Integrating Road Safety into Traffic Control Policy

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The 3rd workshop on
Traffic Control Systems for Future Mobility
Shanghai, December 4, 2025

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Introduction (1/2)

- Road transport is responsible for the majority of transport fatalities, with 1,2 million fatalities worldwide each year.

- Road safety is a field with typically high risk of important investments but not matching results.

- Absence of monitoring, integration and accountability limits seriously road safety performance.

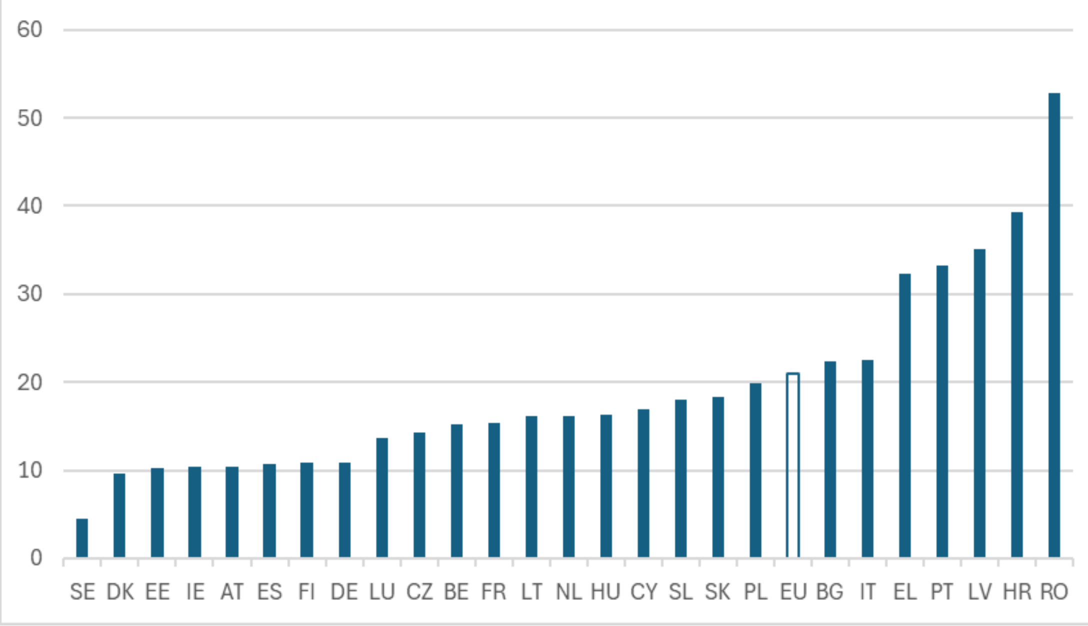
Introduction (2/2)

- Within urban areas, Vulnerable Road Users (VRUs), (i.e. pedestrians, cyclists and users of powered two-wheelers) represent almost 70% of total fatalities (EU CARE, 2022)

- VRUs represent between 77% and 94% of road fatalities in the six most densely populated cities (those with over 10,000 inhabitants per km^2) (ITF, 2020).

- In urban areas, traffic control tools are most often used for efficiency problems but not for the most critical safety problems.

Urban fatalities per million inhabitants in the EU between 2013-2023



Different patterns in different countries

Road Fatalities 2023 (source: CARE)

Power Two Wheelers

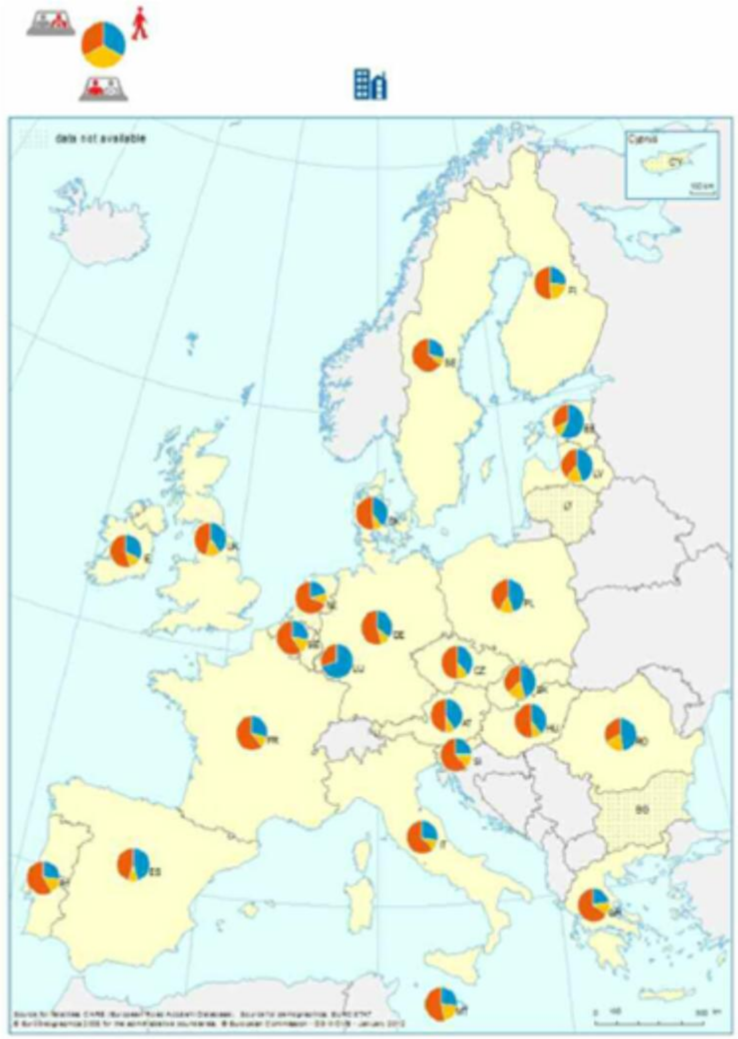
	Urban	Total	%
North-Western countries	449	2710	17%
Southern countries	864	2701	32%
Eastern countries	273	2456	11%

Cyclists

	Urban	Total	%
North-Western countries	613	2710	23%
Southern countries	188	2701	7%
Eastern countries	301	2456	12%

Pedestrian

	Urban	Total	%
North-Western countries	856	2710	32%
Southern countries	813	2701	30%
Eastern countries	964	2456	39%



Addressing the problem with Traffic Control

- Arterials, collectors, distributors, and local roads serve non-motorized users as well.
- Two challenging problems exist (1) the broader **road space allocation** and (2) the **curb-space management**, as different modes, users, and needs are present.

Passenger cars Taxis/ride-hailing Trucks Buses Bicycles E-scooter Pedestrians	Commuters Employees Children Elderly Disabled/Impaired individuals Tourists	Retail activity Residents Recreation

- Carefully selected policies can accommodate all users' needs, while ensuring efficiency and safety.
- Prioritisation of **active travel modes** can establish **livability,** improve **public health** & **security**, and boost **economic activity.**

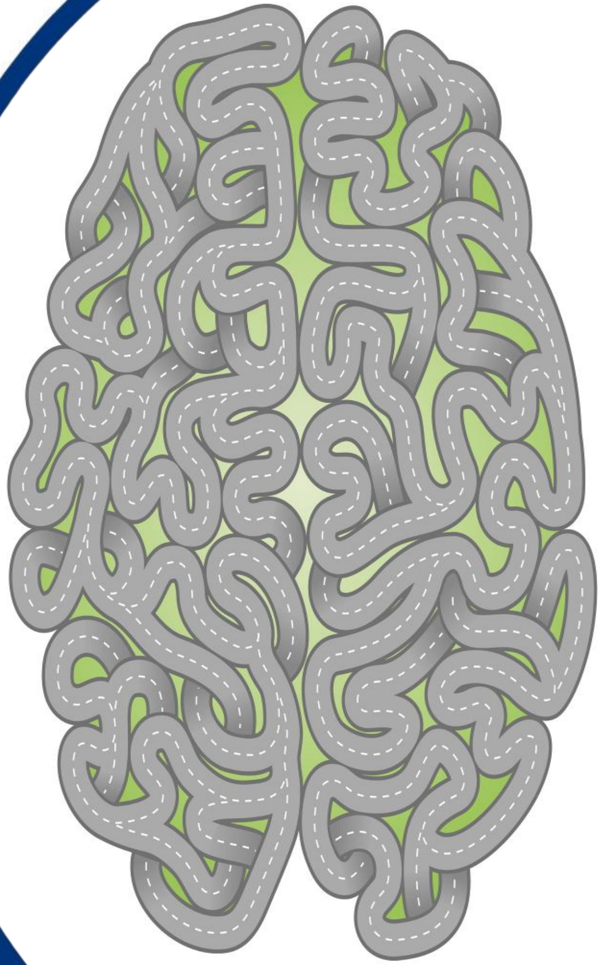
Traffic Control and Road Safety Choices

- The high complexity of the urban environment makes broadening typical traffic control objectives a very difficult task, attempting to balance conflicting social needs and economical restraints.

  - Traffic Efficiency (Speed) Versus Traffic Safety
  - Vehicles Versus Vulnerable Road Users
  - Expensive but safe Versus Cheap but unsafe (vehicle, infrastructure, management)
  - Priorities in policies, measures, research, etc.

Traffic Control Choices and Prioritization

- Safety should be prioritized over efficiency; efficiency should be prioritized over speed.
- Maximum separations to be maintained between motorized vehicles and VRUs, as well as between passenger and freight traffic.
- Use traffic control not only to ensure safety for all users, but to make the safest mode choices (i.e. public transport) the most attractive



Safety-Relevant Urban Traffic Control Policies

- **Policies to reduce car trips in local roads:**
  - Efficient parking management
  - Congestion pricing & access restriction measures
  - Creation of low-speed zones (20 or 30 km/h)
  - Increase public transport capacity and accessibility
  - Implementation of bus-only lanes
  - Prioritization of pedestrians/bicycles traffic signals

- **Measures to increase walkability:**
  - Installation of new and improvement of existing crossing facilities: clearly marked crosswalks, separated crosswalks, longer green time, actuated signals
  - Sidewalk improvement: wider and paved sidewalks
  - Proper lighting
  - Mixed traffic zones

Traffic Control-oriented facilities

- Compared to walking, for which facilities exist in all cities, cycling requires building new facilities along segments and at intersections so that people of all ages and abilities can shift towards utilitarian cycling.
- Due to the COVID19 pandemic, many cities world-wide (e.g., Milan, London, Boston) allocated road space for cyclists by implementing protected bike lanes (i.e., pop-up bike lanes), showing that achieving higher bicycle mode share is easier than thought.
- To establish safe cycle trips, cycling facilities are needed along segments and intersections:
  - Low-speed/volume streets: share roads with cars
  - Speed > 30 km/h: bike lanes or cycle tracks
  - Intersection markings, cycle signals, protected intersection are intersection-level treatments

Intelligent Traffic Control in a Safety Context

- Innovative big data-driven solutions could contribute to a proactive approach of addressing urban traffic safety problems, being a core principle of the Safe System Approach.
- The rise of smartphones, sensors and connected objects offers deeper and broader transport data, many of which are already used for traffic control.
- The interpretation of these data can be made possible thanks to progress in computing power, data science and artificial intelligence (AI).

Surrogate Safety Measures (SSMs)

- Big Data → SSMs, e.g. traffic conflicts, harsh driving events, spatial/temporal headways, and many others.
- SSMs show less underreporting; can even aid with crash reporting.
- Readily available for proactive analyses before crashes occur or in areas with limited or no crash data availability.
- Research on the validation of surrogate safety metrics is essential
  1. to reveal which metrics not only are correlated with reported crashes but also have predictive capabilities
  2. to forecast the number of fatalities and/or injuries
- SSMs can be integrated within traffic control policies as a responsive and agile objective through of safety-focused AI

AI Advances in Road Safety Risk Estimation

- Methods related to Artificial Neural Networks are the most promising for road safety, contributing to ADAS.
- Apart from incident detection, all other problems addressed are mode-specific.
- Knowledge could be transferred from the safety field of AVs to other modes.
- Pattern recognition has received heightened attention (e.g. 85% accuracy of pedestrian detection from video recording using Convolutional Neural Networks)
- However, it remains a challenge to detect and block intentional malicious manipulation of training datasets.

AI in Automated Driving

- **Depth perception** (e.g., LiDAR, radar, etc.)
- **Data fusion** from environment data (from cameras, lidar, radar, etc.)
- **Object recognition** and **movement prediction**.
- Dynamic **Decision-Making algorithms** (real-time trajectory planning, optimization and response).
- Vehicle-to-Everything (**V2X**) communication between a vehicle and any entity that may affect, or may be affected by, the vehicle (data exchange).
- Machine Learning for **personalized adaptation** in-cabin and driving experience.

AI + Traffic Control = Road Safety

AI facilitates traffic safety through proactive management during traffic control in various ways:

- Collection of data on road infrastructure conditions and traffic events through wide and broad-scale sensors and systems such as real-time computer vision.
- Identification of high-risk locations proactively, through predictive multi-layer models.
- Enabled by multiparametric big data, AI pushes the limits of pattern recognition and reaction times beyond human capabilities and may thus uncover new crash-prone road configurations.
- Recent developments in the field of so-called “explainable AI (XAI)” begin to cope with the challenge of the “black box” phenomenon.

AI-Driven Detection and Real-Time Decision-Making

- Smart Robots and Edge Devices: AI-powered robots and wearable systems using machine learning, LiDAR, and video cameras detect vehicles, pedestrians, and cyclists at crossings, providing real-time guidance and alerts to the traffic controller

- Computer Vision and Deep Learning: Convolutional neural networks (CNNs) and other vision-based AI models automate safety assessments at crossings, identify high-risk scenarios, and support large-scale, objective audits of pedestrian infrastructure.

- These rapid-response, safety focused traffic control tools significantly enhance potential safety gains for specific groups, especially children and visually impaired users

Road Safety Challenges in Traffic Control (1/3)

- Traffic control is usually operationally conducted under the lens of traffic efficiency and delay minimization and in an unscaled manner

- Therefore, the foundational objective is often inaccurate or incomplete, as most road users would trade-off efficiency for their safety

- This is reflected in applied traffic simulation models, which do not typically account for traffic safety indicators, at least in a holistic way

Road Safety Challenges in Traffic Control (2/3)

- Event migration or drivers non-complying after passing enforcement zones undermines localized interventions
- Human Factors: Driver behavior influenced by underlying culture as well as risk underestimation, reducing the transferability of safety solutions
- Resource and Policy Constraints: Insufficient funding, outdated infrastructure, and inconsistent enforcement hinder the implementation of modern safety strategies
- This is particularly evident in rapidly urbanizing or resource-constrained regions

Road Safety Challenges in Traffic Control (3/3)

- **Technological Limitations:** Many advanced models perform well in simulations but lack robustness in real-world settings, especially under unusual or oversaturated conditions
- The **representation of crashes and related abnormal circumstances** in simulation environments is disjoined and untested
- Further challenges include **data accuracy**, interoperability, and computational requirements
- Automated and intelligent systems show promise but face hurdles in real-world deployment, including **cost, maintenance, and public acceptance**

Intelligent Traffic Signal Control and Safety

- **AI and Reinforcement Learning:** Multi-objective algorithms optimize signal timing, focusing on both efficiency and safety, reducing traffic conflicts and **crash risks** at intersections by up to 40% compared to traditional systems

- **Sensor Integration:** Real time monitoring of traffic conditions and enforcement of signal compliance help prevent violations and **reduce crashes**, especially at high-risk intersections and pedestrian crossings

- **Connected Vehicles and V2X Communication:** Integration with connected and **autonomous vehicles** enables adaptive, data driven signal control, improving both safety and operational efficiency

Integrating Safety into Traffic Control (1/2)

- **Real-Time Prediction and Adaptive Control:** AI models, such as GRU, LSTM and BiLSTM to predict congestion and **dynamically** adjust signals and routing based on sensor, camera, and IoT data, minimizing bottlenecks and delays but also SSMs

- **Dynamic Routing and Signal Optimization:** AI-driven systems reroute vehicles and optimize **signal timings** to avoid congestion and critical event hotspots

- **Integration with Smart City Infrastructure:** AI frameworks use data from connected vehicles, drones, and IoT sensors to enable **city-wide optimization** and support priority for pedestrian and micromobility users' safety, and emergency vehicles too

Integrating Safety into Traffic Control (2/2)

- **Integrated Safety Audits and Data-Driven Interventions:** Crash prediction models, and big data analytics help identify high-risk locations and guide targeted **interventions**, such as signal upgrades or median installations

- Digital twin platforms and open-source standards for traffic control should **facilitate safety-inclusive simulation and testing of new strategies**, ensuring adaptability to evolving traffic patterns and technologies, especially within the VRU safety context

Accounting for User Intentions

- **Intention Recognition:** AI models, including neural networks and fuzzy logic, predict pedestrians' and cyclists' intentions and trajectories
- **Adaptive Signal Control:** Some proposed systems (e.g. IntelliCross, VENUS) dynamically adjust crossing signals based on real-time **pedestrian flows**, vehicle density, weather conditions
- These measures enable proactively responses such as adjusting **signal timing** or issuing alerts

Conclusions (1/2)

- Multiple-criteria based exploration and decision analysis to determine those **Surrogate Safety Measures** that can be obtained from the available Big Data and are most appropriate for traffic control integration.
- Safety-aware traffic control AI modelling accounting can reveal complex, **non-linear relationships** such as interactions or distraction factors affecting drivers (e.g. using a smartphone).
- High-resolution multi-parametric data can expose risk-critical behaviours (e.g., harsh braking, gap dynamics), allowing **safety metrics to function as operational inputs to traffic control.**

Conclusions (2/2)

- Linking SSMs with real-time traffic states enables proactive control strategies that mitigate emerging risks before they escalate into conflicts.

- Completely unexplored directions remain in several road safety aspects (crowdsourcing options, measure effectiveness, data harmonization).

- Big Data and Artificial Intelligence can become efficient catalysts for achieving Vision Zero road fatalities by 2050 alongside traditional traffic control objectives.

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