

# An integrated ordered logit and latent variable model for road crash severity

*A Swiss case study using disaggregate crash reports*

1st EPFL Symposium on Transportation Research  
February 15–17, 2023 | Annecy, France

N. Ortelli<sup>1,2</sup>, S. Varotto<sup>2</sup>, M. Bierlaire<sup>2</sup>, M. de Lapparent<sup>1</sup>

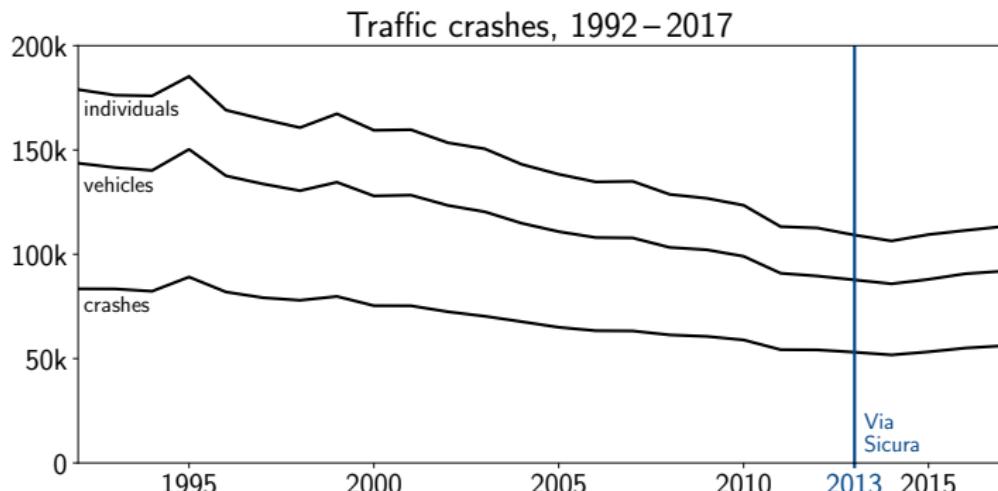
<sup>1</sup> School of Management and Engineering Vaud, HES-SO, Switzerland

<sup>2</sup> École Polytechnique Fédérale de Lausanne (EPFL), Switzerland

# Road safety in Switzerland

## Via Sicura (FEDRO, 2005)

- Action program for road safety.
- "Reduce the number of major and fatal injuries on Swiss roads."
- 20 legislative measures, both **preventive** and **repressive**.



# Official evaluation

## Approach (FEDRO, 2017)

- Regression on yearly totals of major and fatal injuries:
  - Estimate on 2000–2012.
  - Predict on 2013–2015, **as if Via Sicura did not exist!**
- 4 distinct models, averaged.

	2013	2014	2015
Ridge	4'471	4'599	4'313
Lasso	4'495	4'546	4'504
PLS	4'354	4'442	4'332
Non-linear	4'269	4'180	4'025

# Official evaluation

## Approach (FEDRO, 2017)

- Regression on yearly totals of major and fatal injuries:
  - Estimate on 2000–2012.
  - Predict on 2013–2015, **as if Via Sicura did not exist!**
- 4 distinct models, averaged.

	2013	2014	2015
Ridge	4'471	4'599	4'313
Lasso	4'495	4'546	4'504
PLS	4'354	4'442	4'332
Non-linear	4'269	4'180	4'025
Average	4'397	4'442	4'294

# Official evaluation

## Approach (FEDRO, 2017)

- Regression on yearly totals of major and fatal injuries:
  - Estimate on 2000–2012.
  - Predict on 2013–2015, **as if Via Sicura did not exist!**
- 4 distinct models, averaged.

	2013	2014	2015
Ridge	4'471	4'599	4'313
Lasso	4'495	4'546	4'504
PLS	4'354	4'442	4'332
Non-linear	4'269	4'180	4'025
Average	4'397	4'442	4'294
Observed (with Via Sicura!)	4'398	4'286	4'351

# Official evaluation

## Approach (FEDRO, 2017)

- Regression on yearly totals of major and fatal injuries:
  - Estimate on 2000–2012.
  - Predict on 2013–2015, **as if Via Sicura did not exist!**
- 4 distinct models, averaged.

	2013	2014	2015
Ridge	4'471	4'599	4'313
Lasso	4'495	4'546	4'504
PLS	4'354	4'442	4'332
Non-linear	4'269	4'180	4'025
Average	4'397	4'442	4'294
Observed (with Via Sicura!)	4'398	4'286	4'351
Difference	+1	-156	+57

# Official evaluation

## Approach (FEDRO, 2017)

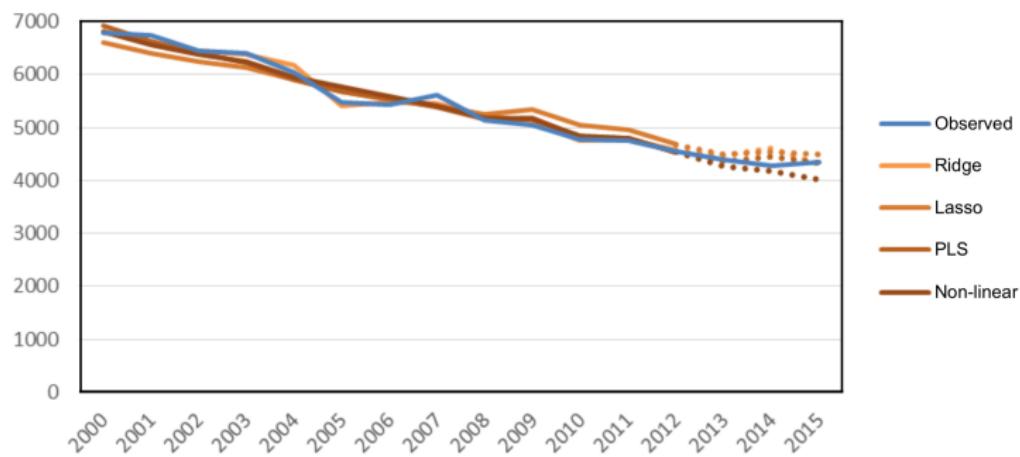
- Regression on yearly totals of major and fatal injuries:
  - Estimate on 2000–2012.
  - Predict on 2013–2015, **as if Via Sicura did not exist!**
- 4 distinct models, averaged.

	CV-error	2013	2014	2015
Ridge	108	4'471	4'599	4'313
Lasso	213	4'495	4'546	4'504
PLS	134	4'354	4'442	4'332
Non-linear	141	4'269	4'180	4'025
Average		4'397	4'442	4'294
Observed (with Via Sicura!)		4'398	4'286	4'351
Difference		+1	-156	+57

# Official evaluation

## Outcome (FEDRO, 2017)

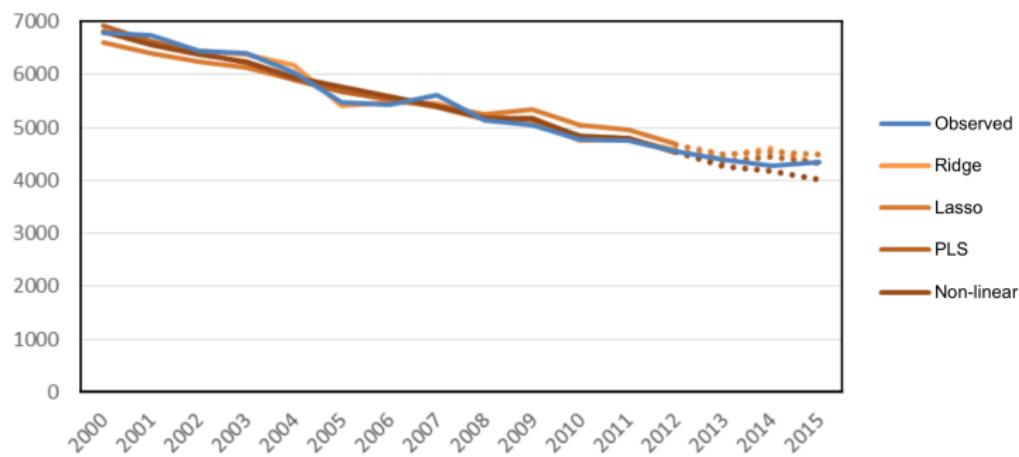
- The effect of Via Sicura is **not significant**...



# Official evaluation

## Outcome (FEDRO, 2017)

- The effect of Via Sicura is **not significant**...
- ... but is the method appropriate?



# Can we do better?

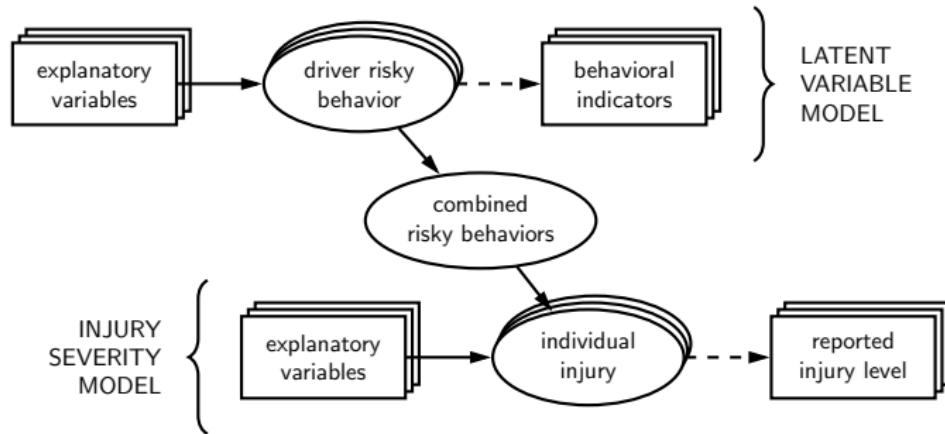
## Hybrid model ( $\approx$ Lavieri et al., 2016)

- Disaggregate approach.
- Ordered logit for individual injury severity.
- Risky behavior as a latent variable.
- Capture dissuasive effect of repressive measures.

## Available data

- **All traffic crashes** reported in Switzerland between 1992 and 2017:
  - 1.8M crashes.
  - 3.0M vehicles.
  - 3.7M individuals.
- Model validation on 2012–2013.

# Model structure



# Latent variable model

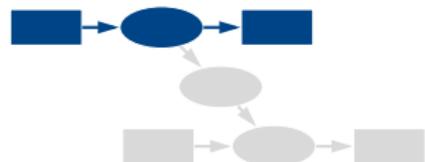
## Driver risky behavior

$$x_d^* = \sum_{\ell} \gamma_{\ell} z_{d\ell} + \omega_d, \quad \omega_d \sim \mathcal{N}(0, \sigma)$$

## Behavioral indicators

$$I_{id}^* = \alpha_{i,0} + \alpha_{i,1} x_d^* + \nu_{id}, \quad \nu_{id} \sim \mathcal{N}(0, 1)$$

$$\begin{cases} P(I_{id} = 0) = P(I_{id}^* < 0) \\ P(I_{id} = 1) = P(I_{id}^* \geq 0) \end{cases}$$



# Ordered logit model

Combined risky behaviors

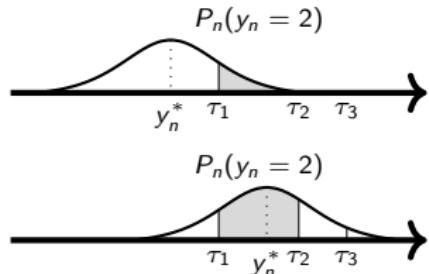
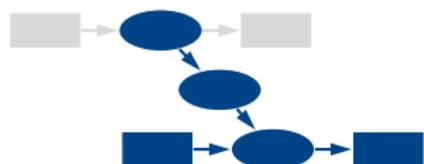
$$x^* = \frac{1}{D} \sum_{d=1}^D x_d^*$$

Individual injury

$$y_n^* = \sum_k \beta_k x_{nk} + \beta^* z^* + \varepsilon_n, \quad \varepsilon_n \sim \mathcal{L}(0, \sigma_\varepsilon)$$

Reported injury level

$$P_n(y_n = j) = P(\tau_{j-1} < y_n^* < \tau_j)$$



# Estimation report

## Sequential estimation

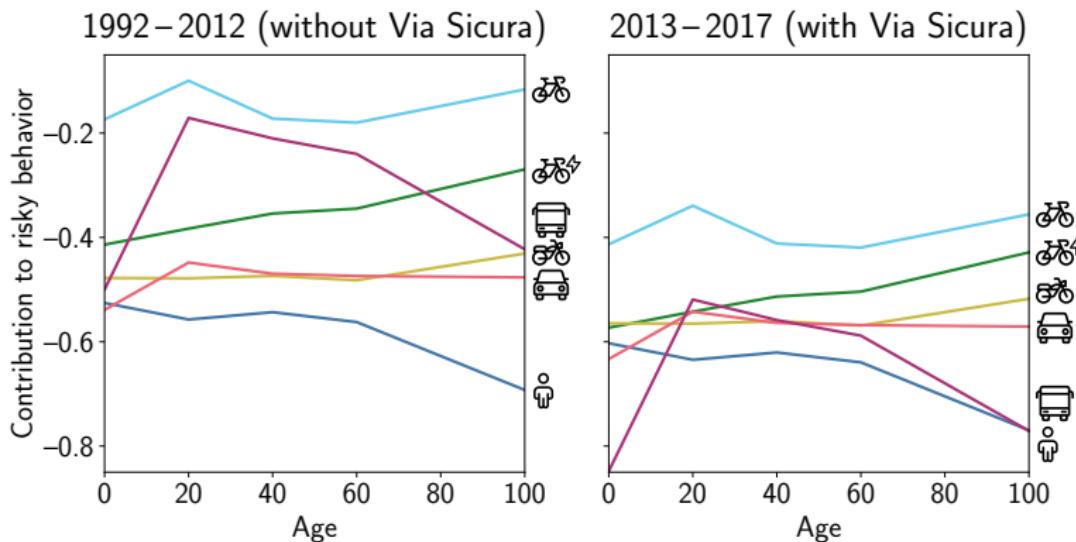
- Using Biogeme (Bierlaire, 2018; 2020).

	LV model	OL model
Sample size	2.5M	2.1M
Est. parameters	48	20
Norm. init. LL	-0.439	-1.077
Norm. final LL	-0.438	-0.486
Norm. val. LL	-0.420	-0.504
Optimization time	0:59:33	4:27:12

# Latent variable model

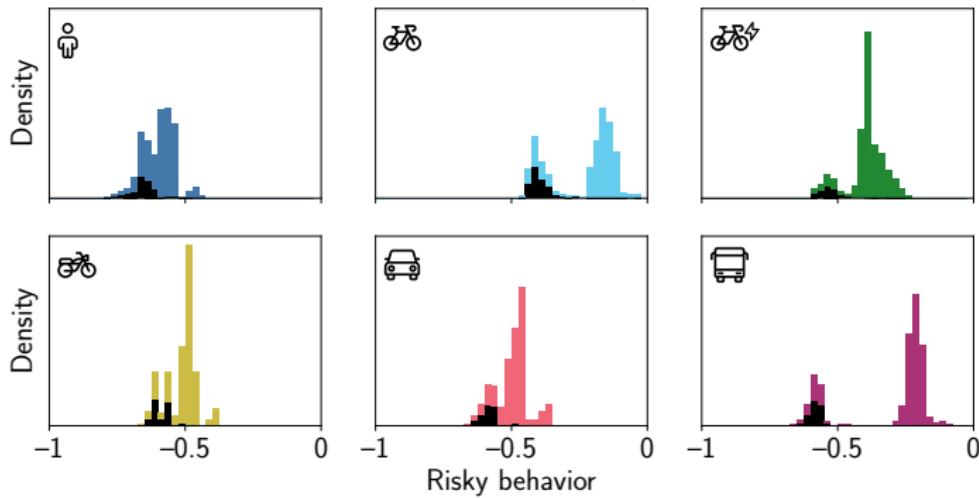
	Value	Rob. t-test
$\gamma_{\text{female\_driver}}$	-0.0298	-49.3
$\gamma_{\text{two\_phase}}$	-0.0454	-53.8
$\gamma_{\text{passenger\_aboard}}$	-0.0263	-44.3
$\gamma_{\text{child\_aboard}}$	-0.0214	-16.5
$\gamma_{\text{late\_night}}$	0.0991	69.4
$\gamma_{\text{bad\_visibility}}$	-0.0153	-11.3
$\gamma_{\text{bad\_road}}$	-0.00451	-7.23
$\gamma_{\text{bad\_weather}}$	-0.00917	-13.2

# Latent variable model

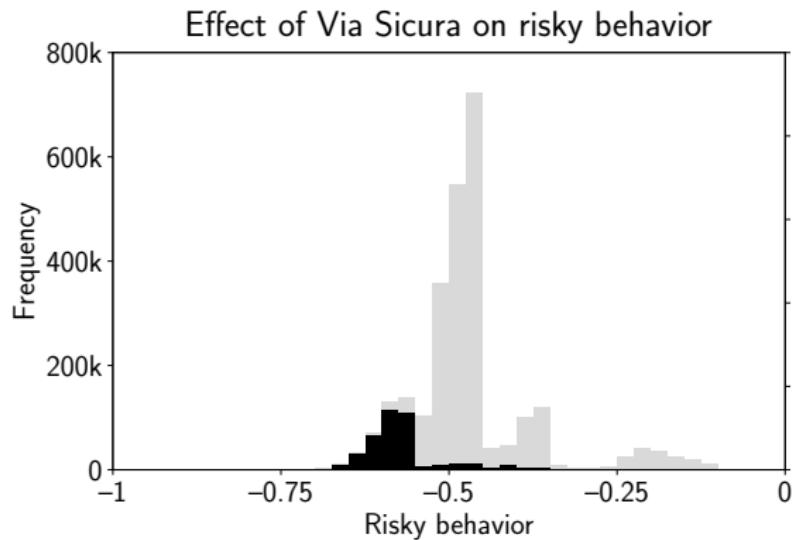


# Latent variable model

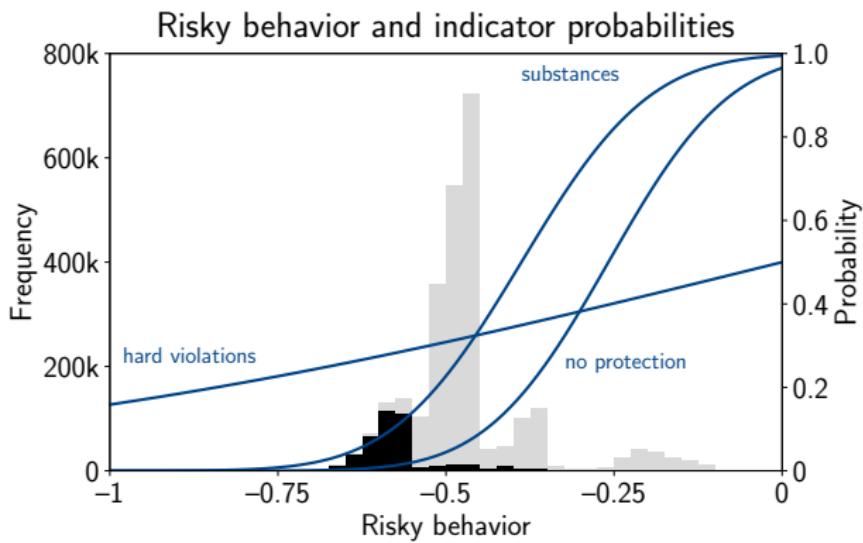
Effect of Via Sicura on risky behavior



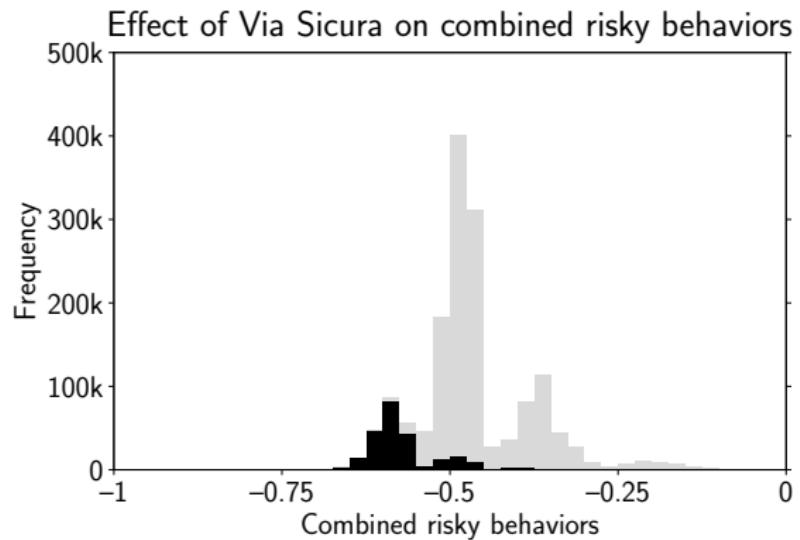
# Latent variable model



# Latent variable model

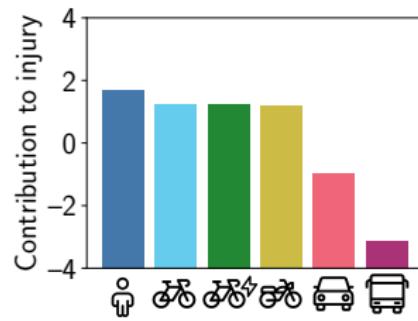
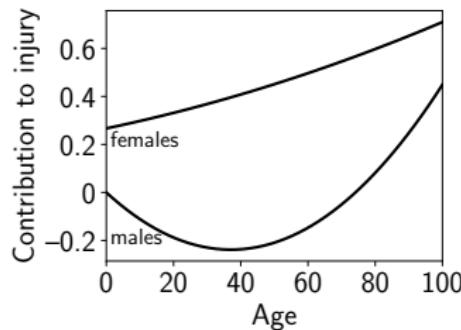


# Ordered logit model



# Ordered logit model

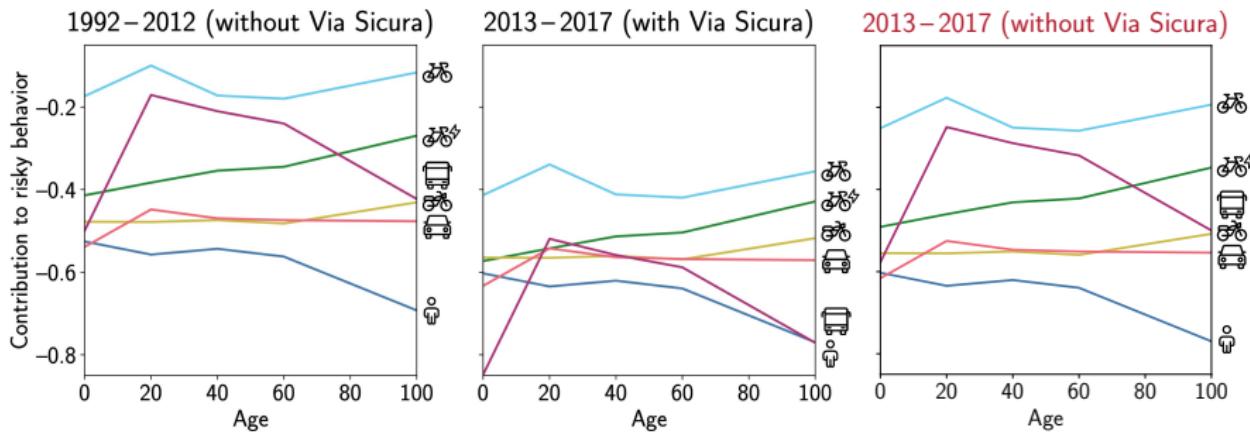
	Value	Rob. t-test
$\beta_{RISKY}$	0.630	22.2
$\beta_{BELT}$	-1.310	-168.0
$\beta_{HELMET}$	-0.292	-11.3
$\beta_{MAX\_SPEED\_TRAFFIC\_HIGH}$	0.797	87.6
$\beta_{MAX\_SPEED\_TRAFFIC\_NORMAL}$	0.998	173.0



# So... is Via Sicura effective?

## Counterfactual

- Our model misses out plenty of effects on risky behavior.
- The Via Sicura coefficient mistakenly captures some of them.
- What if Via Sicura was abandoned today?



# So... is Via Sicura effective?

## Counterfactual

- A world without the Via Sicura measures...
- ... but with the effects mistakenly captured by its coefficient.

	Levels of injury, 2013–2017		
	Observed	without Via Sicura	counterfactual
No injury	250'576 (77.3%)	247'963 (76.5%)	249'783 (77.1%)
Minor	57'930 (17.9%)	59'535 (18.4%)	58'323 (18.0%)
Major	14'640 (4.5%)	15'578 (4.8%)	15'012 (4.6%)
Fatal	833 (0.3%)	904 (0.3%)	862 (0.3%)

# Conclusion

## Summary

- Ordered logit and latent variable model.
- Via Sicura has a dissuasive effect on drivers' risky behavior.
- In turn, crash severity is also influenced.

## Future work

- Combining risky behaviors.
- Generalized ordered logit model.
- Data from other countries for a proper counterfactual.

# References

## Data

- Verkehrsunfall Jahressatz (DWH-VU), Federal Roads Office FEDRO.

## Via Sicura

- Federal Roads Office FEDRO (2005). Via Sicura, Programme d'action de la Confédération visant à renforcer la sécurité routière.
- Federal Roads Office FEDRO (2017). Evaluation von Via Sicura, Technischer Bericht.  
Swiss Federal Council (2017). Évaluation du programme via Sicura, Rapport du Conseil Fédéral en réponse au postulat 16.3267 de la Commission des Transports et des Télécommunications du Conseil des États du 14 avril 2016.

## Methodology

- Lavrier, P. S., Bhat, C. R., Pendyala, R. M. and Garikapati, V. M. (2016). Introducing latent psychological constructs in injury severity modeling: multivehicle and multioccupant approach, *Transportation research record*.
- Ortelli, N., Bierlaire, M. and de Lapparent, M. (2021). Can we infer on behavioral impacts of public policy on accident severity outcomes? Proceedings of the 21st Swiss Transportation Research Conference.

## Model estimation

- Bierlaire, M. (2018). Pandasbiogeme: a short introduction, Technical report, TRANSP-OR 181219. Transport & Mobility Laboratory, ENAC, EPFL.
- Bierlaire, M. (2020). A short introduction to pandasbiogeme, Technical report, TRANSP-OR 200605. Transport & Mobility Laboratory, ENAC, EPFL.

## Miscellaneous

- Paul Tol's notes. Colour schemes and templates. URL: <https://personal.sron.nl/~pault/>
- Tamzid Hasan @thenounproject.com. URL: [https://thenounproject.com/th\\_studio/](https://thenounproject.com/th_studio/)

# An integrated ordered logit and latent variable model for road crash severity

*A Swiss case study using disaggregate crash reports*

EPFL Transport Symposium  
February 15–17, 2023 | Annecy, France

N. Ortelli<sup>1,2</sup>, S. Varotto<sup>2</sup>, M. Bierlaire<sup>2</sup>, M. de Lapparent<sup>1</sup>

<sup>1</sup> School of Management and Engineering Vaud, HES-SO, Switzerland

<sup>2</sup> École Polytechnique Fédérale de Lausanne (EPFL), Switzerland