Analyzing Hard Braking Events of Automated Shuttles from Naturalistic Urban Pilot Sites

George Yannis
NTUA Professor

Together with:
Marios Sekadakis and Apostolos Ziakopoulos

Department of Transportation Planning and Engineering
National Technical University of Athens

2025 IRCOBI Europe conference

Vilnius, 10-12 September 2025

The SHOW project

- **66 project 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 (Grant agreement No 875530).
- **Project website:**
  - Full information at: show-project.eu

SHOW
AUTOMATED URBAN MOBILITY

4+ years

66 partners

13 European Countries

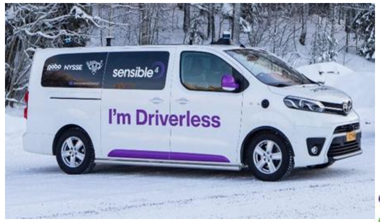
Over **20** cities involved across Europe

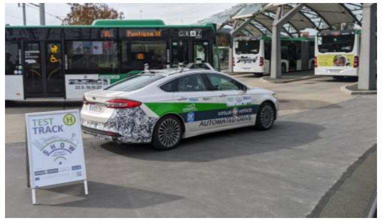
HORIZON 2020

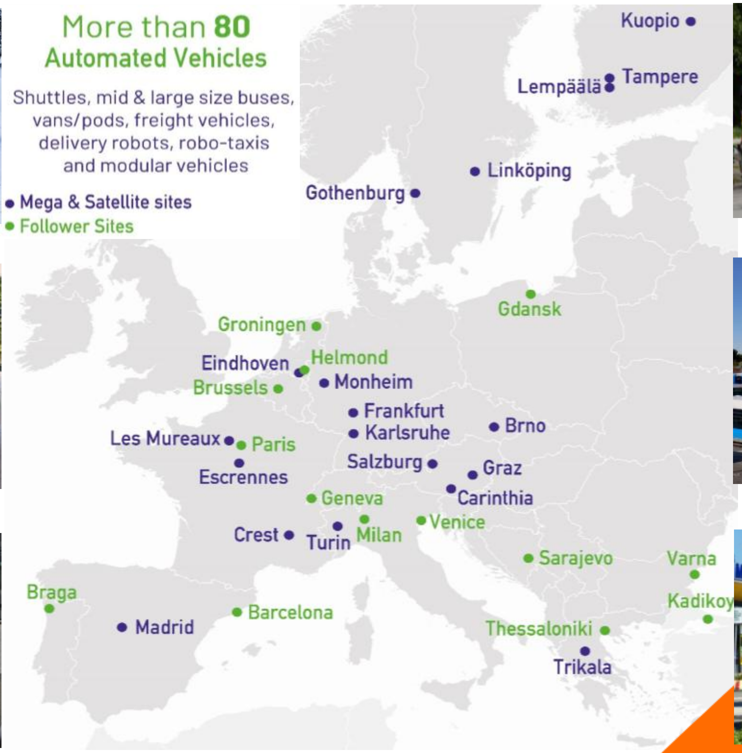
IRCOBI

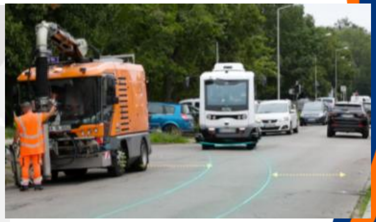
Project Objectives

- The SHOW project aimed at developing **shared automation** operating models for worldwide adoption.
- The project vision was to investigate the **integration of AVs** into various transport schemes.
- SHOW conducted **large-scale trials across 21 cities**, transporting over 150,000 passengers and completing more than 5,000 cargo deliveries.









Introduction

- Cooperative, Connected, and Automated Mobility (CCAM) is rapidly expanding, yet its safety impacts are not fully understood.

- Hard Braking (HB) events are a key indicator of safety performance for automated shuttles in real traffic.

- This study analyses real-world data from 10 European pilot sites within the SHOW project to understand the safety performance of automated shuttles in daily operation.

Objectives & Data

- Main objective: to **identify the factors** that influence HB events and to capture their variations across different European cities.

- The dataset includes 1,796 daily shuttle observations and a total of **4,820 HB events:** one of the largest analyses of automated shuttle operations in naturalistic conditions.

- **Thresholds** were kept constant across all sites, and unique HB events were extracted from high-frequency data, ensuring consistency and comparability in event detection.

IRCOBI

Methodology

- A Negative Binomial regression model was chosen because the data showed strong overdispersion, with variance far exceeding the mean.

- The explanatory variables in the model included average shuttle speed, acceleration variance, and the pilot site as a categorical factor.

- To ensure that site-specific traffic conditions and operational strategies were not overlooked, a random intercept structure was included, making the results more robust and comparable across locations.

IRCOBI

Key Results

- Higher average speeds significantly increased the likelihood of HB events: risks of faster shuttle operation in complex traffic environments.
- Acceleration variance showed a strong positive association with HB frequency: less smooth driving patterns directly translate into harsh brakings.
- Substantial differences were observed across the 10 pilot sites: local operational and infrastructural contexts strongly affect safety outcomes.

Negative Binomial Regression Results for Hard Braking Events

Variable	Estimate	Std. Error	z-value	p-value	
Intercept	-4.938	0.232	-21.267	<0.0001	***
Average Speed	0.292	0.024	12.256	<0.0001	***
Average Acceleration Variance	0.052	0.010	5.133	<0.0001	***
Site: Brno [Ref. Cat. Linköping]	1.579	0.302	5.225	<0.0001	***
Site: Carabanchel [Ref. Cat. Linköping]	3.262	0.210	15.500	<0.0001	***
Site: Graz [Ref. Cat. Linköping]	5.962	0.287	20.790	<0.0001	***
Site: Karlsruhe [Ref. Cat. Linköping]	4.098	0.289	14.164	<0.0001	***
Site: Klagenfurt [Ref. Cat. Linköping]	6.179	0.269	22.963	<0.0001	***
Site: Les Mureaux [Ref. Cat. Linköping]	2.738	0.183	14.933	<0.0001	***
Site: Pörtschach [Ref. Cat. Linköping]	6.057	0.210	28.894	<0.0001	***
Site: Tampere [Ref. Cat. Linköping]	1.455	0.330	4.407	<0.0001	***
Site: Trikala [Ref. Cat. Linköping]	5.127	0.268	19.101	<0.0001	***

Dependent variable: Hard Braking Counts per day
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Null deviance: 3109.5 on 1795 df. Residual deviance: 1218.4 on 1784 df. AIC: 4843.4

Site Variations & Effects

- Linköping recorded the lowest HB counts, reflecting smoother operations. Klagenfurt, Pörtschach, Graz, and Trikala had the **highest rates:** more challenging conditions.

- Just **1 km/h increase in average speed** led to additional 0.155 HB events per day: High sensitivity of safety performance to speed.

- A unit $(m/s^2)^2$ increase in **acceleration variance** resulted in nearly one extra HB event per day (0.863): Vehicle control smoothness directly influences passenger comfort and safety.

Marginal Effects to the Mean (MEM)

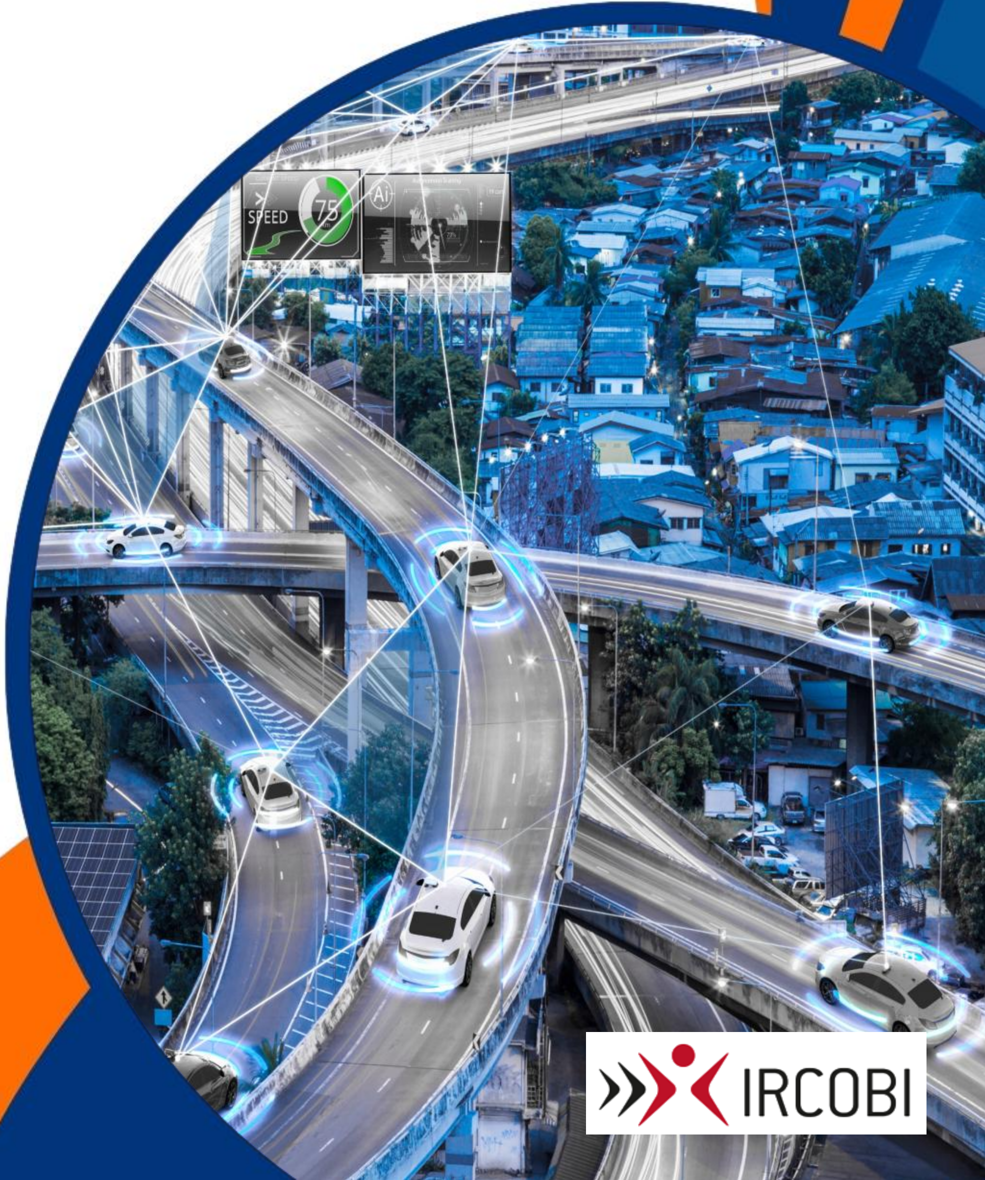
Marginal Effects	Estimate	SE	z	p	lower	upper
Average Speed	0.155	0.036	4.304	0.000	0.084	0.225
Average Acceleration Variance	0.863	0.121	7.133	0.000	0.626	1.101
Site: Brno [Ref. Cat. Linköping]	0.646	0.204	3.170	0.002	0.246	1.045
Site: Carabanchel [Ref. Cat. Linköping]	4.205	0.884	4.755	0.000	2.472	5.938
Site: Graz [Ref. Cat. Linköping]	64.933	22.191	2.926	0.003	21.440	108.426
Site: Karlsruhe [Ref. Cat. Linköping]	9.920	2.931	3.385	0.001	4.176	15.664
Site: Klagenfurt [Ref. Cat. Linköping]	80.705	27.912	2.891	0.004	25.999	135.412
Site: Les Mureaux [Ref. Cat. Linköping]	2.422	0.377	6.419	0.000	1.682	3.161
Site: Pörtschach [Ref. Cat. Linköping]	71.382	20.510	3.480	0.001	31.183	111.581
Site: Tampere [Ref. Cat. Linköping]	0.551	0.137	4.021	0.000	0.282	0.819
Site: Trikala [Ref. Cat. Linköping]	28.065	8.656	3.242	0.001	11.100	45.030

Discussion

- The results highlight that both **speed and smoothness** of operation are crucial for ensuring the safety of automated shuttles.

- Observed **differences between sites** can be explained by local traffic conditions, pedestrian volumes, and urban design.

- Findings point to the need for **adaptive, context-aware automation strategies** that can adjust to different urban conditions rather than applying uniform operational rules.



IRCOBI

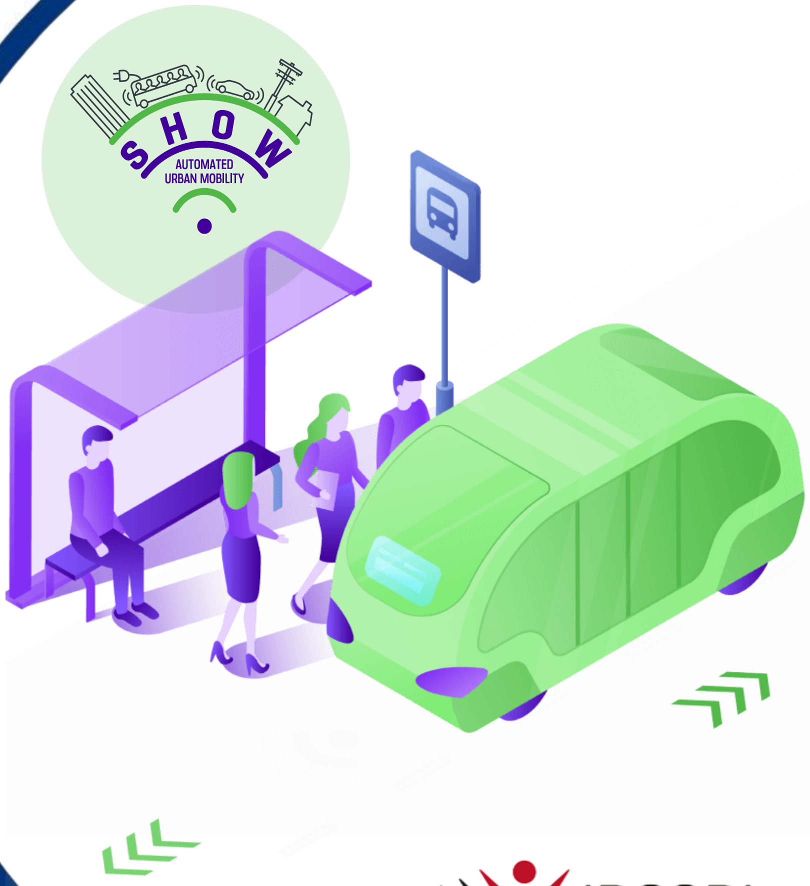
Implications & Conclusion

- **Automated vehicle algorithms** should be improved to anticipate and manage traffic interactions reducing harsh braking occurrence.

- The importance of **site-specific deployment strategies** that account for local infrastructure, traffic flows, and vulnerable road users is highlighted.

- Analyzing Hard Braking events offers valuable insights for **advancing CCAM safety protocols**

- This supports the safe **integration of automated shuttles** into urban mobility systems across Europe.



Analyzing Hard Braking Events of Automated Shuttles from Naturalistic Urban Pilot Sites

George Yannis
NTUA Professor

Together with:
Marios Sekadakis and Apostolos Ziakopoulos

Department of Transportation Planning and Engineering
National Technical University of Athens

2025 IRCOBI Europe conference

Vilnius, 10-12 September 2025