Specification, estimation and validation of a pedestrian walking behavior model

Thomas Robin

Michel Bierlaire

Gianluca Antonini

Javier Cruz

European Transport Conference 2008

6-8 October 2008
Leeuwenhorst Conference Centre
The Netherlands

TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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**

- **Introduction**
- Model specification
- Model estimation
- Model validation
- Simulator
- Conclusion

Introduction

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

  → **Discrete choice model**

- 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

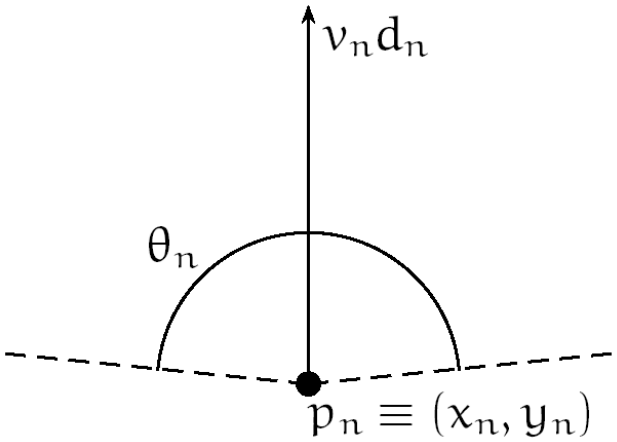
TRANSP-OR

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

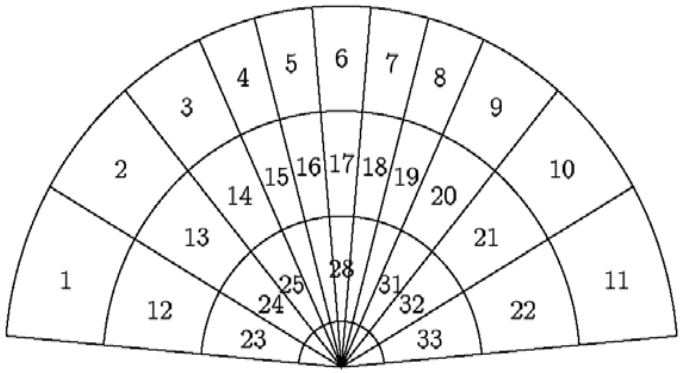
- Introduction
- **Model specification**
- Model estimation
- Model validation
- Simulator
- Conclusion

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

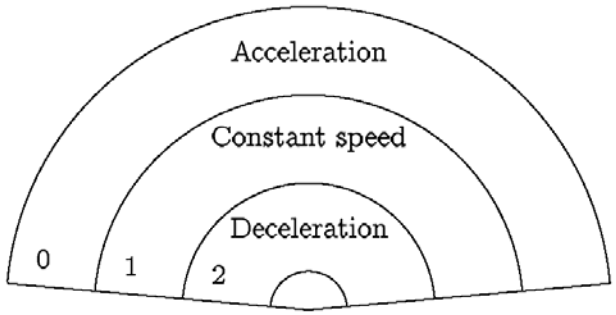


Choice set : discretization of the visual space

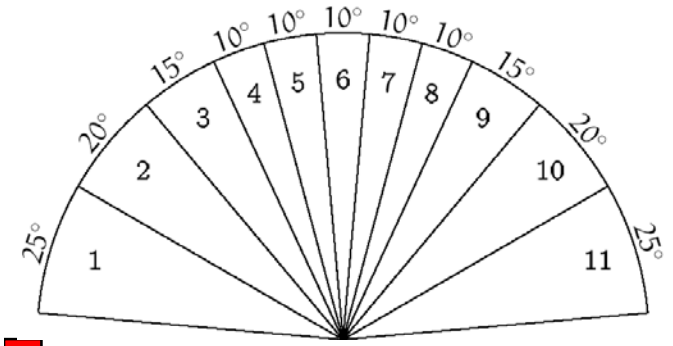
➡ At each step the **choice set** depends on the pedestrian **speed** and **direction**

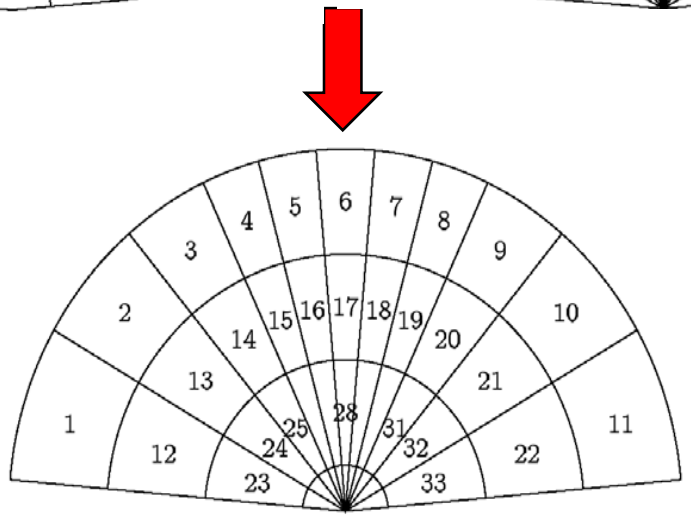
Model specification : the choice set

3 speed regimes



11 directions





33 alternatives

TRANSP-OR

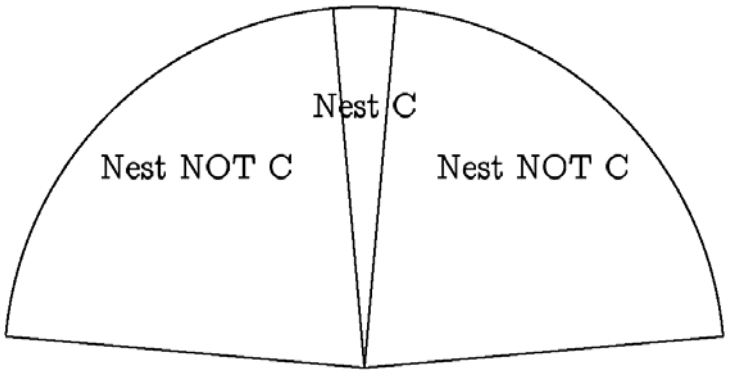
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Model specification : cross nested structure

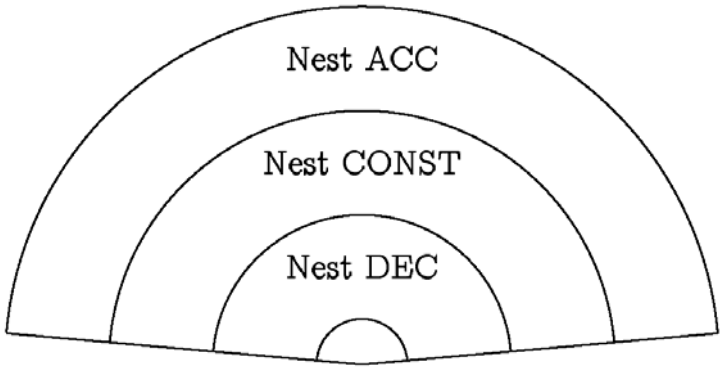
- **Hypothesis** : alternatives correlated along speed regimes and directions

  ➡ **Cross Nested Logit model**

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

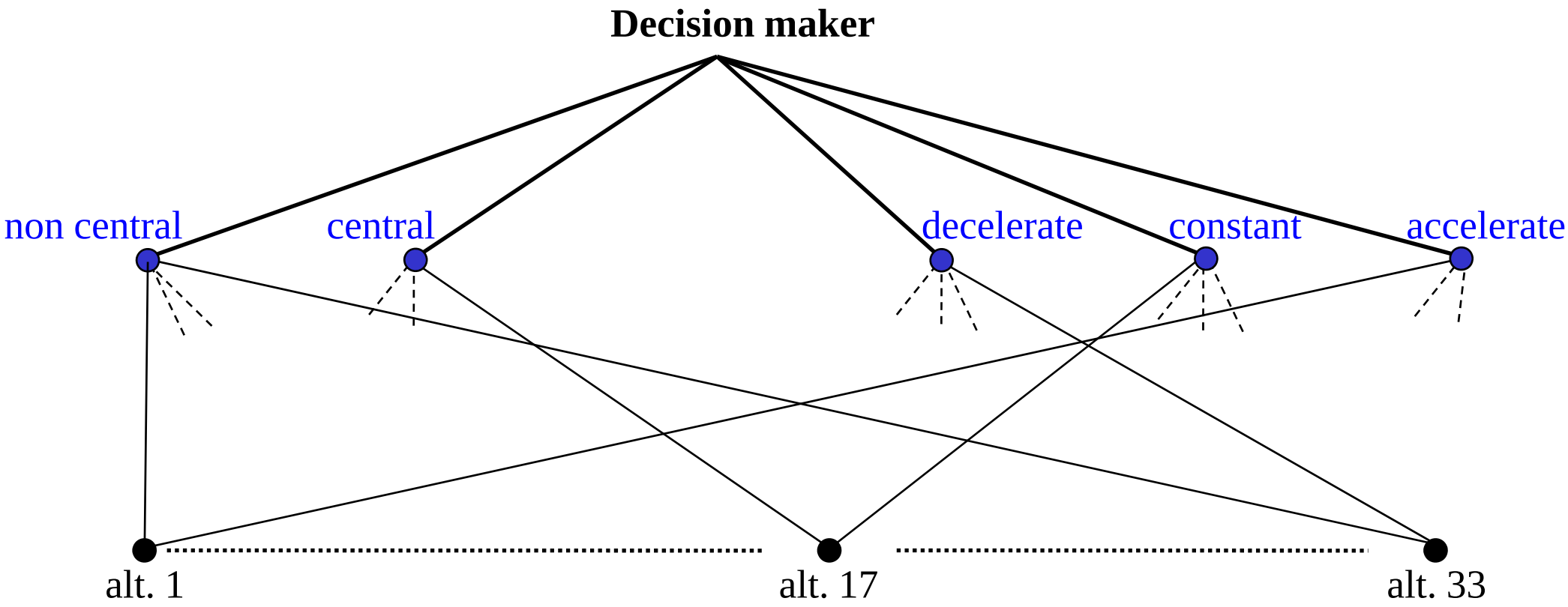


Nesting based on direction



Nesting based on speed regime

Model specification : cross nested structure



TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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

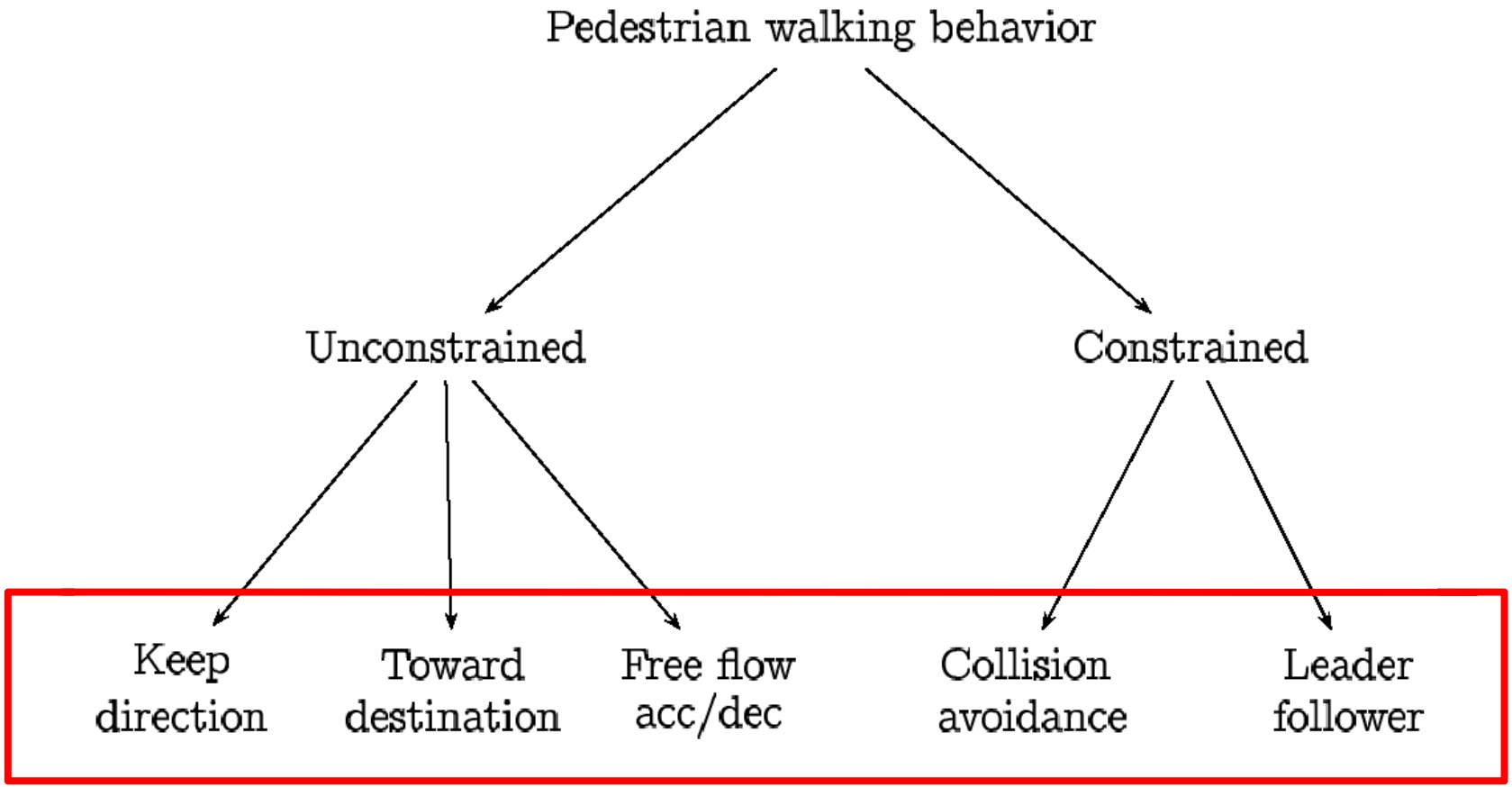
V_i : utility of alternative i

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



TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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

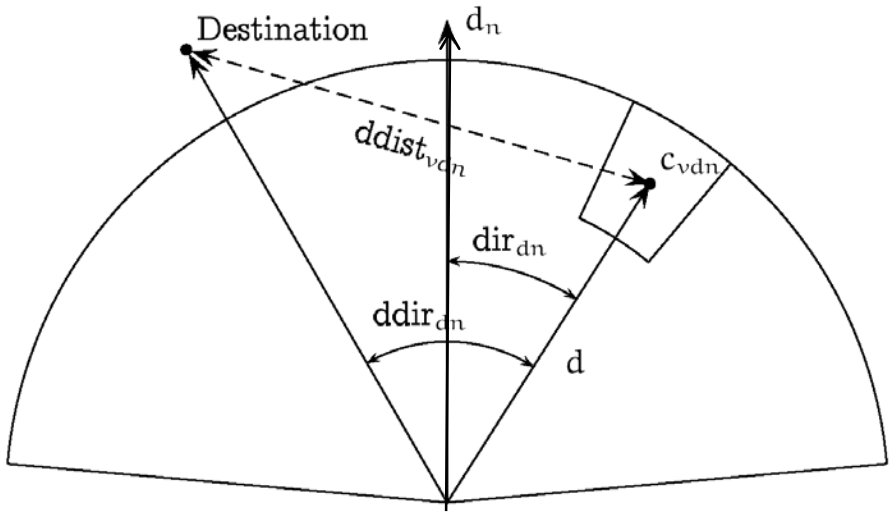
TRANSP-OR

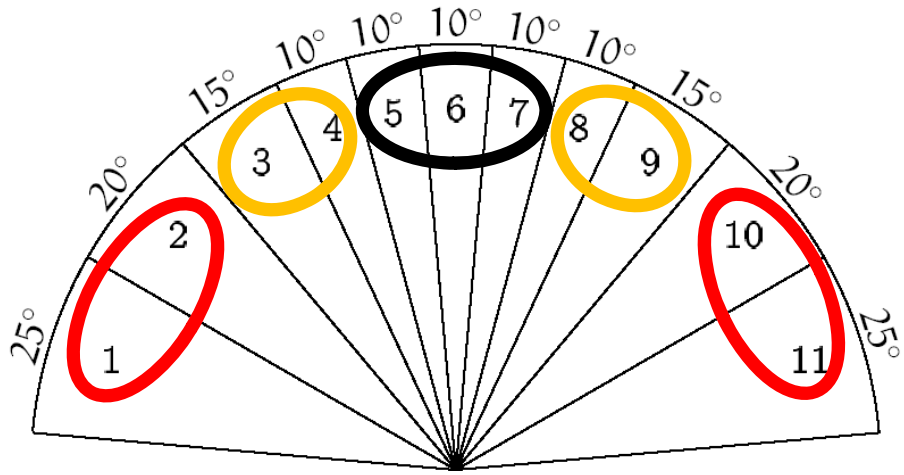
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Model specification : utility specification

- Keep direction (**unconstrained**) :

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





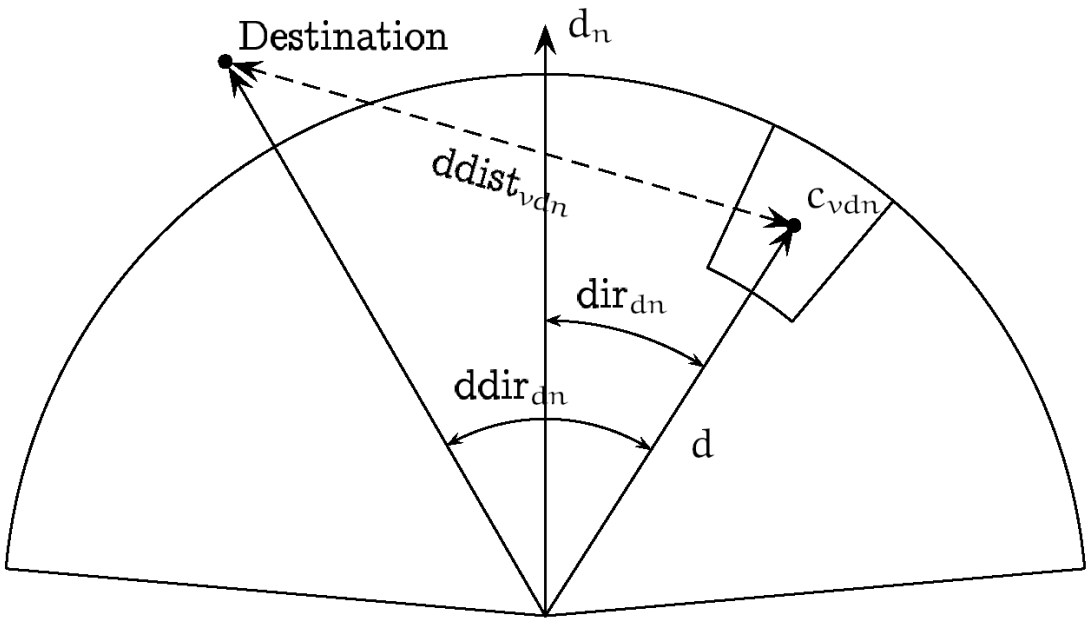
TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Model specification : utility specification

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

distance **direction**



TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Model specification : utility specification

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

  - Acceleration :

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

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

  - Deceleration :

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

<0 *<0*

TRANSP-OR

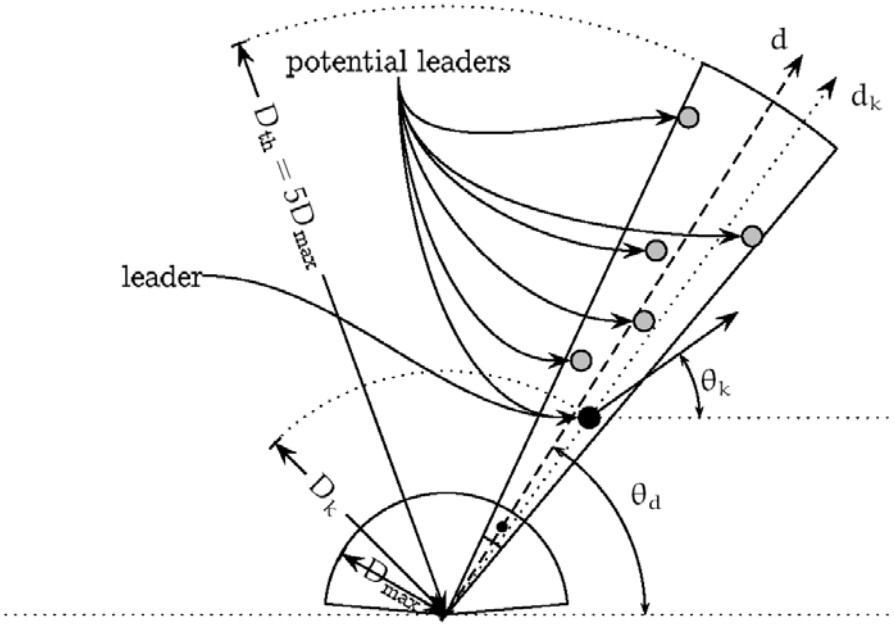
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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*

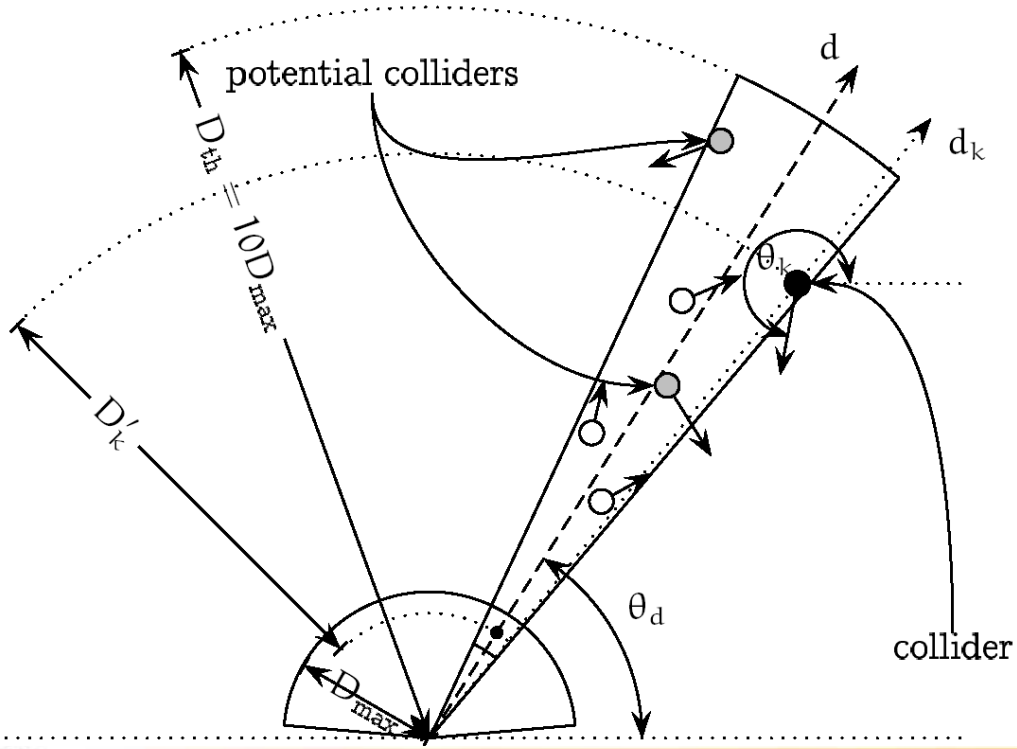


TRANSP-OR

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Model specification : utility specification

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



- Introduction
- Model specification
- **Model estimation**
- Model validation
- Simulator
- Conclusion

The Japanese data set : video sequence

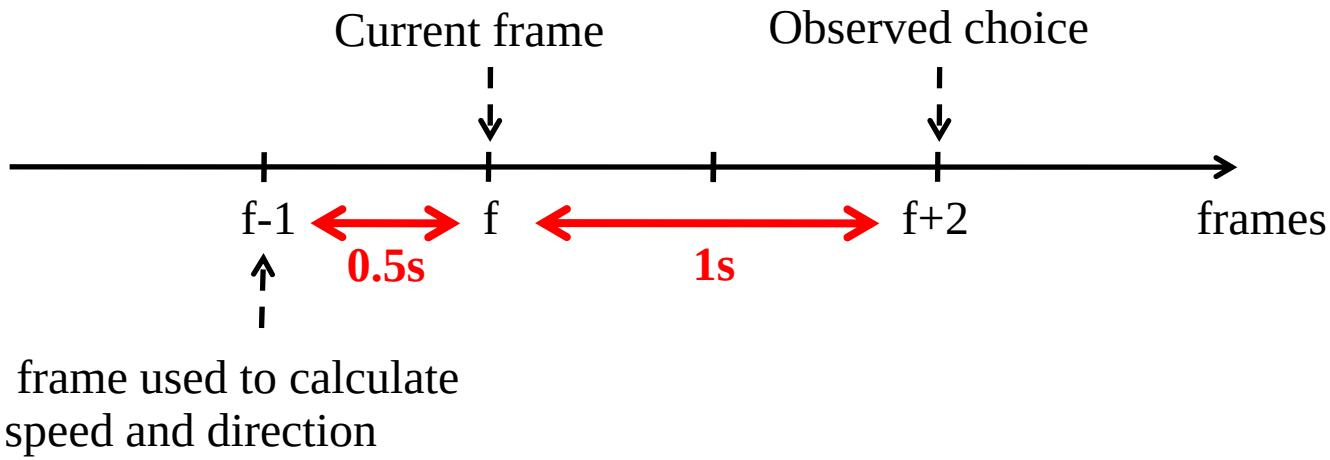
- Collected in Sendaï, Japan, on August 2000, large pedestrian **crossing road**

TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

The Japanese data set : data processing

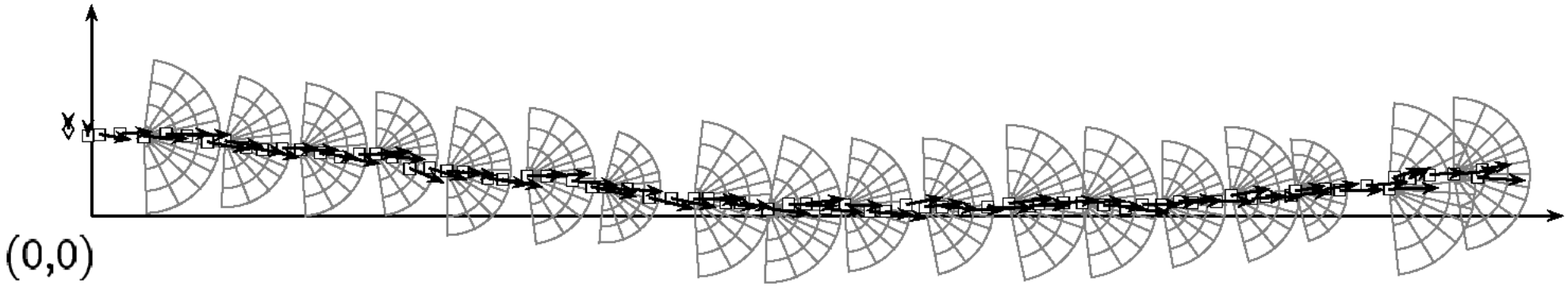
- Tracking from video sequence: **2 observations per second**
- Pedestrians trajectories extracted using 3D-calibration (DLT algorithm)
- For each pedestrian trajectory :



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	t test 0	Variable name	Coefficient estimate	t test 0	t test 1
β_{ddir}	-0.0793	-24.14	ρ^L_{acc}	-0.465	-1.78	
β_{ddist}	-1.52	-11.63	γ^L_{acc}	0.552	1.98	
$\beta_{dir\_extreme}$	-0.0343	-9.71	α^L_{dec}	3.78	5.41	
β_{dir_side}	-0.0553	-22.71	ρ^L_{dec}	-0.654	-6.70	
$\beta_{dir\_central}$	-0.0320	-13.90	γ^L_{dec}	0.658	5.48	
β_{accLS}	-4.94	-25.20	δ^L_{acc}	-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^L_{acc}	0.735	1.87	$\mu_{not\_central}$	1.82	13.12	5.91

- Introduction
- Model specification
- Model estimation
- **Model validation**
- Simulator
- Conclusion

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 : 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)**

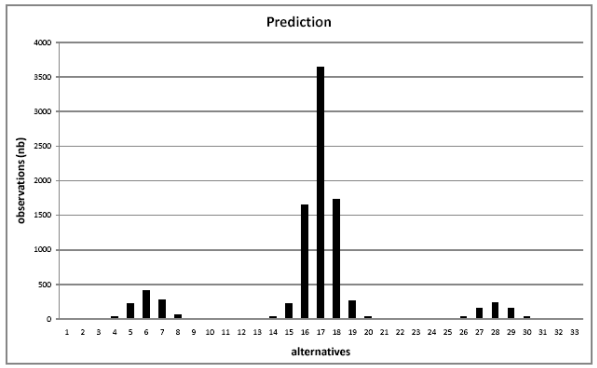
- It reproduces the aggregated observations proportions of the estimation data.
- The ASC model **used for comparison** (for example the number of outliers).

Model validation

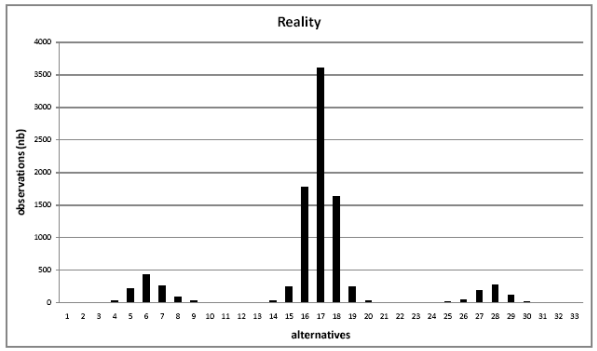
- **Validation of the specification**
- Validation of the model

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%

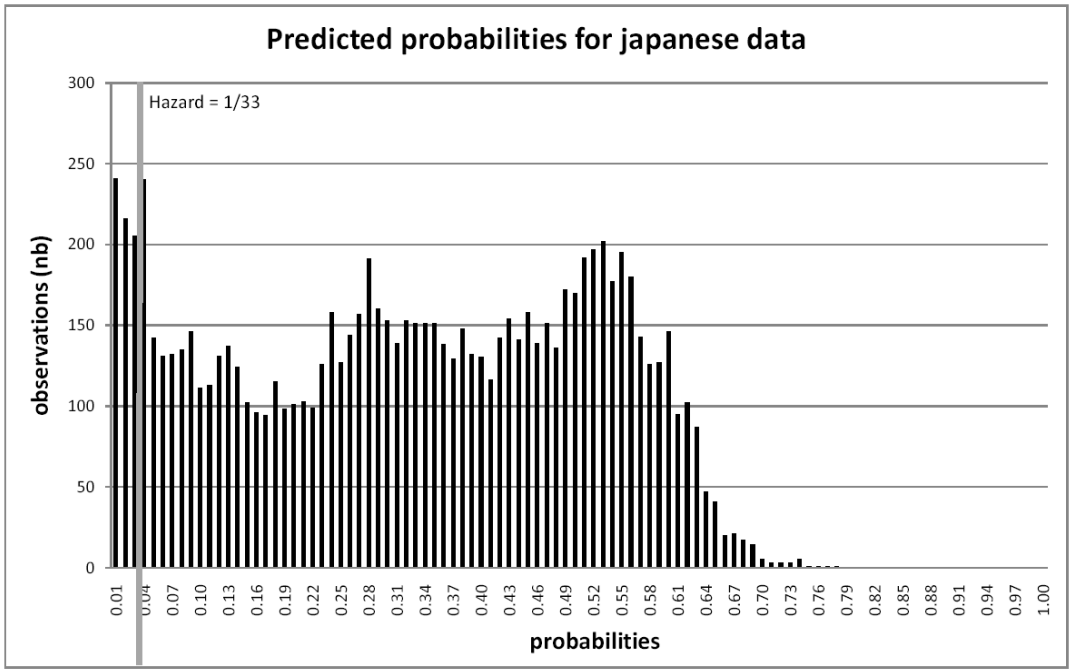
Area	Γ	M_Γ	R_Γ	$(M_\Gamma - R_\Gamma)/R_\Gamma$
acceleration	$1-11$	1059.85	1065	−0.48%
constant speed	$12-22$	7588.28	7565	0.31%
deceleration	$23-33$	632.87	651	−2.79%

TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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

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



Number of outliers:
- **7.10**% for proposed model
- **19.90**% for ASC model

TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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.	8.62%	6.52%	7.44%	7.87%	5.87%
Constant only	20.79%	20.70%	17.13%	19.88%	18.64%

→ **Robust specification**

Model validation

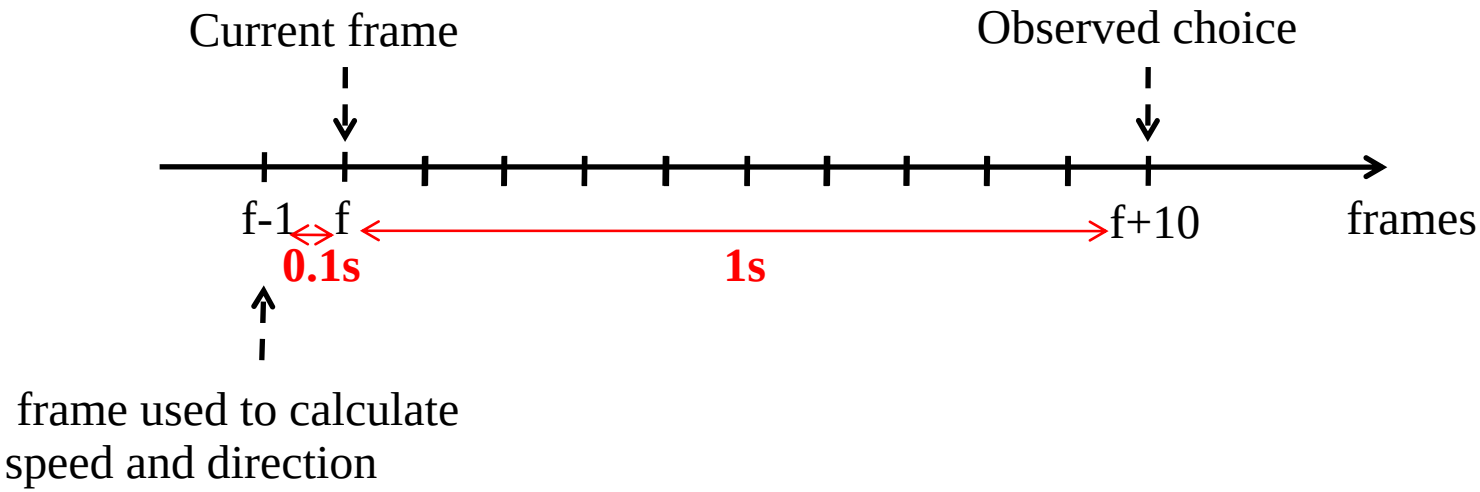
- Validation of the specification
- **Validation of the model**

The Dutch data set : video sequence

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

The Dutch data set : general information

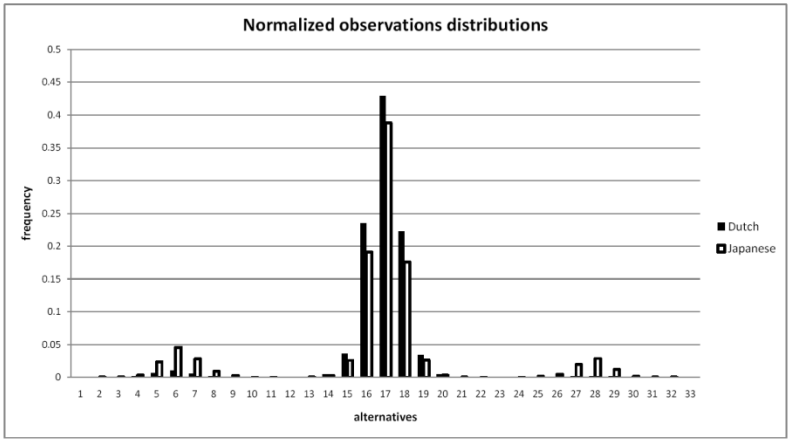
- **Experimental** data set
- Video sequence recorded at **10 frames per second**
- Pedestrians trajectories extracted from the video sequence
- For each pedestrian trajectory :



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%

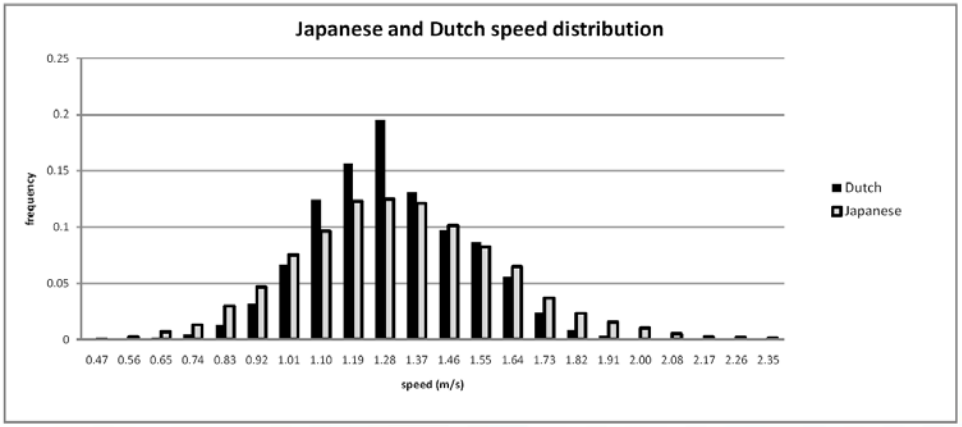
Nest	# steps	% of total
acceleration	1273	2.68%
constant speed	45869	96.61%
deceleration	339	0.71%
central	20950	44.12%
not central	26531	55.88%

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)

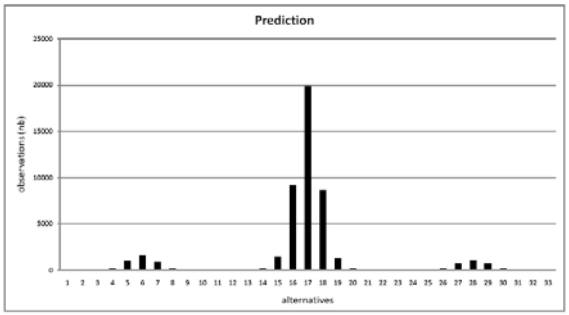


TRANSP-OR

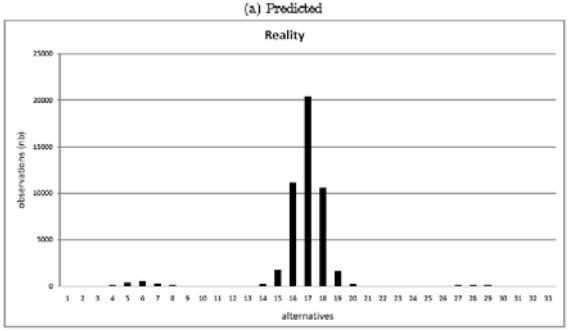
EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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

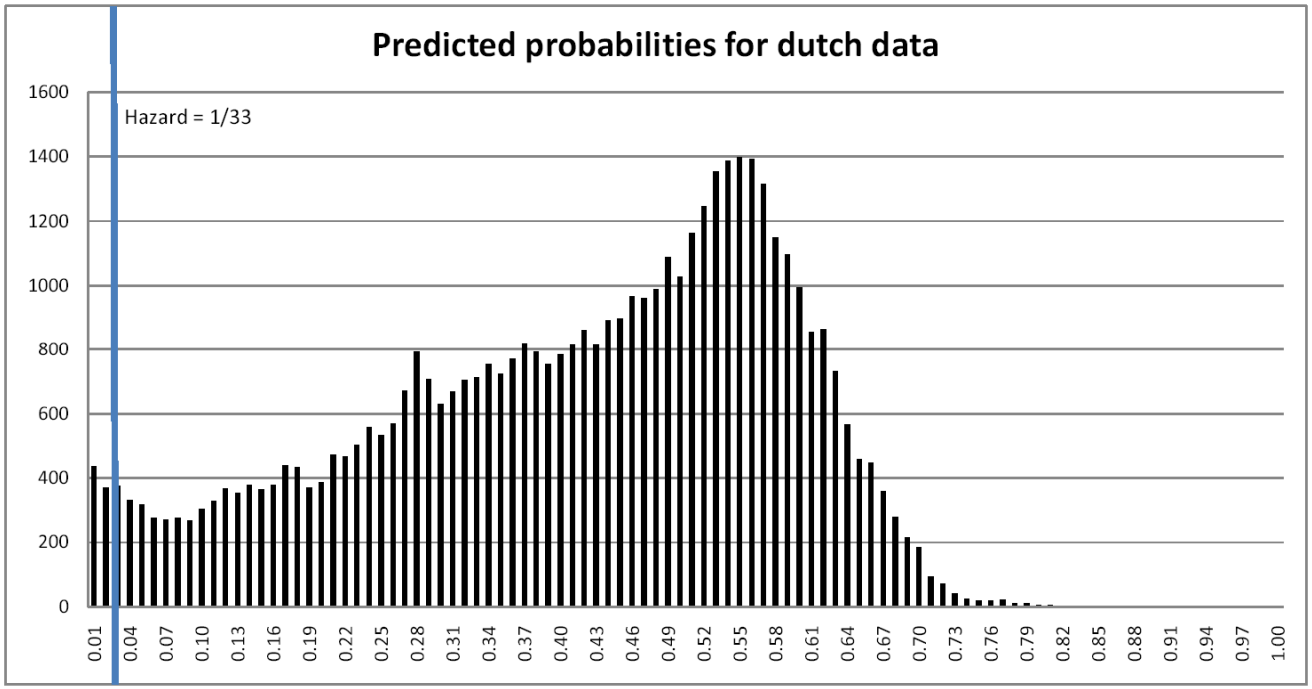
Cone	Γ	M_Γ	R_Γ	$(M_\Gamma - R_\Gamma)/R_\Gamma$
Front	$5-7, 16-18, 27-29$	43552.36	43374	0.41%
Left	$3, 4, 14, 15, 25, 26$	1948.77	2089	−6.71%
Right	$8, 9, 19, 20, 30, 31$	1853.34	1972	−6.02%
Extreme left	$1, 2, 12, 13, 23, 24$	43.91	27	62.61%
Extreme right	$10, 11, 21, 22, 32, 33$	82.62	19	334.85%

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**%

TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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

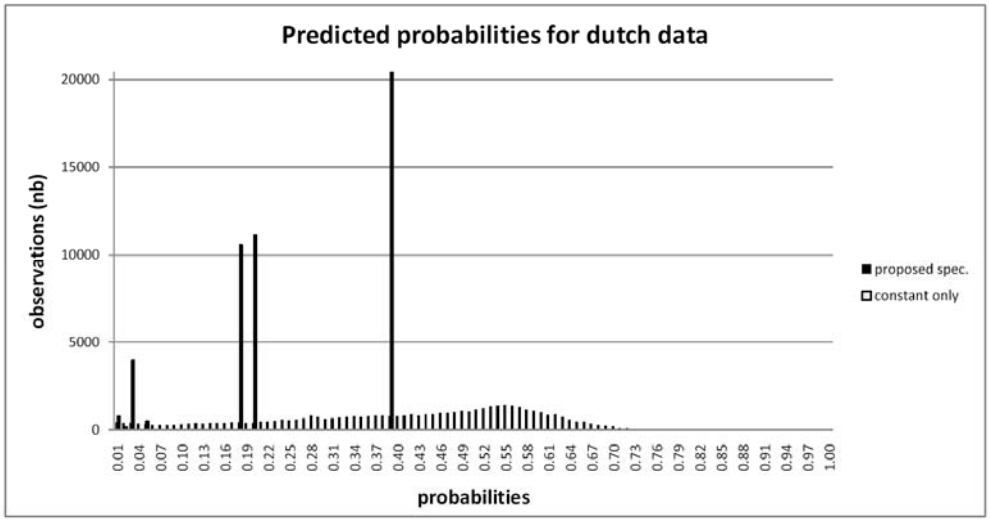
Cone	Γ	M_Γ	R_Γ	$(M_\Gamma - R_\Gamma)/R_\Gamma$
Front	$5-7, 16-18, 27-29$	43552.36	43374	0.41%
Left	$3, 4, 14, 15, 25, 26$	1948.77	2089	−6.71%
Right	$8, 9, 19, 20, 30, 31$	1853.34	1972	−6.02%
Extreme left	$1, 2, 12, 13, 23, 24$	43.91	27	62.61%
Extreme right	$10, 11, 21, 22, 32, 33$	82.62	19	334.85%

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%

→ **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: { **2.41**% for proposed model
10.31% for ASC model

➡ **Superiority of the proposed model**

TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

- Introduction
- Model specification
- Model estimation
- Model validation
- **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

Ex1 : low density, 2 pedestrians per second entering

Ex2 : high density, 5 pedestrians per second entering

TRANSP-OR

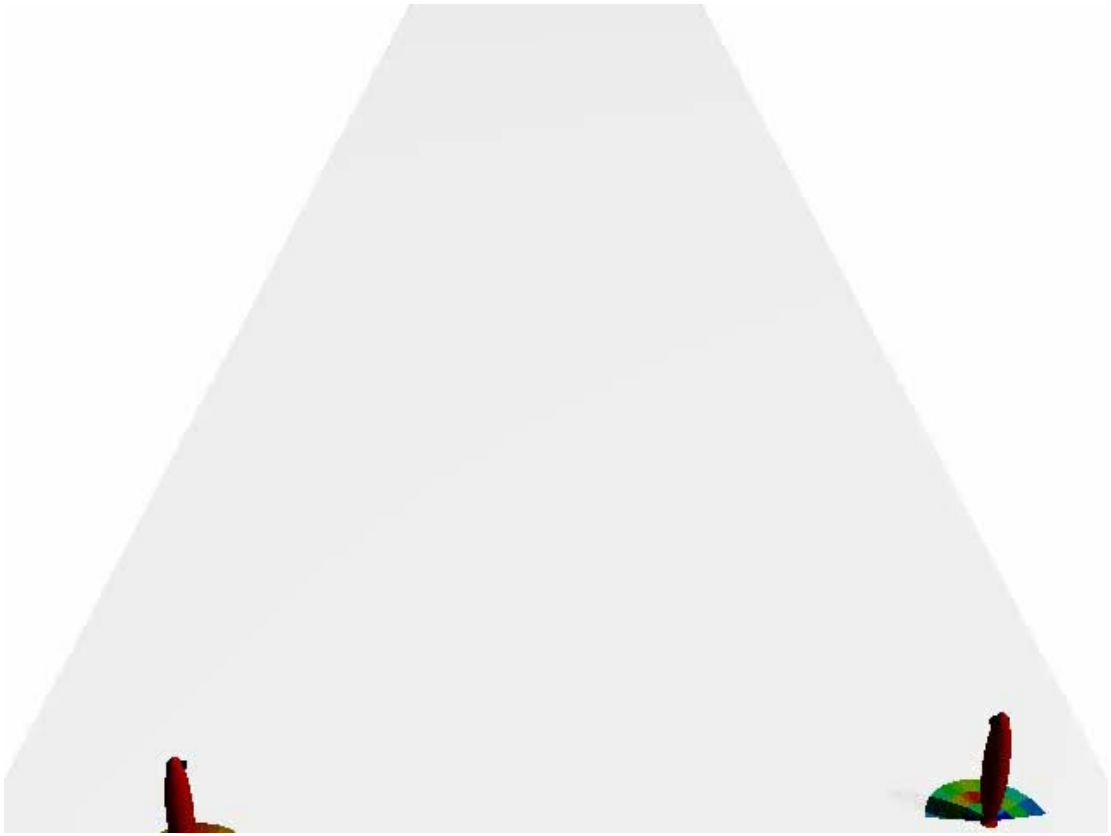
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Simulator

- **Low** density :

Simulator

- **High** density :



TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Simulator

- Introduction
- Model specification
- Model estimation
- Model validation
- Simulator
- **Conclusion**

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