New Technologies for Sustainable Mobility: A Simulator-Based Approach to Risk Assessment and Transport Safety

Eva Michelaraki

Transportation Engineer, Research Associate

Together with:
George Yannis, NTUA Professor

Department of Transportation Planning and Engineering
National Technical University of Athens

23rd European Transport Congress 2025

Future of European Transport: Infrastructure, Service and Technologies

Paris Cergy, 26-27 June 2025

CERGY PARIS UNIVERSITÉ

European Platform of Transport Sciences

Introduction

- Transport systems are a **crucial component of modern society**, linking spaces, facilitating economic growth and enabling cultural exchange

- However, the environmental footprint of the transport sector remains a **pressing issue**, with approximately 25% of global energy consumption and carbon dioxide emissions originating from transportation

- Modern cities **face growing challenges,** such as excessive land use, rapid urbanization and heavy reliance on private vehicles, leading to high traffic congestion and air pollution, with negative consequences for public health

Background

- Advancements in intelligent vehicle technologies are emerging as a key enabler of sustainable mobility

- The integration of Advanced Driver Assistance Systems (ADAS) is transforming transport safety and efficiency, offering real-time monitoring and driver support to mitigate risks

- ADAS technologies utilize cutting-edge sensors, data analytics and automation to improve driving behaviour, reduce fuel consumption and minimize environmental impact, thereby contributing to a more sustainable transport network

Objectives

- Exploration of the role of advanced simulator technologies in assessing risk factors associated with sustainable mobility in both urban and rural environment

- Implementation of a controlled experimental setup, leveraging simulator-based methodology to analyze key mobility risks

- Integration of real-world data from vehicles, drivers, road conditions and environmental factors to evaluate potential hazards and enhance transport safety

Data Overview

- The core concept builds upon a Safety Tolerance Zone (STZ) framework, designed to change attitudes and promote safe driving behaviour by continuously assessing:
- Task complexity relates to the current status of the real world context in which a vehicle is being operated:
  - road layout (i.e. highway, rural, urban)
  - time and location
  - traffic volumes (i.e. high, medium, low)
  - weather conditions
- Coping capacity is dependent upon two underlying factors and it consists of several aspects:
  - vehicle state (e.g. technical specifications, current status)
  - driver state (e.g. behaviour, sociodemographic profile)

Task complexity	Coping capacity - vehicle state	Coping capacity - operator state		Risk
Car wipers	Vehicle age	Distance	Inter Beat Interval	Headway map levels
Car high beam	First vehicle registration	Duration	Headway	Speeding map levels
Time indicator	Fuel type	Average speed	Overtaking	Overtaking map levels
Distance	Engine Cubic Centimeters	Harsh acceleration/ braking	Fatigue	Fatigue map levels
Duration	Engine Horsepower (HP)	Forward collision warning (FCW)	Gender	Harsh acceleration
Month	Gearbox	Pedestrian collision warning (PCW)	Age	Harsh braking
Day of the week	Vehicle brand	Lane departure warning (LDW)	Educational level	Vehicle control events

Experimental Design

Driving simulator experiment:

- 55 drivers
- 165 trips across different road environments

Three location types:

- Six-lane two-way highways
- Rural undivided two-lane roads
- Urban single-lane roads

Three consecutive scenarios:

- Customized interventions in safety-critical situations (i.e. close to the boundary of the STZ) were proposed
- Real-time and in-vehicle warnings

Experiment Phases

Scenario 1 (Baseline)	• **Intervention:** NO • **Description:** a reference period to monitor driving behaviour without interventions • **Duration:** 15 minutes
Scenario 2	• **Intervention:** Real-time • **Description:** an intervention scenario influencing driving behaviour with fixed timing thresholds (and/or message and/or display) • **Duration:** 15 minutes
Scenario 3	• **Intervention:** Real-time • **Description:** an intervention scenario with modifying condition influencing driving behaviour with variable timing thresholds (and/or message and/or display) • **Duration:** 15 minutes

Methodological Approach

- Explanatory analyses such as Generalized Linear Models (GLM) were performed to identify correlations between driving performance metrics

- Latent analyses such as Structural Equation Models (SEM) were employed to establish relationships between observable risk factors (i.e. number of speeding events) and latent or unobserved variables (i.e. crash risk)

- Risk levels were assessed using the STZ framework, categorizing driving behaviour into three levels:
  - normal (low risk)
  - dangerous (moderate risk)
  - avoidable accident (high risk)

GLM Results

- Time indicator was positively correlated with speeding, which means that higher speeding events occur at night compared to during the day

- On the other hand, the indicator of weather found to have a negative correlation with speeding, indicating that there are fewer speeding events during adverse weather conditions (e.g. rain)

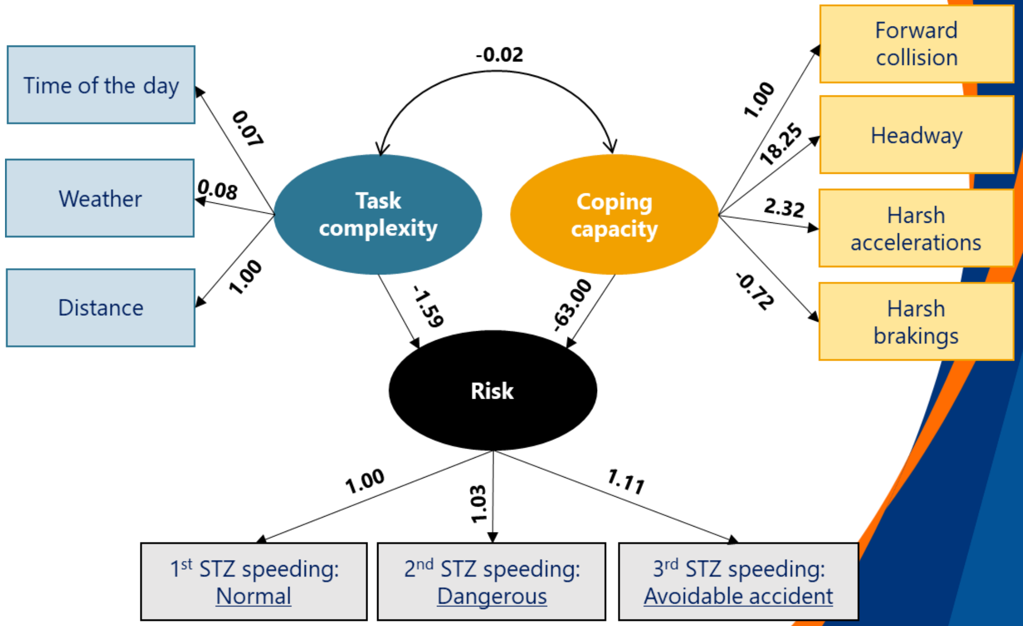
- Harsh accelerations, FCW and headway had a positive relationship with speeding

- Distance travelled and harsh brakings were negatively correlated with speeding, suggesting that as the distance travelled increases, the likelihood of speeding events decreases

Variables	Estimate	Std. Error	z-value	Pr(|z|)	VIF
(Intercept)	0.334	0.036	9.241	< .001	-
Time indicator	0.363	0.026	13.866	< .001	1.022
Weather	-0.395	0.072	-5.485	< .001	1.023
Distance	-7.299	1.101	-6.631	< .001	1.191
Harsh accelerations	0.374	0.047	8.050	< .001	1.022
Harsh brakings	-1.180	0.100	-11.835	< .001	1.021
FCW	2.685	0.586	4.580	< .001	1.001
Headway	0.317	0.030	10.610	< .001	1.150

SEM Results

- **Task complexity and risk** showed a negative coefficient, which means that increased task complexity relates to decreased risk. This might be due to the fact that complex tasks often require more detailed planning, careful execution and greater attention to detail, which can mitigate potential risks
- **Coping capacity and risk** demonstrated a negative coefficient, which means that as coping capacity increases, the associated risk decreases. Drivers with higher coping capacity are generally better at managing and mitigating risks, they are more adept at handling stress and challenges
- Overall, **task complexity and coping capacity** were inter-related with a negative correlation, indicating that as the complexity of a task increases, driver's coping capacity tends to decrease



Model Fit measures	Value
CFI	0.942
TLI	0.913
RMSEA	0.038
GFI	0.992
Hoelter's critical N (α = .05)	1033.331
Hoelter's critical N (α = .01)	1219.436
AIC	1.230×10+6
BIC	1.230×10+6

Discussion

- Simulator experiments offer a cost-effective, data-driven approach to evaluate risk factors and design evidence-based interventions
- From a technological perspective, advancements in AI-driven ADAS, multimodal transport solutions and smart urban planning are essential to achieving safe, efficient and environmentally friendly transport network
- The application of simulator-based risk assessment models can inform the development of real-world interventions that improve driving behaviour, reduce congestion and lower emissions
- Policymakers, transport planners and industry stakeholders may exploit the potential of new vehicle technologies to support the transition toward sustainable mobility in both urban and rural areas

Conclusions

- Efforts should be made to **enhance public awareness** and increase the political and social acceptance of transport decarbonization policies

- Driver education on the **benefits of smart transport technologies** could be also promoted

- Behavioural adaptation and training programs can complement technological advancements, ensuring that both drivers and automated systems work in synergy to **create safer and more sustainable mobility solutions** for the future

New Technologies for Sustainable Mobility: A Simulator-Based Approach to Risk Assessment and Transport Safety

Eva Michelaraki
Transportation Engineer, Research Associate

Together with:
George Yannis, NTUA Professor

Department of Transportation Planning and Engineering
National Technical University of Athens

23rd European Transport Congress 2025

Future of European Transport: Infrastructure, Service and Technologies

Paris Cergy, 26-27 June 2025

CY CERGY PARIS UNIVERSITÉ

European Platform of Transport Sciences