INFLOWENCE

OPTIMIZING URBAN TRAFFIC FLOWS THROUGH AUTONOMOUS VEHICLES FOR AN ENHANCED CITY ECOSYSTEM

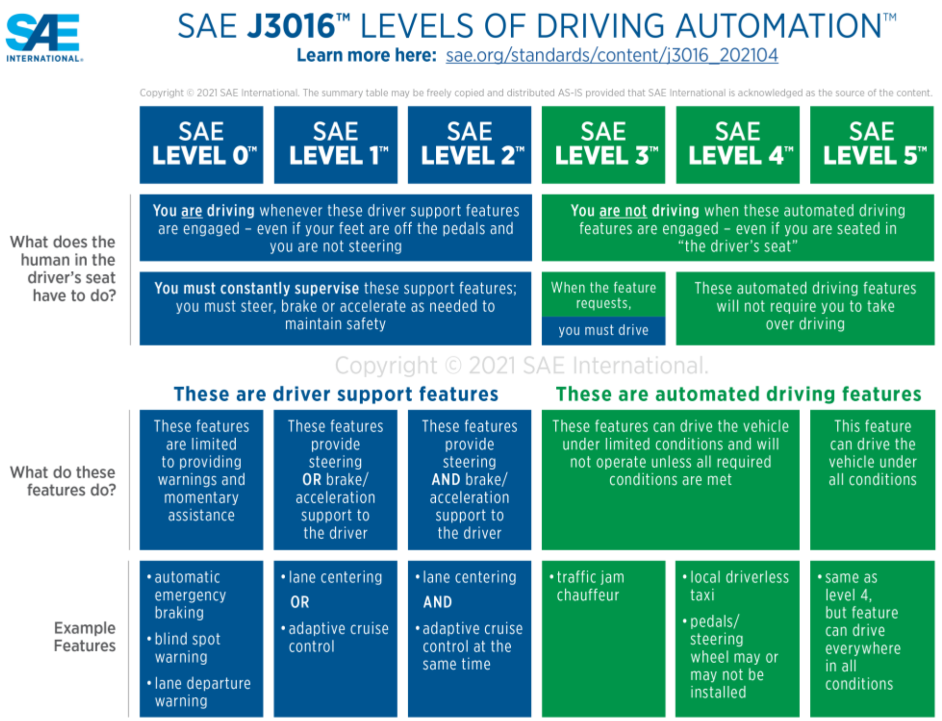
JORGE BANDEIRA, ELOÍSA MACEDO, MARGARIDA COELHO, PAULO FERNANDES, SANDRA RAFAEL

universidade de aveiro theoria poiesis praxis

THE CONTEXT

TRANSPORT IMPACTS AND THE OPPORTUNITIES AND RISKS OF AUTOMATION.

CONTEXT



- CAV (L3-L5) will be becoming increasingly prevalent in urban environments with autonomous driving systems.
- Progressively, human intervention in driving is expected to be negligible or only required in emergency situations.
- However, a significant percentage of **conventional vehicles** (CV) with internal combustion engines will continue to operate on road networks.
- CV contribute to air and noise pollution and increase the risk of negative externalities such as road accidents.

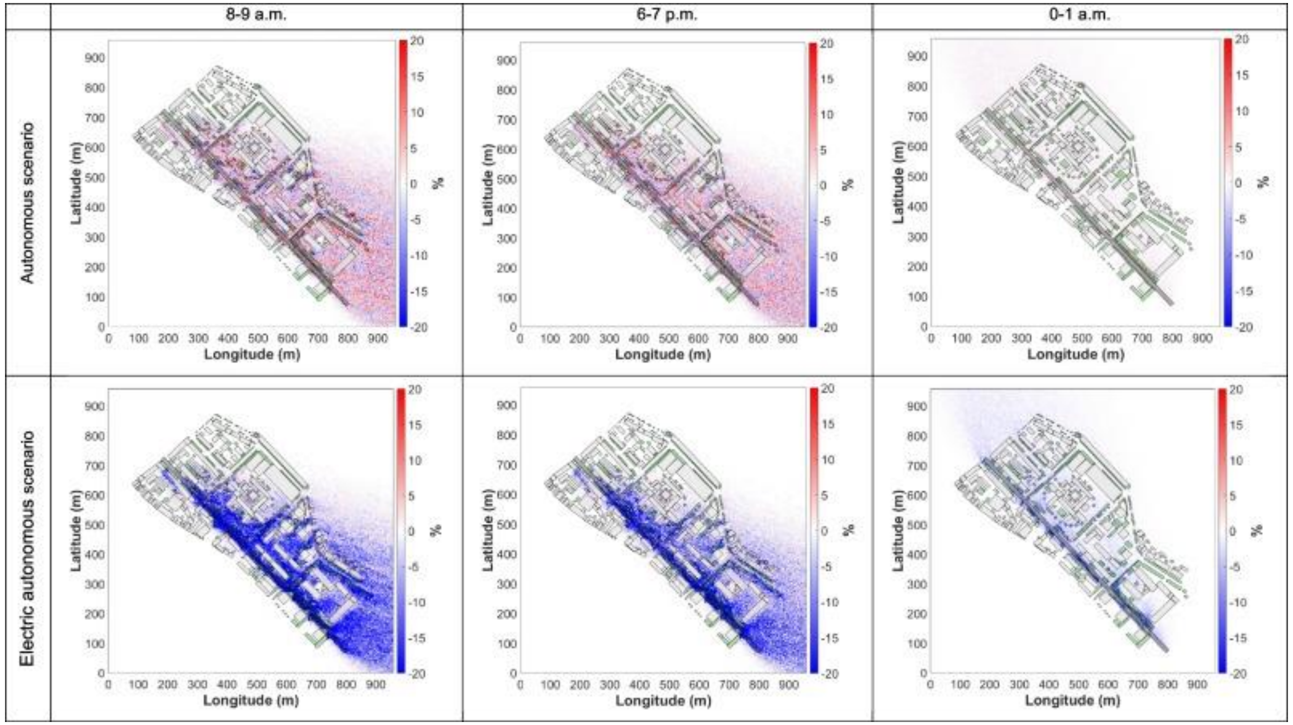
CONTEXT

- In 2019, approximately 307,000 premature deaths occurred in the EU due to exposure to air pollution and more than 22 000 people died from road accidents.
- Introduction of connected vehicles and automated driving systems (CAVs) is expected to improve road safety.
- Academic studies suggest that CAVs can have a beneficial environmental performance and optimize the performance of other vehicles if they follow specific operational behaviors (Bandeira et al 2021).
- But, if CAVs adopt a *default* response behavior independent of road infrastructure and traffic conditions, it can lead to a serious deterioration in traffic performance, safety, congestion, pollutant emissions, and air quality Rafeel et al 2020.

Balancing CAV behavior to achieve both environmental benefits and traffic performance is crucial!

EX. NON-COOPERATIVE CAVS

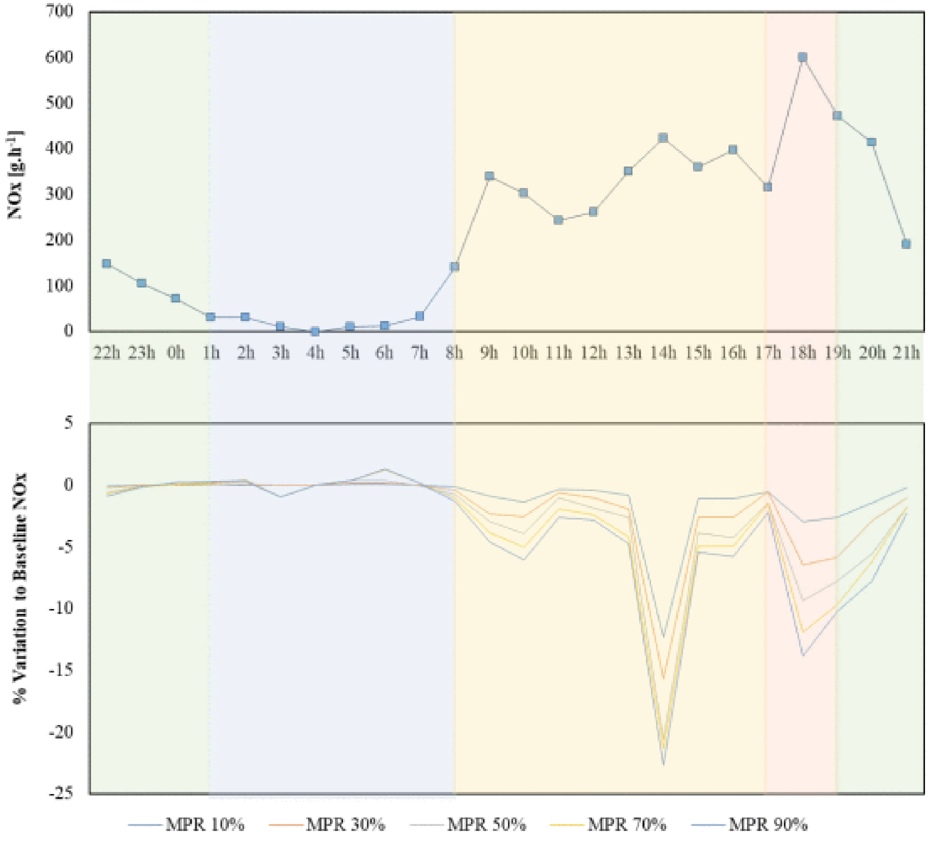
- Standard, non-optimised CAVs driving behavior can have a negative impact on air quality.
- Spatial distribution of the relative difference (in percentage) between the tested scenarios and baseline case across the computational domain, for 1.5 m high horizontal streamlines.



Rafael et al 2020
https://www.sciencedirect.com/science/article/pii/S0048969720300565

EX. ACTIVE COOPERATIVE CAVS FOR REDUCING NOX

- During the night period (1h–8h), with very low demand, the impact of the CAVs contribution to emissions change is small.
- As demand increases, **the contribution of CAVs for the reduction of network-wide NOx emissions also increases.** With (Volume/Capacity) ratio between 0.75 and 0.80, reductions between 12 and 23% were observed.
- During the maximum peak-period (17h–19h), there is also a considerable reduction in emissions (up to 15%).



In Bandeira et al 2021 https://ieeexplore.ieee.org/abstract/document/9538812

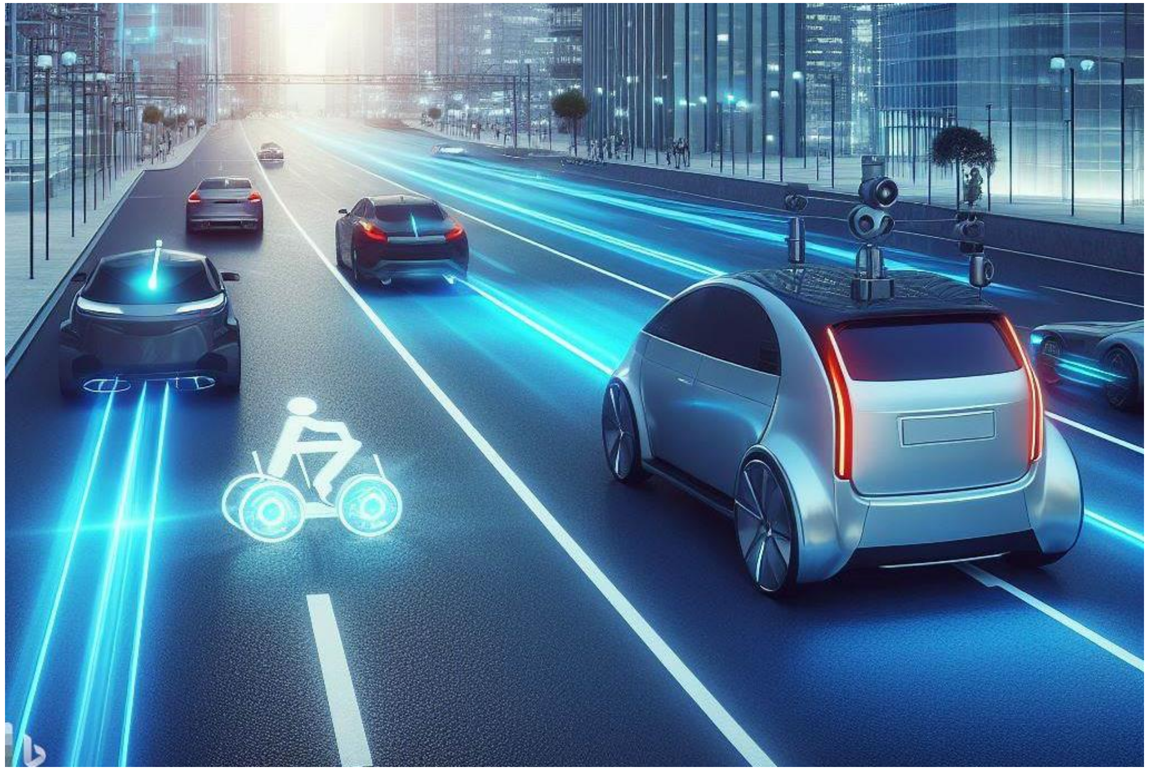
Fig Top: Hourly emissions produced in An Urban Street and the relative variation achieved for each hour for different Market penetration rates (MPR), of Cooperative CAVS
i) Extremely reduced demand overnight (blue), ii) Daytime average demand (yellow); iii) Evening Rush Hour (red) ; iv) Reduced demand (Early night) green.

OUR VISION

Make CAVs active eco-agents in promoting efficient, safe and clean traffic flows in critical urban links

THE CHALLENGES

- The optimization of Connected and Automated Vehicles (CAVs) operational performance can be achieved through the implementation of algorithms embedded in the vehicles themselves
- However, **minimizing the negative externalities** in a traffic flow that includes both CAVs and conventional vehicles (CV) **is more complex than scenarios involving only CAVs or CVs**



A DYNAMIC CHALLENGE

- The impacts of traffic flows change over time.
- Vulnerabilities and risks are felt differently over time

STOCHASTIC NATURE OF T TRAFFIC FLOWS

- The contribution of CAVs to traffic flow performance and resulting impacts can vary depending on their market penetration rate and the level of technology achieved (Bandeira et al. 2021).

- The environmental impact of traffic flow varies based on the composition of the mixed fleet, including:
  - the percentage of CAVs and CVs,
  - the type of propulsion technology,
  - the percentage of vehicles complying with different emission standards (e.g., Euro 1, Euro 2, ... Euro 6),
  - Etc.

ENVIRONMENT IS DYNIMIC

- Days with stable atmospheric conditions and low wind speed can lead to the accumulation of air pollutants in a critical zone adjacent to highways, degrading air quality.
- Conversely, air pollution tends to disperse on rainy and windy days.

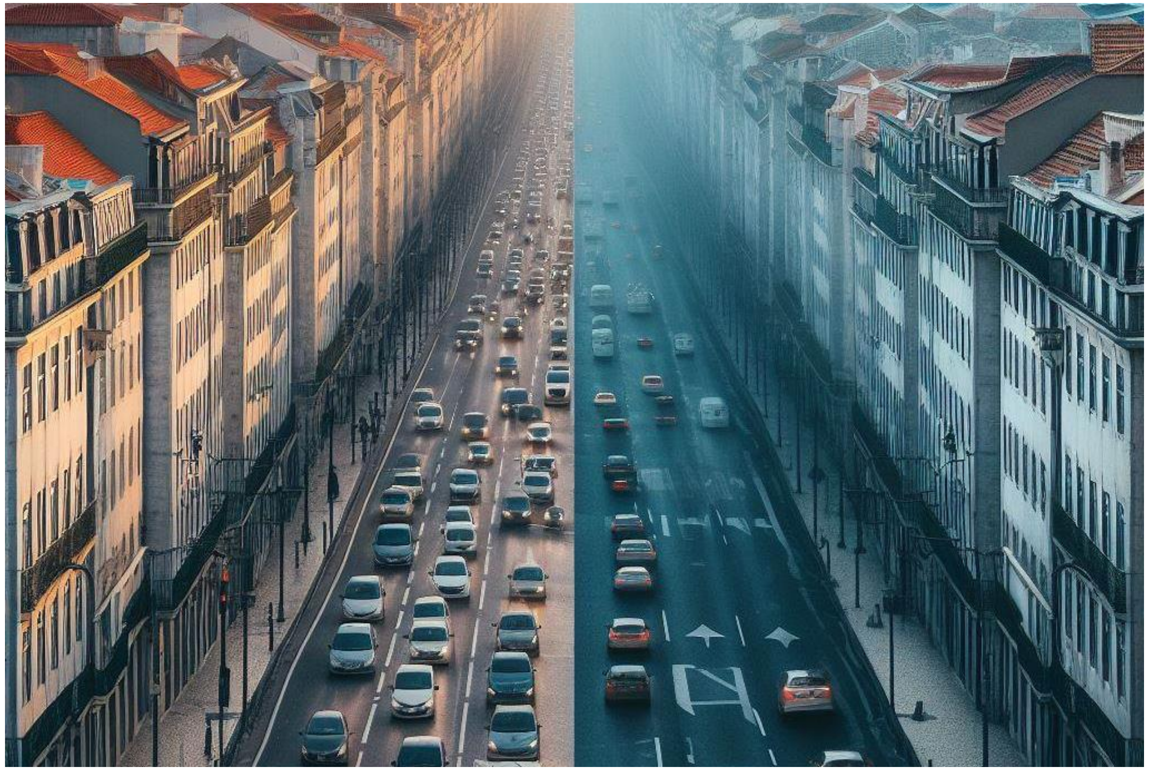
SOLUTIONS THAT VARY OVER TIME…

- Minimizing various traffic externalities may require different strategies:
  - For instance, reducing nitrogen oxide emissions (NOx) may involve smoother accelerations,

… while minimizing greenhouse gas emissions may require a dynamic behavior to reduce congestion and travel time.

CHALLENGES AND OPORTUNITES THAT VARY OVER TIME…

- During peak hours, congestion and high emissions lead to elevated pollutant concentrations and more pronounced negative externalities.
- During the day, moderate congestion and air pollution levels coexist with increased vehicle noise due to higher speeds.
- Vehicles have variable potential to change their driving behavior during these periods.



SOLUTIONS THAT VARY OVER TIME…

- Real-time or near real-time optimization of CAV behavior to minimize negative externalities in a mixed traffic flow, considering varying demand levels and fleet compositions, requires computationally intensive calculations and long computation times. This can impact the feasibility and relevance of the optimization process.

- Furthermore, negative externalities related to pollution or air quality can also vary depending on atmospheric conditions

WHAT WE PURPOSE ?

COMPUTER-IMPLEMENTED METHOD FOR MINIMIZING NEGATIVE EXTERNALITIES IN ROAD TRAFFIC

- Collects and processes information on negative externalities such as air pollution, noise, congestion, and safety in a road traffic segment
- Identifies and prioritizes critical issues in the traffic segment at different time periods
- Provides **CAV with adaptive behaviors** to minimize negative externalities
- Behaviors determined based on traffic characteristics in an upstream section of the road traffic segment

Patent application PT 118 732
Priority date of 19-06-2023

FOUR MAIN STEPS OF THE COMPUTER-IMPLEMENTED METHOD

A

Determine vulnerabilities in a delimited road traffic segment

→

B

Determine traffic profiles, negative externalities, and priorities in the delimited road traffic segment

→

C

Define scenarios that relate different traffic profiles to adaptive behaviors through initial model training

→

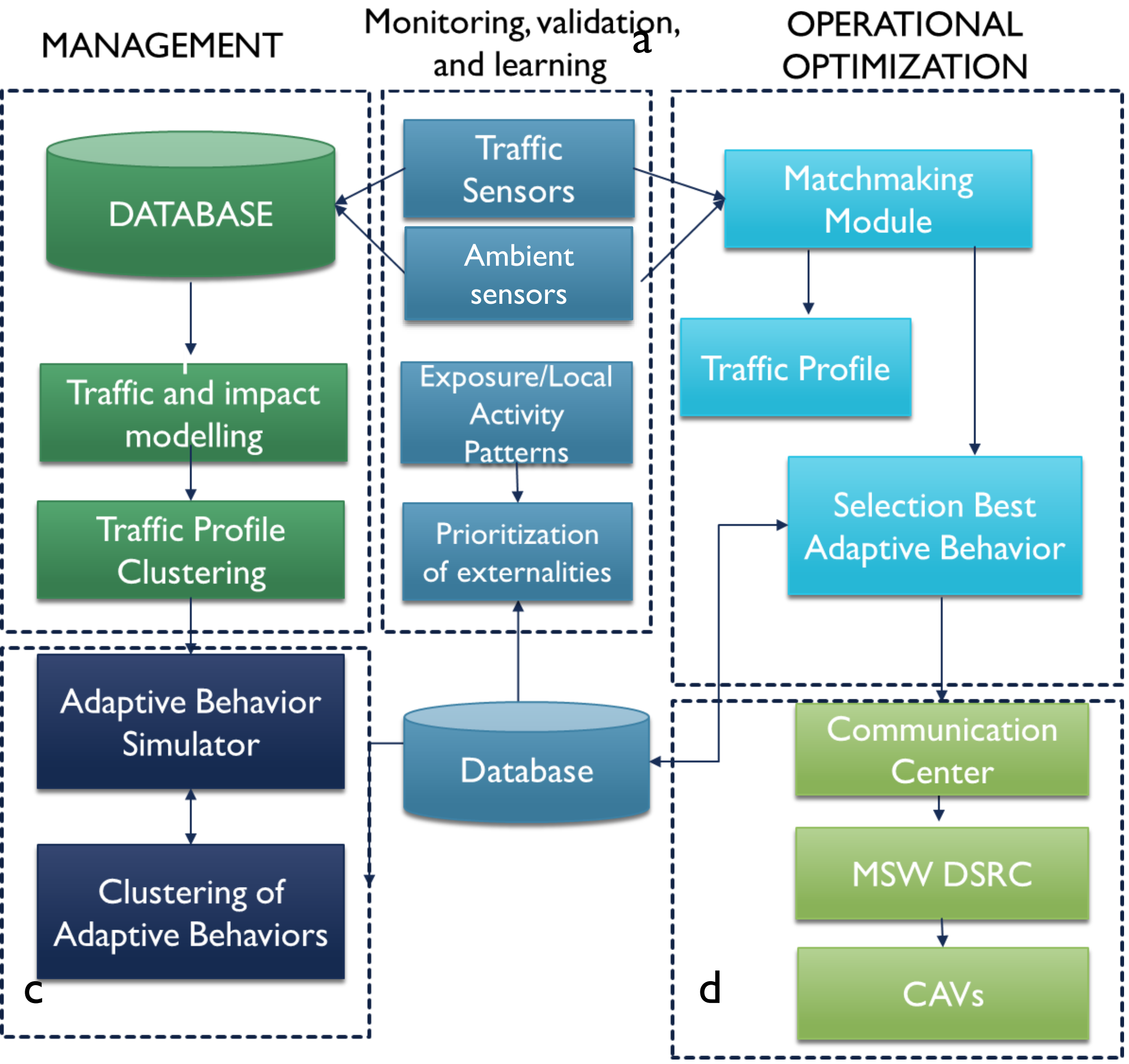
D

Recognize traffic profile patterns, identify and communicate adaptive behaviors, and continue model training

METHOD AND SYSTEM ADVANTAGES

- Prior definition of vulnerabilities, negative externalities, and priorities
- Effective adaptive behaviors to reduce negative externalities
- Real-time recognition of adaptive CAV driving behavior to minimize negative externalities
- Continuous learning of the applied model using deep learning and combined methods

DIAGRAM OF THE FOUR MAIN STAGES



a) Identifying vulnerabilities in a road traffic segment, environmental sensors collect data on environmental parameters and the presence of people or users.

b) Traffic profiles, negative externalities, and priorities in the delimited road segment are determined by collecting second data using traffic sensors installed upstream. This data includes information on vehicle types, such as the percentage of autonomous vehicles (CAVs) and conventional vehicles (CVs),

c) Microsimulation to train a model using input data such as adaptive behaviors, negative externalities, traffic profiles, and priorities

The computational control and evaluation module defines scenarios based on traffic profiles, negative externalities, and priorities calculated in step b) The output consists of scenarios that determine the most suitable adaptive behaviors to be applied to CAVs in real-life situations.

d) Involves a communication network that transmits the best adaptive behavior toCAVs based on real-time data and learned scenarios. The decision, selection, and transmission module determines the reduction of negative externalities and repeats the process for continuous model training. This step is performed multiple times within a processing cycle.

A) DETERMINATION OF VULNERABILITIES IN DELIMITED ROAD TRAFFIC SEGMENT

- Environment sensors installed in the road traffic segment collect initial data on environmental parameters (e.g., air pollution, noise levels, presence of people)
- Data helps determine existing vulnerabilities in the traffic segment
- Additional vulnerability data can be retrieved from a database or manually inserted by an operator or system manager

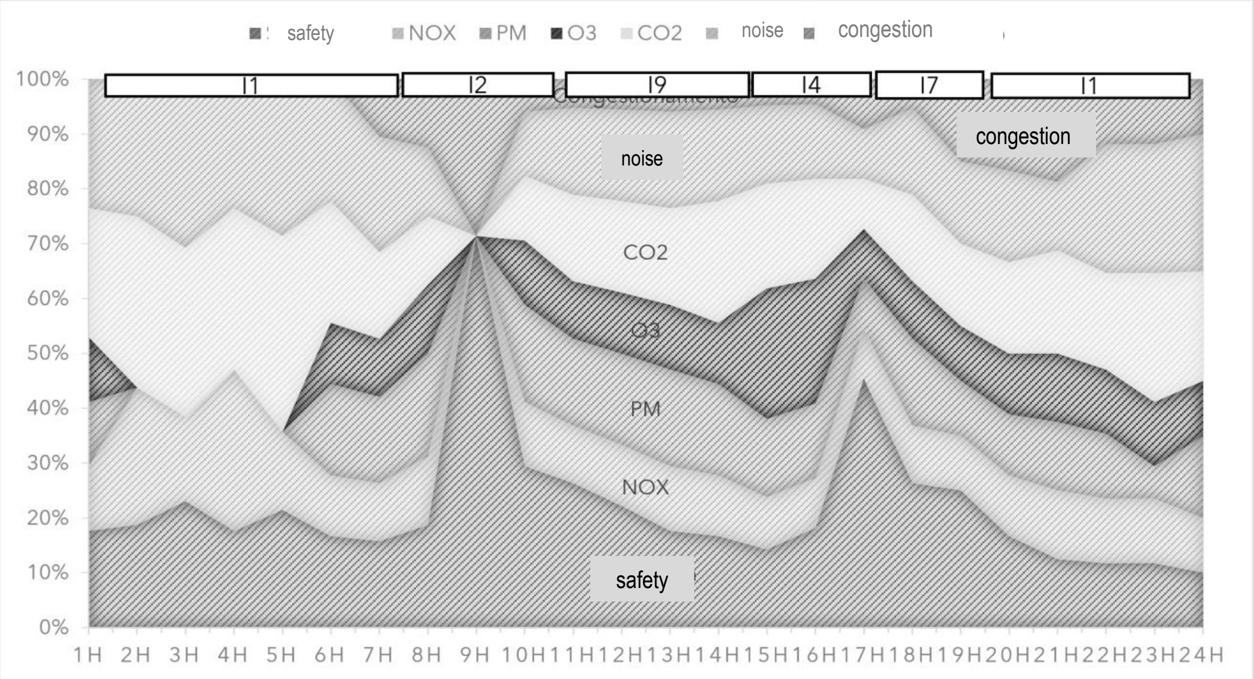
- Sensors installed upstream of the traffic segment collect second data on traffic parameters
- Second data includes the number of vehicles with automation level 3 or higher, number of conventional vehicles, fleet composition (percentage of autonomous vehicles vs. conventional vehicles)
- The control and evaluation computational module defines scenarios based on the determined traffic profiles, negative externalities, and priorities
- Microsimulation is performed to train a model for application to the specific traffic segment

B) DETERMINING TRAFFIC PROFILES AND NEGATIVE EXTERNALITIES

- Sensors installed upstream of the traffic segment collect second data on traffic parameters.
- Second data includes the number of vehicles with automation level 3 or higher, number of conventional vehicles, fleet composition, etc.
- The control and evaluation computational module defines scenarios based on the determined traffic profiles, negative externalities, and priorities.

HOW SUCH NEGATIVE EXTERNALITIES CAN BE PRIORITIZED AND GROUPED OVER 24 HOURS

- The graph shows how these externalities can be prioritized and grouped over a 24-hour period. For instance, the following periods were identified in n urban street:
  - I1: Nighttime rest period with low pedestrian density, focusing on minimizing noise and greenhouse gas emissions.
  - I2: Period with high pedestrian concentration and minor road crossings, prioritizing pedestrian safety.
  - I9: Period with moderate pedestrian concentration and air pollution below limits, where various negative externalities are evenly addressed.
  - I4: Period where ozone concentration approaches health limits, emphasizing air quality and NOx/PM emissions.
  - I7: Peak hour period in the late afternoon, prioritizing congestion relief and pedestrian safety.



Example of priorization of traffic related externalities

C) DEFINING SCENARIOS

- The computational module defines scenarios that **relate different traffic profiles with adaptive behaviors for the delimited road traffic segment.**
- Initial training of a model is performed to determine these scenarios.
- The model is trained using supervised and/or unsupervised learning algorithms.

STEP D) RECOGNIZING PATTERNS

- The trained model from step c) is applied in real-time.
- Communication network includes a device in at least one autonomous vehicle (CAV), a radio communication network, and the CAV.
- The decision, selection, and transmission module transmits adaptive behavior recommendations based on learned scenarios to one or more autonomous vehicles in real-time.

OVERVIEW

- Circulation of Connected Autonomous Vehicles (CAV) (60) and Conventional Vehicles (CV) (70) in an upstream zone (11) of the traffic segment (10)
- Environment sensors (20) collect data associated with the traffic segment (10) and send it to the computational control and evaluation module (30)
- Traffic sensors (21) collect data associated with traffic composition, and send it to the computational control and evaluation module (30).
- The recommendation is sent by the decision, selection, and transmission computational module (40) and transmitted by the transmission unit (50).
- Adaptive behaviors may include recommendations to increase speed, acceleration, reduce speed, change lanes, or change direction.

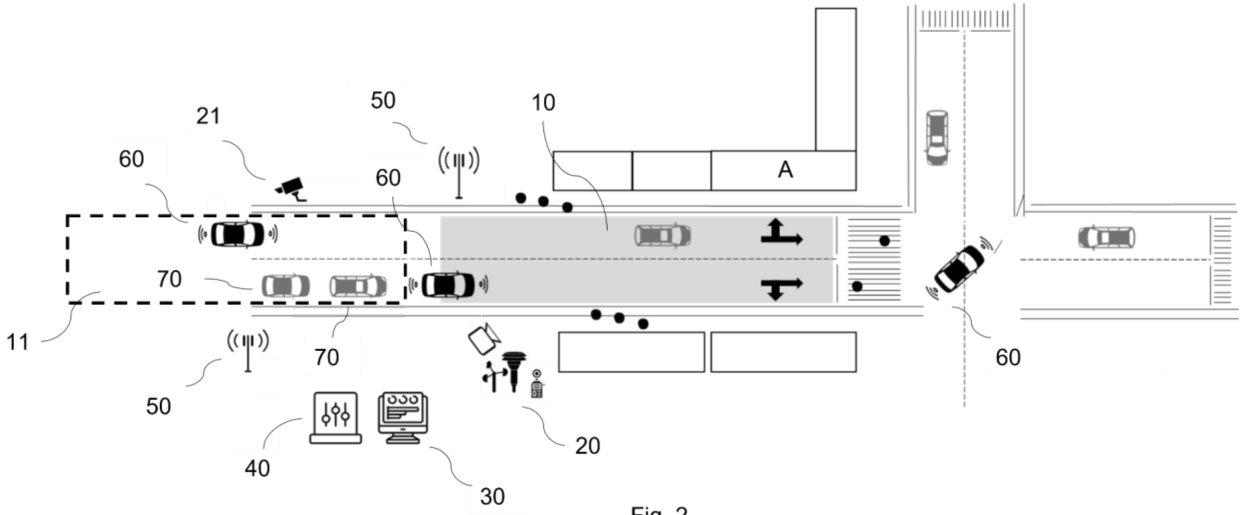
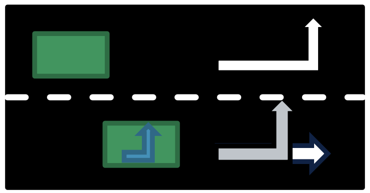
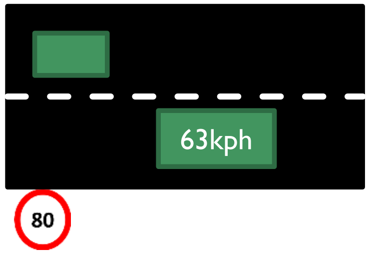


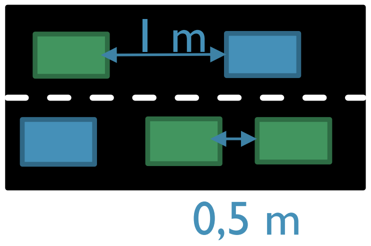
Fig. 2

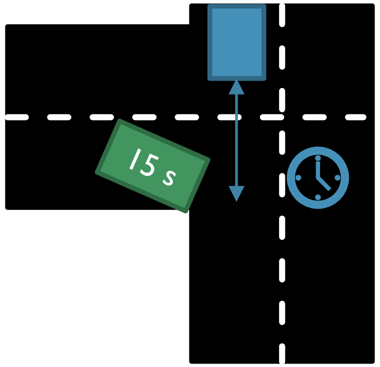
POSSIBLE ADAPTATIVE BEHAVIOURS

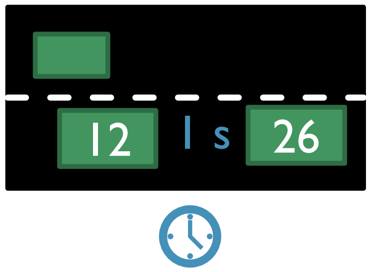
Lateral behaviour lane choice	Circulation speed (free flow)	Longitudinal distance between vehicles	Reaction time and safety intervals	Acceleration rates











CONTINUOUS TRAINING

- New real-time data collected by environment sensors is compared with previous data to evaluate the reduction of identified negative externalities.
- The continuous training of the initially trained model involves repeating these sub-stages multiple times.
- The reduction of at least one negative externality is considered a positive impact.

SHAPING A FUTURE WHERE TECHNOLOGY POSITIVELY IMPACTS AND IMPROVES THE LIVES OF PEOPLE AROUND OUR CITIES

The computer-implemented method involves collecting data from environment sensors to determine vulnerabilities, collecting traffic data to determine profiles and negative externalities, and using this information to define adaptive behaviors and continuously improve the model.

The method can help minimize negative externalities in road traffic segments and improve overall traffic flow.

EXISTING TECHNIQUE AND MARKET POTENTIAL

EXISTING TECHNIQUE

System for Mapping and Monitoring Pollutants in a Geographical Region Patent: US 11,360,236 B1, by Prathamesh Khedekar.

- System comprises autonomous units with sensors and a cognitive **emissions and pollutants mapping module**
- Units map the surrounding environment, detect pollutants, and overlay data on a map
- Data transmitted securely to servers to compile a real-time **3D map with pollution data**
- Relevant third parties notified for action on pollutant sources

Simulation-based V2X Testing System for Traffic Efficiency and Emission Reduction Patent: CN111405522, Inventor: Suzhou Kunpeng Intelligent Network Tech Co Ltd)

- System simulates V2X communication between vehicles, infrastructure, and pedestrians
- Tests real-time communication signals and analyzes tunnel communication conditions
- Improves traffic safety and efficiency by accelerating vehicles connected to the intelligent network
- Importance in emission reduction highlighted

NEED FOR COMPREHENSIVE SOLUTION TO MINIMIZE NEGATIVE EXTERNALITIES IN ROAD TRAFFIC SEGMENTS

- Existing patents address mapping pollutants and simulating V2X communication
- **Challenges remain** in real-time action on traffic, considering both autonomous and non-autonomous vehicles
- Current solutions **do not consider traffic patterns, safety, air pollution, noise, and applicable regulations simultaneously**
- Requirement for a complete technological solution to efficiently minimize negative externalities in road traffic segments!

MARKET PERSPECTIVES

- Some analysis suggests that over 85% of all new cars are already classed as connected, and by 2025 there will be over 470 million connected vehicles on the roads in Europe, the USA and China alone1.
- Other reports conclude that by 2035, it is expected that more than 330 million units in the United States will be connected to the internet, either in multiple ways or by embedded, tethered, or via smartphone integration2.
- With a general market view that connected vehicles have already overtaken non-connected
- Deloitte report that connected services are increasingly of interest to consumers and therefore it seems reasonable to assume that connectivity in vehicles is an increasingly important feature
- As a baseline requirement for the solution connectivity can be assumed to be present in increasing levels. While there may be variation between different geographies as to whether connectivity is provided by embedded technical solutions the penetration of connections is assumed sufficient to allow the adoption of the C-ART solution, at least from the vehicle / device perspective.

MARKET PERSPECTIVES

- Significant percentage of connected and autonomous vehicles expected in European cities by 2030/40
- Implementation of the invention provides advantages for cities and is economically beneficial
- European regulations and strategies support the incorporation of active safety systems
- Alignment with the Stockholm Declaration and the Safe System approach is desirable for addressing major road traffic externalities
- Mayors of C40 cities are committed to using an inclusive, science-based and collaborative approach to cut their fair share of emissions in half by 2030, help the world limit global heating to 1.5°C, and build healthy, equitable and resilient communities.”

CANDIDATE ACQUIRING ORGANISATIONS

- Large IT system integrators
- Tech companies
- Industrial Tech companies
- Automotive OEMs:
- Automotive Tech suppliers

TAKE AWAY MESSAGES

InFLOWene: Adapting to Dynamic City Needs

- Cities are dynamic ecosystems with diverse and evolving needs.
- InFLOWene recognizes and adapts to these unique requirements for effective traffic management.

Empowering Automated Cars

- InFLOWene's advanced optimization algorithms enable intelligent real-time decisions.
- Overcoming human behavioral inertia enhances safety, efficiency, and environmental impact.

Optimizing Traffic Flows

- InFLOWene's clustering approach and machine learning algorithms optimize traffic flows according priorities and scenarios
- Paving the way for smarter automation and a more efficient transportation system.

Unlocking Potential: Realizing Real-World Implementation

- Our solution, currently in the proof of concept stage using microsimulation, holds immense potential.
- To scale up TRL, bring it to market, and advance our project, we actively seek funding opportunities."

THANK YOU

Contacts

Jorgebandeira@ua.pt

University of Aveiro PORTUGAL