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Dublin, Ireland, April 15-18, 2024

Safety evaluation via conflict classification during automated shuttle bus service operations

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SHOW AUTOMATED URBAN MOBILITY

The SHOW project

- 70 partners from 13 EU-countries

  National Technical University of Athens

- Duration of the project:

  48 months (January 2020 - September 2024)

- Framework Program:

  Horizon 2020 - The EU Union Framework Programme for Research and Innovation - Mobility for Growth

- Project Website:

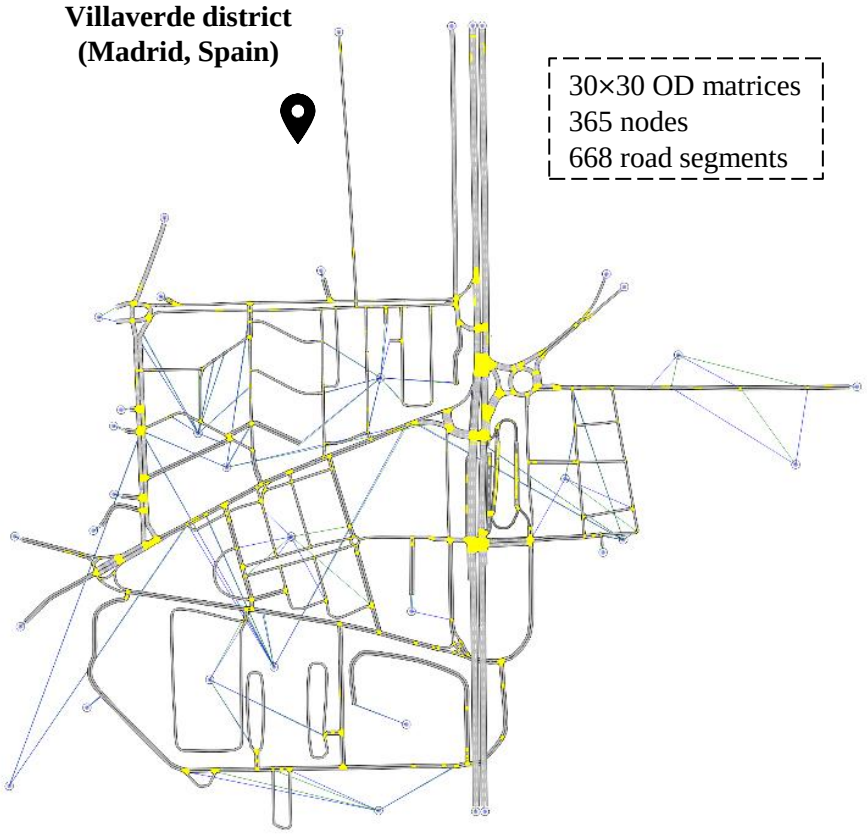
  Full information at: show-project.eu

Introduction

- The SHOW project aims at developing shared automation operating models for worldwide adoption.
- Real-life mass transit Autonomous Vehicle (AVs) demonstrations are taking place in 20 cities across Europe.
- The project vision is to investigate the integration of AVs into various transport aspects.
- The present study aims to examine the safety effects of different shuttle bus service speeds in various future mobility conditions.

Study area

- One such demonstration site of the project is the Madrid site of Villaverde, which comprises a dense urban traffic network.
- The network is simulated in the Aimsun Next software.
- In order to provide impacts of AV operation that could not feasibly be measured in reality, the microscopic simulation method was used.
- The simulated network consisted of 365 nodes and 668 sections, featuring vehicle O-D matrices of 30×30 centroids.

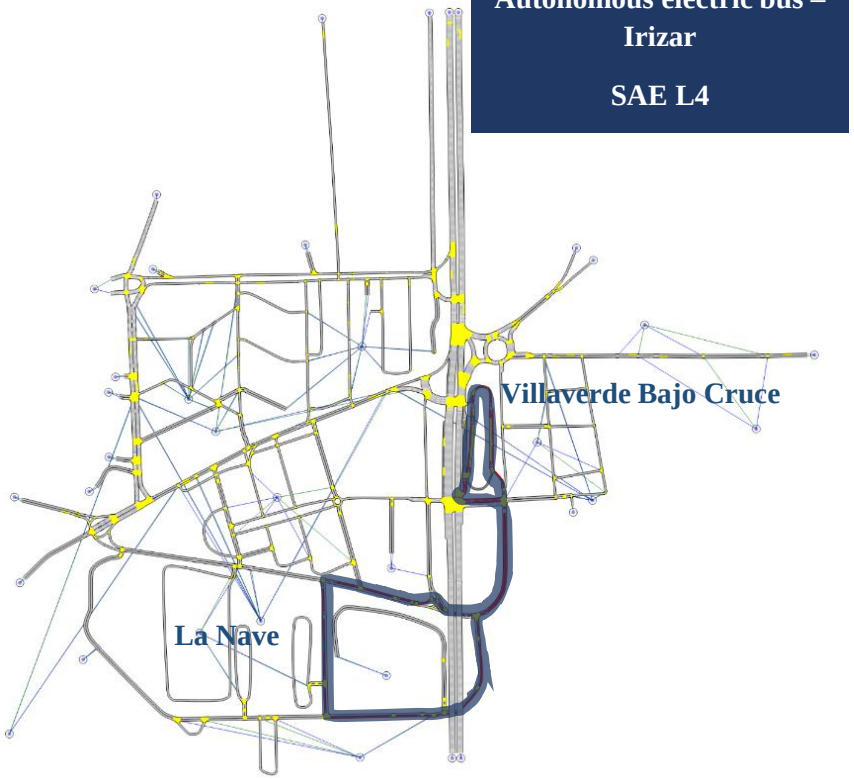


AV operation & integration

- An autonomous shuttle bus line was implemented, operating along with the existing 23 public transport lines
- Cycle route frequency: 15 min
- Total capacity: 60 passengers & 25 seated passengers
- 3+1 simulated operational speeds of the service: 15km/h, 30km/h, and 45km/h + baseline (no shuttle)
- Eleven simulated traffic mixes: 0%-100% (10% increments) Market Penetration Rate of AVs in general traffic
- Thus, (3+1) x 11 = 44 simulated scenarios in total

Autonomous electric bus – Irizar

SAE L4



Traffic conflicts: Surrogate Safety Measures

- Traffic conflicts serve as Surrogate Safety Measures (SSMs) from the microsim analysis to gauge safety levels proactively (as crashes are not simulated)

- Conflicts are registered when time-to-collision (TTC) <0.5s and post-encroachment time (PET) <5.0s for AVs.

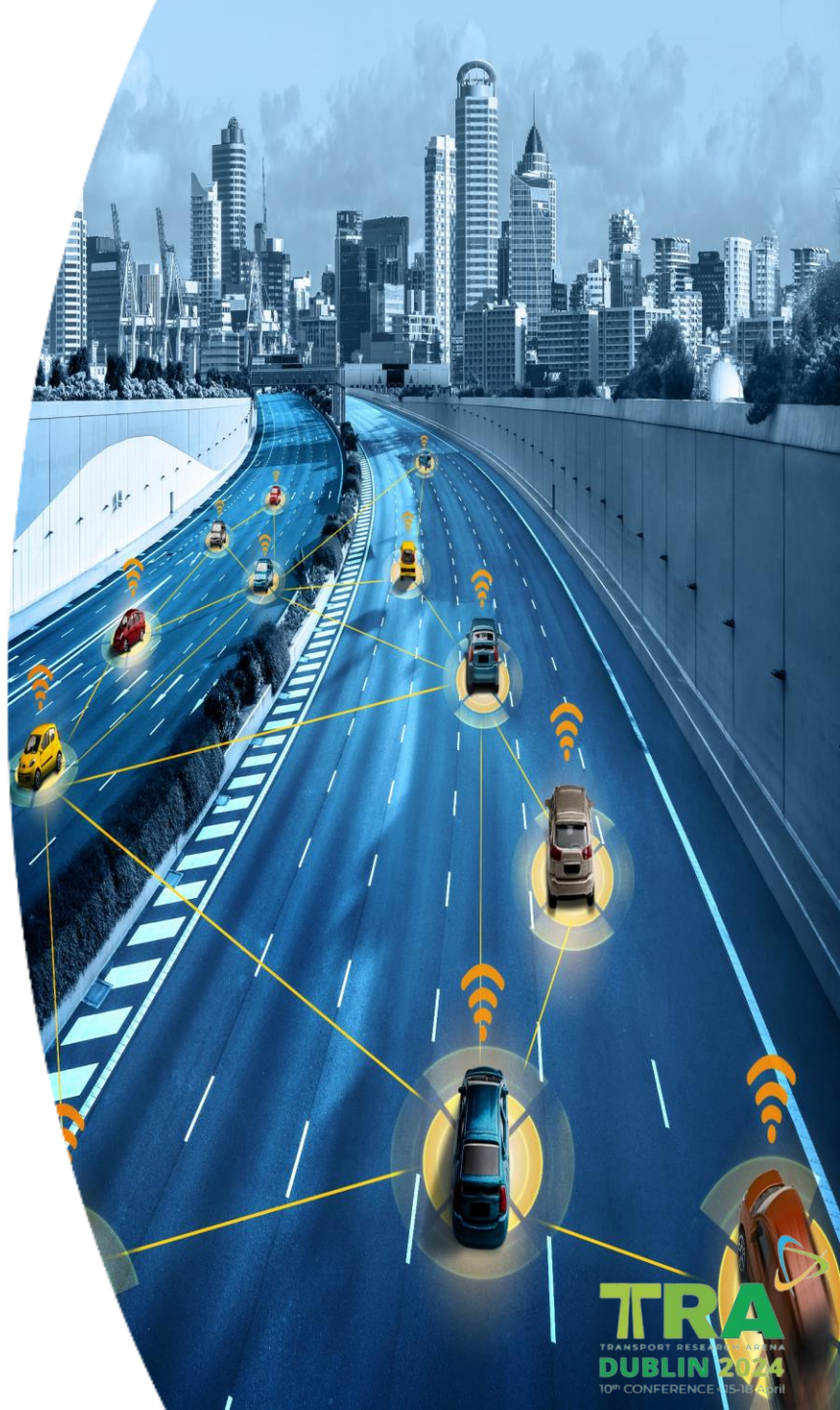
- A database comprising 638,163 conflicts was extracted from the SSAM add-on software

Variable	Source	Type	Description	Units	N	Min	Median	Mean	Max	Std.
PET	SSAM	Numeric	The minimum post encroachment time observed during the conflict	seconds	638,163	0.00	0.40	0.883	4.80	1.098
MPR	SSAM	Numeric	The total Market Penetration Rate of CAVs	%	638,163	0.00	40.00	41.210	100.00	30.747
MaxDeltaV	SSAM	Numeric	The maximum difference in vehicle speeds of the involved vehicles in the occurred conflict	km/h	638,163	0.00	3.47	4.656	25.30	4.061
ConflictAngle	SSAM	Numeric	The angle of hypothetical collision between conflicting vehicles, based on the estimated heading of the each vehicle	degrees	638,163	-180.00	-0.35	-10.420	180.00	72.190

Variable	Source	Type	Description	Levels	N	Percentage
Conflict type	SSAM	Factor	Type of the recorded conflict	Rear-end	312,368	48.9%
				Lane change	105,571	16.5%
				Crossing	220,224	34.5%
				Total	638,163	(100.0%)

Modelling scope

- Traffic conflicts are maneuvers describing physical movement of the vehicles.
- Classification of conflict types supported by geometrical, network and traffic variables.
- Mixed-Effects Multinomial Logit Regression (ME-MLR) models are fitted.
- For the best model, the constant varies across MPR percentages.
- ME-MLR models outperform fixed-effects MLR models (lower residual Deviance).



ME-MLR model

- Crossing conflicts are the reference category for multiclass classification.
- Almost all variables are statistically significant
- A lot of information to unpack, an interpretation mechanism will help…

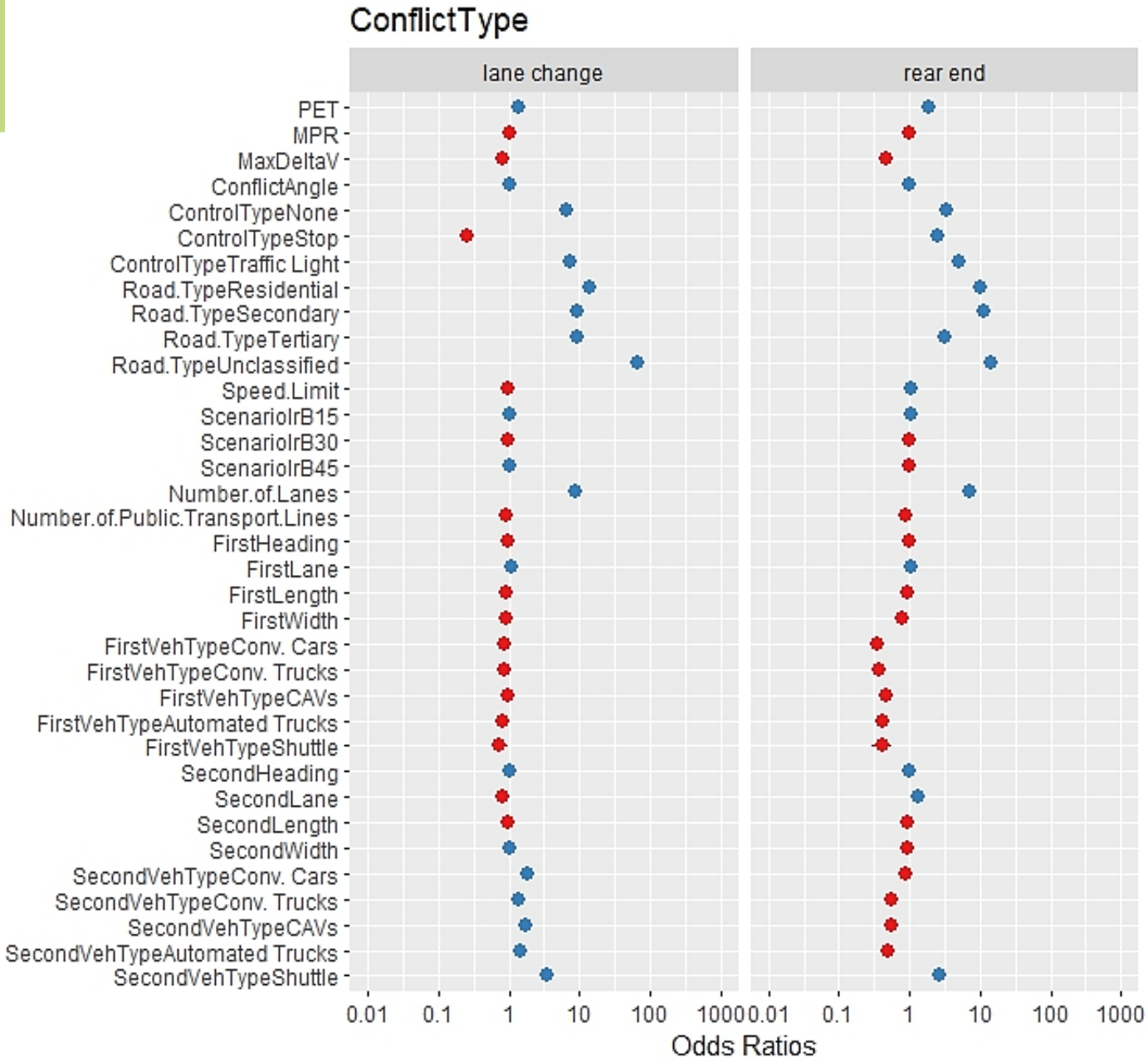
ME-MLM results with **crossing conflicts** as reference category

	ConflictType: lane change					ConflictType: rear end				
Predictors	**Coefficient**	**SE**	**OR**	**CI**	**p**	**Coefficient**	**SE**	**OR**	**CI**	**p**
Intercept	-6.043	0.266	0.00	0.00 - 0.00	**<0.001**	-2.169	0.299	0.11	0.06 – 0.21	**<0.001**
PET	0.329	0.007	1.39	1.37 – 1.41	**<0.001**	0.656	0.007	1.93	1.90 – 1.95	**<0.001**
MPR	-0.000	0.001	1.00	1.00 – 1.00	0.511	-0.001	0.001	1.00	1.00 – 1.00	0.124
MaxDeltaV	-0.178	0.002	0.84	0.83 – 0.84	**<0.001**	-0.741	0.003	0.48	0.47 – 0.48	**<0.001**
ConflictAngle	0.010	0.000	1.01	1.01 – 1.01	**<0.001**	0.006	0.000	1.01	1.01 – 1.01	**<0.001**
ControlTypeNone [Give way]	1.867	0.027	6.47	6.13 – 6.82	**<0.001**	1.200	0.024	3.32	3.17 – 3.48	**<0.001**
ControlTypeStop [Give way]	-1.358	0.108	0.26	0.21 – 0.32	**<0.001**	0.928	0.040	2.53	2.34 – 2.74	**<0.001**
ControlTypeTraffic Light [Give way]	2.006	0.036	7.43	6.93 – 7.97	**<0.001**	1.591	0.032	4.91	4.61 – 5.22	**<0.001**
Road.TypeResidential [Primary]	2.617	0.049	13.69	12.44 – 15.06	**<0.001**	2.312	0.047	10.09	9.21 – 11.06	**<0.001**
Road.TypeSecondary [Primary]	2.238	0.041	9.37	8.66 – 10.14	**<0.001**	2.440	0.039	11.47	10.62 – 12.39	**<0.001**
Road.TypeTertiary [Primary]	2.258	0.046	9.56	8.73 – 10.47	**<0.001**	1.138	0.046	3.12	2.85 – 3.41	**<0.001**
Road.TypeUnclassified [Primary]	4.181	0.048	65.45	59.56 – 71.92	**<0.001**	2.633	0.050	13.92	12.61 – 15.36	**<0.001**
Speed.Limit	-0.017	0.001	0.98	0.98 – 0.99	**<0.001**	0.028	0.001	1.03	1.03 – 1.03	**<0.001**
ScenarioIrB15 [Baseline]	0.013	0.014	1.01	0.99 – 1.04	0.338	0.073	0.016	1.08	1.04 – 1.11	**<0.001**
ScenarioIrB30 [Baseline]	-0.009	0.013	0.99	0.96 – 1.02	0.483	-0.032	0.015	0.97	0.94 – 1.00	**0.039**
ScenarioIrB45 [Baseline]	0.007	0.013	1.01	0.98 – 1.03	0.627	-0.018	0.015	0.98	0.95 – 1.01	0.254
Number.of.Lanes	2.171	0.020	8.78	8.44 – 9.13	**<0.001**	1.968	0.019	7.16	6.89 – 7.43	**<0.001**
Number.of.Public.Transport.Lines	-0.089	0.004	0.92	0.91 – 0.92	**<0.001**	-0.146	0.004	0.86	0.86 – 0.87	**<0.001**
FirstHeading	-0.003	0.000	1.00	1.00 – 1.00	**<0.001**	-0.002	0.000	1.00	1.00 – 1.00	**<0.001**
FirstLane	0.062	0.003	1.06	1.06 – 1.07	**<0.001**	0.075	0.003	1.08	1.07 – 1.08	**<0.001**
FirstLength	-0.061	0.011	0.94	0.92 – 0.96	**<0.001**	-0.051	0.012	0.95	0.93 – 0.97	**<0.001**
FirstWidth	-0.099	0.042	0.91	0.83 – 0.98	**0.018**	-0.262	0.048	0.77	0.70 – 0.85	**<0.001**
FirstVehTypeConvCars [Conv Buses]	-0.125	0.100	0.88	0.73 – 1.07	0.213	-1.046	0.109	0.35	0.28 – 0.44	**<0.001**
FirstVehTypeConvTrucks [Conv Buses]	-0.160	0.058	0.85	0.76 – 0.96	**0.006**	-0.967	0.060	0.38	0.34 – 0.43	**<0.001**
FirstVehTypeCAVs [Conv Buses]	-0.042	0.101	0.96	0.79 – 1.17	0.678	-0.768	0.109	0.46	0.37 – 0.57	**<0.001**
FirstVehTypeAutomatedTrucks [Conv Buses]	-0.219	0.059	0.80	0.72 – 0.90	**<0.001**	-0.884	0.061	0.41	0.37 – 0.47	**<0.001**
FirstVehTypeShuttle[Conv Buses]	-0.310	0.130	0.73	0.57 – 0.95	**0.017**	-0.893	0.167	0.41	0.28 – 0.57	**<0.001**
SecondHeading	0.006	0.000	1.01	1.01 – 1.01	**<0.001**	0.003	0.000	1.00	1.00 – 1.00	**<0.001**
SecondLane	-0.175	0.011	0.84	0.82 – 0.86	**<0.001**	0.252	0.012	1.29	1.26 – 1.32	**<0.001**
SecondLength	-0.037	0.012	0.96	0.94 – 0.99	**0.002**	-0.058	0.014	0.94	0.92 – 0.97	**<0.001**
SecondWidth	0.013	0.043	1.01	0.93 – 1.10	0.760	-0.078	0.050	0.93	0.84 – 1.02	0.119
SecondVehTypeConvCars [Conv Buses]	0.606	0.104	1.83	1.49 – 2.25	**<0.001**	-0.111	0.118	0.90	0.71– 1.13	0.349
SecondVehTypeConvTrucks [Conv Buses]	0.333	0.057	1.39	1.25 – 1.56	**<0.001**	-0.579	0.063	0.56	0.50– 0.63	**<0.001**
SecondVehTypeCAVs [Conv Buses]	0.578	0.104	1.78	1.45 – 2.19	**<0.001**	-0.607	0.118	0.55	0.43– 0.69	**<0.001**
SecondVehTypeAutomatedTrucks [Conv Buses]	0.394	0.059	1.48	1.32 – 1.66	**<0.001**	-0.733	0.066	0.48	0.42– 0.55	**<0.001**
SecondVehTypeShuttle[Conv Buses]	1.236	0.043	3.44	3.16 – 3.75	**<0.001**	0.984	0.069	2.68	2.34 – 3.07	**<0.001**
lane change/crossing x VCov(~1,~1)	0.004	0.000				0.001	0.000			
rear end/crossing x VCov(~1,~1)	0.001	0.000				0.008	0.000			
Groups by MPR	11									
Observations	602,710									

Modelling results (1/3)

Interpretation via Odds Ratios (ORs):

- OR>1 (Blue) contributes towards examined category
- OR<1 (Red) contributes towards reference category



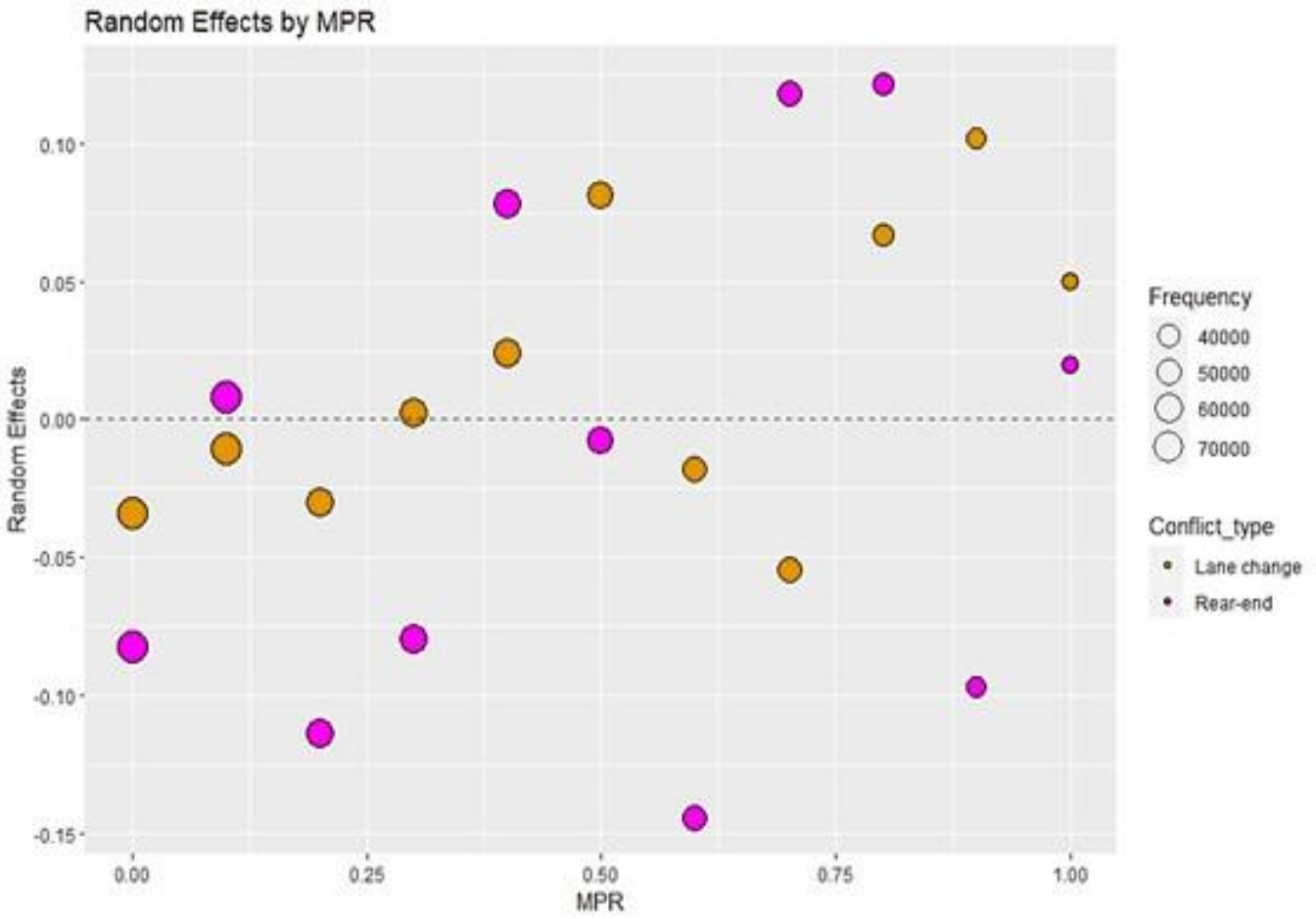
Modelling results (2/3)

- Lane change and rear-end conflicts are more likely to occur when:
- PET increases
- MPR, overall lanes and higher maximum speed difference decrease
- Road type is not Primary
- More rear-end conflicts during 15 km/h and 30 km/h operational speed
- Different control types and no control type exist instead of the ‘Give way’ control type (but not always in ‘Stop’)

… and more…

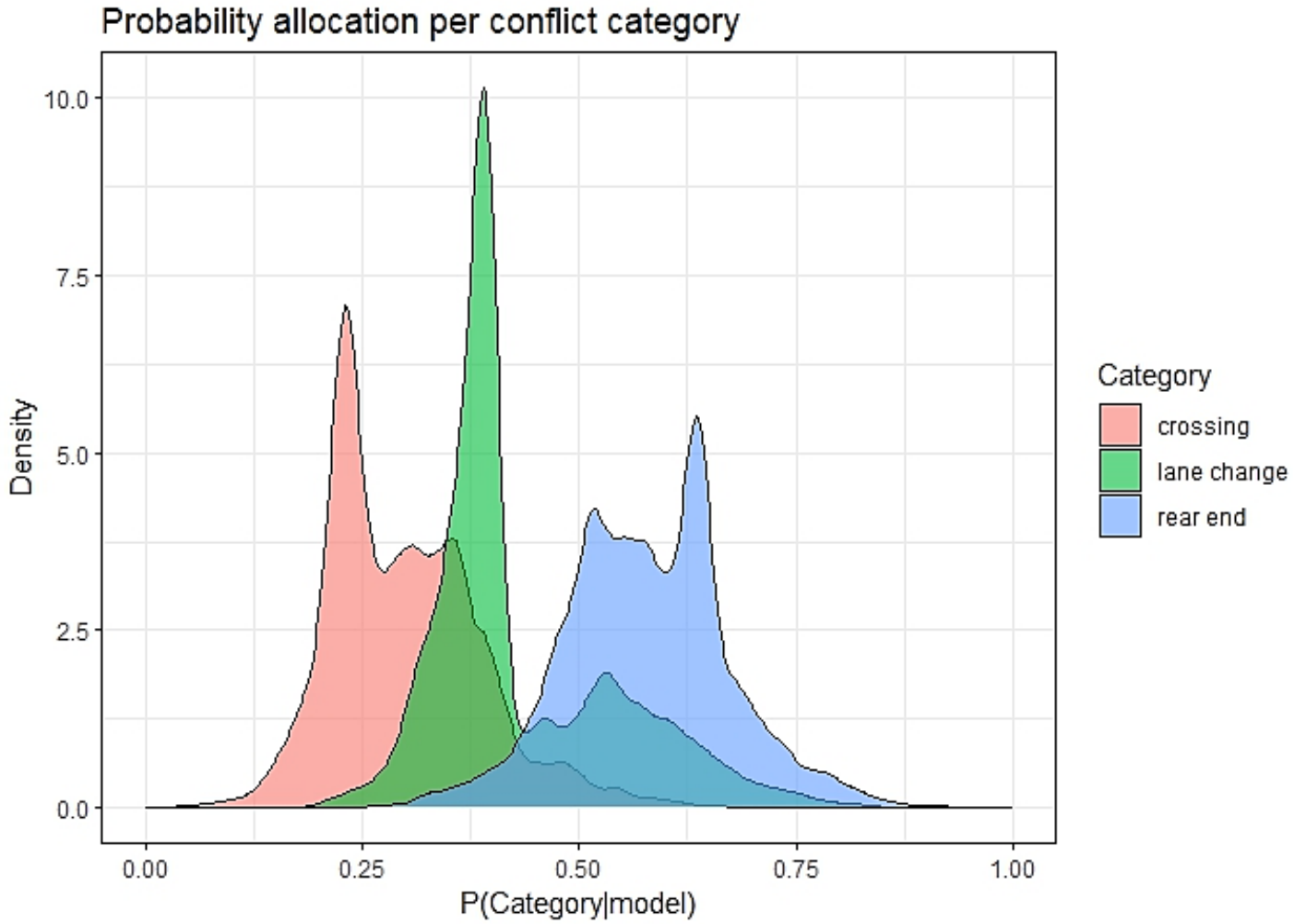
Modelling results (3/3)

- Random effects are statistically significant.
- Each MPR value provides a unique constant component to the model (in addition to the entire variable).
- Random effects fluctuate more:
  In lower MPR values for rear-end conflicts and…
  In higher MPR values for lane change conflicts.



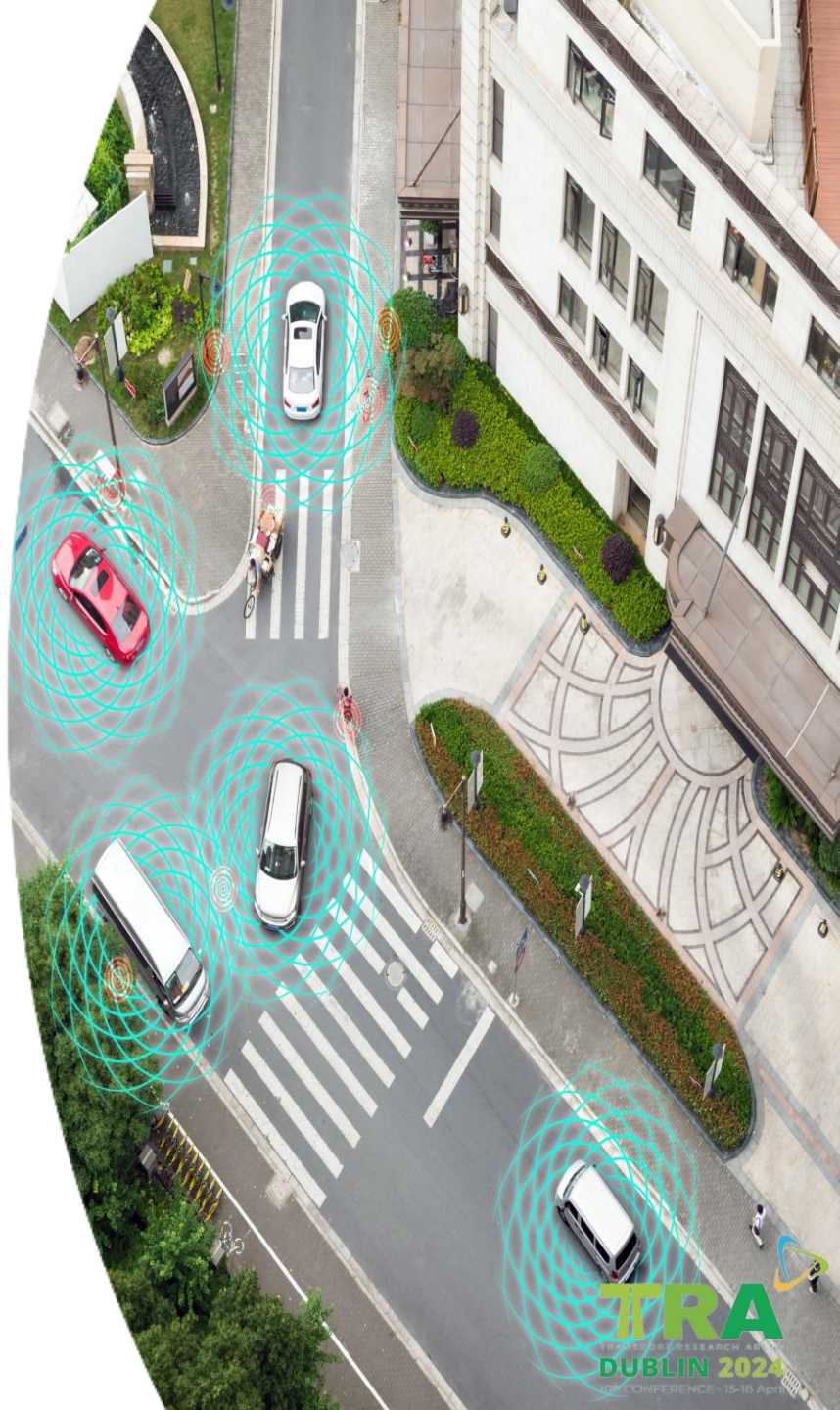
Probability predictions

- The overall probability predictions are plotted for each conflict category.
- Sharper curves:
  More concentrated density, indicating higher certainty in predictions.
- Present model performance appears quite satisfactory.



Conclusions

- The quantification of safety impacts is critical to enable stakeholders for the deployment and operation of automated services.
- A large array of geometric, network and traffic variables influence conflict type classification.
- MPR, describing the automated traffic mix, strongly governs conflict type generation and frequency.
- Surrogate Safety Measures offer insights in uncharted scenarios before crashes occur; nonetheless, validation is required.



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