Impacts of Automated Shuttles on Traffic Safety: Findings from the SHOW project

ECTRI Annual Meeting: Thematic Group Safety

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The SHOW project

- **66 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 (GA No. 875530)

- **Project Website:**
  Full information at: show-project.eu

SHOW
AUTOMATED URBAN MOBILITY

4+ years

66 partners

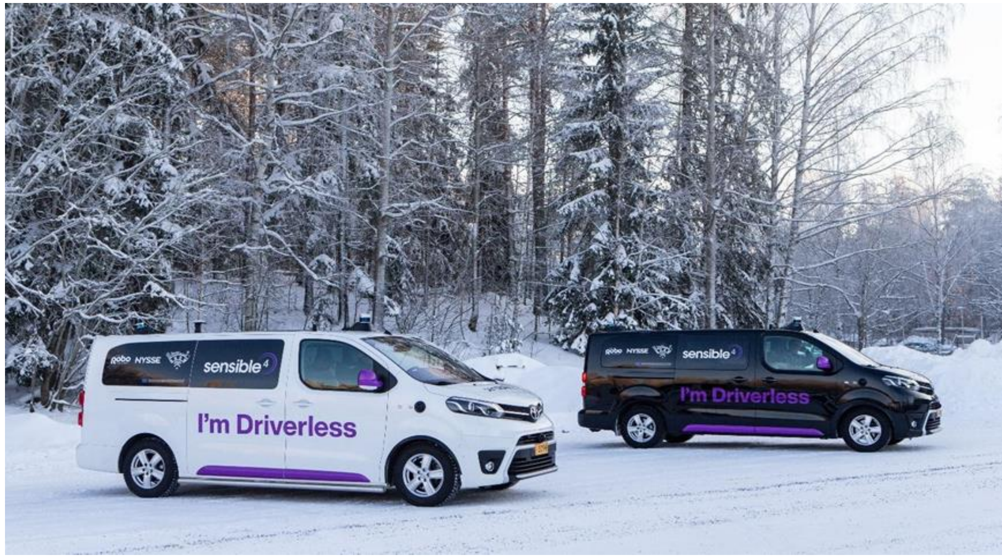
13 European Countries

Over **20** cities involved across Europe

European Commission
HORIZON 2020

Introduction

- The SHOW project aimed at developing **shared automation** operating models for worldwide adoption.
- **Real-life mass transit Autonomous Vehicle (AV) demonstrations** took place in 21 European cities.
- The project vision was to investigate the **integration of AVs** into various transport schemes.
- The **present study** examines the safety impacts of different AD shuttle operations in various pilot and simulation sites.



Real Life Operations of CCAM services

More than **80** Automated Vehicles

Shuttles, mid & large size buses, vans/pods, freight vehicles, delivery robots, robo-taxis and modular vehicles

- Mega & Satellite sites
- Follower Sites

- In 21 Cities - mixed traffic
- In open traffic & confined/ industrial environments
- Transferring more than 150,000 passenger rides (residents, commuters, tourists, employees, elderly and disabled, children) & 5000 cargo units

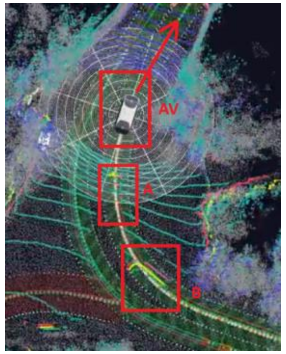
Impact on Road Accidents

- **Ten minor accidents** occurred across seven pilot sites, mostly due to interactions with other human drivers, not AD system failures.
- Incidents often happened in **challenging areas** (e.g., bus stations, parking lots) and involved **human drivers' errors**, such as failing to notice shuttles or making abrupt maneuvers.
- Two very **minor injuries** were reported, affecting safety drivers.
- **Lessons learned** highlight the need to enhance shuttles' risk detection, response capabilities, and communication with human drivers.

Site	Number of Accidents	Cause	Manual or AD
Linköping, Sweden	2	Collisions with bus and truck near bus station	AD
Karlsruhe, Germany	1	Collision with car exiting a parking space	AD
Salzburg, Austria	1	Steered into oncoming lane	AD
Crest, France	1	Failed overtaking maneuver by another car	AD
Tampere & Kuopio, Finland	3	Early departure from stop, overtaking-related crash, sudden stop due to conditions	Manual & AD
Klagenfurt, Austria	2	Reversing car and lawn tractor collision	AD

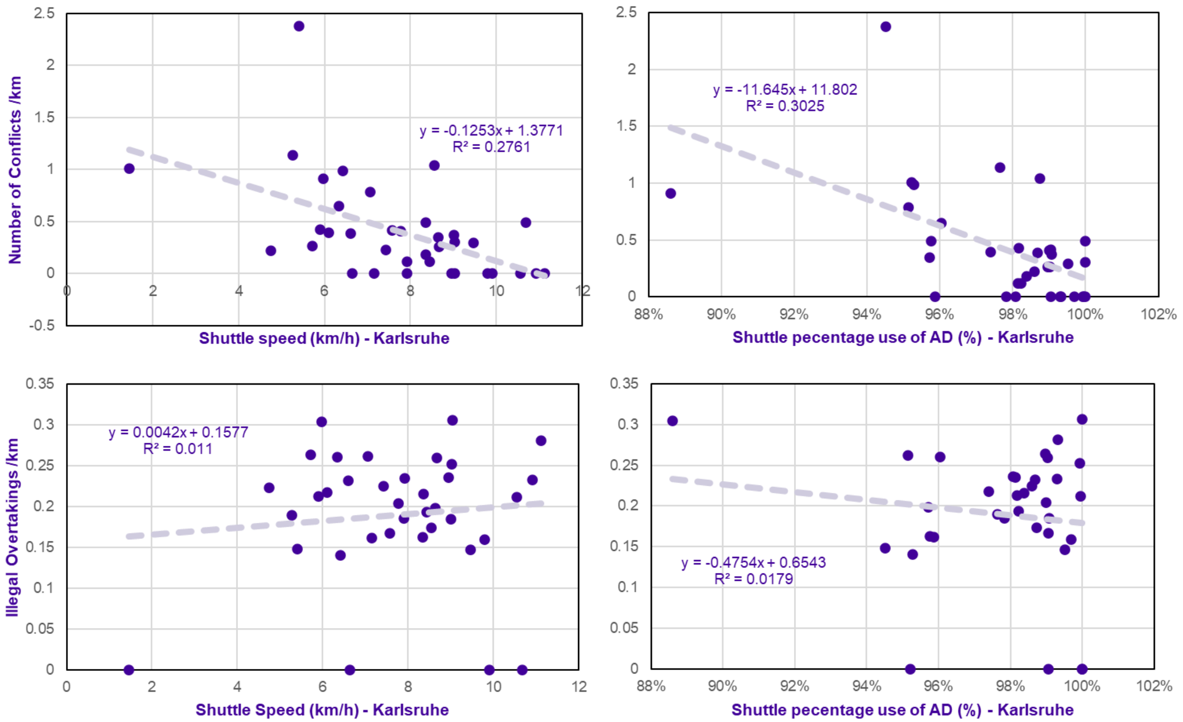
Accident with NAVYA N°P146

in Crest, France August 2nd 2024



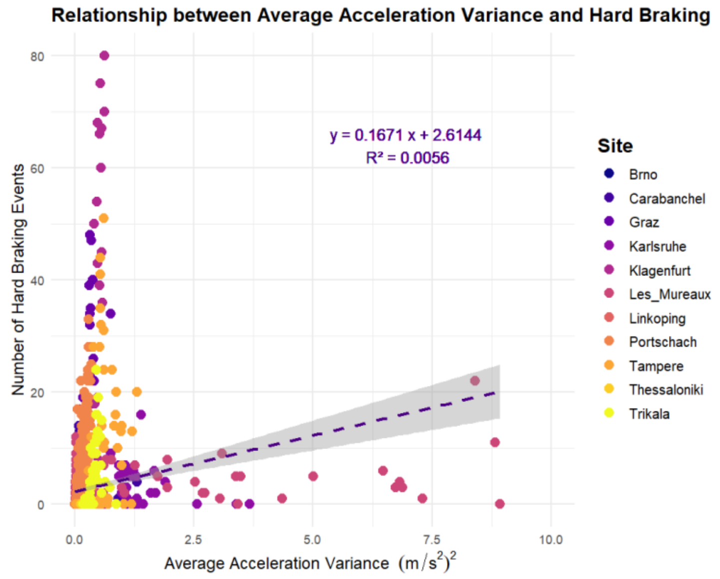
Impact on Conflicts & Illegal Overtakings

- Conflicts and illegal overtaking incidents were **correlated with traffic KPIs** (speed, acceleration variance, % of AD use, and unscheduled stops).
- **Higher speeds** are linked to fewer conflicts, indicating better adaptation to traffic flow and reduced interaction risks, but there is no significant linear relationship with illegal overtaking.
- **Higher acceleration variance** correlates with fewer conflicts due to quicker adaptations to traffic but shows a modest association with an increase in illegal overtaking incidents.
- **Increased automation** is associated with fewer conflicts, highlighting the safety benefits of consistent and predictable driving behavior.



Impact on Hard Brakings

- Insights were derived using **statistical modeling**, including Binomial Logistic Regression and Marginal Effects to the Mean.
- **Higher speeds** increase hard braking due to longer stopping distances and sudden deceleration.
- **Greater acceleration variance** leads to more hard braking, reflecting unstable driving patterns.
- **Site-specific factors** significantly influence hard braking frequency.
- An increase of **1 km/h speed** results in 0.86 additional hard braking events per day.
- An increase of **1 $(m/s^2)^2$ acceleration variance** leads to 0.15 more hard braking events per day.



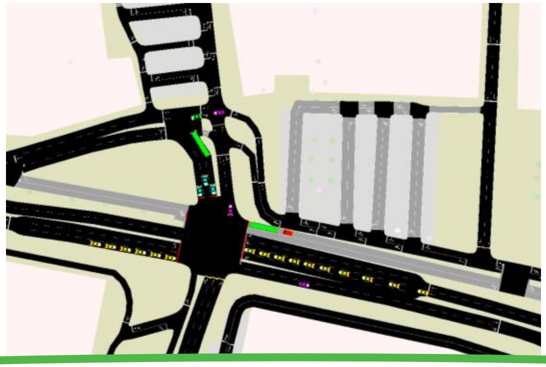
Binomial Logistic Regression for Hard Braking Occurrence

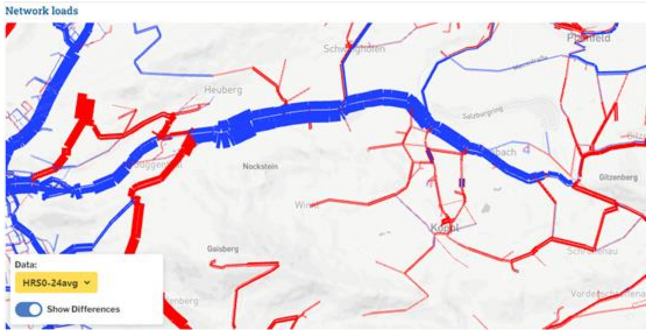
Variable	*Estimate*	*Std. Error*	*z value*	*p-value*	
Intercept	-4.938	0.232	-21.267	<0.0001	***
Average Speed	0.292	0.024	12.256	<0.0001	***
Average Acceleration Variance	0.052	0.010	5.133	<0.0001	***
Site: Brno [Ref. Linköping]	1.579	0.302	5.225	<0.0001	***
Site: Carabanchel [Ref. Linköping]	3.262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

Dependent variable: Hard Braking Counts
*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

Null deviance: 3109.5 on 1795 degrees of freedom
Residual deviance: 1218.4 on 1784 degrees of freedom
AIC: 4843.4

Simulations to support pilots





Simulation Tools: VISSIM, New Mobility Modeller, Urban Strategy, SIL Simulator, ROS, Autoware Sim, SUMO, Menge, CARLA, Gazebo, AIMSUM, SSAM, ANY LOGIC, TRANSCAD, MATSim, AVSS

Vulnerable Road Users

- highest level of detail required
- at bus stops and other shared spaces
- safety of VRUs (passengers, pedestrians, cyclists) in the vicinity of AVs

Street level

- applied on test site level
- interactions between different kinds of road users
- examining AV-logic and safety issues
- change in transport mode choice not in focus

City level

- to provide region or city-wide results
- using DRT applications
- address modal split changes due to the introduction of automated DRT services

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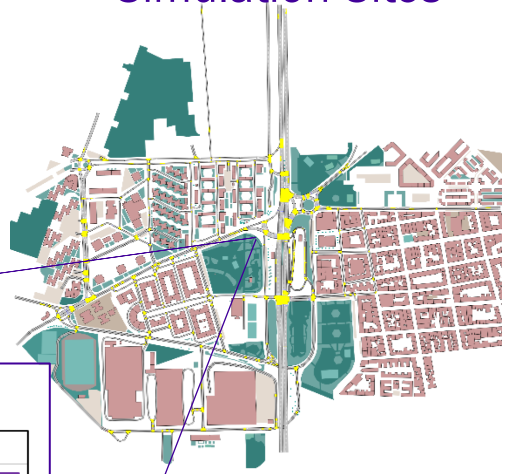
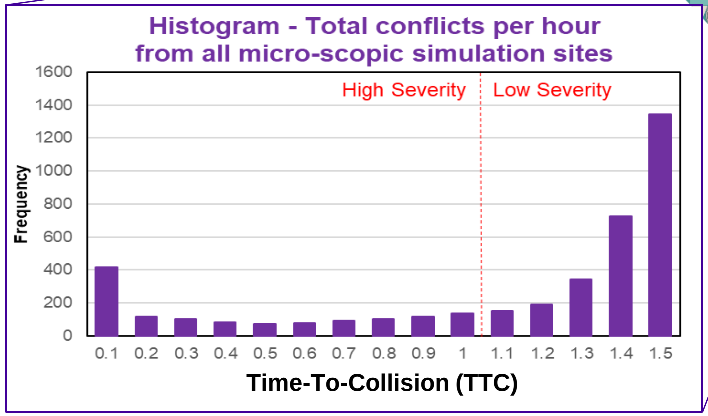
Impact on Conflicts (Simulations)

- Conflicts were identified by analyzing **trajectory data** from simulations in a standardized manner, using the Surrogate Safety Assessment Model (SSAM) software.
- Time-to-Collision (TTC) was categorized to assess **conflict severity**.
- While slower speeds, induced by the SHOW AV shuttles, led to **more frequent interactions** across the entire simulated network, these were **generally low-severity conflicts**.
- The introduction of automated shuttles **reduced the likelihood of severe conflicts**, contributing to safer traffic interactions in the network.
- Additionally, automation **increased TTC**, providing more time before potential collisions, thus improving overall safety.





Binomial Logistic Regression for Conflict Severity

	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-0.663	0.051	-13.014	<2e-16	***
Scenario (without or with AVs)	-0.099	0.020	-5.051	4.39e-07	***
MaxDeltaV	0.292	0.005	54.697	<2e-16	***
MaxD	-0.026	0.001	-19.54	<2e-16	***
Conflict Type: Lane Change (Ref: crossing)	-0.270	0.050	-5.43	5.64e-08	***
Conflict Type: Rear End (Ref: crossing)	-0.837	0.046	-18.117	<2e-16	***

Dependent variable: Conflict Severity (0 for low severity and 1 for high severity)
*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*
Null deviance: 78733 on 62141 degrees of freedom
Residual deviance: 68154 on 62136 degrees of freedom
AIC: 68166

Impacts in Road Safety

- Higher shuttle speeds are associated with an **increase in hard braking events**.
- Greater use of automated driving functions and higher speeds resulted in **fewer conflicts** overall.
- Unscheduled stops by the shuttle often **triggered illegal overtaking maneuvers** by other drivers attempting to bypass the vehicle.
- The introduction of AVs enhances safety by **reducing the likelihood of severe conflicts** (and increased TTC), but they are more prone to causing low-severity conflicts across the network due to their lower speeds and cautious interactions with other road users.
- These findings highlight the importance of **careful speed profile management** to minimize risks.
- Enhancing the shuttles' **risk detection, response capabilities, and communication with human drivers** is essential for improving safety outcomes.

Relevant Publications

- To learn more and explore detailed findings, consider reading some of the following relevant publications and conference papers:

Journals

- Ziakopoulos A., Oikonomou M., Sekadakis M., Yannis G. (2024). "**Safety evaluation via conflict classification during automated shuttle bus service operations**", European Transport Research Review, 16 (1), 38.
- Oikonomou M., Sekadakis M., Katrakazas C., Yannis G. (2024). "**Analyzing the safety effects of different operating speeds for an autonomous shuttle bus service**", Traffic Safety Research (TSR) journal (3rd revisions).

Conferences

- Ziakopoulos A., Oikonomou M., Sekadakis M., Yannis G. (2024). "**Safety evaluation via conflict classification during automated shuttle bus service operations**", at the Transport Research Arena (TRA) 2024, Dublin, Ireland (15-18 April 2024).
- Oikonomou M., Ziakopoulos A., Sekadakis M., Yannis G. (2023). "**Correlations of automated mobility conditions with traffic conflict types**", at the ITS2023: Intelligent Systems And Consciousness Society, Patras, Greece (2-3 November 2023).
- Oikonomou M., Sekadakis M., Katrakazas C., Goñi A. A., Lattarulo A. R., Yannis G. (2023). "**Impacts of automated driving vehicles on bus depot operation using naturalistic data**", at the 11th International Congress On Transportation Research (ICTR), Heraklion, Greece (20-22 September 2023).
- Oikonomou M., Sekadakis M., Katrakazas C., Yannis G. (2023). "**Safety impacts of autonomous shuttle bus with different operational speeds towards increasing market penetration rate of connected and automated vehicles**", at the 102nd Transportation Research Board (TRB) Annual Meeting, Washington, D.C. (8-12 January 2023).
- Oikonomou M., Sekadakis M., Katrakazas C., Hillebrand, J., Vlahogianni, E., Yannis G. (2022). "**Traffic & environmental impact assessment under distinct operational speeds for automated shuttle bus services**", at the Transport Research Arena (TRA) 2022, Lisbon, Portugal (14-17 November 2022). Published: Transportation Research Procedia, Vol. 72, 2023, Pages 517-524
- Oikonomou M., Sekadakis M., Katrakazas C., Ziakopoulos A., Vlahogianni E., Yannis G. (2021). "**Identifying KPIs for the safety assessment of autonomous vehicles through traffic microsimulation**", at the 10th International Congress On Transportation Research (ICTR), Rhodes, Greece (1-3 September 2021).

Thank you for your attention!

www.show-project.eu

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