

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**
- **Model estimation**
- **Model validation**
- **Simulator**
- **Conclusion**

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- **Introduction**
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Introduction

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

➔ **Discrete choice model**

- Different **behavioral levels** :

Strategical : destination

Tactical : route choice

Operational level : short range behavior

instantaneous decisions

} **Fixed**

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

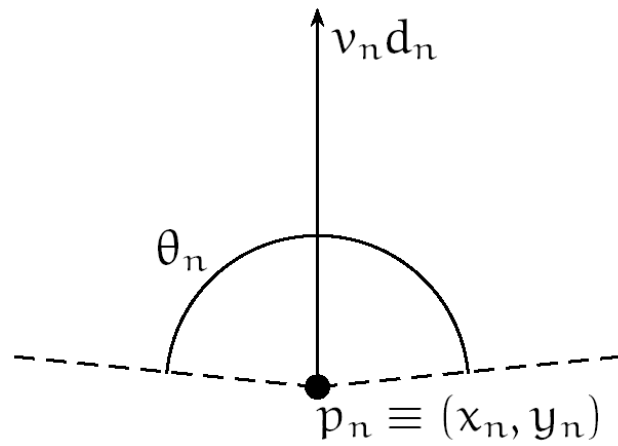
Leader follower

Collision avoidance

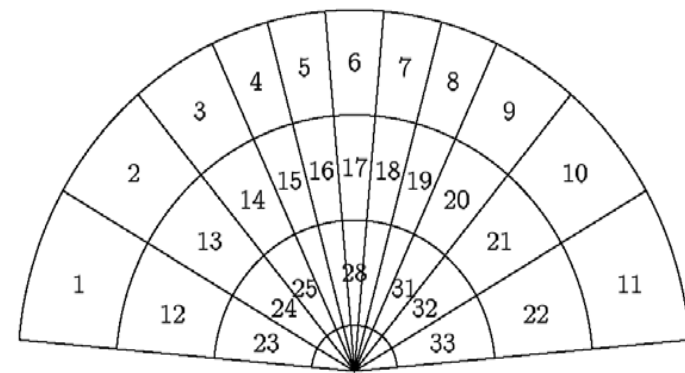
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- Introduction
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Model specification : the space discretization

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



Pedestrian visual space

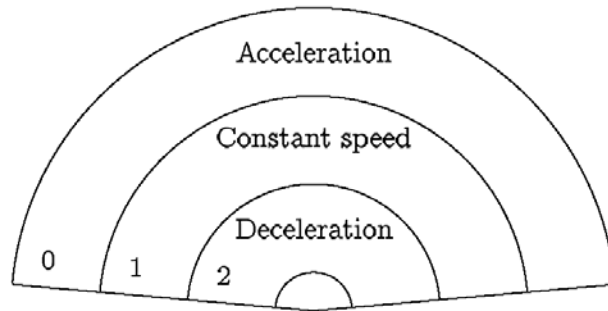


Choice set : discretization of the visual space

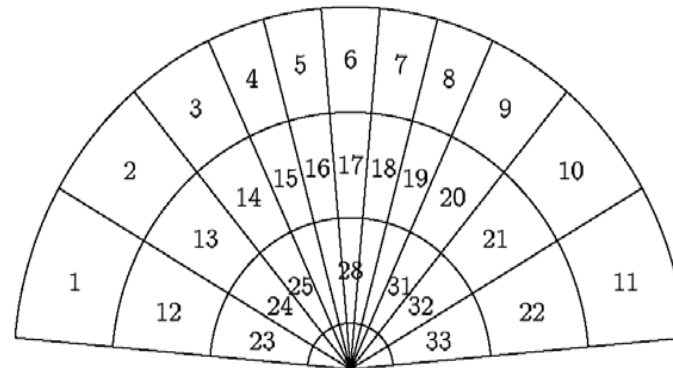
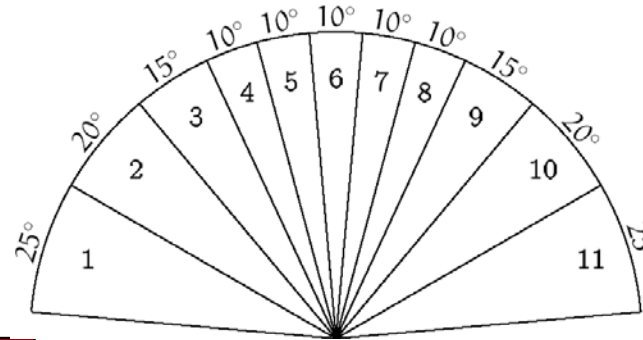
→ At each step the **choice set** depends on the pedestrian **speed** and **direction**

Model specification : the choice set

3 speed regimes



11 directions



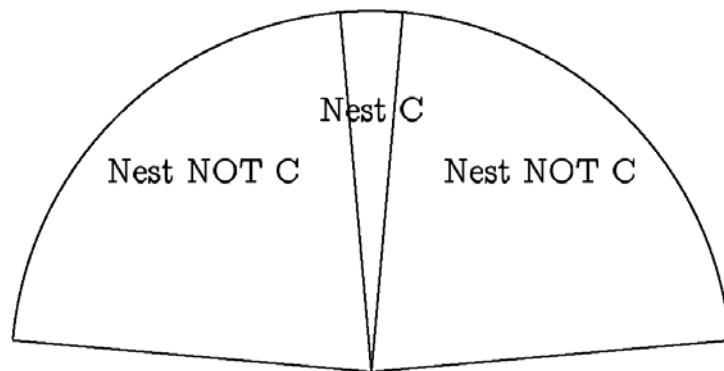
33 alternatives

Model specification : cross nested structure

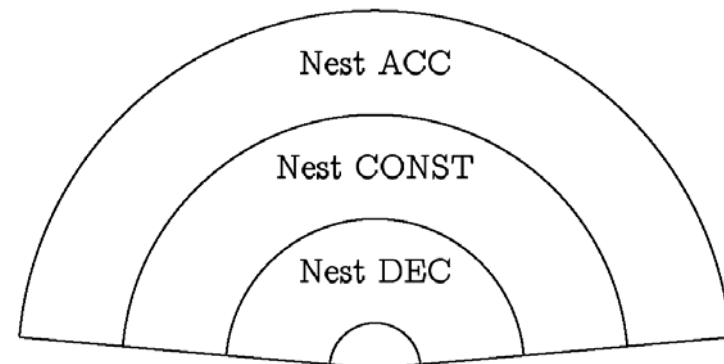
- **Hypothesis** : alternatives correlated along speed regimes and directions

➔ **Cross Nested Logit model**

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

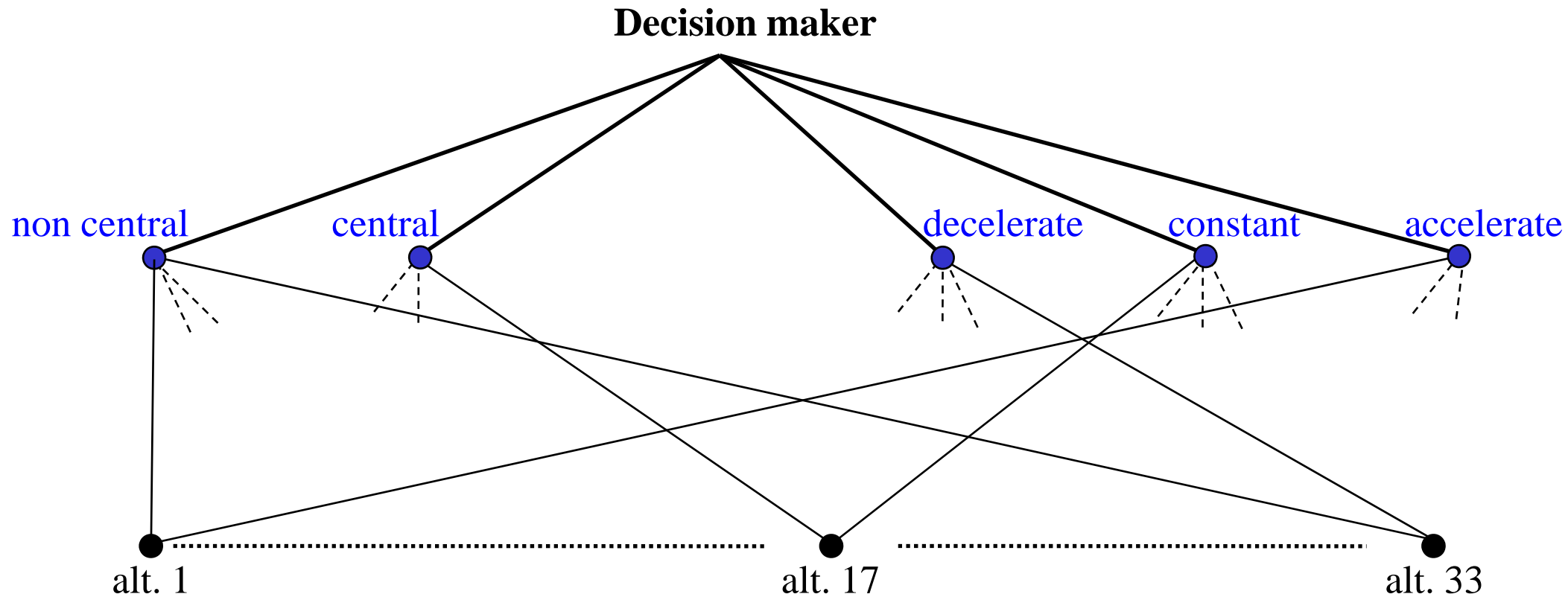


Nesting based on
direction



Nesting based on
speed regime

Model specification : cross nested structure



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

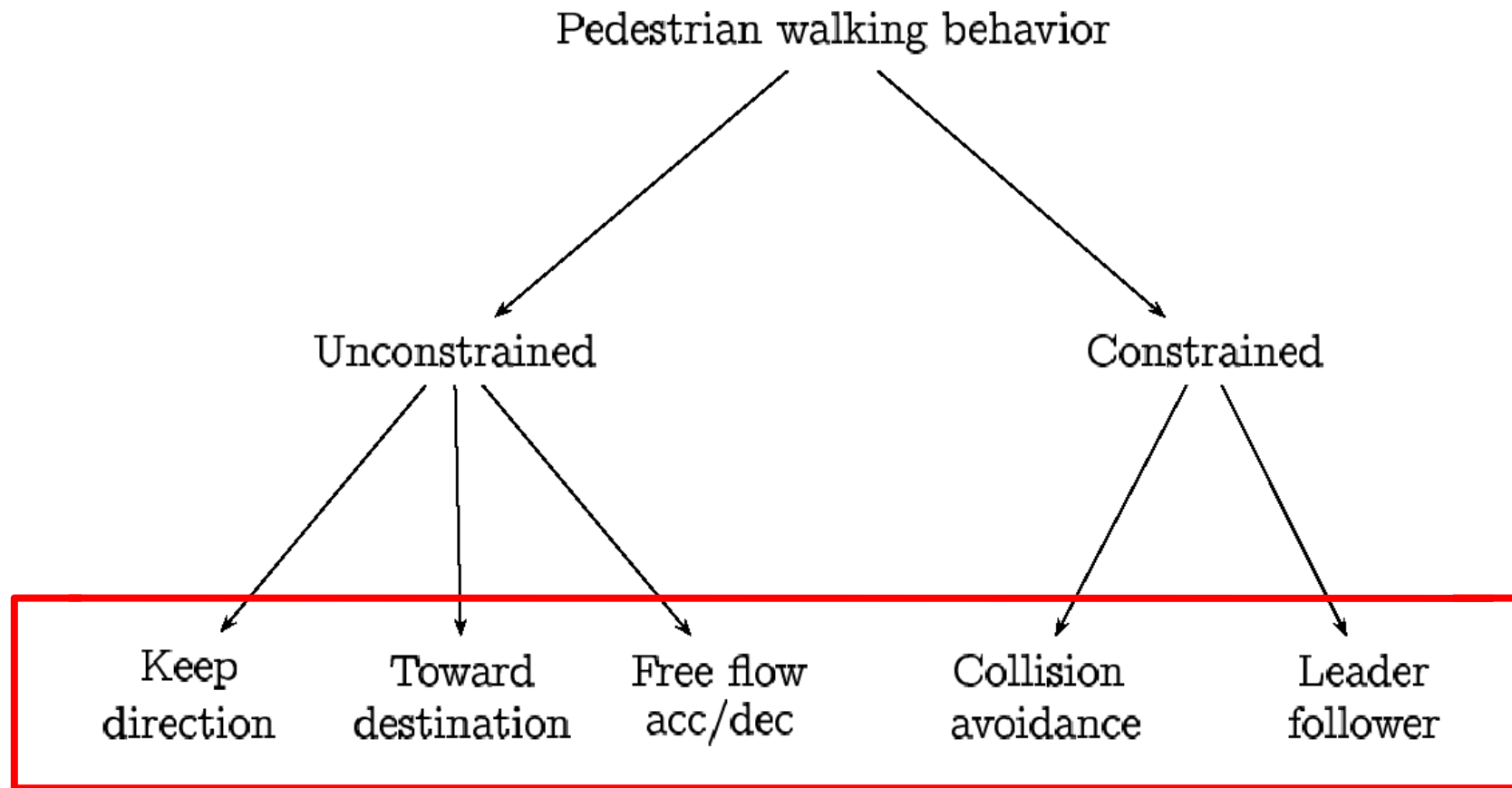
V_i : utility of alternative i

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



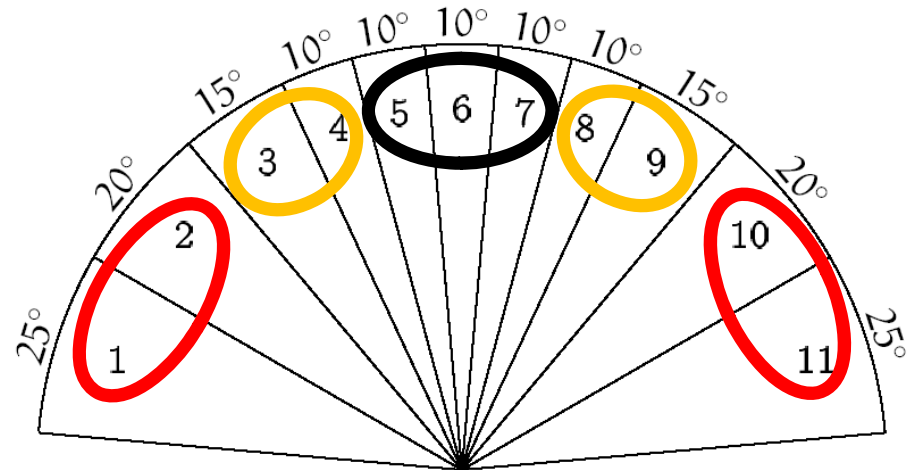
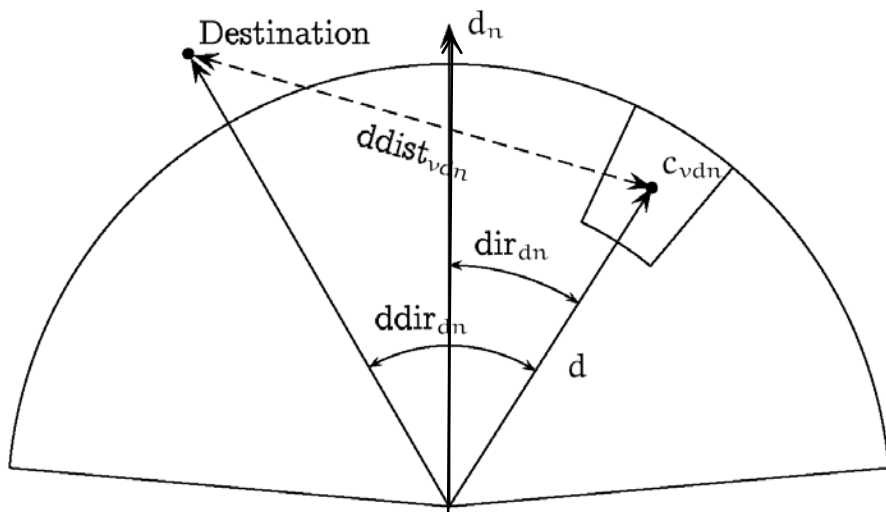
Model specification : utility specification

$$\begin{aligned}
 V_{v_{dn}} = & \left. \begin{aligned}
 & \beta_{dir_central} dir_{dn} I_{central} & + \\
 & \beta_{dir_side} dir_{dn} I_{side} & + \\
 & \beta_{dir_extreme} dir_{dn} I_{extreme} & +
 \end{aligned} \right\} \textit{keep direction} \\
 & \left. \begin{aligned}
 & \beta_{ddist} ddist_{v_{dn}} & + \\
 & \beta_{ddir} ddir_{dn} & +
 \end{aligned} \right\} \textit{toward destination} \\
 & \left. \begin{aligned}
 & \beta_{dec} I_{v,dec} (v_n/v_{max})^{\lambda_{dec}} & + \\
 & \beta_{accLS} I_{LS} I_{v,acc} (v_n/v_{maxLS})^{\lambda_{accLS}} & + \\
 & \beta_{accHS} I_{HS} I_{v,acc} (v_n/v_{max})^{\lambda_{accHS}} & +
 \end{aligned} \right\} \textit{free flow acceleration} \\
 & \left. \begin{aligned}
 & I_{v,acc} I_{acc}^L \alpha_{acc}^L D_L^{\rho_{acc}^L} \Delta v_L^{\gamma_{acc}^L} \Delta \theta_L^{\delta_{acc}^L} & + \\
 & I_{v,dec} I_{dec}^L \alpha_{dec}^L D_L^{\rho_{dec}^L} \Delta v_L^{\gamma_{dec}^L} \Delta \theta_L^{\delta_{dec}^L} & +
 \end{aligned} \right\} \textit{leader-follower} \\
 & \left. \begin{aligned}
 & I_{d,dn} I_C \alpha_C e^{-\rho_C D_C} \Delta v_C^{\gamma_C} \Delta \theta_C^{\delta_C} & +
 \end{aligned} \right\} \textit{collision avoidance}
 \end{aligned}$$

Model specification : utility specification

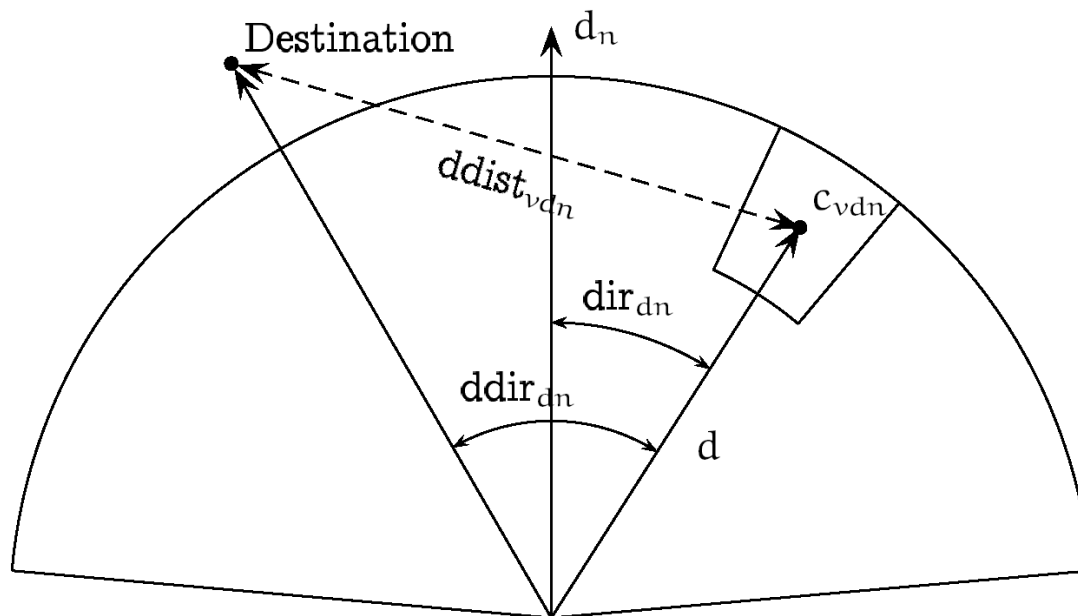
- Keep direction (unconstrained) :

$$\underbrace{\beta_{\text{dir_central}} \text{dir}_{\text{dn}} I_{\text{central}}}_{<0} + \underbrace{\beta_{\text{dir_side}} \text{dir}_{\text{dn}} I_{\text{side}}}_{<0} + \underbrace{\beta_{\text{dir_extreme}} \text{dir}_{\text{dn}} I_{\text{extreme}}}_{<0}$$



Model specification : utility specification

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



Model specification : utility specification

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

- Acceleration :

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

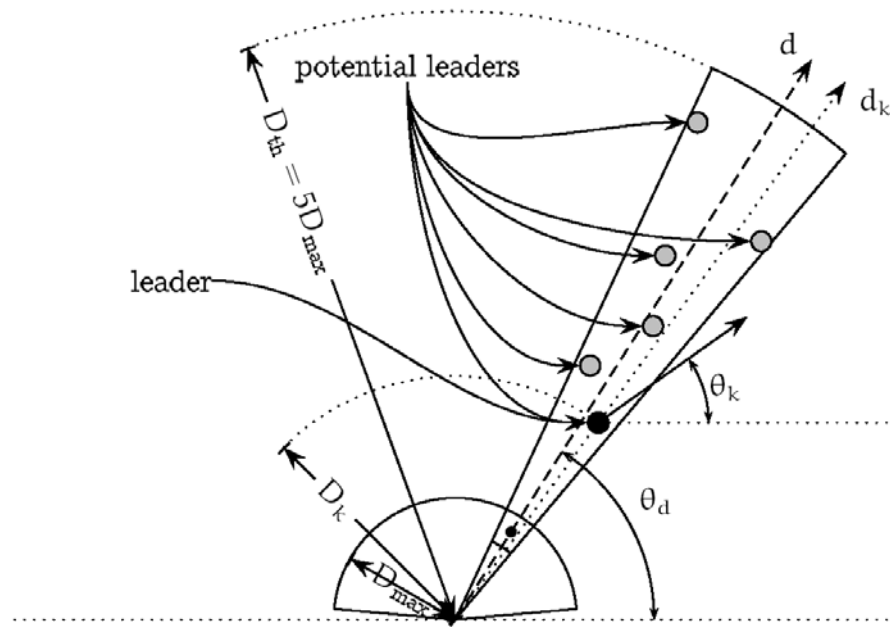
- Deceleration :

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

Model specification : utility specification

- Leader follower (constrained) :

$$I_{v,acc} I_{acc}^L \underbrace{\alpha_{acc}^L D_L^{\rho_{acc}^L}}_{\text{sensitivity}} \underbrace{\Delta v_L^{\gamma_{acc}^L} \Delta \theta_L^{\delta_{acc}^L}}_{\text{stimulus}} + I_{v,dec} I_{dec}^L \underbrace{\alpha_{dec}^L D_L^{\rho_{dec}^L}}_{\text{sensitivity}} \underbrace{\Delta v_L^{\gamma_{dec}^L}}_{\text{stimulus}}$$

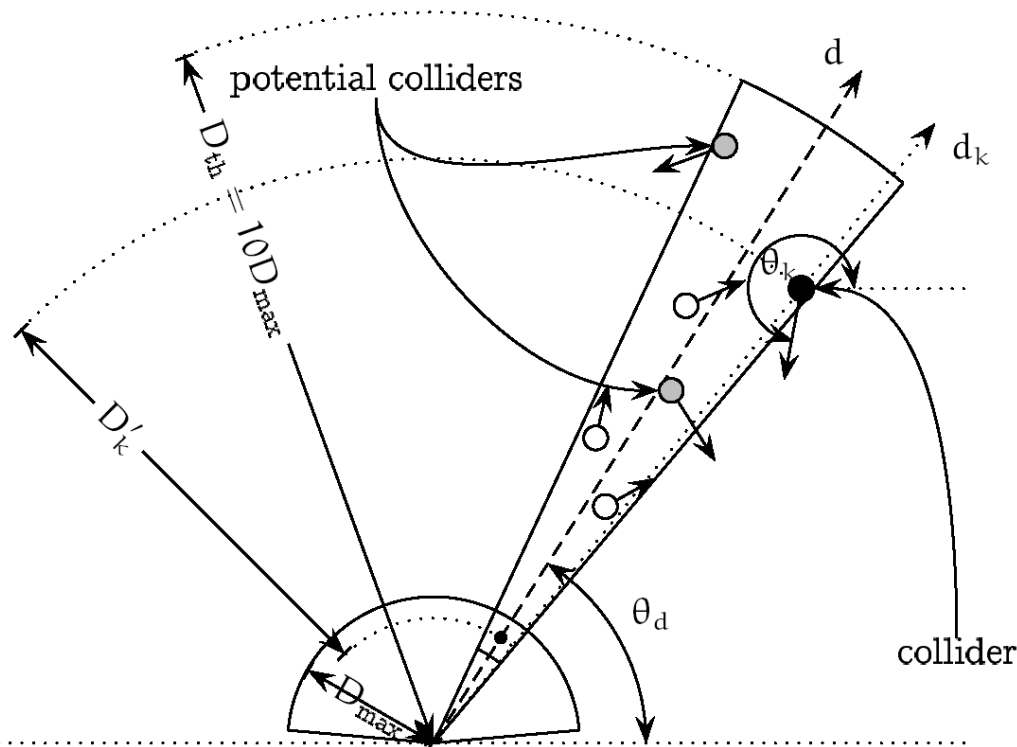


Model specification : utility specification

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

<0
 >0
sensitivity

>0
 >0
stimulus



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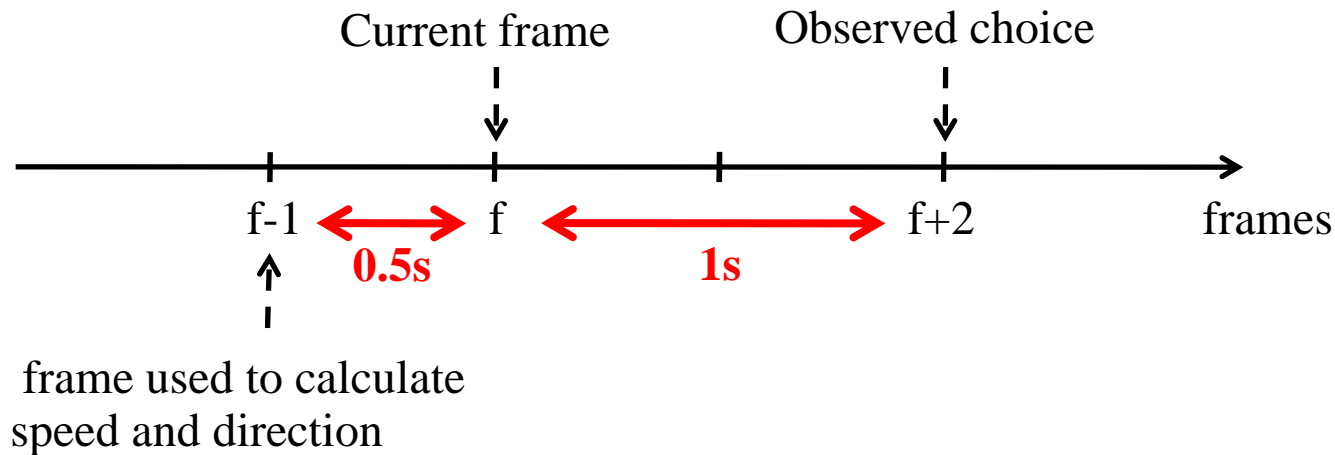
The Japanese data set : video sequence

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



The Japanese data set : data processing

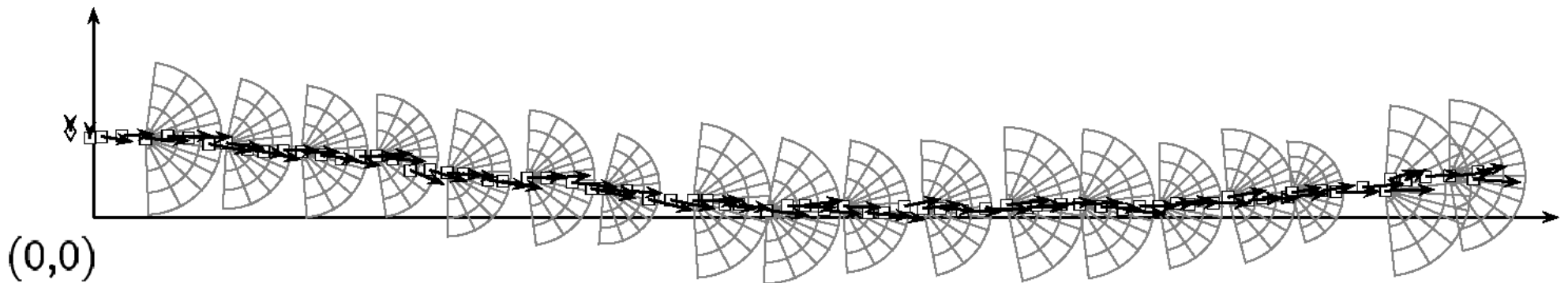
- Tracking from video sequence: **2 observations per second**
- Pedestrians trajectories extracted using 3D-calibration (DLT algorithm)
- For each pedestrian trajectory :



➔ 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 : -13944.74

Likelihood ratio test : 37013

$$\bar{\rho}^2 = 0.570$$

- Parameters values consistent with hypothesis

Model estimation : parameters values

Variable name	Coefficient estimate	<i>t</i> test 0	Variable name	Coefficient estimate	<i>t</i> test 0	<i>t</i> test 1
β_{ddir}	-0.0793	-24.14	ρ_{acc}^L	-0.465	-1.78	
β_{ddist}	-1.52	-11.63	γ_{acc}^L	0.552	1.98	
$\beta_{dir_extreme}$	-0.0343	-9.71	α_{dec}^L	3.78	5.41	
β_{dir_side}	-0.0553	-22.71	ρ_{dec}^L	-0.654	-6.70	
$\beta_{dir_central}$	-0.0320	-13.90	γ_{dec}^L	0.658	5.48	
β_{accLS}	-4.94	-25.20	δ_{acc}^L	-0.179	-2.22	
β_{accHS}	-7.41	-5.10	α_C	-0.00730	-10.84	
β_{dec}	-0.0645	-2.46	ρ_C	-0.212	-8.38	
λ_{accLS}	4.37	20.06	μ_{acc}	1.66	9.97	3.95
λ_{accHS}	0.354	2.02	μ_{const}	1.45	16.99	5.25
λ_{dec}	-2.40	-8.50	$\mu_{central}$	5.76	2.84	2.34
α_{acc}^L	0.735	1.87	$\mu_{not_central}$	1.82	13.12	5.91

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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 : ASC model

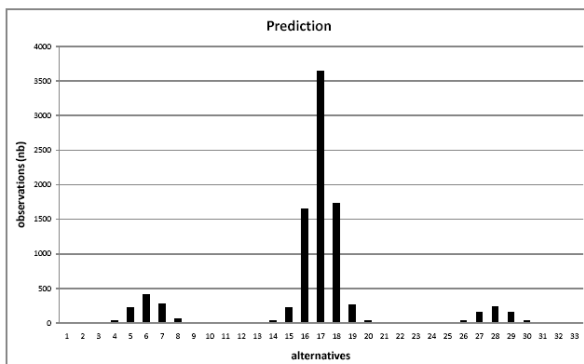
- The simplest model : utility of each alternative represented only by an alternative specific constant (ASC).
- ASC model estimated on the Japanese data set.
 - ➔ **28 parameters (33, minus 4 never chosen, minus 1 for normalization)**
- It reproduces the aggregated observations proportions of the estimation data.
- The ASC model **used for comparison** (for example the number of outliers).

Model validation

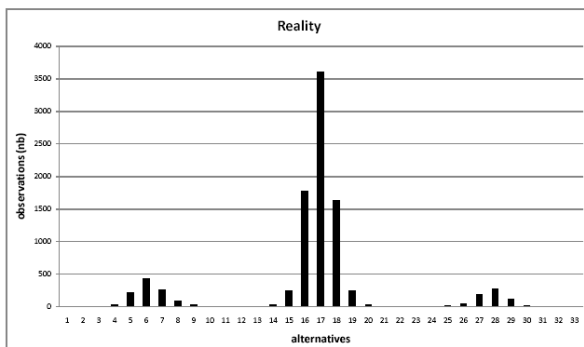
- **Validation of the specification**
- Validation of the model

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



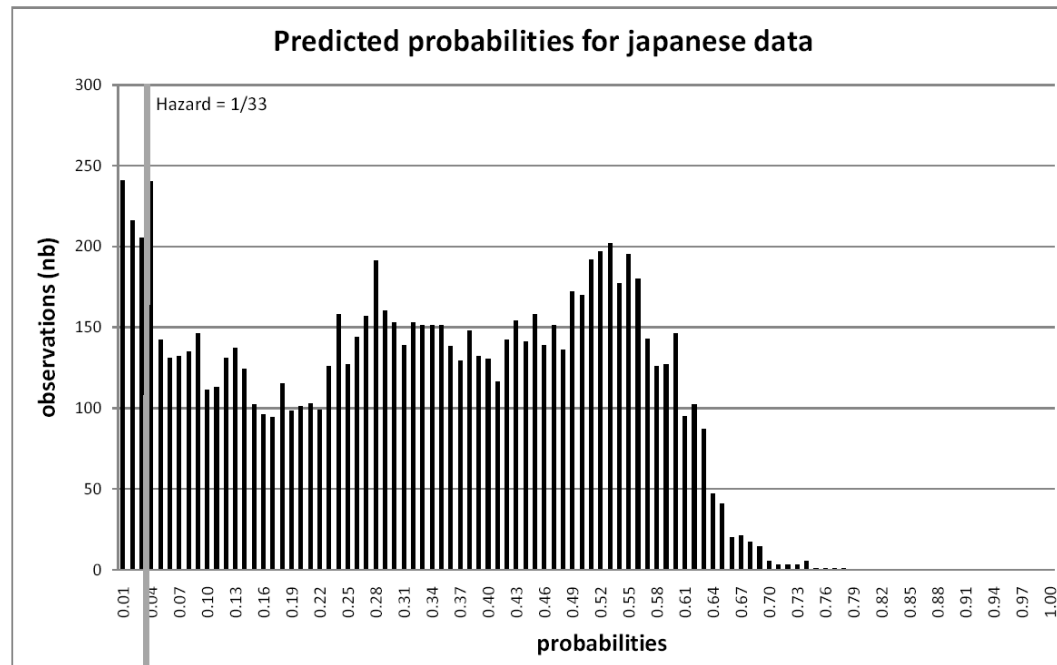
(b) Observed shares

Cone	Γ	M_Γ	R_Γ	$(M_\Gamma - R_\Gamma)/R_\Gamma$
Front	5 – 7, 16 – 18, 27 – 29	8486.16	8481	0.06%
Left	3, 4, 14, 15, 25, 26	348.86	367	-4.94%
Right	8, 9, 19, 20, 30, 31	419.29	407	3.02%
Extreme left	1, 2, 12, 13, 23, 24	12.29	10	22.92%
Extreme right	10, 11, 21, 22, 32, 33	14.39	16	-10.04%

Area	Γ	M_Γ	R_Γ	$(M_\Gamma - R_\Gamma)/R_\Gamma$
acceleration	1 – 11	1059.85	1065	-0.48%
constant speed	12 – 22	7588.28	7565	0.31%
deceleration	23 – 33	632.87	651	-2.79%

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

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



Number of outliers: $\left\{ \begin{array}{l} \mathbf{7.10\%} \text{ for proposed model} \\ \mathbf{19.90\%} \text{ for ASC model} \end{array} \right.$

Model validation : Cross-validation on the Japanese data set

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

→ 5 experiments : $\left\{ \begin{array}{l} 1 \text{ subset saved for } \mathbf{validation} \\ \mathbf{estimation} \text{ of the model on the 4 remaining} \end{array} \right.$

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

Model	Exp. 1	Exp. 2	Exp. 3	Exp. 4	Exp. 5
Proposed spec.	8.62%	6.52%	7.44%	7.87%	5.87%
Constant only	20.79%	20.70%	17.13%	19.88%	18.64%

→ **Robust specification**

Model validation

- Validation of the specification
- **Validation of the model**

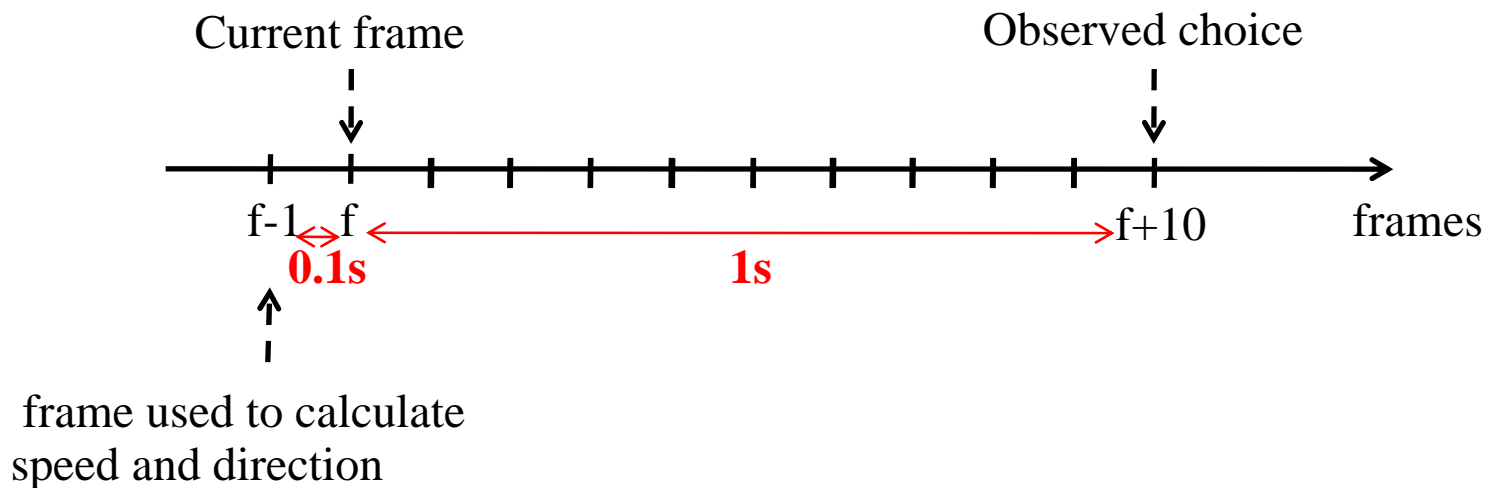
The Dutch data set : video sequence

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



The Dutch data set : general information

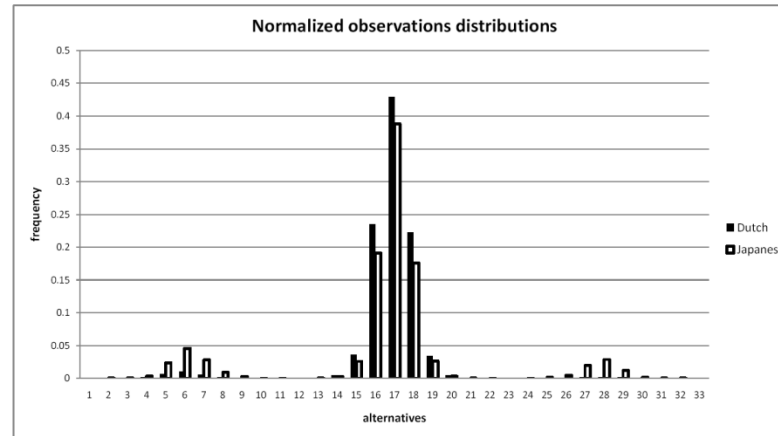
- **Experimental** data set
- Video sequence recorded at **10 frames per second**
- Pedestrians trajectories extracted from the video sequence
- For each pedestrian trajectory :



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%

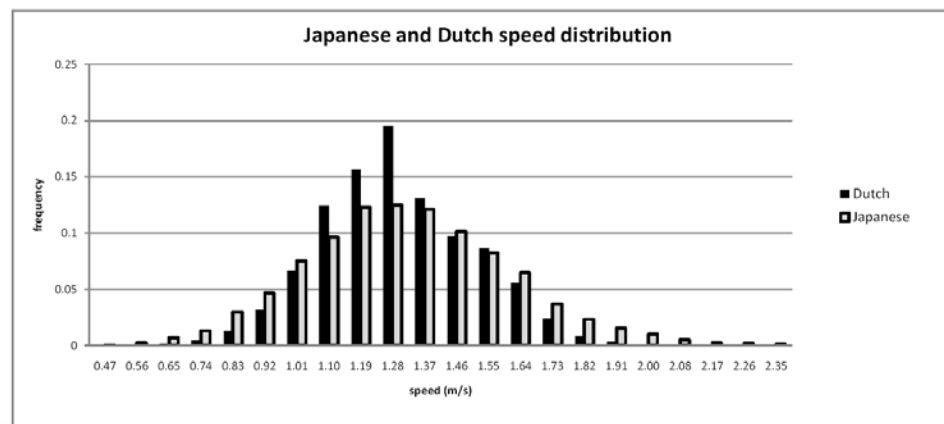
Nest	# steps	% of total
acceleration	1273	2.68%
constant speed	45869	96.61%
deceleration	339	0.71%
central	20950	44.12%
not central	26531	55.88%

The Dutch data set : comparison with the Japanese data set

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

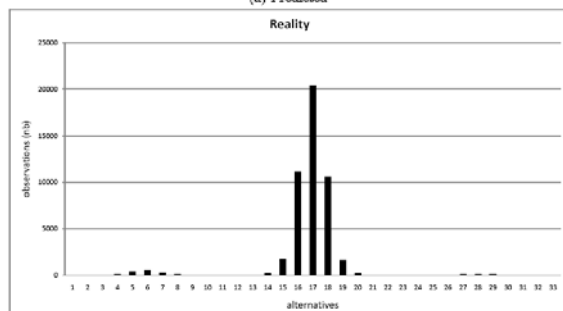
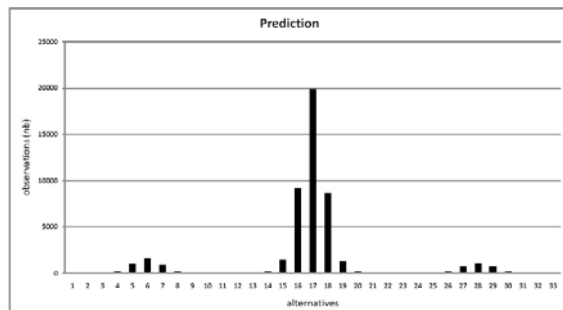
Dataset	extremeleft	left	front	right	extremeright
Japanese	0.11%	3.95%	91.38%	4.39%	0.17%
Dutch	0.06%	4.40%	91.35%	4.15%	0.04%

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



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

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



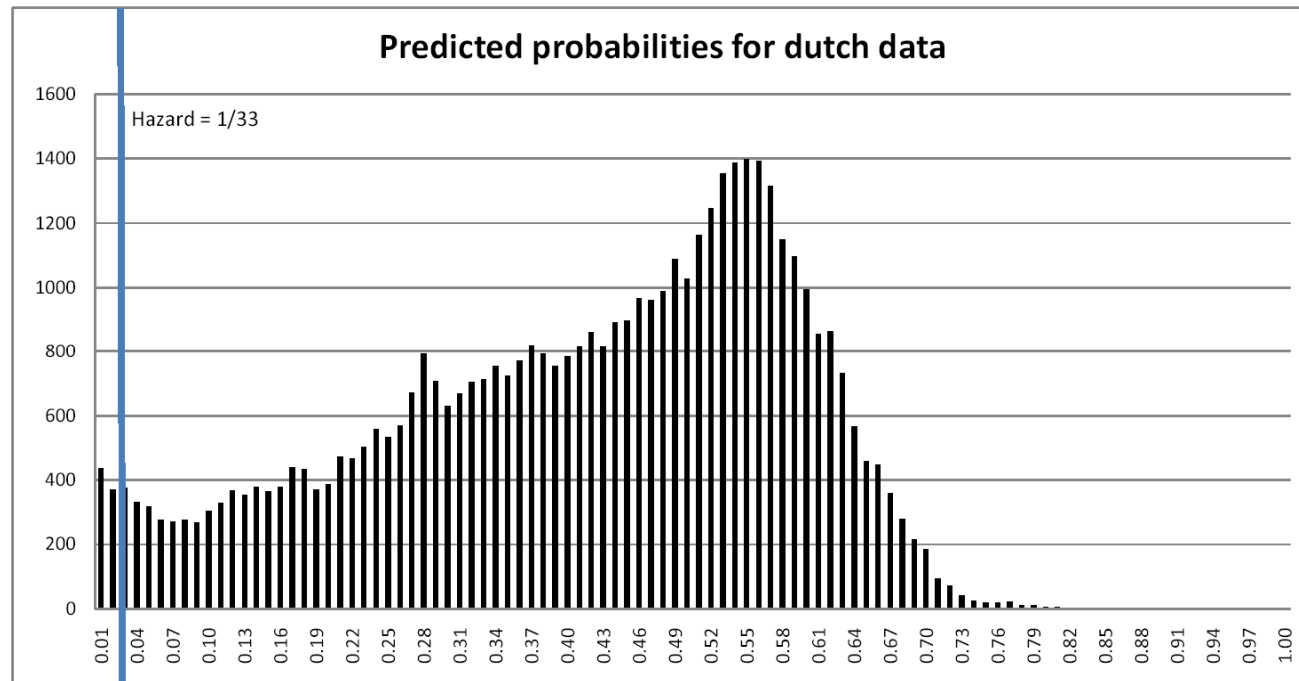
Cone	Γ	M_Γ	R_Γ	$(M_\Gamma - R_\Gamma)/R_\Gamma$
Front	5 – 7, 16 – 18, 27 – 29	43552.36	43374	0.41%
Left	3, 4, 14, 15, 25, 26	1948.77	2089	-6.71%
Right	8, 9, 19, 20, 30, 31	1853.34	1972	-6.02%
Extreme left	1, 2, 12, 13, 23, 24	43.91	27	62.61%
Extreme right	10, 11, 21, 22, 32, 33	82.62	19	334.85%

Area	Γ	M_Γ	R_Γ	$(M_\Gamma - R_\Gamma)/R_\Gamma$
acceleration	1 – 11	4022.32	1273	215.97%
constant speed	12 – 22	40581.06	45869	-11.53%
deceleration	23 – 33	2877.62	339	748.86%

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)



Number of outliers: **2.41%**

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	33.08%

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

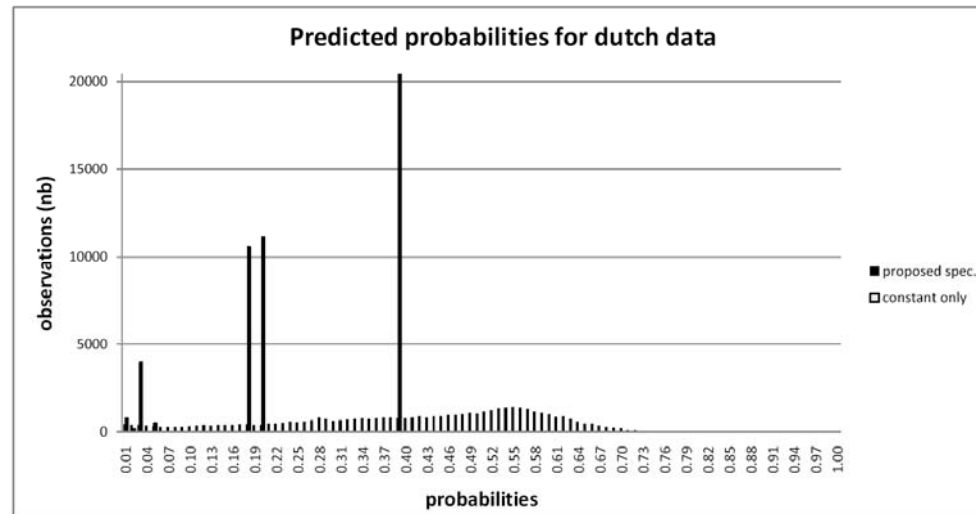
Cone	Γ	M_Γ	R_Γ	$(M_\Gamma - R_\Gamma)/R_\Gamma$
Front	5 – 7, 16 – 18, 27 – 29	43552.36	43374	0.41%
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Extreme left	1, 2, 12, 13, 23, 24	43.91	27	62.61%
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Area	Γ	M_Γ	R_Γ	$(M_\Gamma - R_\Gamma)/R_\Gamma$
acceleration	1 – 11	4022.32	1273	215.97%
constant speed	12 – 22	40581.06	45869	-11.53%
deceleration	23 – 33	2877.62	339	748.86%

 **Equivalent for direction (logical, due to proportions)**

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

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



Number of outliers: $\left\{ \begin{array}{l} \mathbf{2.41\%} \text{ for proposed model} \\ \mathbf{10.31\%} \text{ for ASC model} \end{array} \right.$

→ Superiority of the proposed model

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- Introduction
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 - **Simulator**
 - Conclusion

Simulator

- **Implementation** of the **developped specification** in a simulator
- Simulation of **2 pedestrian crossing flows** with the model
- Examples :
 - Simulation of 300s
 - Start : random speed and direction
 - Finish : random destination



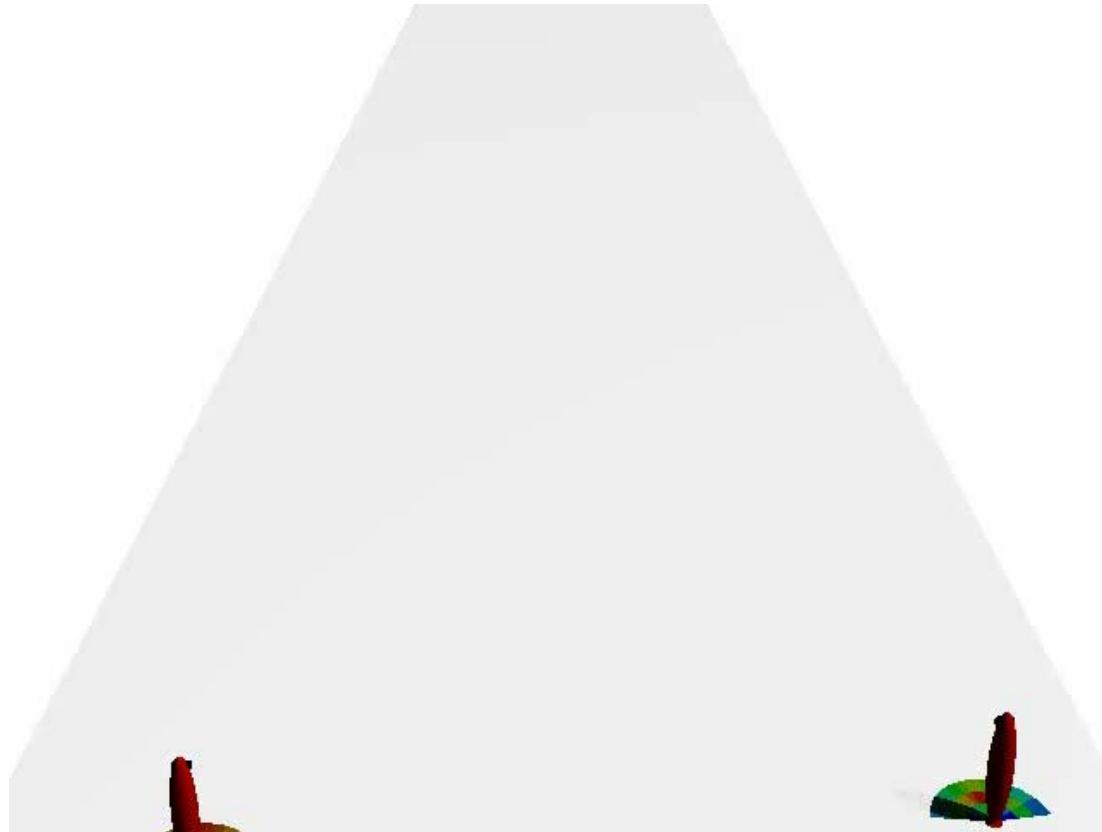
Simulator

- **Low density :**

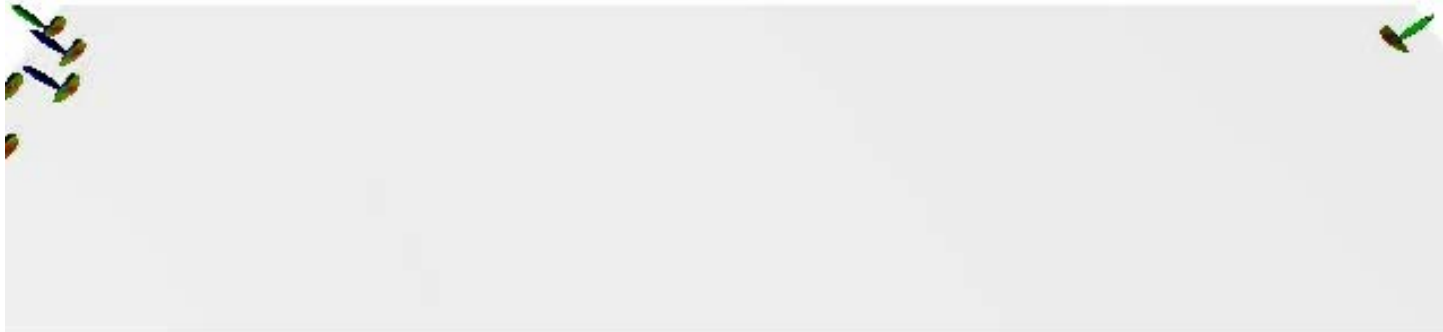


Simulator

- **High density :**



Simulator



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Conclusions and Perspectives

- Conclusions :

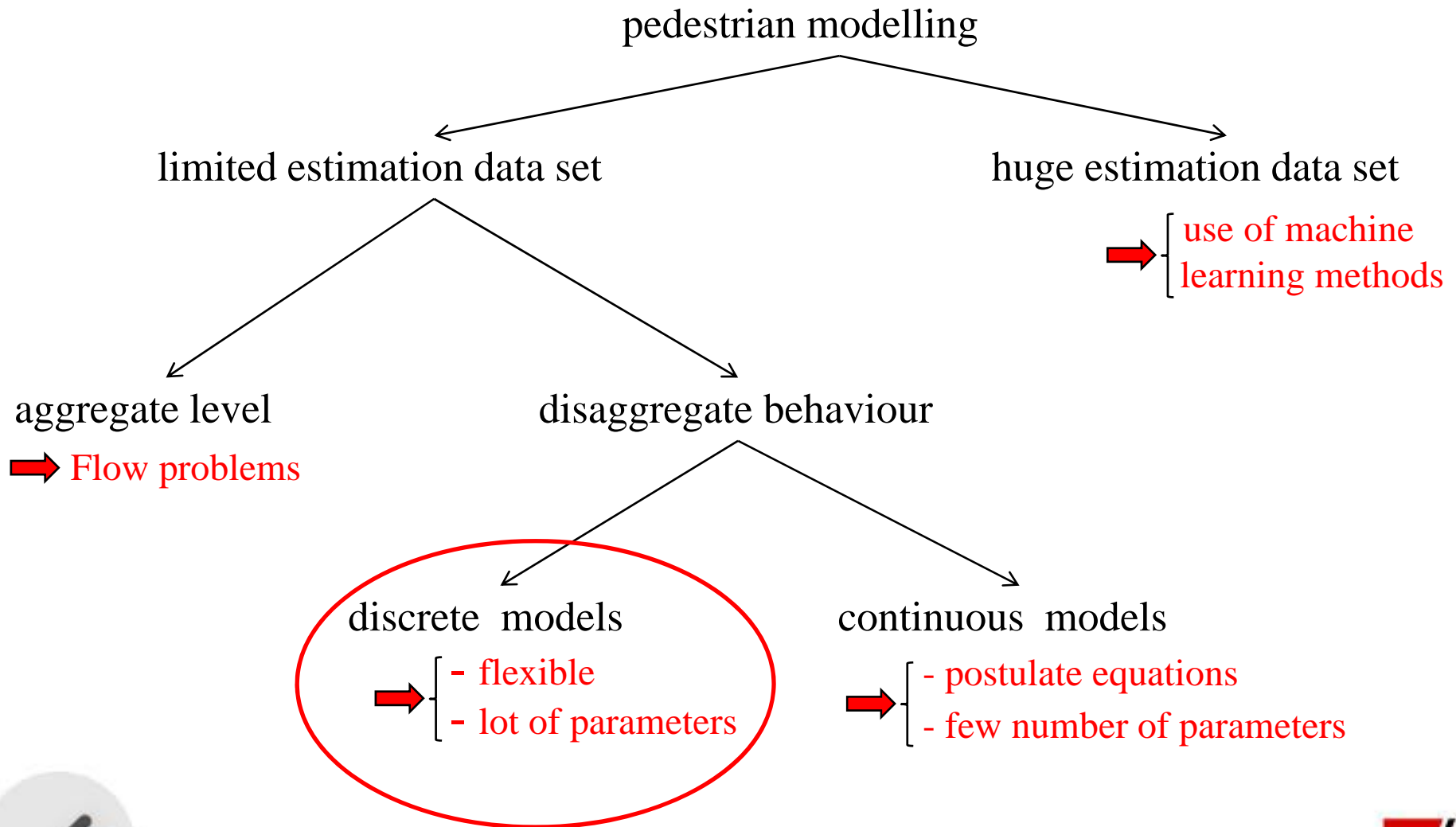
- Discrete choice model for pedestrian walking behavior with ‘**unconstrained**’ and ‘**constrained**’ parameters
- Model **estimated** on a real data set, parameters values consistent with hypothesis
- Model validated on a real data set, **not used for estimation**
- Operating **Simulator**

- Perspectives :

- Improve the **acceleration** and **deceleration** patterns
- Incorporate **physical characteristics** of the pedestrians
- Model the **strategical** and **tactical** behavioural levels

Thanks for your attention

State of the art

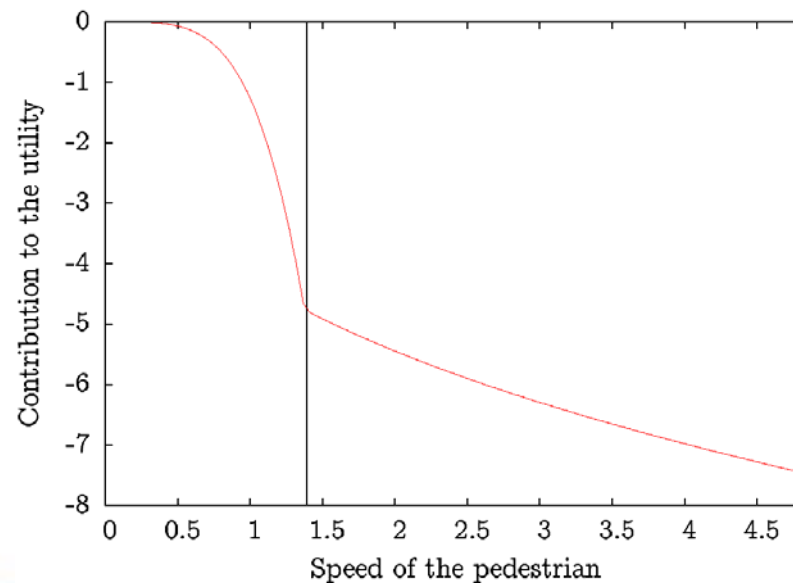


Model estimation : parameters values

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

- Acceleration :

$$\begin{array}{ccccccc}
 -4.94 & & 4.37 & & -7.41 & & 0.354 \\
 \downarrow & & \downarrow & & \downarrow & & \downarrow \\
 \beta_{\text{accLS}} I_{\text{LS}} I_{v,\text{acc}} (v_n/v_{\text{maxLS}})^{\lambda_{\text{accLS}}} & + & \beta_{\text{accHS}} I_{\text{HS}} I_{v,\text{acc}} (v_n/v_{\text{max}})^{\lambda_{\text{accHS}}} \\
 \underbrace{\hspace{15em}}_{\text{Low speed}} & & \underbrace{\hspace{15em}}_{\text{High speed}}
 \end{array}$$



Model estimation : parameters values

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

$$\begin{array}{ccccccccccc}
 0.735 & -0.465 & 0.552 & -0.179 & & & 3.78 & -0.654 & 0.658 \\
 \downarrow & \downarrow & \downarrow & \downarrow & & & \downarrow & \downarrow & \downarrow \\
 I_{v,acc} I_{acc}^L \alpha_{acc}^L D_L^{\rho_{acc}^L} \Delta v_L^{\gamma_{acc}^L} \Delta \theta_L^{\delta_{acc}^L} & + & I_{v,dec} I_{dec}^L \alpha_{dec}^L D_L^{\rho_{dec}^L} \Delta v_L^{\gamma_{dec}^L}
 \end{array}$$

- **Collision avoidance (constrained) :**

$$\begin{array}{ccccccc}
 -0.00730 & 0.212 & & & \text{non significant} & & \\
 \downarrow & \downarrow & & & \downarrow & \downarrow & \\
 I_{d,d_n} I_C \alpha_{C e^{-\rho_C} D_C} \Delta v_C^{\gamma_C} \Delta \theta_C^{\delta_C}
 \end{array}$$