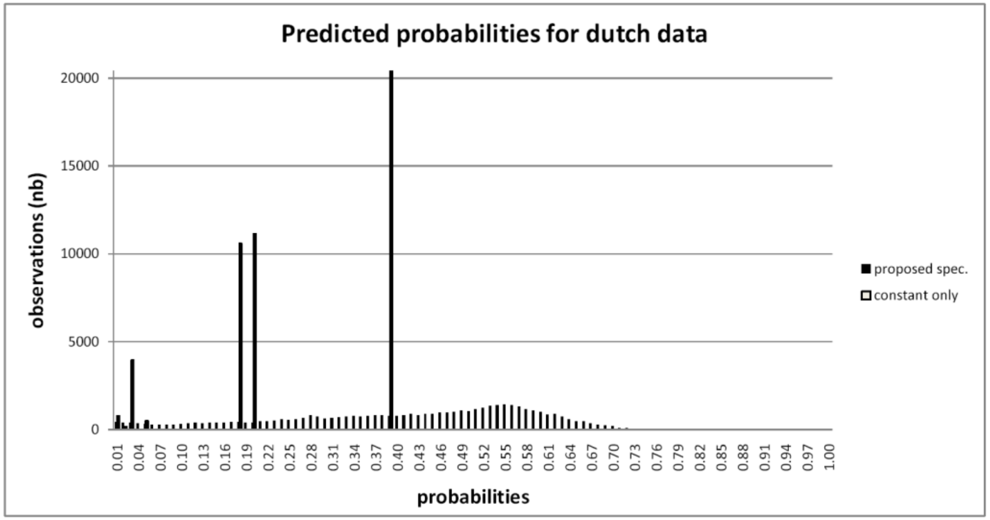
Cone	Γ	M_Γ	R_Γ	$(M_\Gamma - R_\Gamma)/R_\Gamma$
Front	$5-7, 16-18, 27-29$	43619.98	43374	0.57%
Left	$3, 4, 14, 15, 25, 26$	1968.79	2089	−5.75%
Right	$8, 9, 19, 20, 30, 31$	1764.39	1972	−10.53%
Extreme left	$1, 2, 12, 13, 23, 24$	45.86	27	69.85%
Extreme right	$10, 11, 21, 22, 32, 33$	81.97	19	331.44%

Area	Γ	M_Γ	R_Γ	$(M_\Gamma - R_\Gamma)/R_\Gamma$
acceleration	$1-11$	3892.35	1273	205.76%
constant speed	$12-22$	40733.53	45869	−11.20%
deceleration	$23-33$	2855.12	339	742.22%

→ **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