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# Influence of Traffic Flow and Merging / Diverging Ramp Design on Take-Over performance:

## A Cross-Country Comparison of Conditionally Automated Vehicles

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TRAFIKKLAB driving transport innovation powered by NORD University

road safety laboratory powered by Politecnico di Torino

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# Introduction

**Conditional Autonomated Driving** (SAE lvl.3)

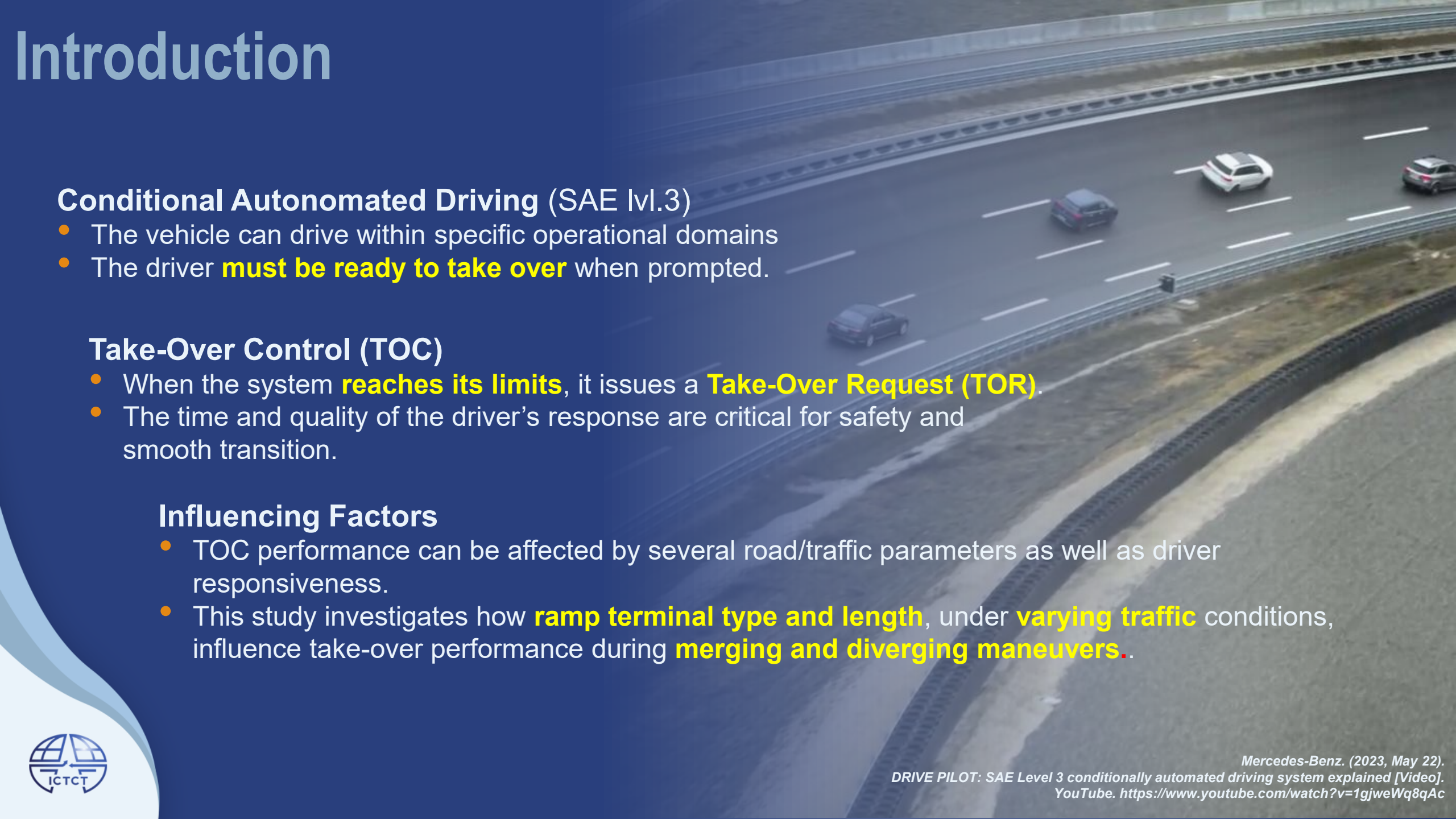
- The vehicle can drive within specific operational domains
- The driver **must be ready to take over** when prompted.

**Take-Over Control (TOC)**

- When the system **reaches its limits**, it issues a **Take-Over Request (TOR)**.
- The time and quality of the driver's response are critical for safety and smooth transition.

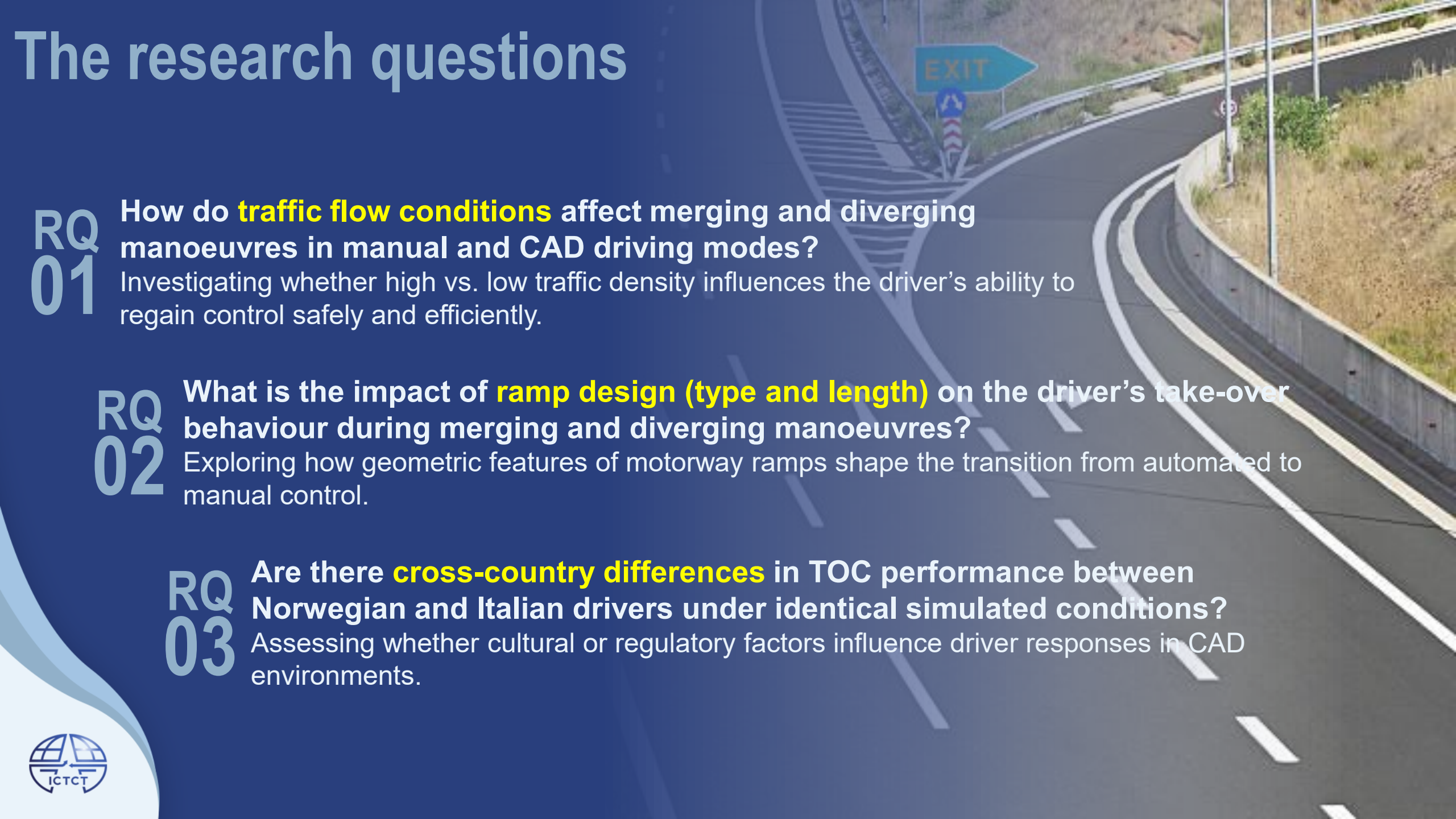
**Influencing Factors**

- TOC performance can be affected by several road/traffic parameters as well as driver responsiveness.
- This study investigates how **ramp terminal type and length**, under **varying traffic** conditions, influence take-over performance during **merging and diverging maneuvers**..



*Mercedes-Benz. (2023, May 22). DRIVE PILOT: SAE Level 3 conditionally automated driving system explained [Video]. YouTube. https://www.youtube.com/watch?v=1gjweWq8qAc*

# The research questions




**RQ 01**

**How do traffic flow conditions affect merging and diverging manoeuvres in manual and CAD driving modes?**

Investigating whether high vs. low traffic density influences the driver's ability to regain control safely and efficiently.

**RQ 02**

**What is the impact of ramp design (type and length) on the driver's take-over behaviour during merging and diverging manoeuvres?**

Exploring how geometric features of motorway ramps shape the transition from automated to manual control.

**RQ 03**

**Are there cross-country differences in TOC performance between Norwegian and Italian drivers under identical simulated conditions?**

Assessing whether cultural or regulatory factors influence driver responses in CAD environments.

# Methodology

## Conditionally Automated Driving System and Human Machine Interface

- SCANeR Studio® software, provided by AV Simulation
- Force feedback steering wheel
- 140° horizontal Field Of View
- 5 s time budget for CAD


(a) automated driving is **active**

(b) automated driving is **inactive**

(c) autonomous mode **available**

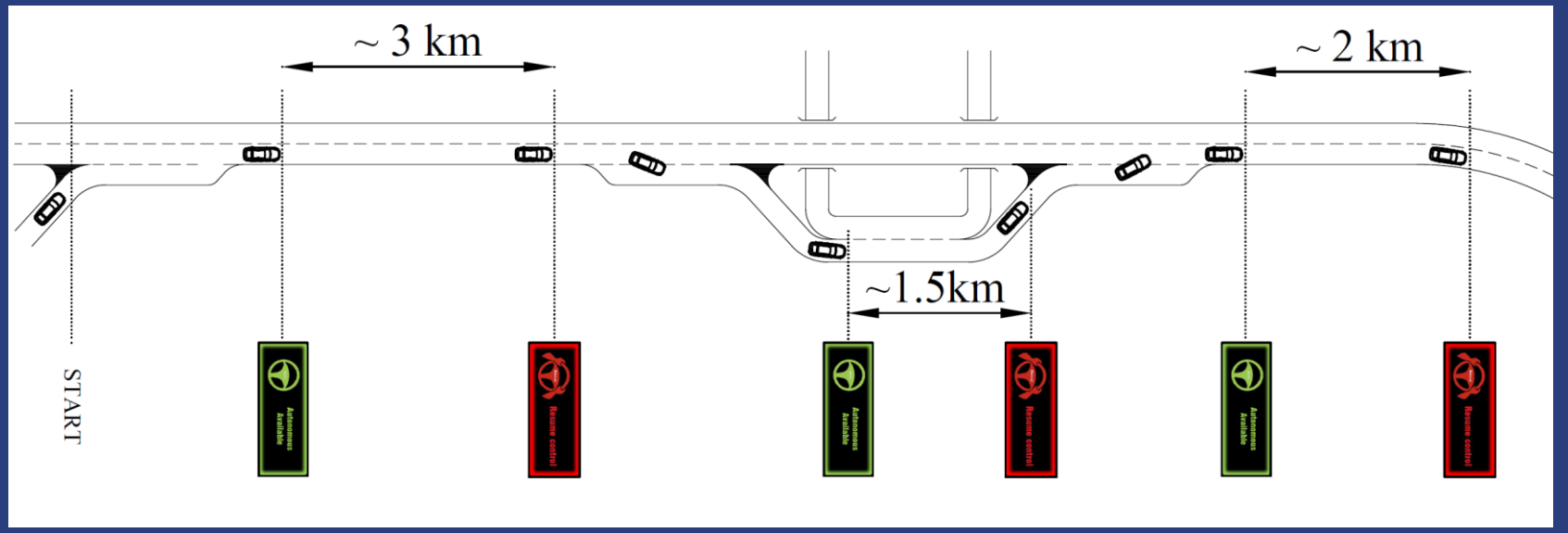
(d) **TOC request** resume control


**Driving simulator at TRAFIKKLAB NORD University, Norway**

# Methodology

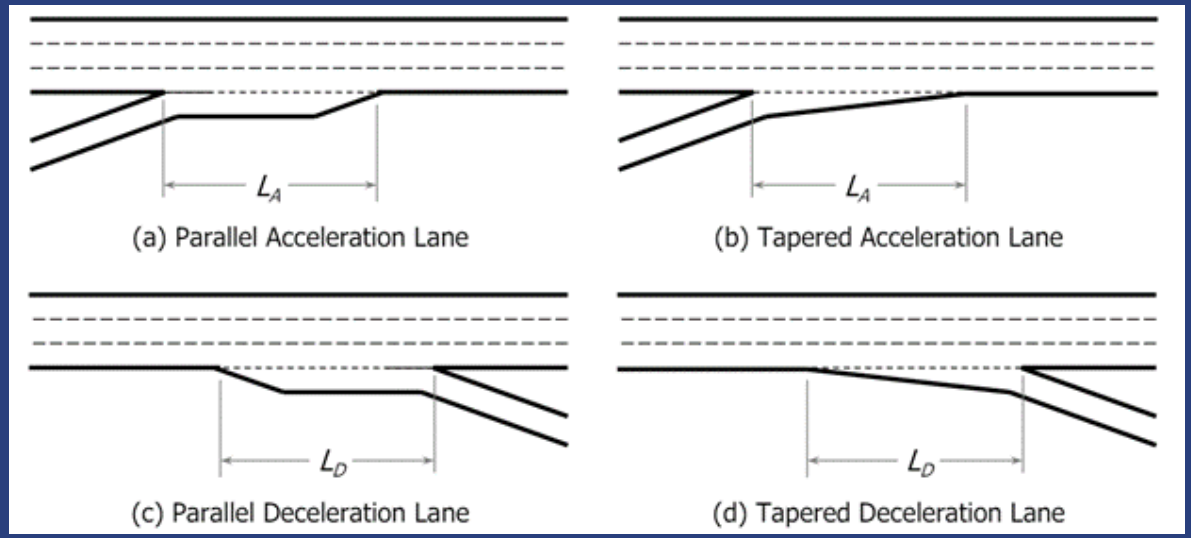
## Test Track and Scenario

- Designed based on AASHTO guidelines
- Two-lane freeway
- Speed limit 130 km/h
- Ramp with 70 km/h speed limit, 200 m radius




## Experiment factors and levels

| | | |
|---|---|---|
| **Terminal ramp length in diverging (C)** | 75 m | 155 m |
| **Terminal ramp length in merging (C)** | 100 m | 375 m |
| **Terminal ramp type (B)** | Tapered | Parallel |
| **Traffic flow rate in the motorway lanes (A)** | 400 pc/h/ln | 1500 pc/h/ln |



# Methodology

## The experimental design

- **80 participants** (40 per country)
- Aged 20–60, all with Class B driving licence
- Same **balanced gender and age distribution** for both laboratories

- Each participant completed:
  - **4 runs in CAD mode**
  - **4 runs in manual mode**
  - **Randomisation of all parameters** for unbiased data

  (Full factorial design with blocking and partial confounding)

- Data collected:
  - **Driving performances** directly from simulator log
  - Eyes movements with eye-tracking glasses
  - Post/drive questionnaires for experienced workload, DS sickness and feedback on the driving scenarios

Stjørdal, NO

Turin, IT

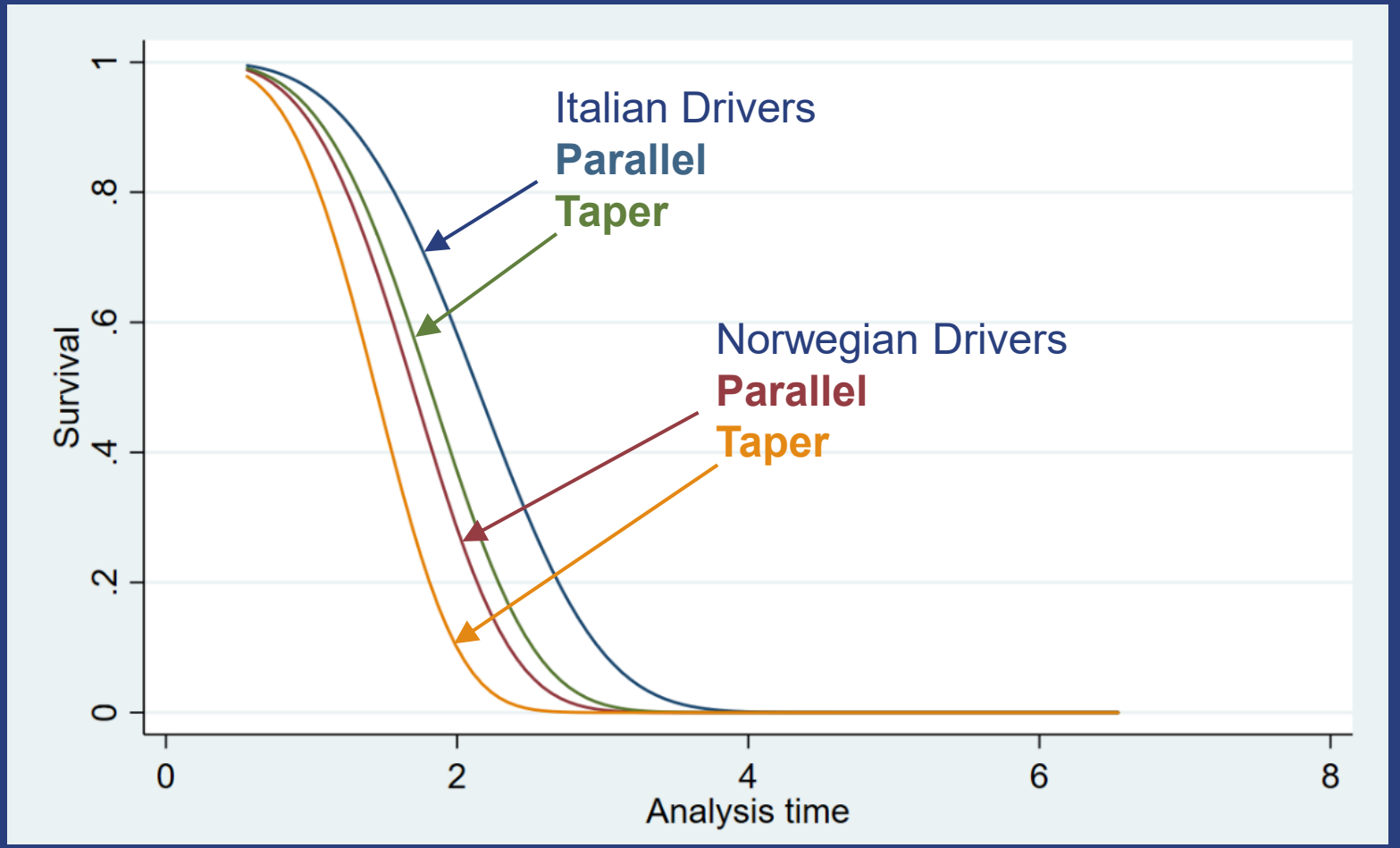
# Diverging manoeuvre


# Merging manoeuvre

# Results - Diverging

## Modelling Take-Over Control time

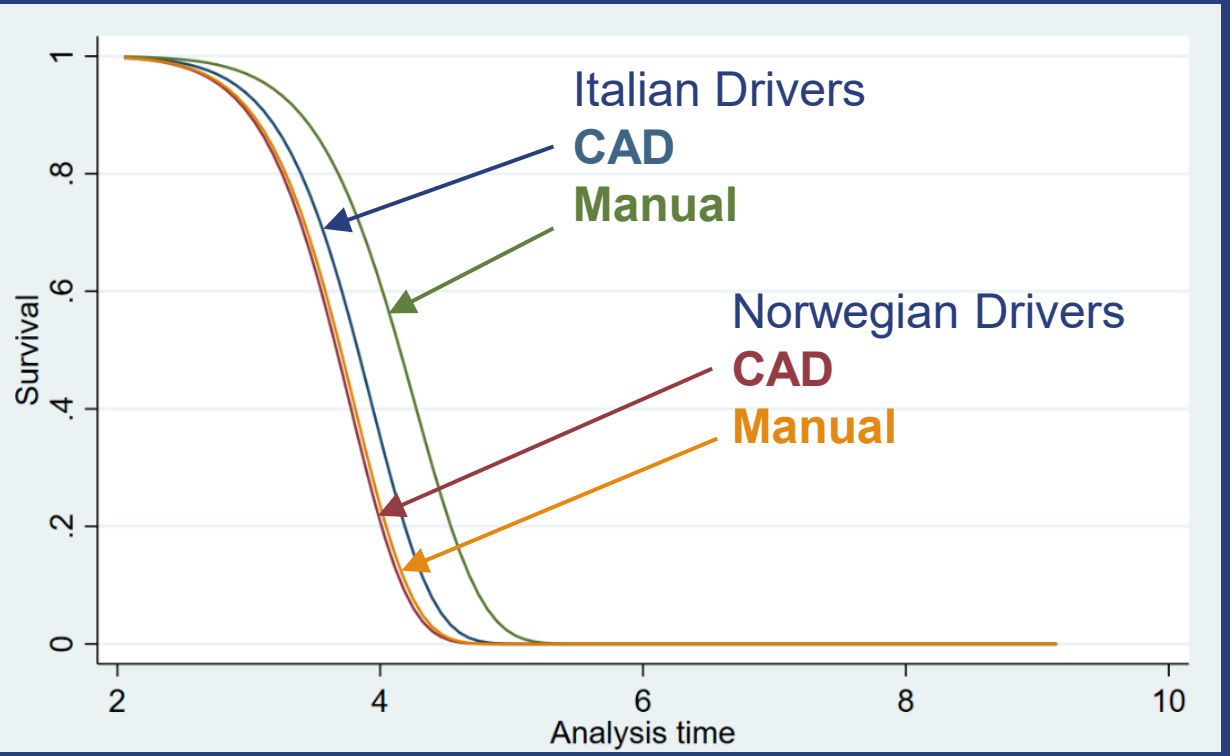
- In general, Italian drivers show longer TOC time respect to Norwegians
- Drivers take over the control significantly faster when the ramp is tapered
- The rest of variables (**Traffic**, **ramp length**, age, gender, …) aren't significant.

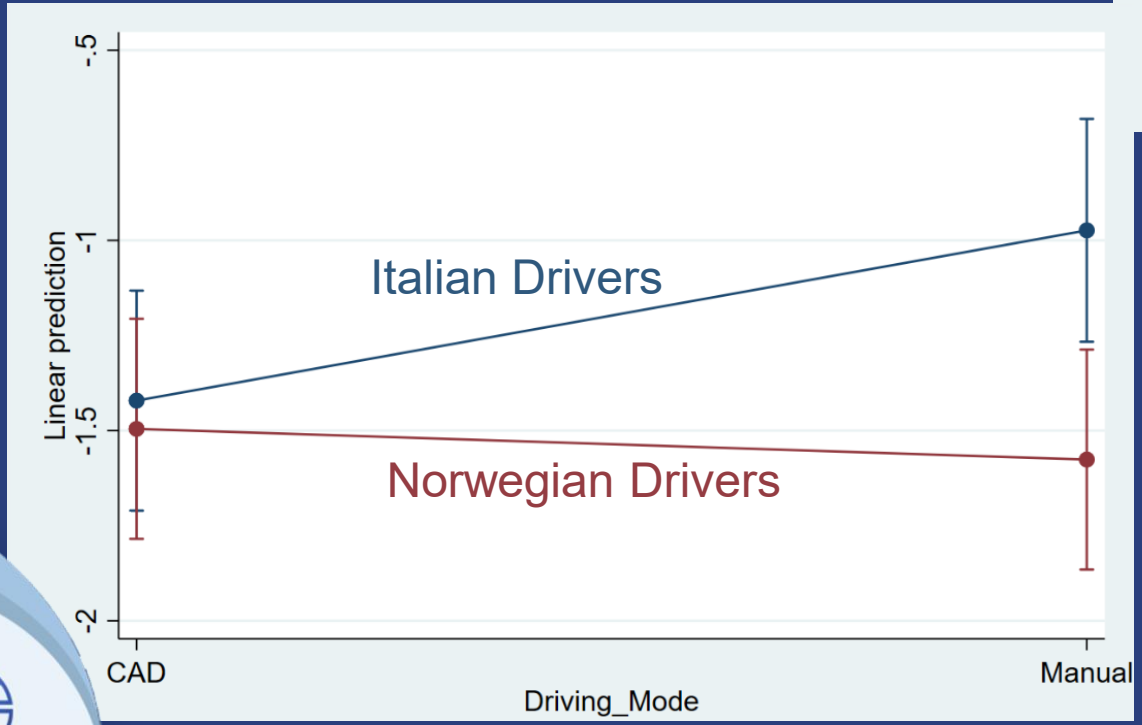


# Results - Diverging

## Travel time inside the deceleration lane

- Norwegian drivers showed no significant difference between CAD and manual scenarios, whereas Italian drivers reached the end section faster in CAD scenarios



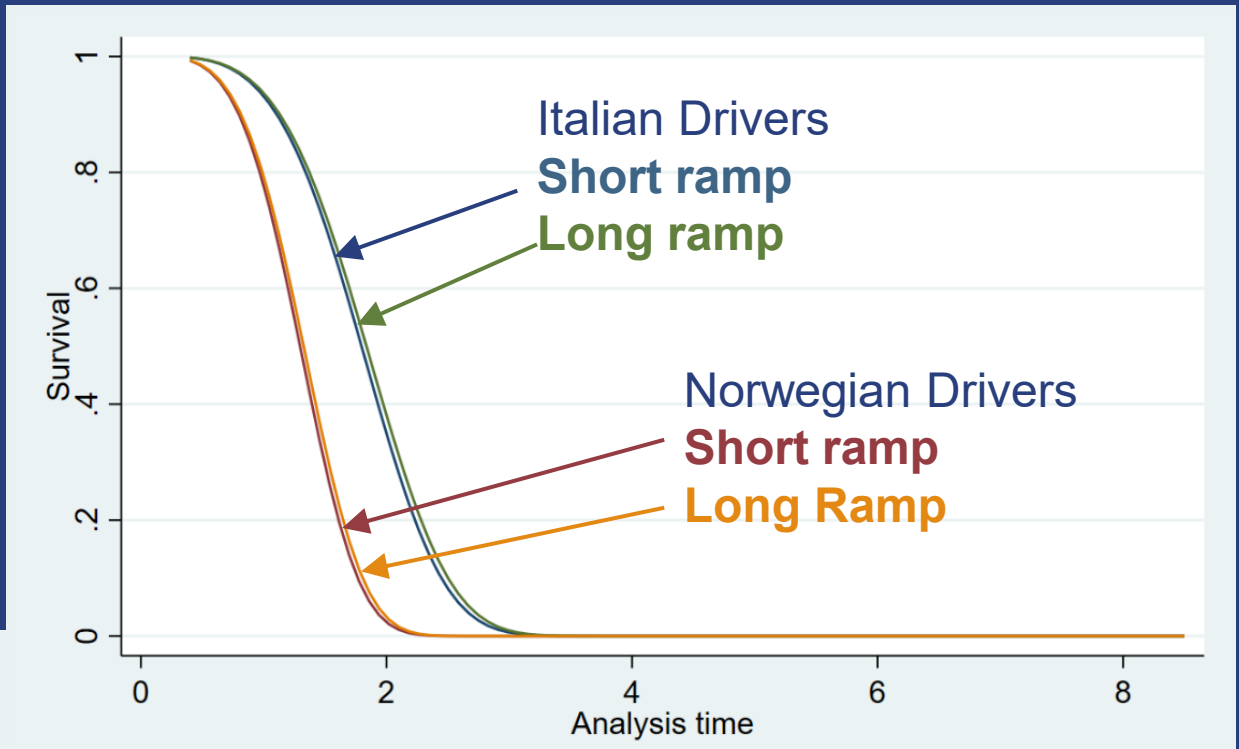

## Deceleration at the start of deceleration lane

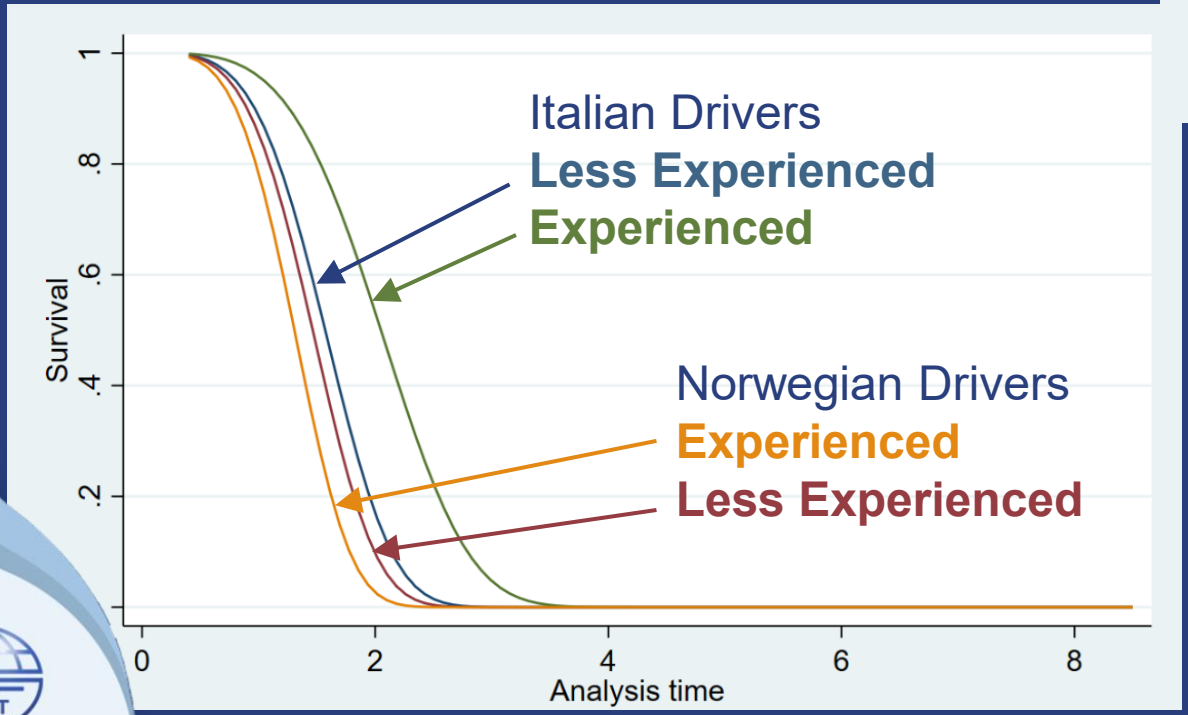
- Italian drivers exhibited **lower deceleration in manual mode** compared to CAD scenarios, while **Norwegian drivers showed no significant difference** between the two driving modes

# Results - Merging

## Modelling Take-Over Control time

- **Norwegian drivers take over control significantly faster than Italian ones**
  However, there are **no differences** with respect to **ramps' length**



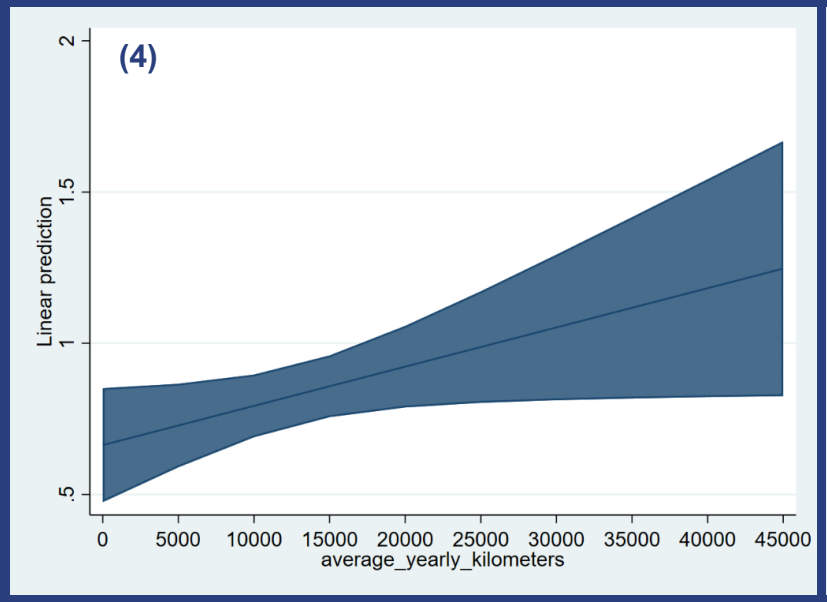



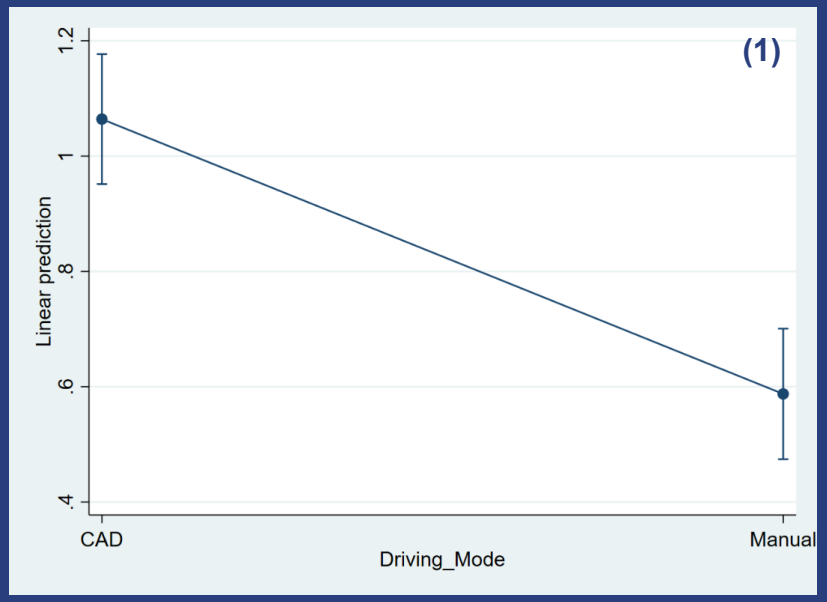

- Among Italian drivers, **experienced drivers took over later** then less-experienced drivers
- **Among Norwegian drivers, the "experience" effect is smaller and reversed**, higher-mileage drivers took over slightly earlier

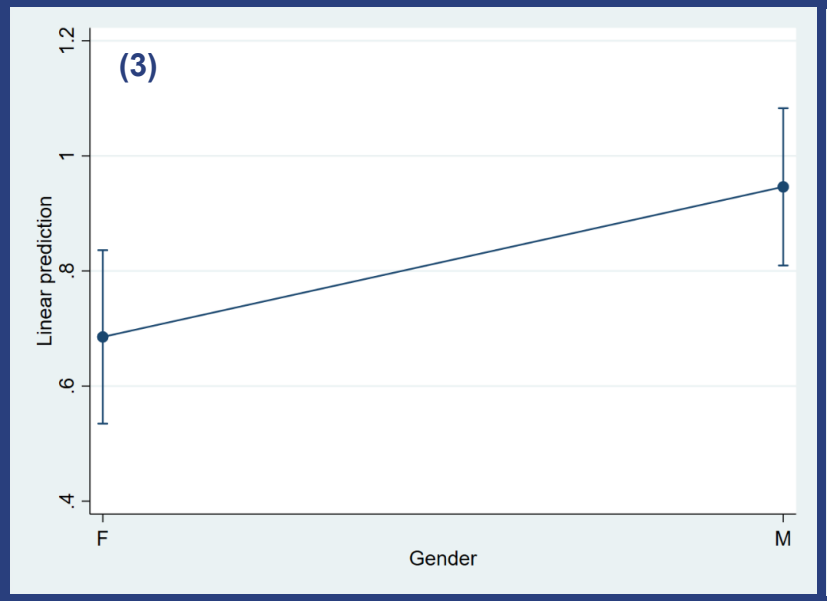
# Results - Merging

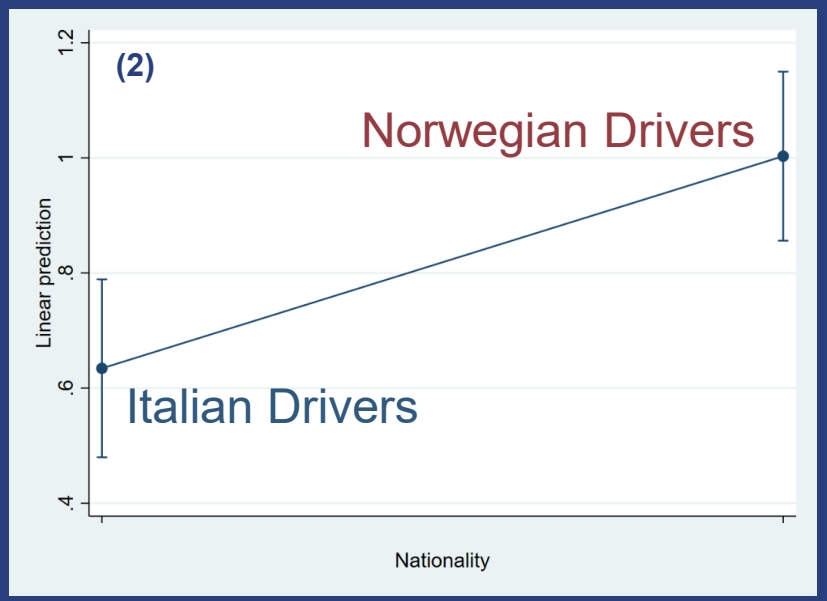
## Modelling longitudinal acceleration at the start of merging ramp

- Drivers choose statistically **higher acceleration in CAD scenarios** (1)
- **Norwegian drivers** have significantly **higher acceleration** (2)
- **Male drivers** have significantly **higher acceleration** (3)
- **Experienced** drivers have significantly **higher acceleration** (4)



# Conclusions - Preliminary Overview

**RQ 01** **How do traffic flow conditions affect merging and diverging manoeuvres in manual and CAD driving modes?**

- **The current parameters do do not show a significant connection between TOC time and traffic conditions,** either in merging or diverging manoeuvres.
- **Further analysis is needed** to highlight the effect of traffic, especially by investigating other relevant parameters, such as TTC (Time to Collision) or LCT (Lane Changing Time)

**RQ 02** **What is the impact of ramp design (type and length) on the driver's take-over behaviour during merging and diverging manoeuvres?**

- **Tapered ramps led to faster TOC times** than parallel ramps in both merging and diverging scenarios, mostly likely due to shorter decision windows.
- **Longer ramps were associated with delayed TOC in merging manoeuvres**, suggesting that extended geometry may reduce urgency.

**RQ 03** **Are there cross-country differences in TOC performance between Norwegian and Italian drivers under identical simulated conditions?**

- **Italian drivers exhibited longer TOC times and greater deceleration in CAD scenarios**, while Norwegian drivers maintained more consistent behavior across driving modes.
- **Driving experience seems to significantly affect most of the parameters analyzed**, with inconsistencies among nationality and driving mode.

# Thanks for your attention

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