



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

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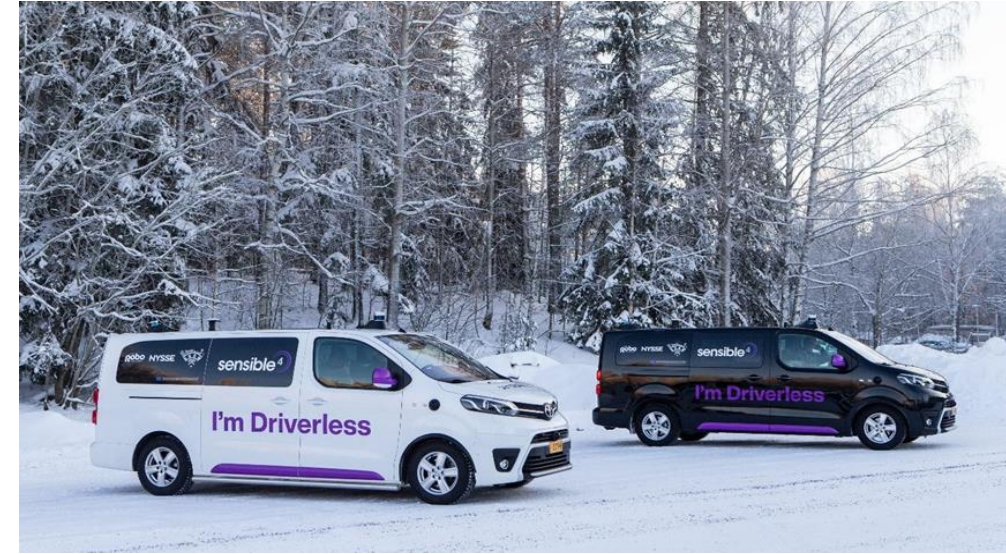
# The SHOW project

- **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](http://show-project.eu)



# 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

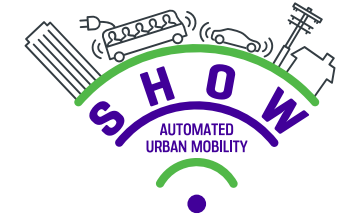
Shuttles, mid & large size buses,  
vans/pods, freight vehicles,  
delivery robots, robo-taxis  
and modular vehicles

- 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

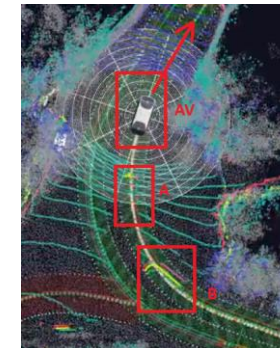
# Impact on Road Accidents



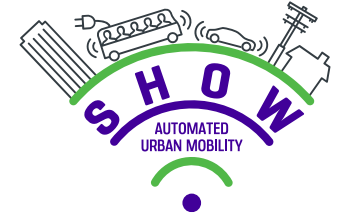
- **Ten minor accidents** occurred across seven pilot sites, mostly due to interactions with other human drivers, not AD system failures.
- Incidents often happened in **challenging areas** (e.g., bus stations, parking lots) and involved **human drivers' errors**, such as failing to notice shuttles or 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

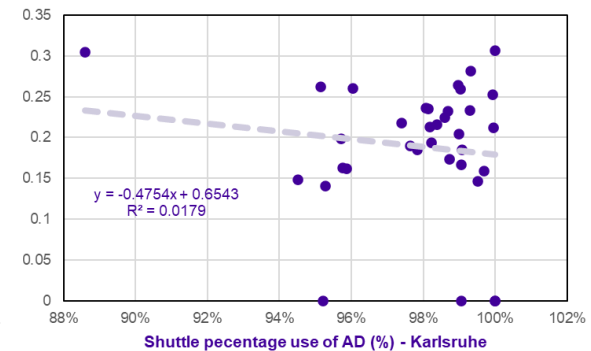
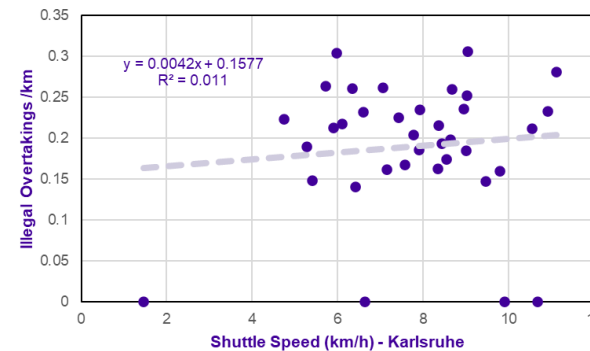
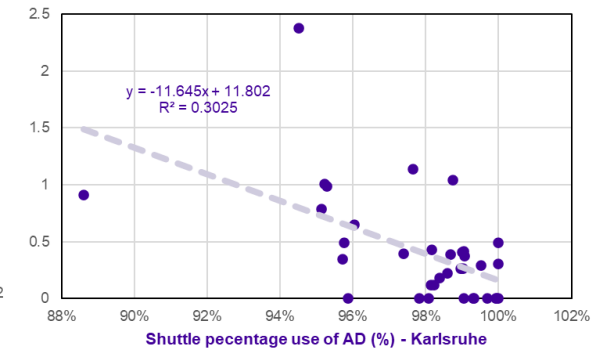
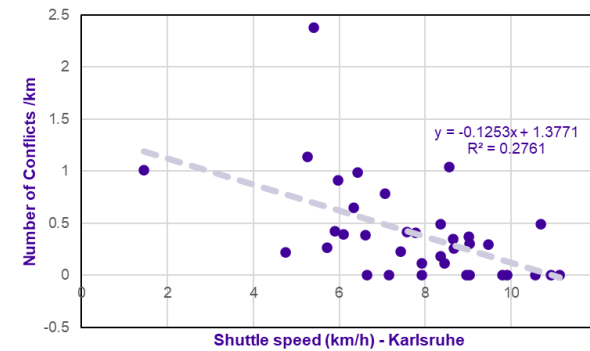
Accident with NAVYA N°P146 in Crest, France August 2<sup>nd</sup> 2024



# Impact on Conflicts & Illegal Overtakings

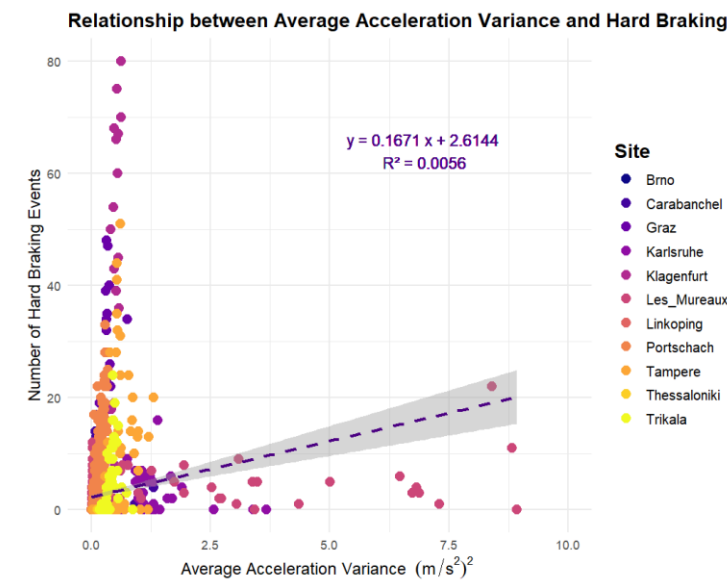


- Conflicts and illegal overtaking incidents were **correlated with traffic KPIs** (speed, acceleration variance, % of AD use, and unscheduled stops).
- **Higher speeds** are linked to fewer conflicts, indicating better adaptation to traffic flow and reduced interaction risks, but there is no significant 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<sup>2</sup>)<sup>2</sup> 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: Pörschach [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

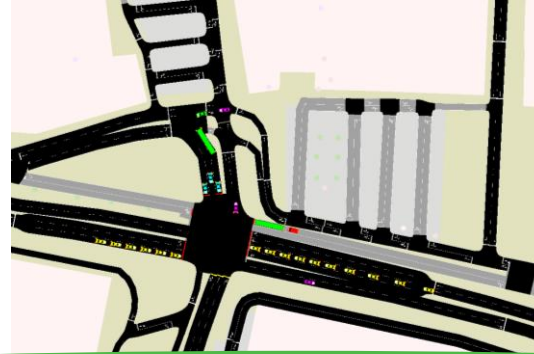
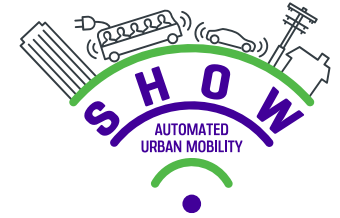
Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

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

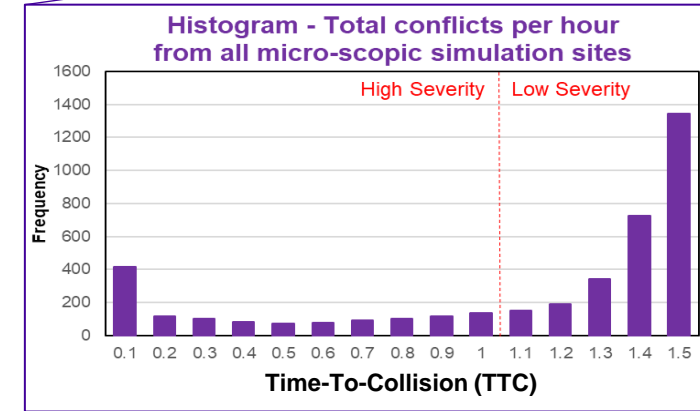
## City level

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



# 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 )	
<b>(Intercept)</b>	-0.663	0.051	-13.014	<2e-16	***
<b>Scenario</b> (without or with AVs)	-0.099	0.020	-5.051	4.39e-07	***
<b>MaxDeltaV</b>	0.292	0.005	54.697	<2e-16	***
<b>MaxD</b>	-0.026	0.001	-19.54	<2e-16	***
<b>Conflict Type: Lane Change</b> (Ref: crossing)	-0.270	0.050	-5.43	5.64e-08	***
<b>Conflict Type: Rear End</b> (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

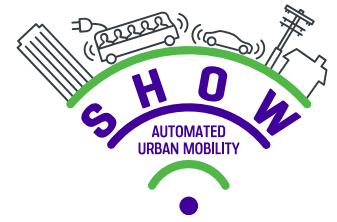
AIC: 68166

# 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 (3<sup>rd</sup> 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 11<sup>th</sup> 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 102<sup>nd</sup> 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).

**Analyzing the safety effects of different operating speeds for an autonomous shuttle bus service**

Maria G. Oikonomou<sup>1</sup>, Apostolos Ziakopoulos<sup>1\*</sup>, Maria G. Oikonomou<sup>1</sup>, Marios Sekadakis<sup>1</sup> and George Yannis<sup>1</sup>

**ORIGINAL PAPER** Open Access

**Safety evaluation via conflict classification during automated shuttle bus service operations**

**Abstract**

This study aims to analyze the safety effects of different operating speeds for an autonomous shuttle bus service on road network. Rate analysis was performed using traffic conflict data simulated within traffic simulation. The assessment method performed using the assessment method is lower when the speed showing the adapting more easily. Furthermore, greater the automated shuttle vehicles. The current autonomous shuttle traffic.

**Keywords:** safe penetration rate.

**Highlights**

- Conflict frequency
- Greater CAV
- Road segment
- Crossing conflict

**Abstract**

The widespread adoption of Connected and Automated Vehicles (CAVs) is being propelled, not only in the realm of private vehicles but also within transit systems. This development serves to enhance urban transport activities, rendering transportation more appealing to passengers. The present study aims to identify and examine the safety effects of testing different operational speed shuttle bus services in various future mobility conditions. To investigate impacts of autonomous shuttle bus services and to further examine their operational speed, the microscopic simulation method was performed. Specifically, four sets of simulation scenarios were comprised: a baseline scenario representing the current conditions and three operational speed scenarios (15 km/h, 30 km/h and 45 km/h) for an autonomous shuttle service. Each one of these sets included eleven CAV market penetration rates (MPRs) of CAVs of the general traffic ranging from 0 to 100% in 10% increments. By analyzing the trajectory data extracted from microsimulation, traffic conflicts were identified and further analyzed by developing Mixed Effects Multinomial Logit Regression models (ME-MLMs) in order to associate conflict type taking into account network characteristics as well as traffic conditions. Several aspects were determined as statistical significant parameters influencing type of conflict. The analysis yielded several significant findings that provide quantitative measurements and assessments of the effects observed, enabling a better understanding of the safety implications associated with the widespread adoption of automated services.

**Keywords:** Traffic simulation, Connected and automated vehicles, Road safety assessment, Automated shuttle bus services, Automated transport systems, Traffic conflicts

**1 Introduction**

In the coming decades, it is anticipated that Connected and Automated Vehicles (CAVs) will become increasingly common on urban road networks. CAVs have the potential to bring about significant changes in how transportation and road systems function. Specifically, CAVs are expected to enhance road capacity, improve fuel efficiency, and reduce harmful environmental emissions, as noted in several studies [9, 10, 16, 36].

In terms of road safety, the dominance of CAVs is expected to lead to a significant reduction in crash numbers. Since there is lack of reliable and generalized crash data, especially for high market penetration rates (MPRs) of CAVs, the microscopic traffic simulation method is considered as a very promising technique for studying automated mobility aspects including road safety. In particular, a microsimulation study conducted by Elawady et al. [7] investigated the impact of CAVs on intersection traffic safety under different MPRs. Similarly, several simulation studies have explored safety considerations in

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*Thank you for your attention!*

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