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
- Implement the model in a **simulator**

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
- **Model simulator**
- **Conclusion**

Introduction

- **Microscopic** model : capture the behavior of each pedestrian
- Different **behavioral levels** :

  Strategical : destination

  Tactical : route choice

  } **Fixed**

  Operational level : short range behavior

  instantaneous decisions

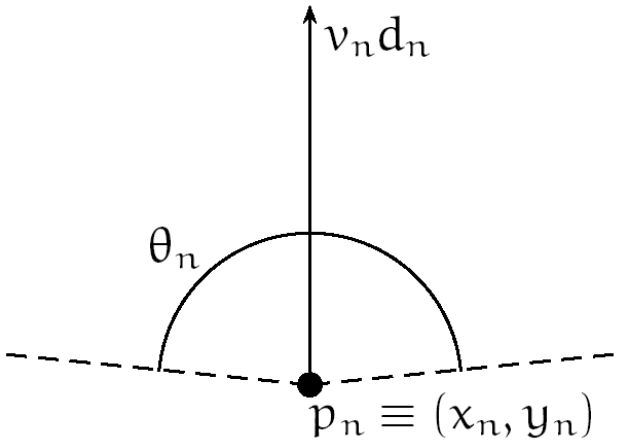
- Concept of **personal space** : interactions with other pedestrians

  Leader follower

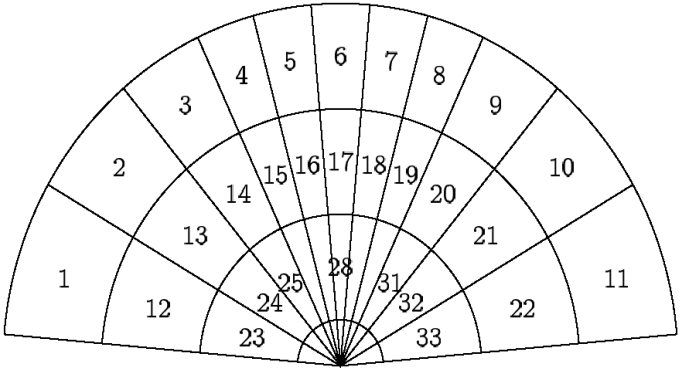
  Collision avoidance

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

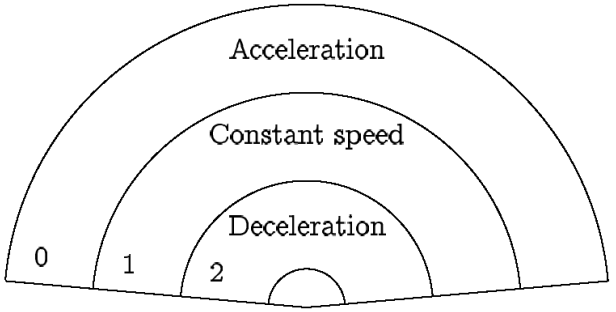


Choice set : discretization of the visual space

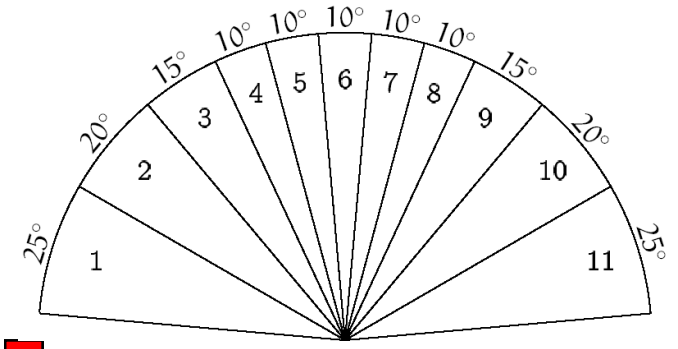
➡ At each step the **choice set** depends on the pedestrian **speed** and **direction**

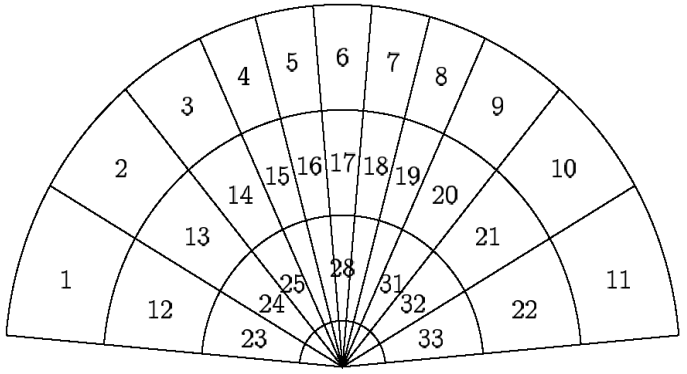
Model specification : the choice set

3 speed regimes



11 directions





33 alternatives

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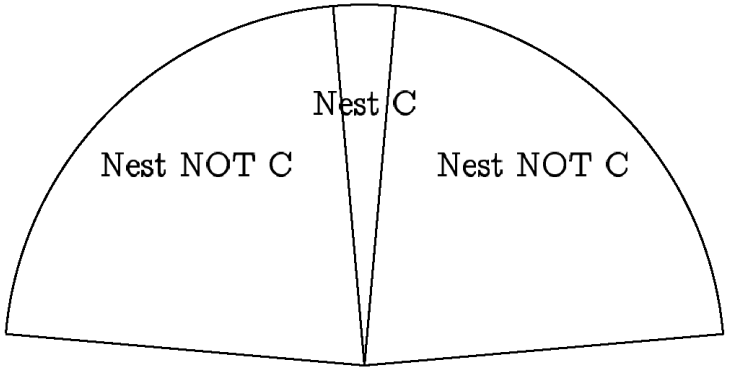
Model specification : cross nested structure

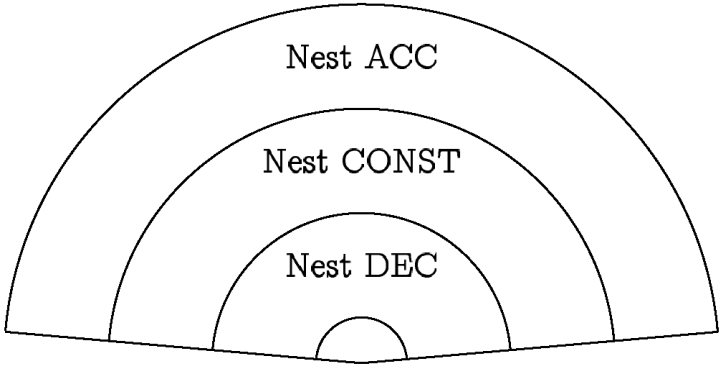
- **Hypothesis** : alternatives correlated along speed regimes and directions

  ➡ **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

$y_i = e^{V_i}$

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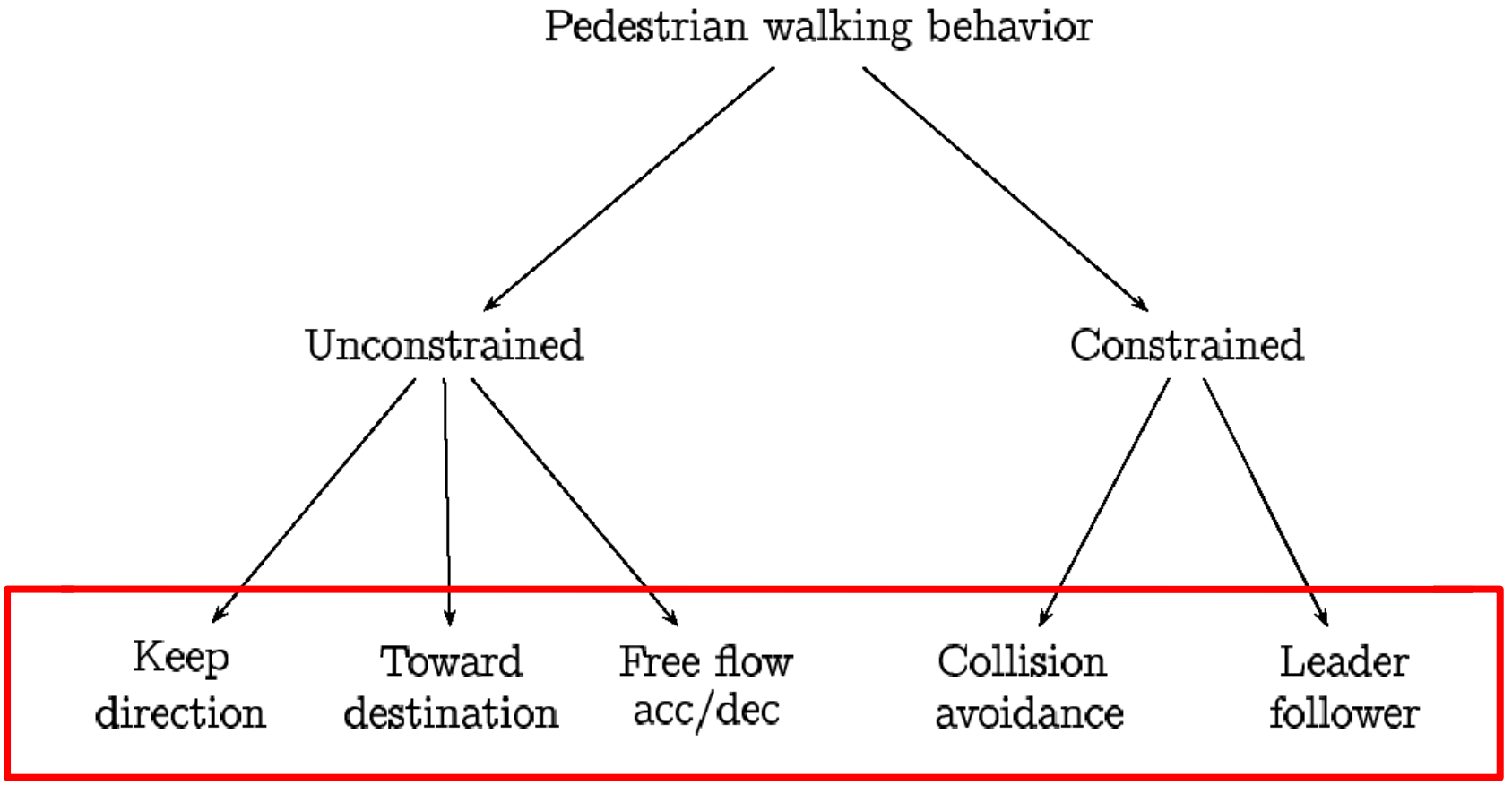
Model specification : utility specification



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Model specification : utility specification

$$
\begin{aligned}
V_{vdn} = & \beta_{dir\_central}\, dir_{dn}\, I_{central} + \\
& \beta_{dir\_side}\, dir_{dn}\, I_{side} + \\
& \beta_{dir\_extreme}\, dir_{dn}\, I_{extreme} + \\
& \beta_{ddist}\, ddist_{vdn} + \\
& \beta_{ddir}\, ddir_{dn} + \\
& \beta_{dec}\, I_{v,dec}\, (v_n / v_{max})^{\lambda_{dec}} + \\
& \beta_{accLS}\, I_{LS}\, I_{v,acc}\, (v_n / v_{maxLS})^{\lambda_{accLS}} + \\
& \beta_{accHS}\, I_{HS}\, I_{v,acc}\, (v_n / v_{max})^{\lambda_{accHS}} + \\
& I_{v,acc}\, I^{L}_{acc}\, \alpha^{L}_{acc}\, D_L^{\rho^{L}_{acc}}\, \Delta v_L^{\gamma^{L}_{acc}}\, \Delta\theta_L^{\delta^{L}_{acc}} + \\
& I_{v,dec}\, I^{L}_{dec}\, \alpha^{L}_{dec}\, D_L^{\rho^{L}_{dec}}\, \Delta v_L^{\gamma^{L}_{dec}}\, \Delta\theta_L^{\delta^{L}_{dec}} + \\
& I_{d,d_n}\, I_C\, \alpha_C\, e^{-\rho_C D_C}\, \Delta v_C^{\gamma_C}\, \Delta\theta_C^{\delta_C}
\end{aligned}
$$

keep direction

toward destination

free flow acceleration

leader-follower

collision avoidance

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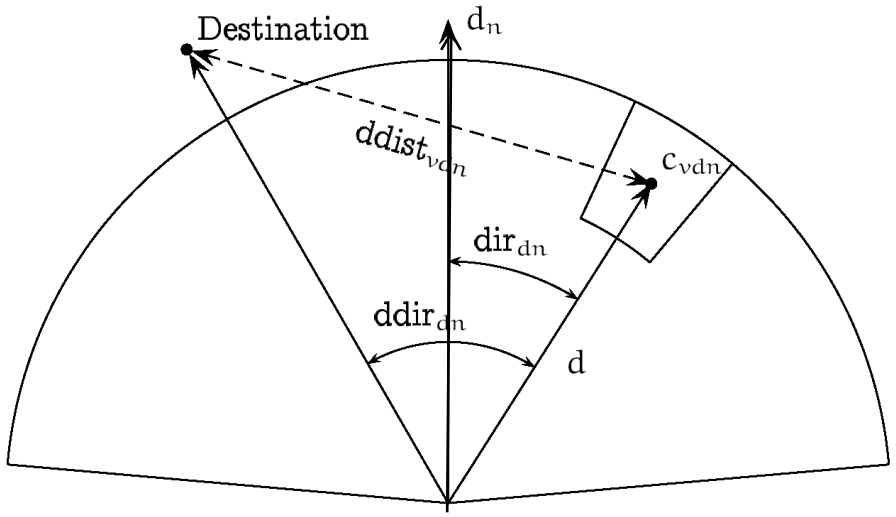
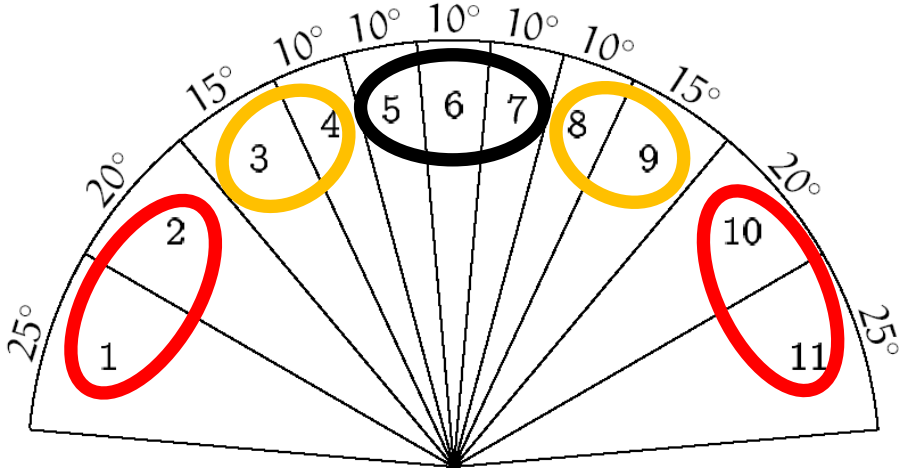
Model specification : utility specification

- Keep direction (**unconstrained**) :

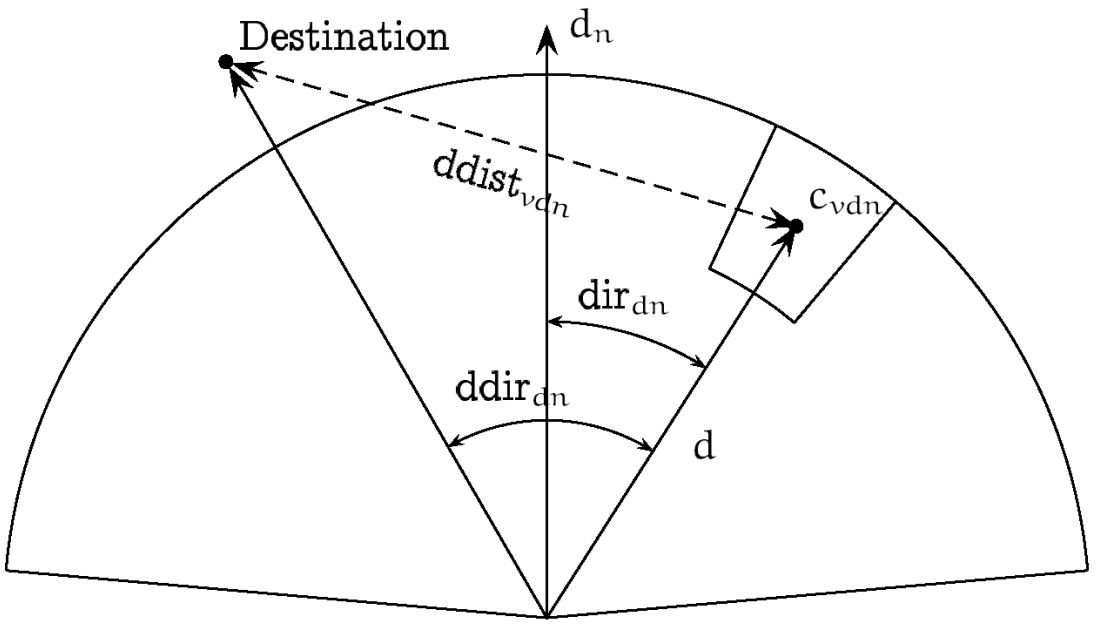
$$\underbrace{\beta_{dir\_central}\, dir_{dn}\, I_{central}}_{<0} + \underbrace{\beta_{dir\_side}\, dir_{dn}\, I_{side}}_{<0} + \underbrace{\beta_{dir\_extreme}\, dir_{dn}\, I_{extreme}}_{<0}$$





Model specification : utility specification

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



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Model specification : utility specification

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

  - Acceleration :

$$\underbrace{\beta_{\text{accLS}}\, I_{\text{LS}}\, I_{\text{v,acc}} \left(v_n / v_{\text{maxLS}}\right)^{\lambda_{\text{accLS}}}}_{\text{Low speed}} + \underbrace{\beta_{\text{accHS}}\, I_{\text{HS}}\, I_{\text{v,acc}} \left(v_n / v_{\text{max}}\right)^{\lambda_{\text{accHS}}}}_{\text{High speed}}$$

<0 *>0* *<0* *>0*

  - Deceleration :

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

<0 *<0*

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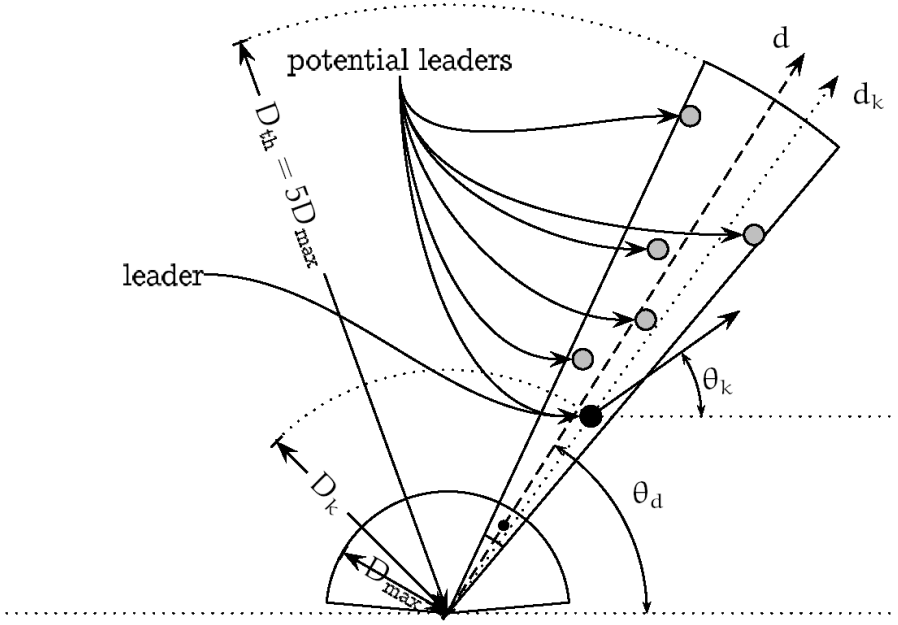
Model specification : utility specification

- Leader follower (**constrained**) :

$$I_{v,acc}\, I_{acc}^{L}\, \underbrace{\alpha_{acc}^{L}\, D_{L}^{\rho_{acc}^{L}}}_{\text{sensitivity}}\, \underbrace{\Delta v_{L}^{\gamma_{acc}^{L}}\, \Delta\theta_{L}^{\delta_{acc}^{L}}}_{\text{stimulus}} + I_{v,dec}\, I_{dec}^{L}\, \underbrace{\alpha_{dec}^{L}\, D_{L}^{\rho_{dec}^{L}}}_{\text{sensitivity}}\, \underbrace{\Delta v_{L}^{\gamma_{dec}^{L}}}_{\text{stimulus}}$$

>0 <0 >0 <0 >0 <0 >0



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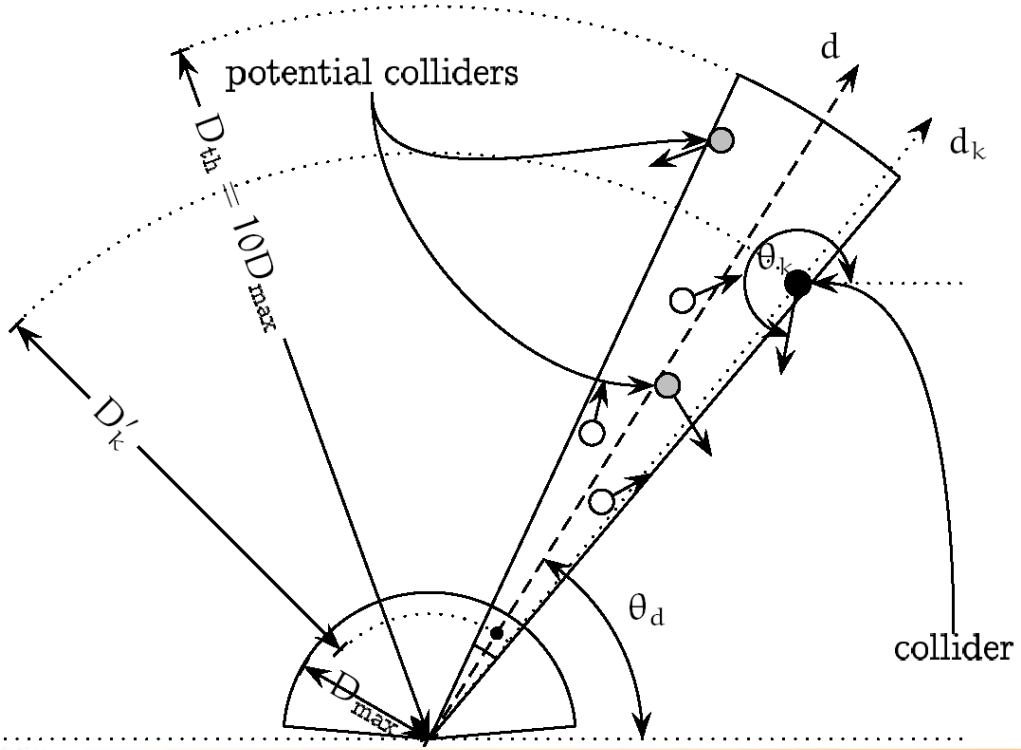
Model specification : utility specification

- Collision avoidance (**constrained**) : $I_{\mathbf{d},d_n} I_C \alpha_C e^{-\rho_C D_C} \Delta v_C^{\gamma_C} \Delta\theta_C^{\delta_C}$

<0 >0 >0 >0

sensitivity stimulus



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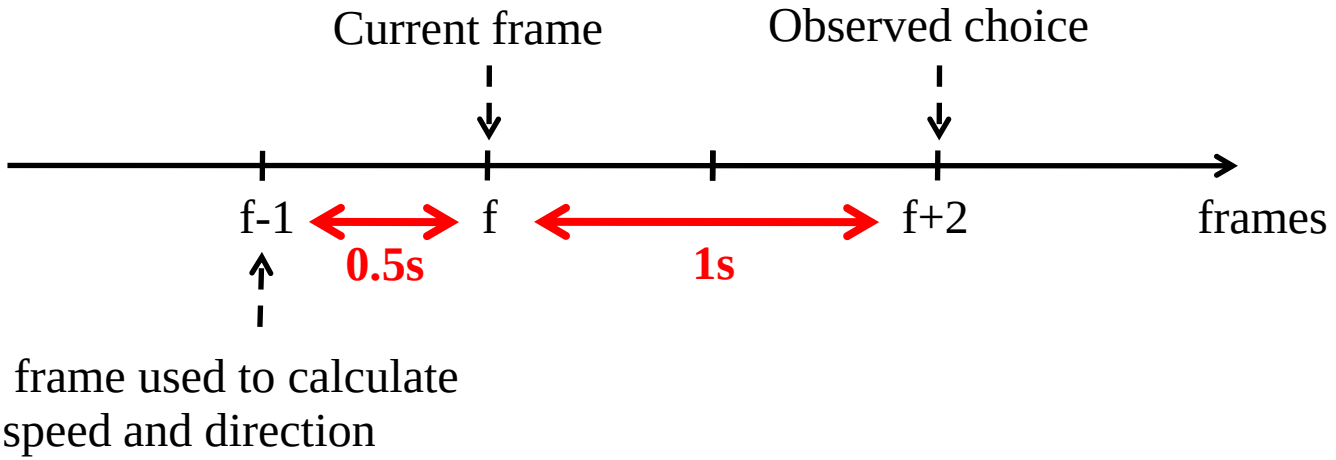
The Japanese data set : video sequence

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

The Japanese data set : data processing

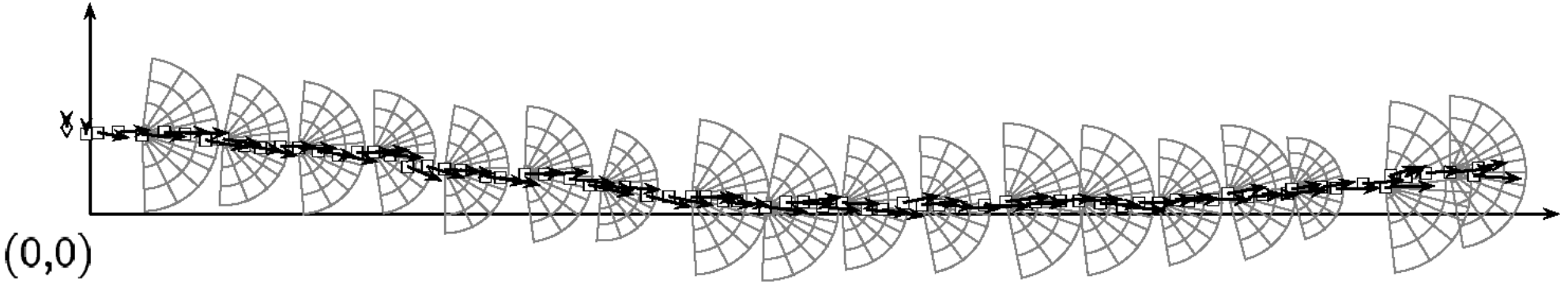
- Tracking from video sequence: **2 observations per second**
- Pedestrians trajectories extracted using 3D-calibration (DLT algorithm)
- For each pedestrian trajectory :



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
Init 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

Variable name	Coefficient estimate	t test 0	t test 1
β_{ddir}	-0.0790	-24.53	
β_{ddist}	-1.55	-11.66	
$\beta_{dir\_extreme}$	-0.0326	-9.30	
β_{dir_side}	-0.0521	-21.87	
$\beta_{dir\_central}$	-0.0252	-8.74	
β_{accLS}	-4.97	-22.61	
β_{accHS}	-7.47	-5.21	
β_{dec}	-0.0630	-2.40	
λ_{accLS}	4.16	15.94	
λ_{accHS}	0.358	2.09	
λ_{dec}	-2.41	-8.43	
α^{L}_{acc}	0.942	2.28	
ρ^{L}_{acc}	-0.489	-2.19	
γ^{L}_{acc}	0.625	2.87	
α^{L}_{dec}	3.69	6.90	
ρ^{L}_{dec}	-0.663	-7.11	
γ^{L}_{dec}	0.652	6.19	
δ^{L}_{acc}	-0.171	-2.33	
α_C	-0.00639	-9.82	
ρ_C	0.239	-8.28	
μ_{acc}	1.66	9.73	3.88
μ_{const}	1.50	13.46	4.48
$\mu_{central}$	2.35	1.93	1.11
$\mu_{not\_central}$	1.75	9.46	4.04

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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.

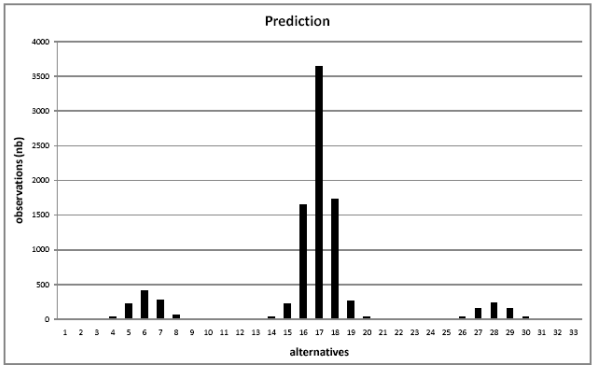
  ➡ **28 parameters (33, minus 4 never chosen, minus 1 for normalization)**

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

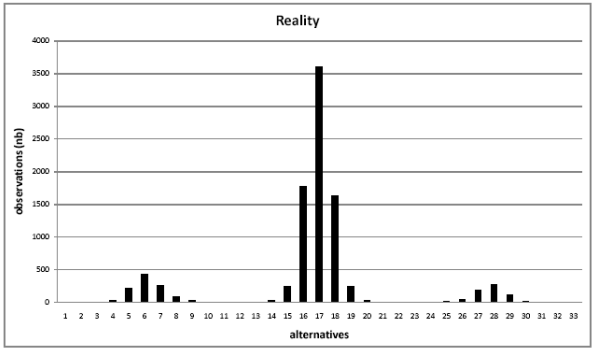
- The ASC model **used for comparison** (for example the number of outliers)

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



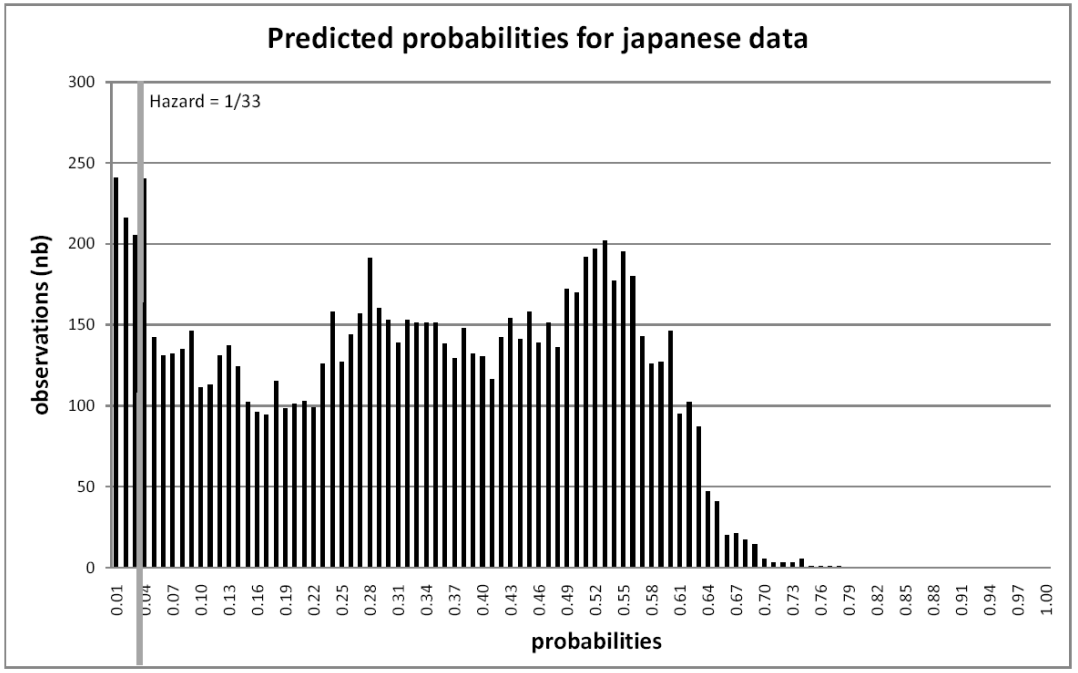
(b) Observed shares

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%

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

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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%

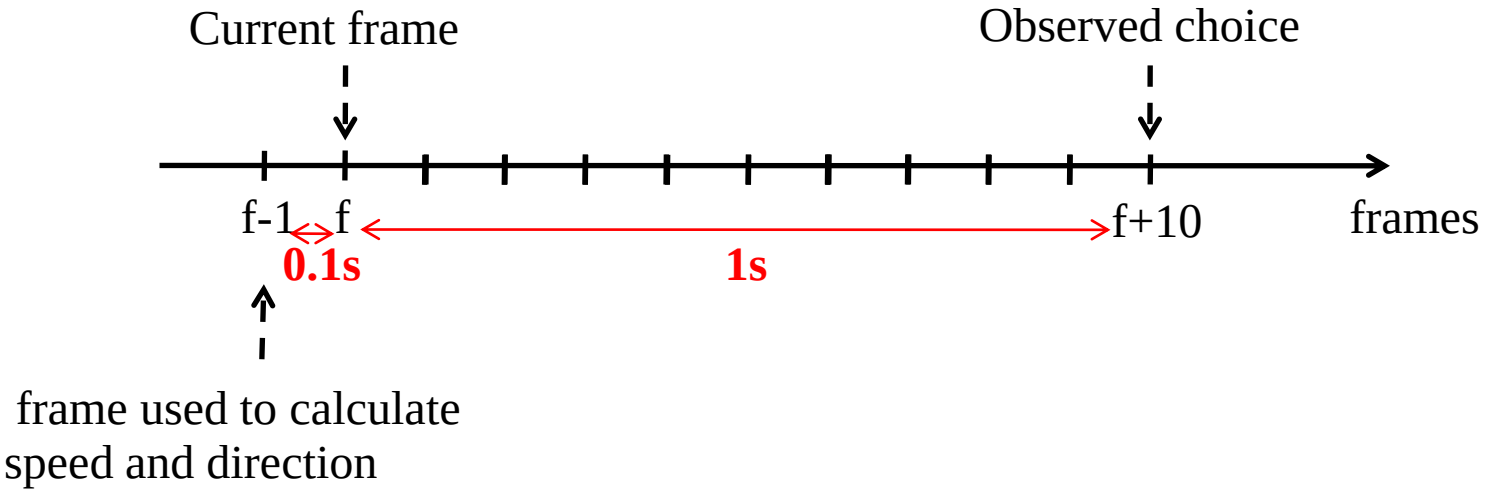
→ **Robust specification**

The Dutch data set : video sequence

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

The Dutch data set : general information

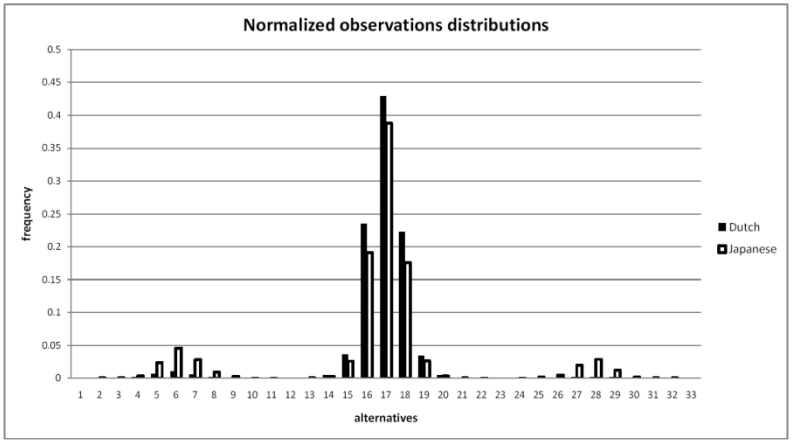
- **Experimental** data set
- Video sequence recorded at **10 frames per second**
- Pedestrians trajectories extracted from the video sequence
- For each pedestrian trajectory :



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%

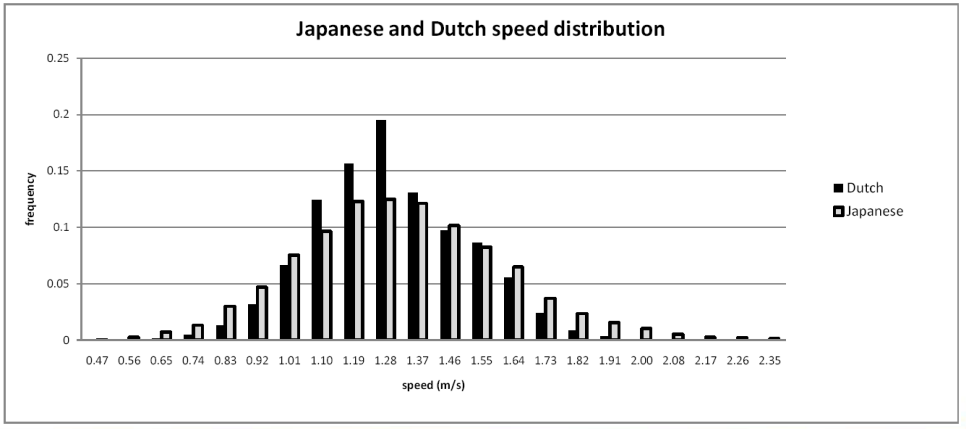
Nest	# steps	% of total
acceleration	1273	2.68%
constant speed	45869	96.61%
deceleration	339	0.71%
central	20950	44.12%
not central	26531	55.88%

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 distributions have different shapes (experimental design of Dutch data set)



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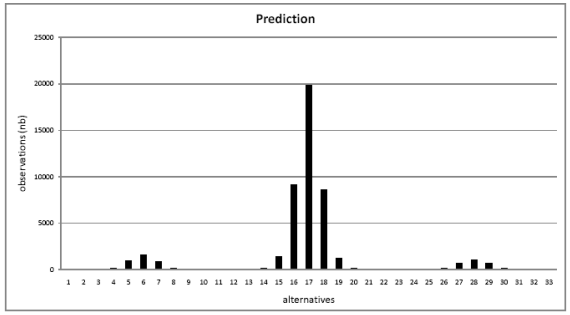
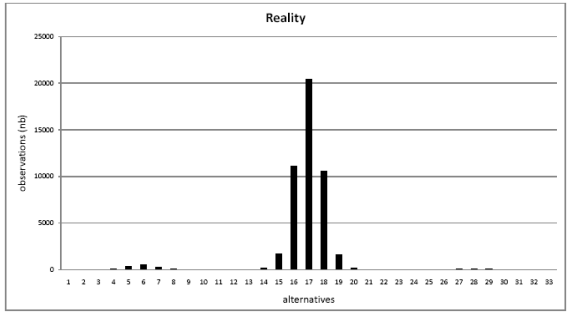
Model validation : simulation on the Dutch data set (Aggregate level)

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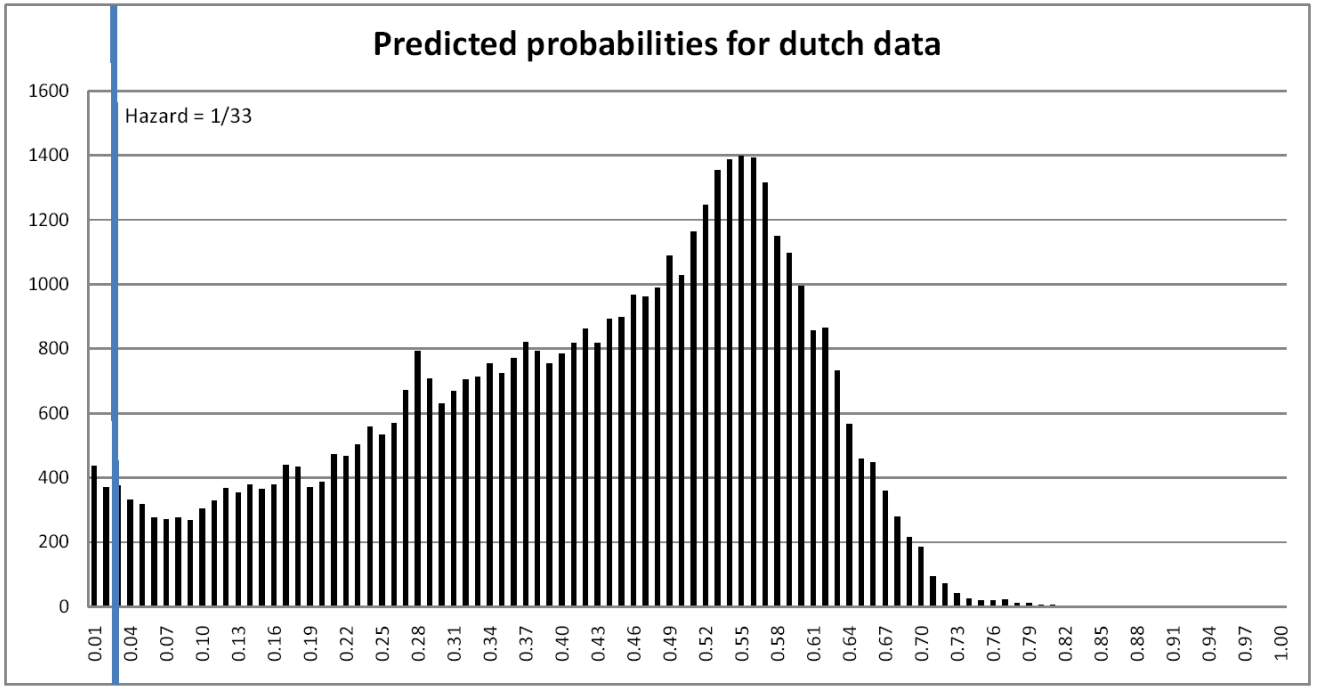
Model validation : simulation on the Dutch data set (Disaggregate level)

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



Number of outliers: **2.48**%

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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

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%

Proposed model

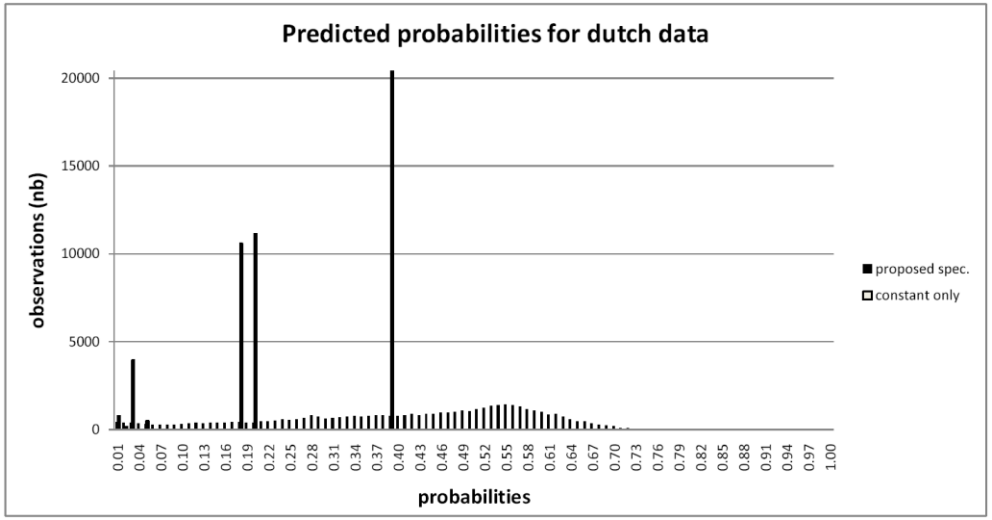
Cone	Γ	M_Γ	R_Γ	$(M_\Gamma - R_\Gamma)/R_\Gamma$
Front	$5-7, 16-18, 27-29$	43619.98	43374	0.57%
Left	$3, 4, 14, 15, 25, 26$	1968.79	2089	−5.75%
Right	$8, 9, 19, 20, 30, 31$	1764.39	1972	−10.53%
Extreme left	$1, 2, 12, 13, 23, 24$	45.86	27	69.85%
Extreme right	$10, 11, 21, 22, 32, 33$	81.97	19	331.44%

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

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Simulator

- Simulation of 2 pedestrian crossing flows with the model
- Example :
  - 2 pedestrians entering on the scene per second
  - Simulation of 300s
  - Random speed and direction

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 hypothesis
  - Model validated on a real data set, **not used for estimation**
  - Operating **Simulator**
- **Perspectives :**
  - Improve the **acceleration** and **deceleration** patterns
  - Incorporate **physical characteristics** of the pedestrians
  - Model the **strategical** and **tactical** behavioural levels

Thanks for your attention

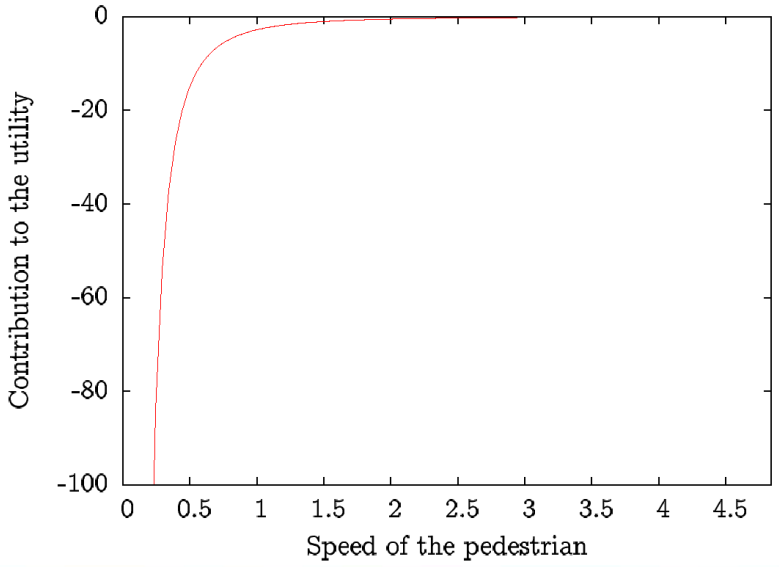
http://transp-or2.epfl.ch/publications.php#techrep

Model estimation : parameters values

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

  - Deceleration : -0.0630 ↓ -2.41 ↓

$$\beta_{dec} I_{v,dec} (v_n / v_{max})^{\lambda_{dec}}$$



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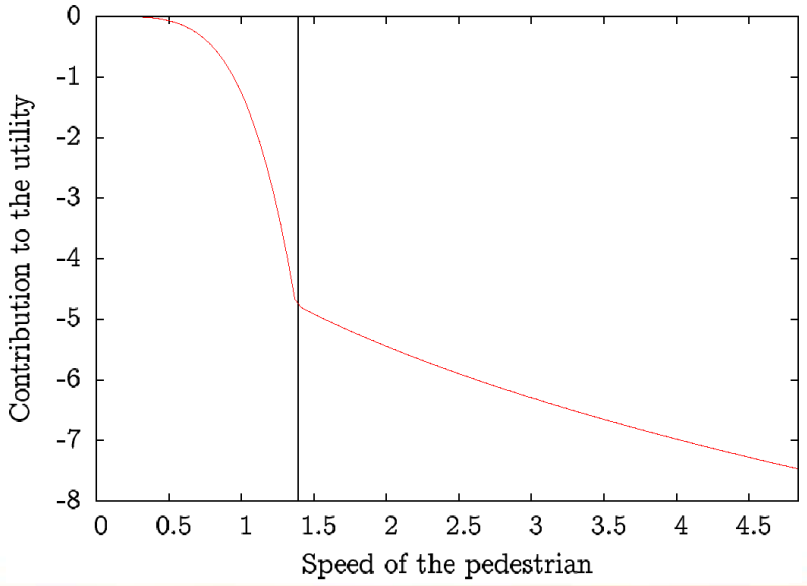
Model estimation : parameters values

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

-4.97 → β_{accLS} ; 4.16 → λ_{accLS} ; -7.47 → β_{accHS} ; 0.358 → λ_{accHS}

$$\beta_{accLS} I_{LS} I_{v,acc} (v_n / v_{maxLS})^{\lambda_{accLS}} + \beta_{accHS} I_{HS} I_{v,acc} (v_n / v_{max})^{\lambda_{accHS}}$$

Low speed **High speed**



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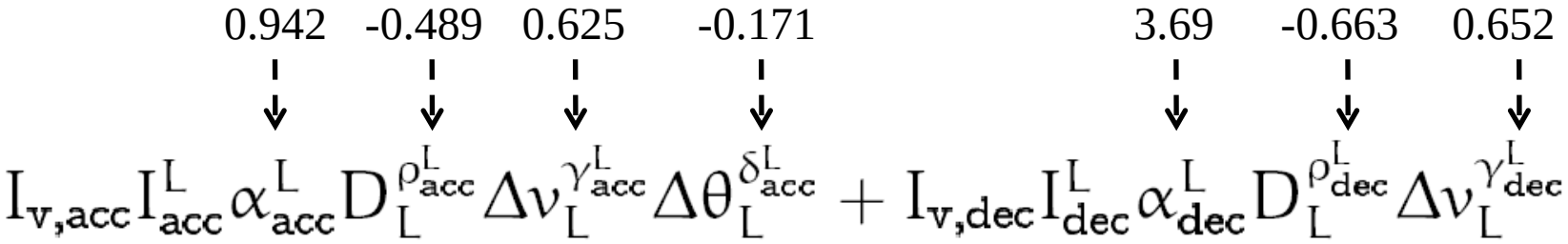
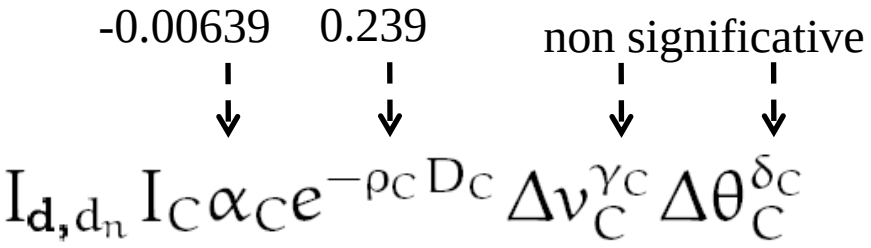
Model estimation : parameters values

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



- **Collision avoidance** (constrained) :



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