Lane-changing as a game: Modelling mandatory lane-changing behaviour in a connected environment

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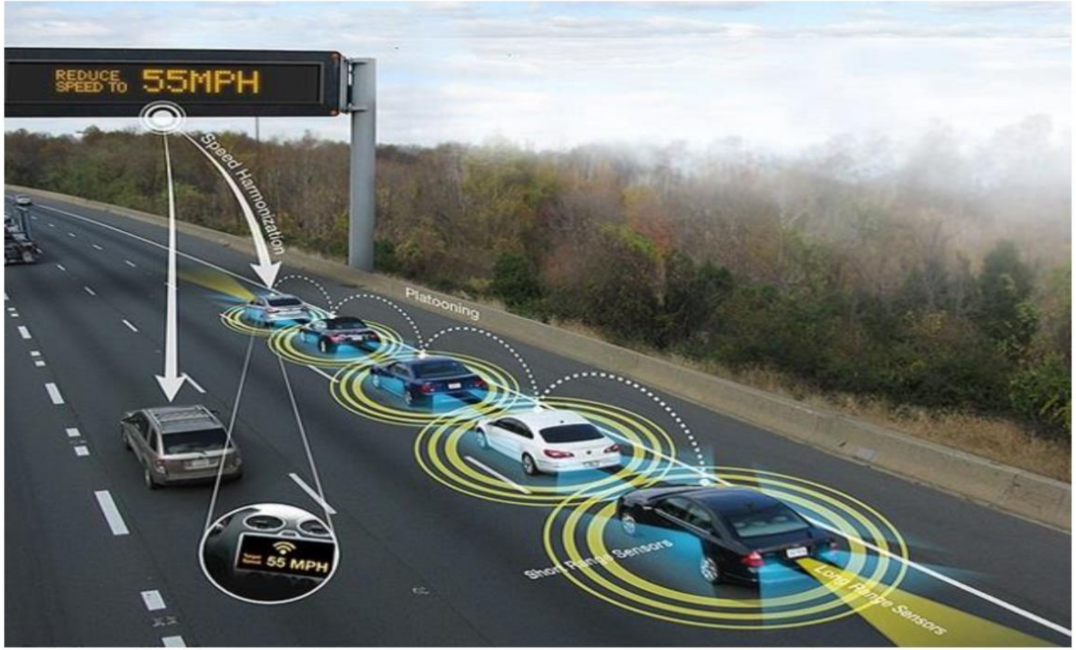
THE UNIVERSITY OF SYDNEY

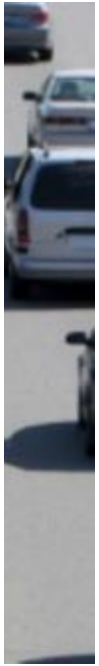
Outline

1. Research Background, Motivation & Objective
2. Model Formulation
3. Data Collection
4. Modelling Results
5. Model Comparison
6. Conclusion

Background

- Traditional
- Connected

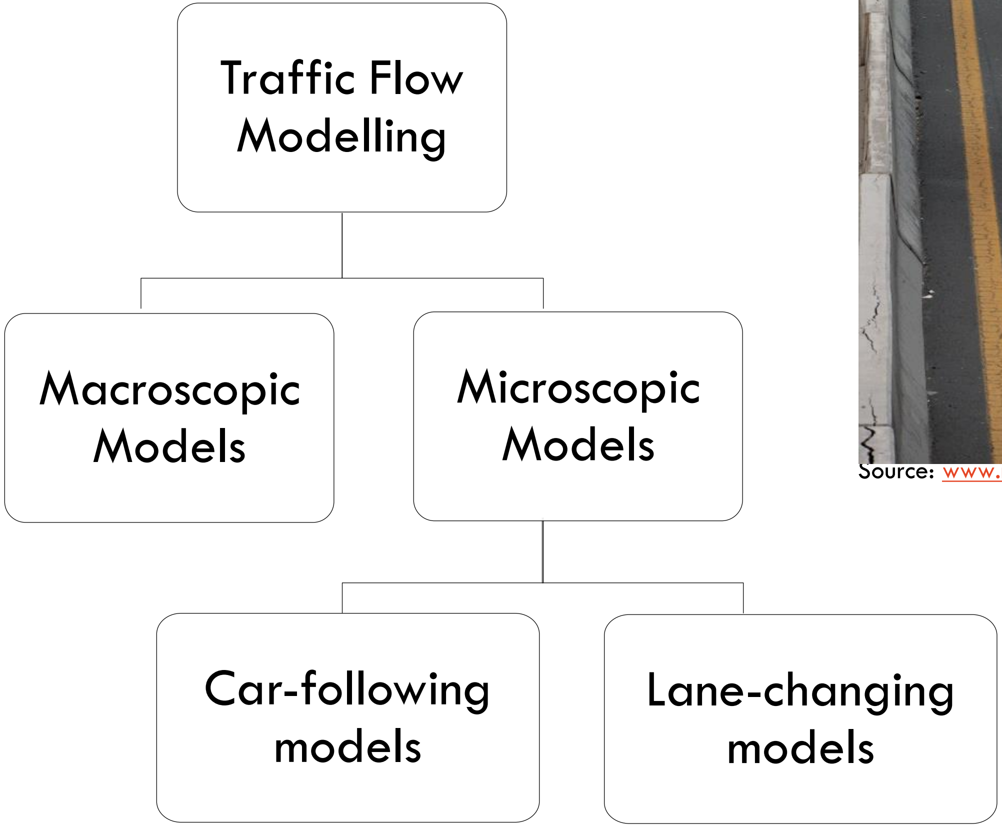




Source: https://www.digitaltrends.com/cars/aaa-study-drivers-like-dont-understand-adas/

Source: U.S. Department of Transportation

Background



Source: www.news.yahoo.com.au/sydney

Background

Negative Impacts of Lane-changing

- Formation of stop-and-go oscillations
- Capacity drop with shockwaves
- Create bottleneck points in freeways under heavy traffic conditions
- Deteriorate traffic safety

Motivation

- Very limited efforts to date are dedicated to model mandatory lane-changing in the connected environment
- Scarcity of the connected environment data
- Methodological and behavioural deficiency (Deficiency I)
- Model calibration deficiency (Deficiency II)

Objective

- To model mandatory lane-changing decision-making behaviour in the connected environment

Development of lane-changing model for traditional environment using the game theory approach → Transforming the developed lane-changing model for the connected environment

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Model Formulation

Game and its components

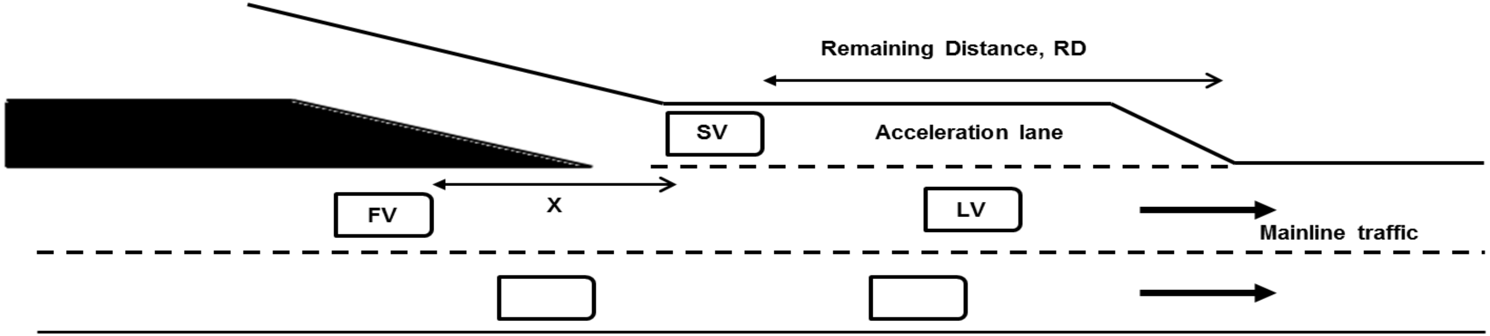
Two players: SV (lane-changer) and FV (immediate follower)

Motive:

- SV- Spends as minimum time as possible
- FV- Resists the change in current state of motion

Strategies:

- SV- merging and waiting
- FV- acceleration, deceleration, changing lane, and doing nothing



A typical merging scenario

Model Formulation

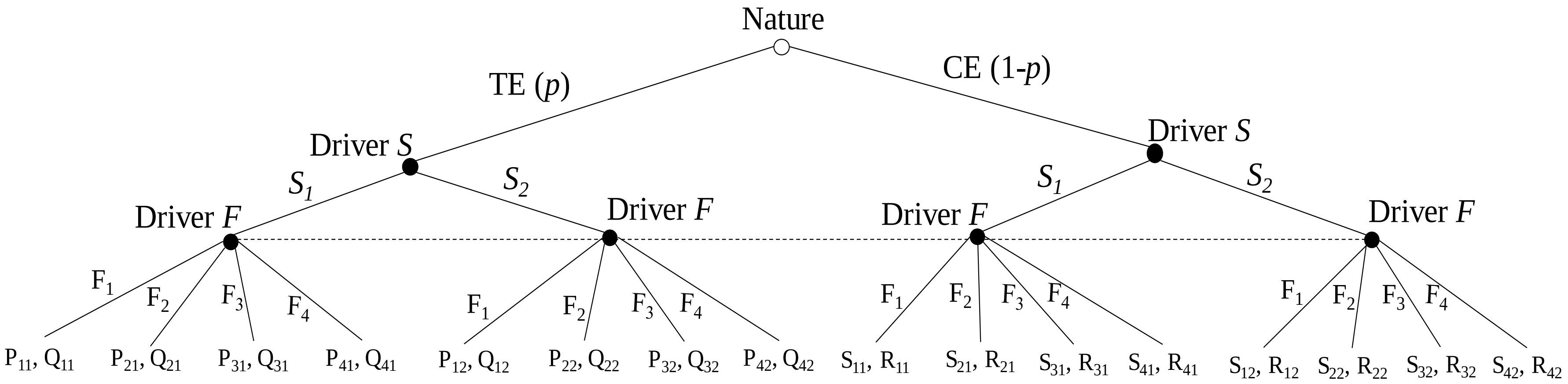
Merging game for traditional and connected environments in the normal form

FV	SV				
	Traditional environment		Connected environment		Probability for FV
	Merging (S_1)	Waiting (S_2)	Merging (S_1)	Waiting (S_2)	
Accelerating/Forced merging (F_1)	P_{11}, Q_{11}	P_{12}, Q_{12}	S_{11}, R_{11}	S_{12}, R_{12}	y_1
Decelerating/Courtesy yielding (F_2)	P_{21}, Q_{21}	P_{22}, Q_{22}	S_{21}, R_{21}	S_{22}, R_{22}	y_2
Doing nothing (F_3)	P_{31}, Q_{31}	P_{32}, Q_{32}	S_{31}, R_{31}	S_{32}, R_{32}	y_3
Changing lane (F_4)	P_{41}, Q_{41}	P_{42}, Q_{42}	S_{41}, R_{41}	S_{42}, R_{42}	y_4
Probability for SV	z_1	z_2	z_1	z_2	

P and Q respectively denote the payoffs for SV, FV in the traditional environment and the corresponding payoffs in the connected environments are respectively S and R; y and z are probabilities of FV's and SV's action, respectively.

Model Formulation

Transformed merging game in the extensive form



Model Formulation

Payoff Functions

	Players		SV	
Payoff for FV	FV	Strategies	Merging (S_1)	Waiting (S_2)
		Accelerating (F_1)	$Q_{11} = \alpha_{11}^0 + \alpha_{11}^1 Acc'_{M-A} + \varepsilon_{11}$	$Q_{12} = \alpha_{12}^0 + \alpha_{12}^1 Acc_{W-A} + \varepsilon_{12}$
		Decelerating (F_2)	$Q_{21} = \alpha_{21}^0 + \alpha_{21}^1 Acc_{M-D} + \varepsilon_{21}$	$Q_{22} = \alpha_{22}^0 + \alpha_{22}^1 Acc_{W-D} + \varepsilon_{22}$
		Doing nothing (F_3)	$Q_{31} = \alpha_{31}^0 + \alpha_{31}^1 Acc_{M-DN} + \varepsilon_{31}$	$Q_{32} = \alpha_{32}^0 + \alpha_{32}^1 Acc_{W-DN} + \varepsilon_{32}$
		Changing lane (F_4)	$Q_{41} or\ Q_{42} = \alpha_{41}^0 + \alpha_{41}^1 Acc_{FV}^{LV\ TL} + \alpha_{41}^2 Acc_{FV}^{FV\ TL} + \alpha_{41}^3 \Delta V + \alpha_{41}^4 G + \varepsilon_{41}$	
Payoff for SV	FV	Accelerating (F_1)	$P_{11} = \beta_{11}^0 + \beta_{11}^1 Acc_{M-A} + \delta_{11}$	$P_{12} = \beta_{12}^0 + \beta_{12}^1 Acc_{W-A} + \delta_{12}$
		Decelerating (F_2)	$P_{21} = \beta_{21}^0 + \beta_{21}^1 Acc_{M-D} + \delta_{21}$	$P_{22} = \beta_{22}^0 + \beta_{22}^1 Acc_{W-D} + \delta_{22}$
		Doing nothing (F_3)	$P_{31} = \beta_{31}^0 + \beta_{31}^1 Acc_{M-DN} + \delta_{31}$	$P_{32} = \beta_{32}^0 + +\beta_{32}^1 Acc_{W-DN} + \delta_{32}$
		Changing lane (F_4)	$P_{41} = \beta_{41}^0 + +\beta_{41}^1 Acc_{M-LC} + \delta_{41}$	$P_{42} = \beta_{42}^0 + \beta_{42}^1 Acc_{W-LC} + \delta_{42}$

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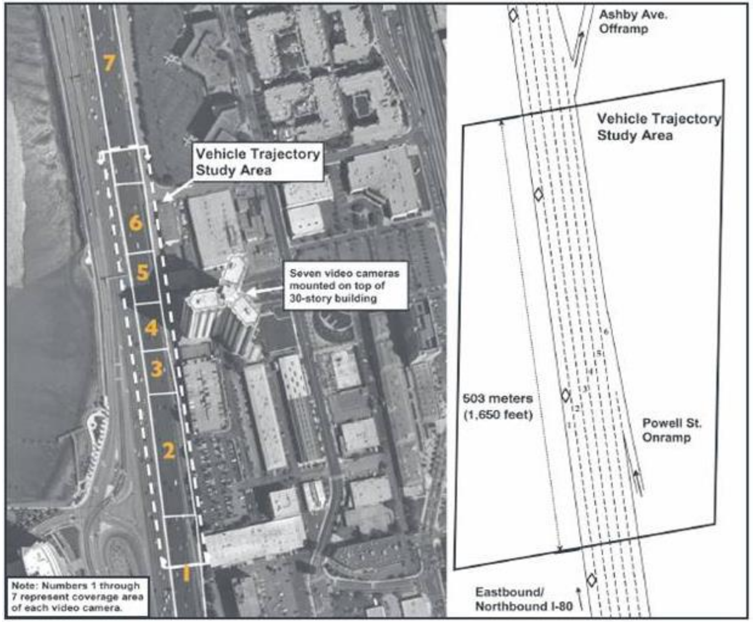
Data

Data

- NGSIM for traditional environment
- Driving simulator for connected environment

NGSIM data for traditional environment
(I-80 dataset)



Data

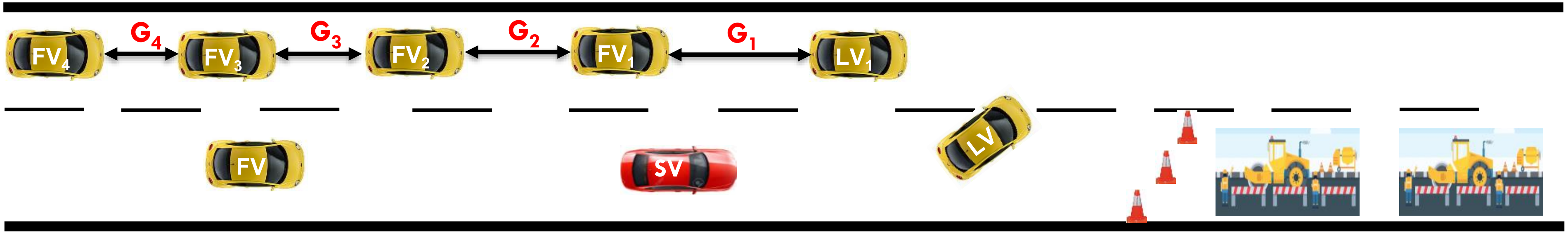
Advanced Driving Simulator data for connected environment

Design of Experiment

- Baseline Scenario
- Connected Environment

Data

Vehicular interactions



Data

Design of driving aids in the connected environment

Warning message: Violating the speed limit of 100 km/h

Fixed message: Speed of and distance to the leader on the current lane (Yellow car)

Advisory message: Text message about upcoming situations

Lane-changing gap information on the adjacent lane

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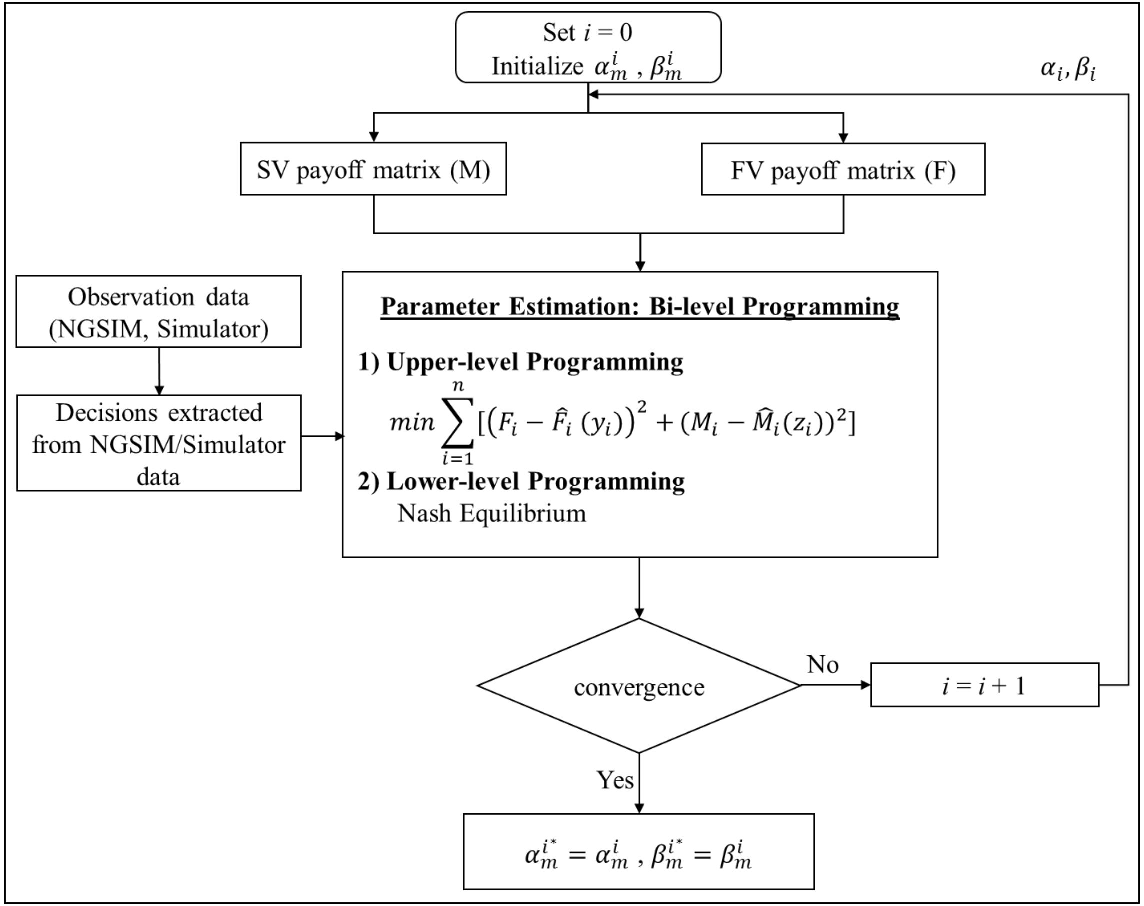
Empirical Evidence of Strategies

Strategy	I-80-F (NGSIM)		Baseline (Simulator data)		CE (Simulator data)	
	Count	Percentage	Count	Percentage	Count	Percentage
Accelerating: Merging	126	5.28	7	2.27	0	0
Decelerating: Merging	98	4.11	20	6.49	17	5.47
Doing nothing: Merging	340	14.24	51	16.56	61	19.61
Changing lane: Merging	0	0	0	0	0	0
Accelerating: Waiting	109	4.57	4	1.3	2	0.64
Decelerating: Waiting	190	7.96	18	5.84	20	6.43
Doing nothing: Waiting	1522	63.76	208	67.53	211	67.85
Changing lane: Waiting	2	0.08	0	0	0	0

Calibration



Calibration

Strategy	Payoff	Parameter	I-80-F	Baseline	CE	Parameter	I-80-F	Baseline	CE
Accelerating: Merging	FV	α_{11}^0	-0.65	-1.60	0	α_{11}^1	0.29	0.58	0
Decelerating: Merging		α_{21}^0	0.13	-1.78	-0.61	α_{21}^1	-0.57	-1.63	-0.6
Doing nothing: Merging		α_{31}^0	0.47	1.87	1.30	α_{31}^1	3.36	3.87	1.71
Accelerating: Waiting		α_{12}^0	2.91	1.78	1.55	α_{12}^1	0.48	2.27	1.76
Decelerating: Waiting		α_{22}^0	3.34	1.57	1.36	α_{22}^1	3.68	1.08	1.07
Doing nothing: Waiting		α_{32}^0	0.19	1.05	1.16	α_{32}^1	0.01	1.25	1.11
Accelerating: Merging	SV	β_{11}^0	0.80	6.39	0	β_{11}^1	1.27	2.64	0
Decelerating: Merging		β_{21}^0	0.44	4.02	6.38	β_{21}^1	-1.19	-4.65	-0.82
Doing nothing: Merging		β_{31}^0	3.20	5.91	2.18	β_{31}^1	-1.17	-5.99	-7.51
Accelerating: Waiting		β_{12}^0	0.79	2.25	2.73	β_{12}^1	0.36	2.16	2.96
Decelerating: Waiting		β_{22}^0	0.96	2.89	0.88	β_{22}^1	2.46	4.20	2.18
Doing nothing: Waiting		β_{32}^0	0.20	1.78	1.79	β_{32}^1	0.08	6.75	0.64
MAE (I-80-F) = 0.15; MAE (Baseline) = 0.15; MAE (CE) = 0.11									

Validation

Cases	I-80-F					Baseline data from simulator					CE data from simulator				
	N	TP	FP	DR (%)	FAR (%)	N	TP	FP	DR (%)	FAR (%)	N	TP	FP	DR (%)	FAR (%)
Overall	685	603	82	88	12	91	81	10	89	11	91	82	9	90	10
Merging	169	114	55	67	33	23	19	4	83	17	23	18	5	78	22
Non-merging	516	489	27	95	5	68	62	6	91	9	68	64	4	94	6
Accelerating: Merging	42	25	17	60	40	5	2	3	40	60	0	0	0	0	0
Decelerating: Merging	28	10	18	36	64	2	2	0	100	0	4	2	2	50	50
Doing nothing: Merging	99	79	20	80	20	16	15	1	94	6	19	16	3	84	16
Accelerating: Waiting	29	26	3	90	10	1	1	0	100	0	1	1	0	100	0
Decelerating: Waiting	31	29	2	94	6	6	6	0	100	0	5	4	1	80	20
Doing nothing: Waiting	456	434	22	95	5	61	55	6	90	10	62	59	3	95	5

TP: true positive; FP: false positive; DR: detection rate; FAR: false alarm rate

Validation

Error	I-80-F	Baseline	CE
	Mean (SD)	Mean (SD)	Mean (SD)
Time (s)	9.3 (5.87)	0.42 (0.72)	0.011 (0.016)
Location (m)	155.4 (47.97)	6.23 (4.93)	1.002 (1.37)
Paired t-test for the time error		*p*-value = 0.01	
Paired t-test for the location error		*p*-value <0.001	

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Model Comparison

Data source	I-80-F		CE from the advanced driving simulator	
Error	AZHW model	Liu's model	AZHW model	Talebpour's model
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Time (s)	2.3 (4.17)	6.69 (7.55)	0.004 (0.008)	0.012 (0.015)
Location (m)	14.31 (21.86)	34.54 (22.44)	0.569 (1.073)	1.51 (1.38)
Paired t-test for the time error	*p*-value <0.001		*p*-value <0.001	
Paired t-test for the location error	*p*-value <0.001		*p*-value <0.001	

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Conclusions

- Developed a behavioural sound mandatory lane-changing model using game theory approach
- Developed model is rigorously tested using bi-level calibration framework and confusion matrix
- Compared the developed model with existing game theory based models

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A game theory-based approach for modelling mandatory lane-changing behaviour in a connected environment

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THANK YOU
Questions