10th INTERNATIONAL CONGRESS ON TRANSPORTATION RESEARCH

ICTR 2021

September 1-3
Rhodes, Greece

# Identifying KPIs for the safety assessment of autonomous vehicles through traffic microsimulation


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# Introduction

- Connected and Autonomous Vehicles (CAVs) have the potential to change radically the transportation systems[1].
- CAVs are estimated to increase road capacity, fuel efficiency, decrease environmental emissions and enhance road safety level[2].
- Microscopic simulation is used widely to evaluate new traffic control and management technologies as well as performing analysis of existing traffic operations[3].
- Simulating traffic flows can evaluate many traffic-related impacts[4].

[1](Fagnant & Kockelman , 2015), [2](Rune Elvik, 2021; Teoh & Kidd, 2017), [3](Owen et al., 2000), and [4](Lopez et al., 2018; Wen-Xing Zhu & Zhang, 2017)

# Background

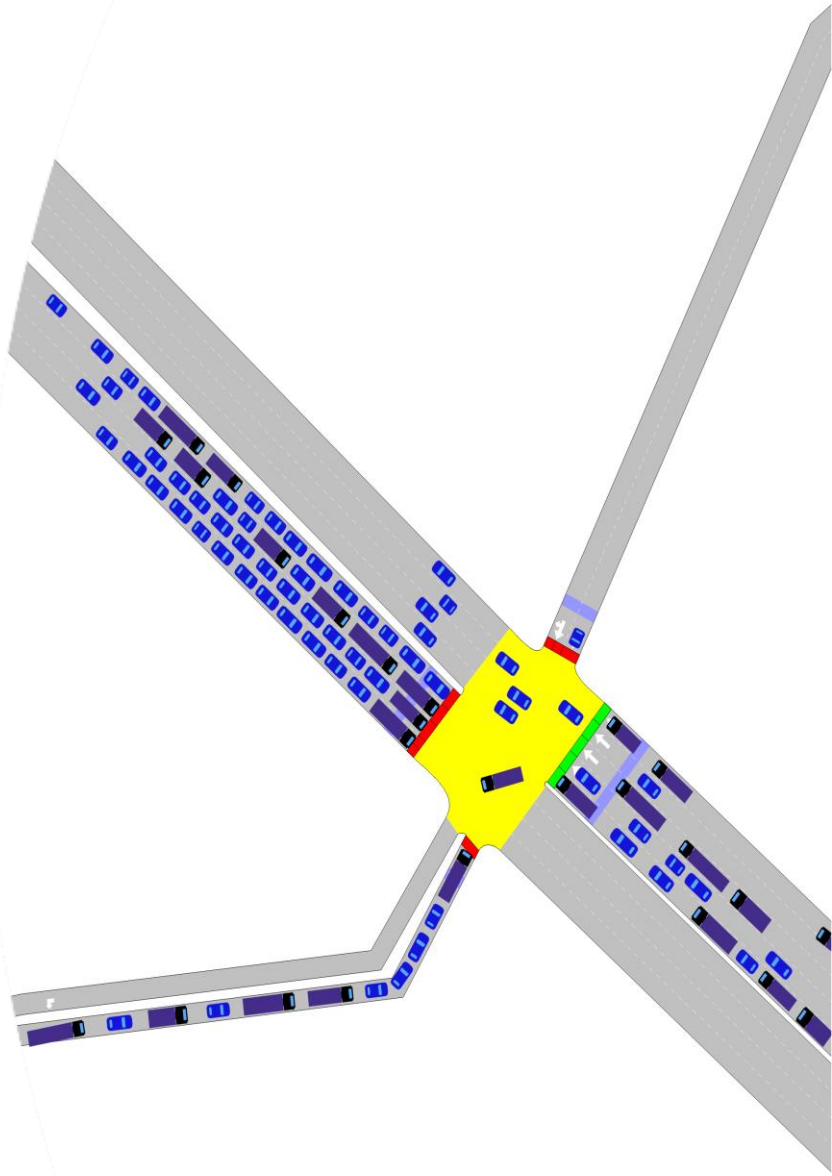
- This paper aims to assist in that direction by pointing out critical safety KPIs that could be evaluated through simulation.
- The exported KPIs list can guide further research in this direction, and it can be expanded to other simulation tools or use cases.
- The present research is conducted within the EU's HORIZON 2020 "SHOW" and "LEVITATE" projects.
  - Simulation model conducted within LEVITATE framework.
  - KPIs derived from SHOW framework.



Horizon 2020
European Union Funding
for Research & Innovation

# Methodology

- In order to identify critical key performance indicators (KPIs) for safety assessment, the microscopic simulation analysis was selected to provide multiple measurements quantifying the impacts of CAVs in different traffic conditions.
- For the requirements of the LEVITATE project, different scenarios were formulated using the Aimsun Next mobility modelling software in the city of Athens network in Greece.



# Simulation Network

- The network of Athens consists of 1,137 nodes and 2,580 road sections.
- The model includes all the necessary related to the prevailing traffic conditions and geometry.
- The OD matrices consisted of 290×292 centroids of the study network and a total number of 82,270 car trips and 3,110 truck trips for peak hour.
- The Athens model included 95 bus and 14 trolley lines and 1,030 public transport stations.
- A point-to-point automated shuttle bus service with four shuttle bus lines connecting several points was simulated in the large-scale network of Athens.

# Simulation Setup

- Overall, the following scenarios were formulated:
  1. **Baseline** (no point-to-point shuttle bus service operation)
  2. Service operation in **mixed traffic** conditions during **peak hour**
  3. Service operation using **dedicated lane** during **peak hour**
  4. Service operation in **mixed traffic** conditions during **off-peak hour**

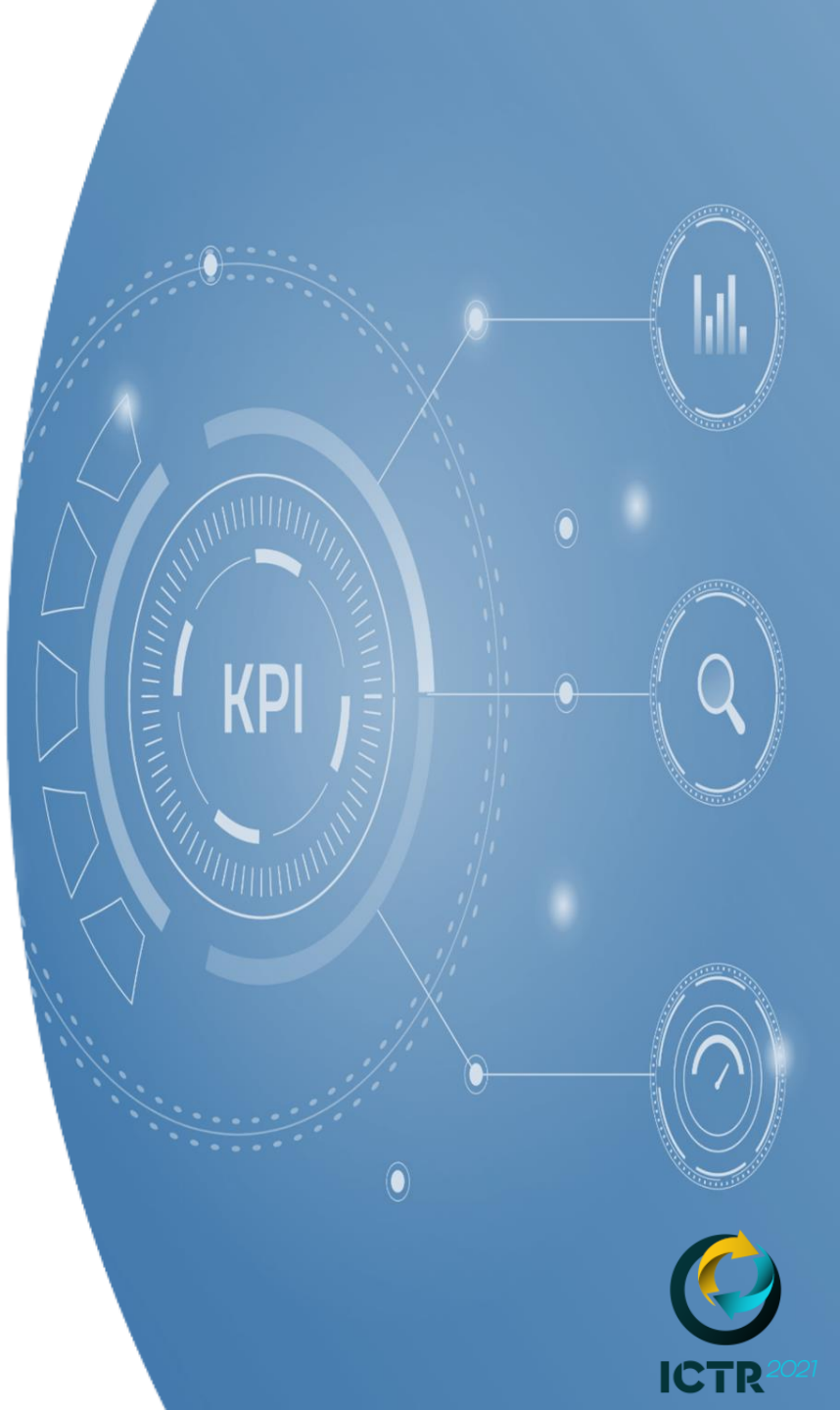
- Two main driving profiles were simulated for modelling CAVs:
  - 1st Generation (Cautious): limited sensing and cognitive ability, long gaps, early anticipation of lane changes than human-driven vehicles and longer time in give way situations.
  - 2nd Generation (Aggressive): advanced sensing and cognitive ability, data fusion usage, confident in taking decisions, small gaps, early anticipation of lane changes than human-driven vehicles, and less time in give way situations.

*Simulated Scenarios and Market penetration rate of CAVs*

| Type of Vehicle | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| **Passenger Vehicles** | | | | | | | | |
| Human-driven Car | 100% | 80% | 60% | 40% | 20% | 0% | 0% | 0% |
| 1st Generation CAV | 0% | 20% | 40% | 40% | 40% | 40% | 20% | 0% |
| 2nd Generation CAV | 0% | 0% | 0% | 20% | 40% | 60% | 80% | 100% |
| **Freight Vehicles** | | | | | | | | |
| Human-driven Truck | 100% | 80% | 40% | 0% | 0% | 0% | 0% | 0% |
| Freight CAV | 0% | 20% | 60% | 100% | 100% | 100% | 100% | 100% |

# KPIs Development

- KPIs were calculated from the in-depth analyses from the different impact areas or collected from demonstration sites and simulations.
- The included KPIs for safety and impact assessment framework were analyzed in the following different activities/categories:
  - Road safety
  - Traffic efficiency, energy, and environmental impacts
  - Societal, employability and equality
  - Urban logistics
  - User experience, awareness and acceptance



# Results (1/3)

- Simulation-related KPIs were divided into the following categories:
  - Traffic safety
  - Traffic efficiency
  - Environment and energy efficiency
- The data needed for each KPI can be collected either through measurements, observations at the demonstration site, simulations or user surveys.

*Simulation-related KPIs Example*

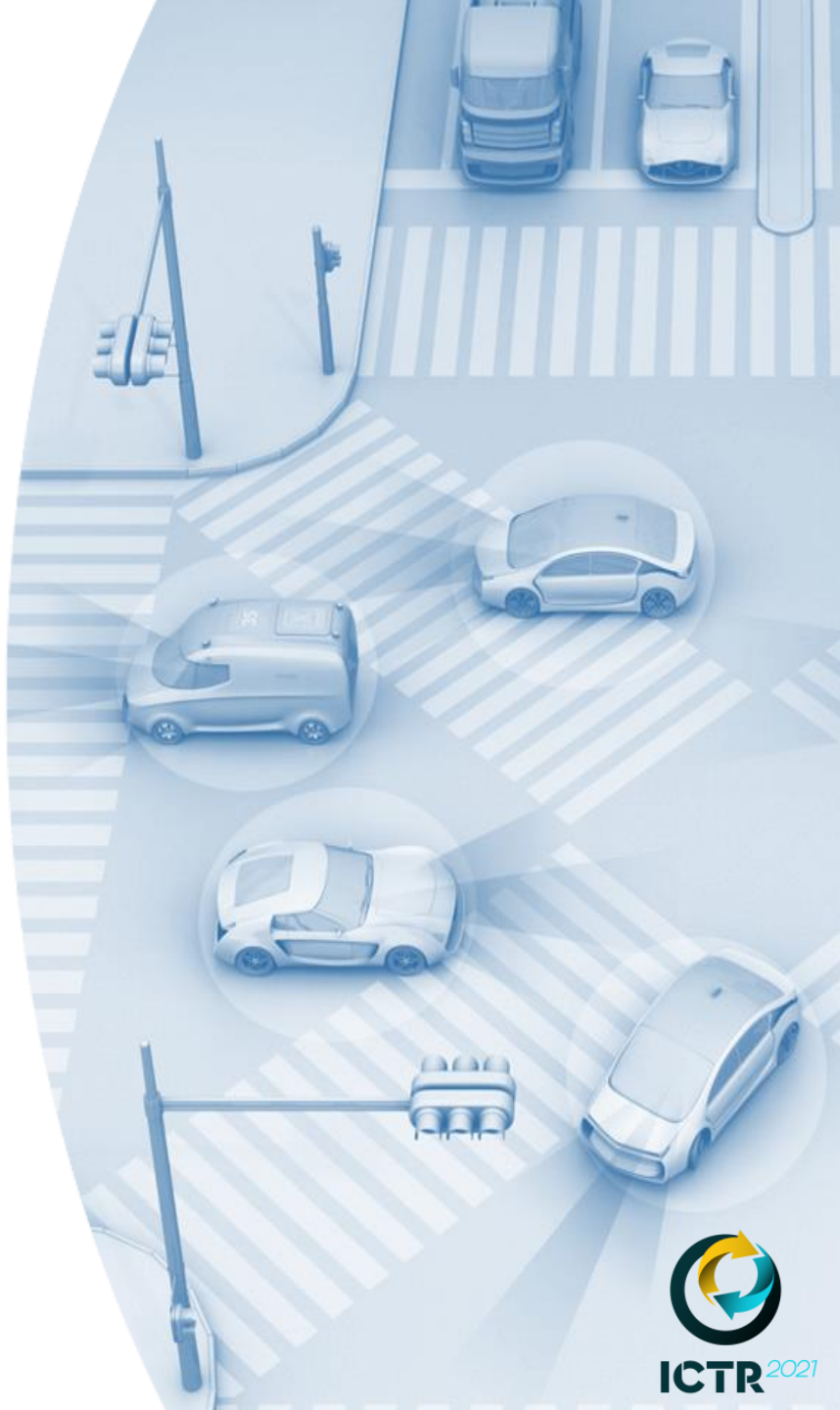
| Broader category | Impact | Research Question or target |
|---|---|---|
| Traffic safety | Road accidents (leading to human injury) | What is the number of accidents that caused even the slightest of injury during the operation of the AV? |
| | Conflicts | What is the number of conflicts with other road users and infrastructure during the operation of the AV? |
| | Road accidents (leading to material damage) | What is the number of accidents that damage to property? |
| Traffic efficiency | Average speed | What is the average speed of pilot vehicles on the pilot route? |
| | Acceleration variance | How does the acceleration of pilot vehicle vary on the pilot route? |
| | Hard brake events | What is the number of hard breaking events per km? |
| | Non-scheduled stops | How often does a pilot vehicle have to make a non-scheduled stop? |
| | Speed per vehicle type | How does the introduction of pilot vehicles impact the average speed for all vehicle types? |
| | Average network speed | How does the introduction of the new mobility system affect the average network speed? |
| Environment and energy efficiency | Energy use | How does the introduction of the new mobility system change energy consumption of vehicles? |
| | $CO_2$, PM, $NO_x$ emissions | How does the introduction of the new mobility system change the amount of vehicle emissions related to transport in the area of interest? |
| | Noise levels | How does the introduction of the new mobility system affect the traffic noise in the area of interest? |

# Results (2/3)

- In the microsimulation, these impacts were quantified by the following KPIs:
  - Number of conflicts: total number of conflicts
  - Traffic flow: mean flow (veh/h)
  - Average speed: mean speed (km/h)
  - Delay Time: mean delay time (sec/km)
  - Number of stops: total number of stops of all vehicles in the simulation period in the whole network
  - Travel Time: mean travel time (sec/km)
  - Distance Travelled: total distance travelled of the vehicles that exited the network (km)
  - $CO_2$ Emissions: total $CO_2$ emissions (kg)
  - $NO_x$ Emissions: total $NO_x$ emissions (kg)
  - $PM_{10}$ Emissions: total $PM_{10}$ emissions (kg)

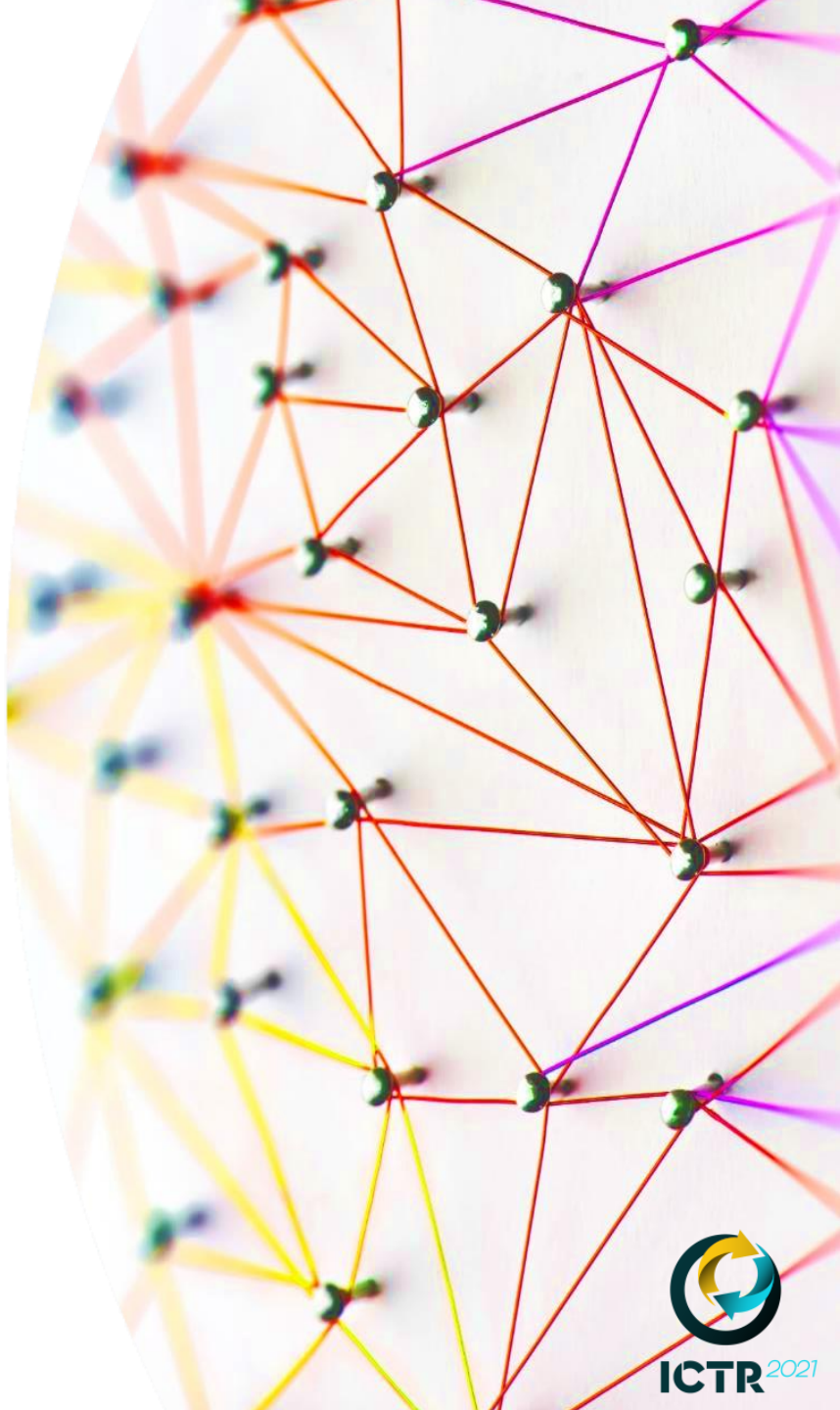
# Results (3/3)

- Automation decreased delay and travel time during both peak hour and off peak hour conditions for high market penetration rates.
- Traffic flows, the number of stops and total distance travelled values seemed to be increased when the number of CAVs was increased.
- The introduction of CAVs led to approximately similar average speed, due to the fact that the study network was a highly congested.
- $CO_2$, $NO_x$ and $PM_{10}$ levels were significantly lower when the number of CAVs was increased.
- In general, the introduction of CAVs seems to lead at first to more congested traffic conditions and finally shift to significantly improved conditions.



# Conclusions

- The present study identified critical KPIs for safety assessment of autonomous vehicles through traffic microscopic simulation.
- Traffic safety, traffic efficiency, and energy - environmental efficiency were found to be the most critical groups of indicators for the safety and impact assessment.
- Many of the proposed KPIs showed significant impact of CAVs in the examined urban environment, considering the microsimulation results.
- A further analysis could also be conducted in order to evaluate a total concrete score of the KPIs. The scoring method could guide stakeholders and decision-makers to form future policies.



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