AdTrans project, 2023-1-PL01-KA220-HED-000158917

ADTRANS
ADVANCED DATA ANALYSIS FOR TRANSPORTATION AND MOBILITY ACADEMIC TEACHERS

Road Traffic Control: Active Mobility Traffic Control (Pedestrians and Cyclists)

Jacek Oskarbski

Co-funded by the European Union

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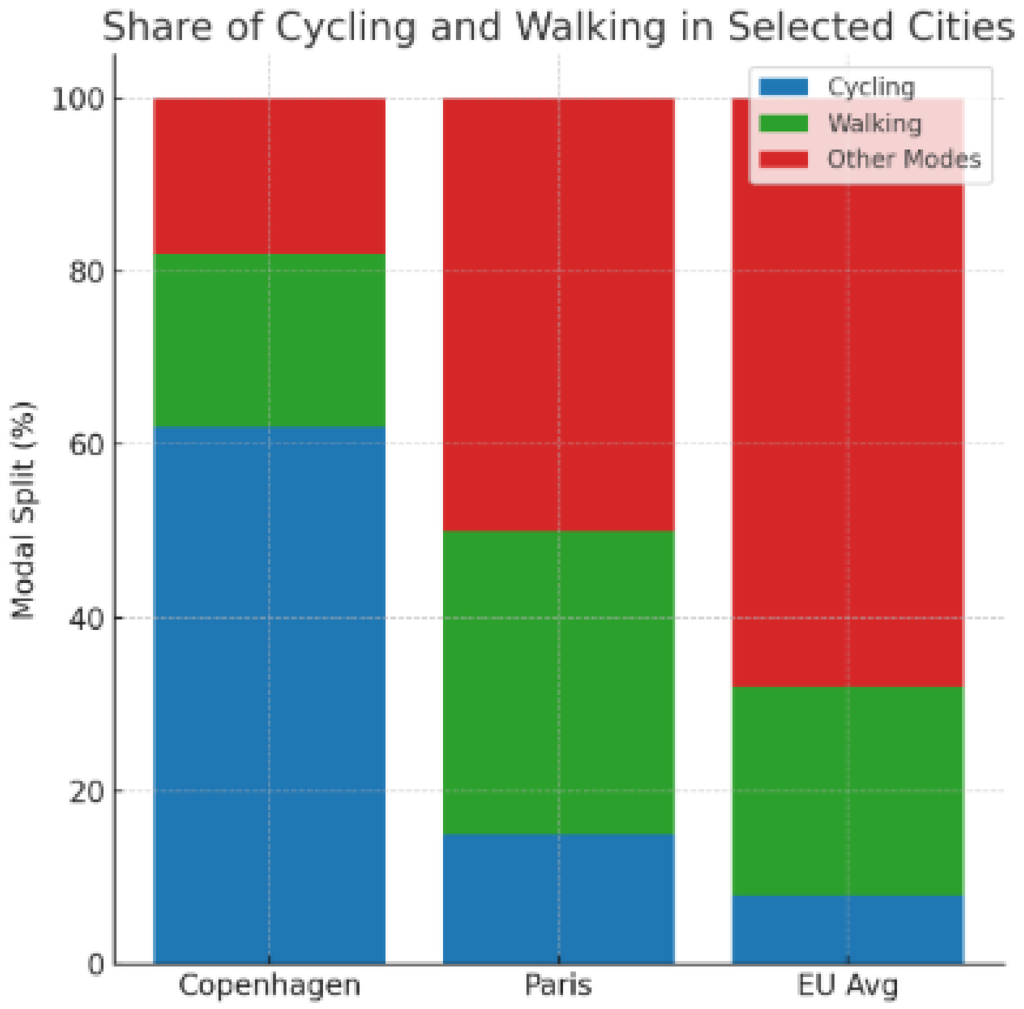
Role of Pedestrians & Cyclists in Smart Cities

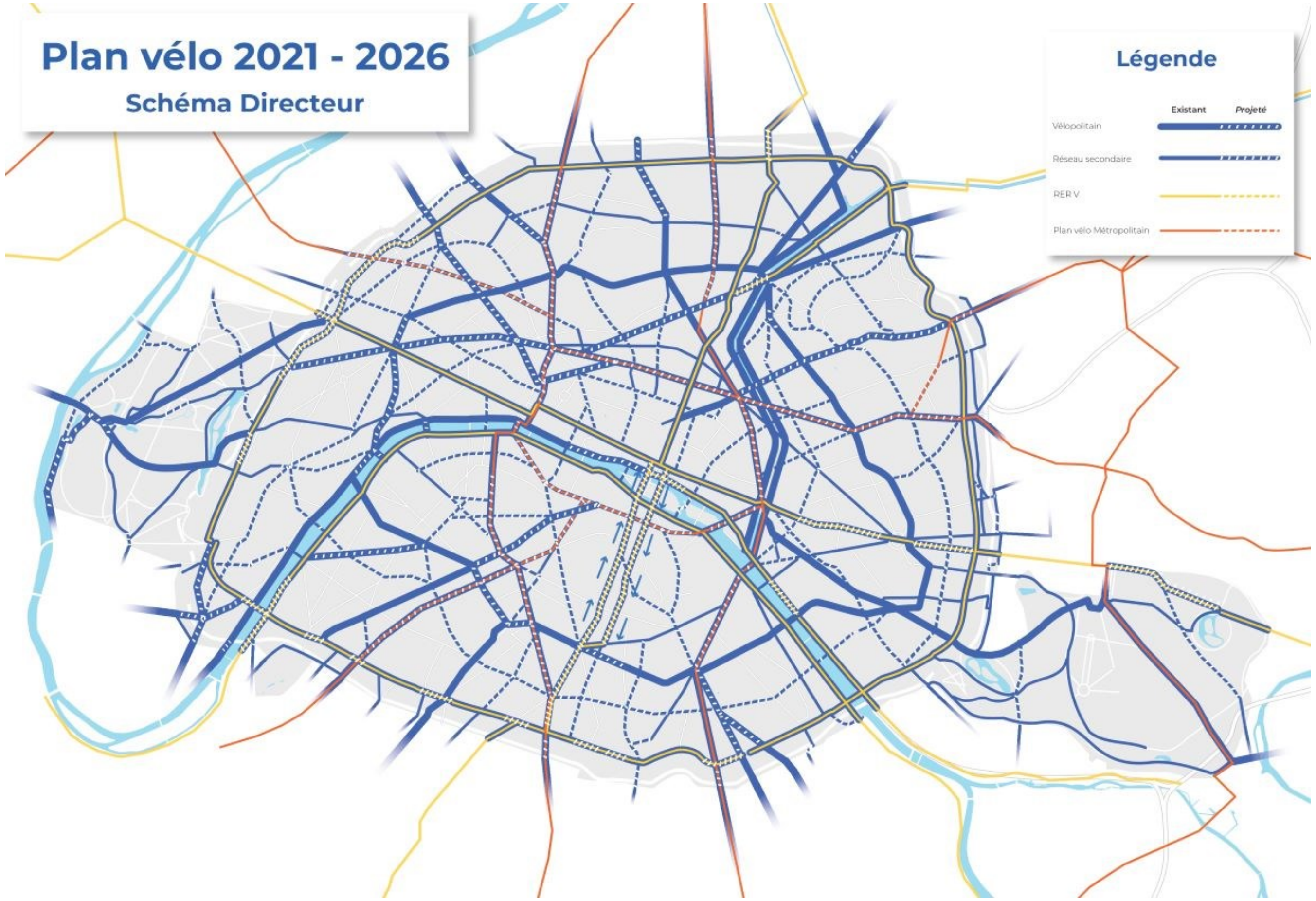
- **Contribution to modal split & sustainability goals** – Walking and cycling are core to achieving mode shift targets in urban mobility plans. A higher active mobility share reduces dependence on motorized modes, easing congestion and emissions.
- **Health & environmental benefits** – Active mobility reduces air pollution, supports cardiovascular health, and encourages more livable cities with cleaner air and less noise.
- **Policy alignment with SDGs (**– Promotes SDG 3 (Good Health and Well-Being), SDG 11 (Sustainable Cities & Communities), and SDG 13 (Climate Action) by reducing CO_2 emissions and enhancing equitable access.
- SDG stands for Sustainable Development Goals. They are a set of 17 global goals, adopted by the United Nations in 2015 as part of the 2030 Agenda for Sustainable Development. The SDGs serve as a roadmap for governments, cities, organizations, and businesses to ensure that social and economic development happens in a sustainable, fair, and environmentally friendly way.



Role of Pedestrians & Cyclists in Smart Cities

- **Copenhagen** – Over 62% of residents commute by bike daily, supported by cycle highways, green waves for bicycles, and high-quality infrastructure.
- **Paris** – With the "Plan Vélo" strategy, the city invests €250M to become 100% cyclable by 2026, expanding bike lanes, parking, and restrictions on private car use.

Source: Erik Kirschbaum / For The Times/https://www.latimes.com/world-nation/story/2019-08-07/copenhagen-has-taken-bicycle-commuting-to-a-new-level

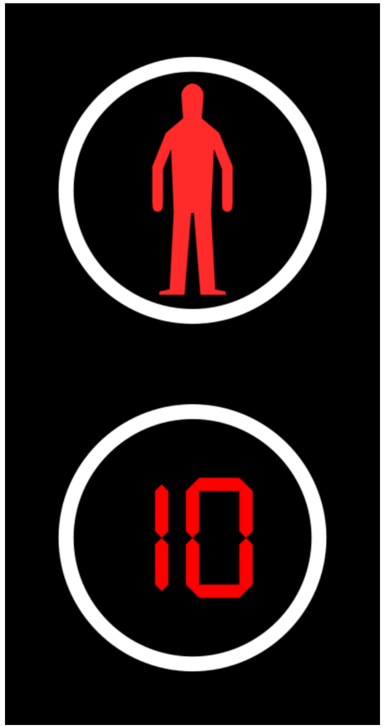


Map of the Bicycle Plan 2021 2026

Source:Ville de Paris

ITS Services for Pedestrians - Pedestrian countdown timers at crossings

- **Intelligent Transportation Systems (ITS) play a crucial role in making cities walkable and inclusive. For pedestrians, ITS goes beyond traditional traffic lights.**
- **Pedestrian countdown timers at crossings** – inform users how much time remains to cross safely, improving comfort and compliance. Countdown timers reduce uncertainty, helping pedestrians judge whether to cross safely or wait, which improves compliance and reduces accidents.



https://www.dreamstime.com/countdown-timer-pedestrian-crossing-traffic-light-countdown-timer-pedestrian-crossing-traffic-light-image24

ITS Services for Pedestrians - Pedestrian countdown timers at crossings

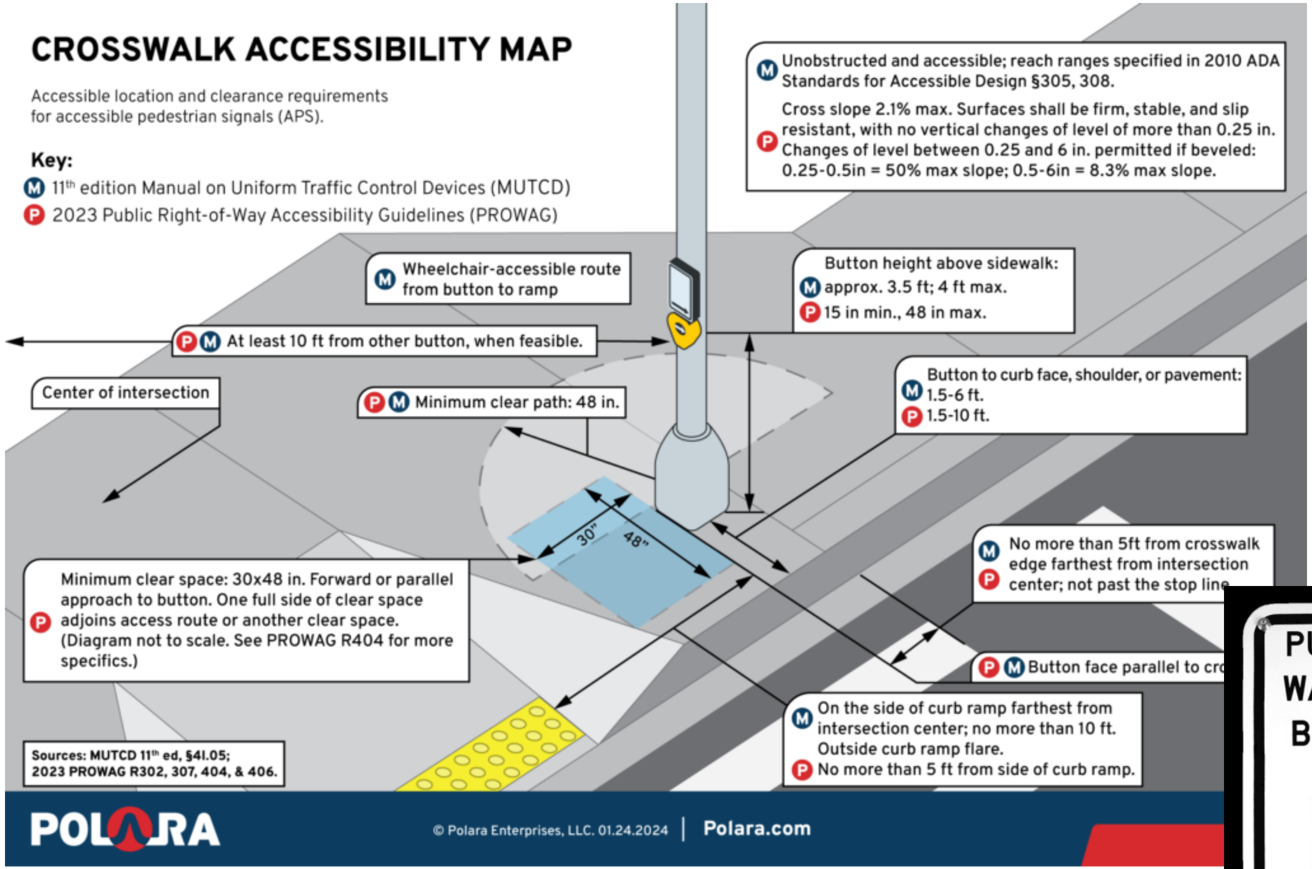
- **Advantages:**
  - Improved safety: Pedestrians know exactly how much time remains to cross, reducing last-second rushing and potential conflicts with vehicles.
  - Reduced uncertainty: Timers lower stress by eliminating the “guesswork” of how long the signal will last.
  - Better compliance: Clear information encourages pedestrians to obey signals, as demonstrated in studies from Singapore and Toronto.
  - Support for vulnerable users: Elderly or mobility-impaired pedestrians can make more informed decisions on whether to start crossing or wait.
  - Indirect benefits for drivers: Fewer pedestrians running into the crosswalk at the last second means less risk of sudden braking and rear-end collisions.

ITS Services for Pedestrians - Pedestrian countdown timers at crossings

- **Disadvantages:**
  - Risk-taking behavior: Some pedestrians may attempt to cross even with only 2–3 seconds left, increasing crash risk.
  - Limited use in adaptive signals: In ITS environments with adaptive cycle lengths, timers can be misleading if the duration changes dynamically.
  - Installation and maintenance costs: Additional electronic equipment increases capital and operational costs.
  - Accessibility limitations: Timers are not useful for blind or visually impaired pedestrians without supplementary auditory or tactile signals.
  - Cultural differences in perception: Research in the U.S. has shown mixed results, with some cities reporting that pedestrians and drivers ignore countdowns.
- **Conclusion:** Pedestrian countdown timers generally improve comfort and safety in dense urban areas with heavy foot traffic, but effectiveness depends on integration with adaptive ITS and user awareness/education. They work particularly well in cities with high pedestrian volumes (e.g., Singapore, Hong Kong, Toronto).

ITS Services for Pedestrians - Smart pedestrian push-buttons with tactile feedback

- **Smart pedestrian push-buttons with tactile feedback** – support accessibility for visually impaired users, confirming activation through vibration, sound, or braille. Smart push-buttons with tactile or auditory feedback ensure accessibility for people with disabilities, meeting inclusive design goals. For example, some systems vibrate or produce a tone when activated.



https://youtu.be/rIGWH41MyPQ

https://polara.com/guide/prowag-accessibility-requirements

ITS Services for Pedestrians - Real-time wayfinding

- **Real-time wayfinding displays for large hubs** – guide pedestrians through complex transport nodes (e.g., stations, airports) with dynamic updates on routes, exits, and disruptions.
- Real-time wayfinding in hubs such as London’s King’s Cross or Tokyo’s Shinjuku Station helps users navigate efficiently by integrating data on congestion, train departures, and accessible routes.

https://travelwayfinding.com/wayfinding-in-japan/

https://www.jcdecaux.co.uk/news/jcdecaux-introduce-new-interactive-digital-screens-london-waterloo-station

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- London (King's Cross): Interactive totems with real-time journey info, live train updates, disruption alerts.
- Tokyo (Shinjuku): Dynamic signage with crowd management, platform info, congestion levels.
- Shared features: Accessibility support, multi-language, integration with MaaS

https://travelwayfinding.com/wayfinding-in-japan/

https://www.jcdecaux.co.uk/news/jcdecaux-introduce-new-interactive-digital-screens-london-waterloo-station

ITS Services for Pedestrians - Weather-Responsive Signal Timing

- Weather impacts behavior of drivers and pedestrians
- Traffic Control Strategies suitable for typical situations do not provide expected level of satisfaction for users during harsh weather conditions
- Active Mobility users are especially affected, because they are exposed to precipitation, cold and heat
- At the same time traffic lights are usually designed to provide best possible Level of Service for drivers, while providing green light for pedestrians and cyclists is an inconvenient necessity
- We aim to improve the conditions for Active Mobility users when the weather conditions are bad

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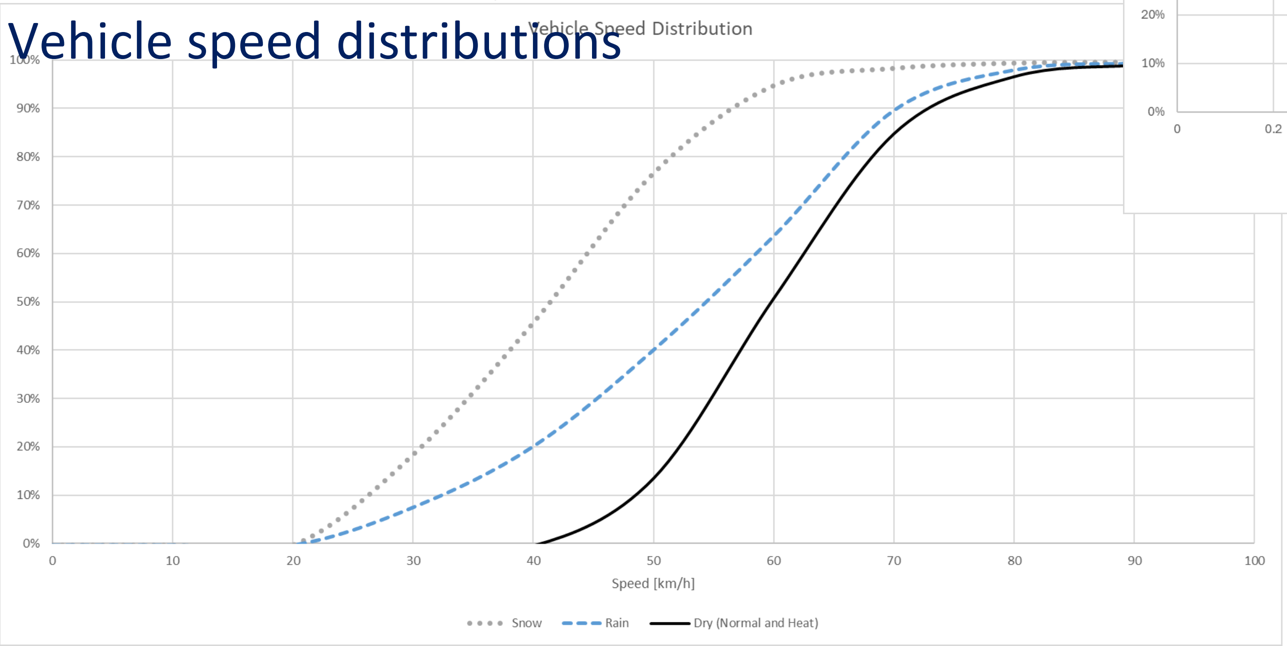
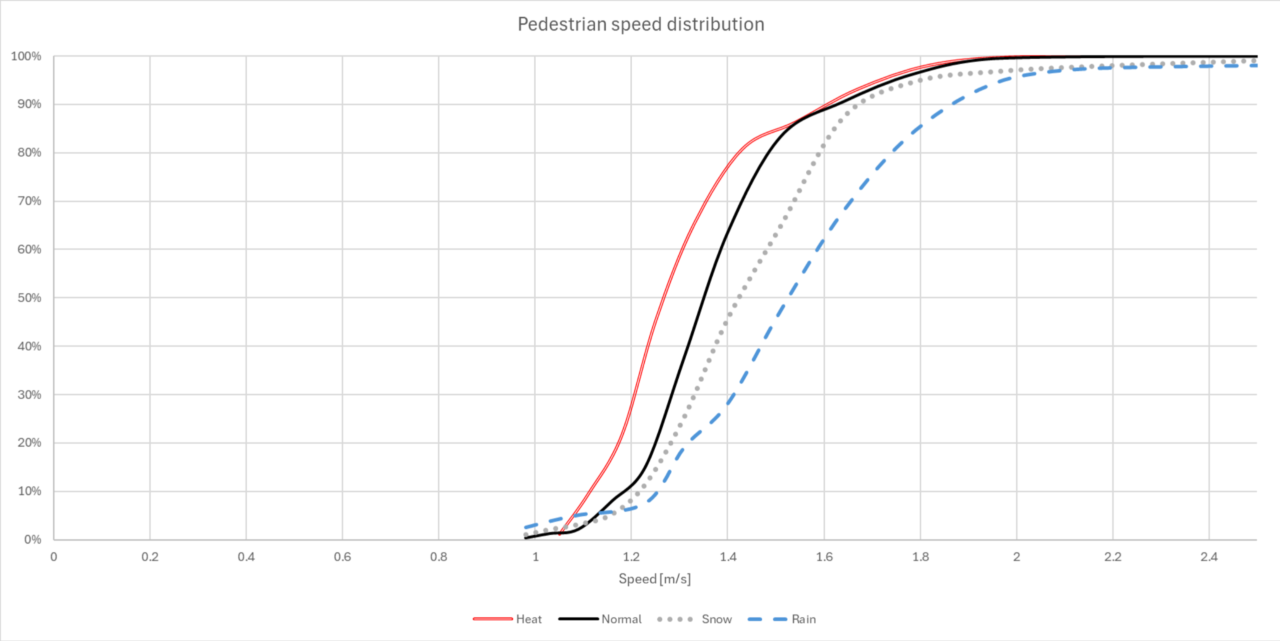
ITS Services for Pedestrians - Weather-Responsive Signal Timing

- Analysed weather conditions
  - Normal – between 10˚C and 20˚C, no precipitation
  - Heat – 23˚C and scorching sun
  - Rain – between 10˚C and 20˚C, rainfall
  - Snow – around 0˚C, snowfall
- Vehicle speed distributions



- Pedestrian speed distributions



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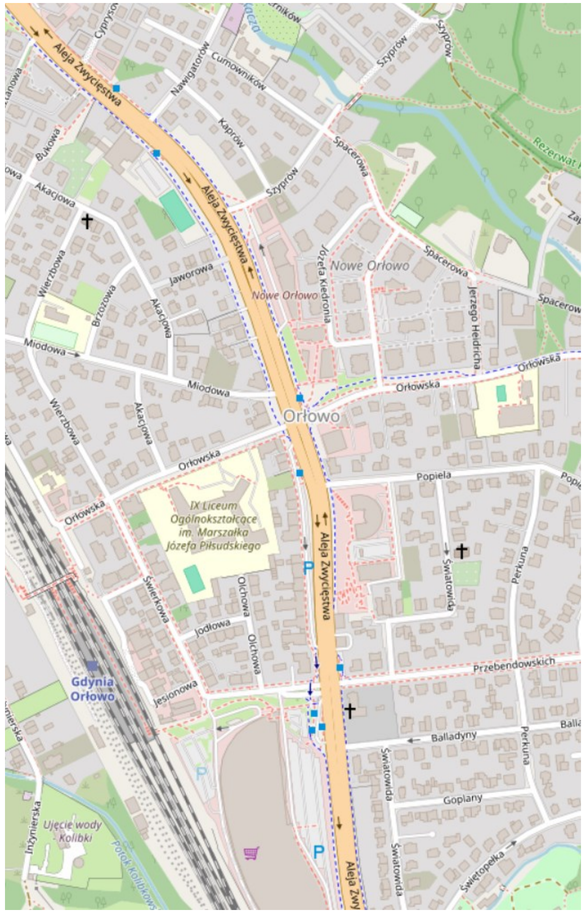
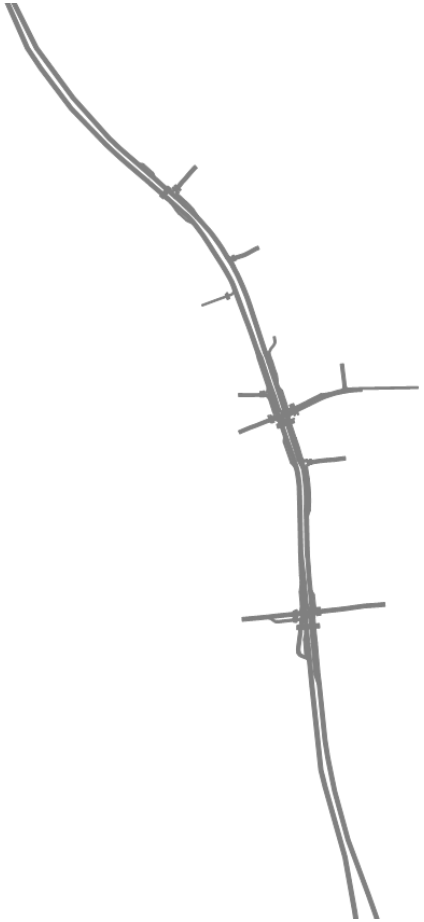
ITS Services for Pedestrians - Weather-Responsive Signal Timing

- Scope of the model





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ITS Services for Pedestrians - Weather-Responsive Signal Timing

- Tested traffic control strategies

Program	Pedestrian speed [m/s]	Max Pedestrian waiting time [s]	Cycle time [s]	Prefered conditions
3	1,2	99	120	Normal
5	1,2	59	80	Precipitation
6	1,4	52	70	Precipitation
7	0,86	93	120	Heat*
8	0,86	58	85	Heat*

*or unfavourable pavement conditions, resulting in significantly lower pedestrian speed because of obstacles like snowdrifts or precautions due to slippery surface

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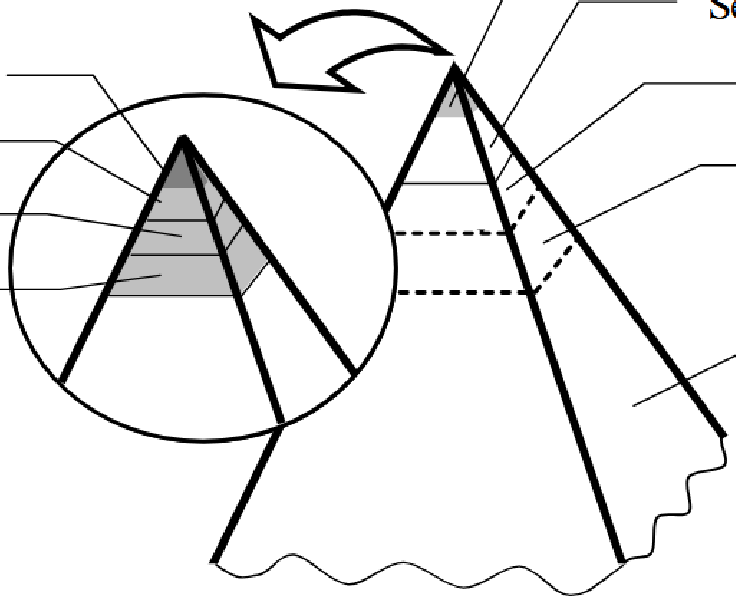
ITS Services for Pedestrians - Weather-Responsive Signal Timing

- „Safety Pyramid”



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ITS Services for Pedestrians - Weather-Responsive Signal Timing

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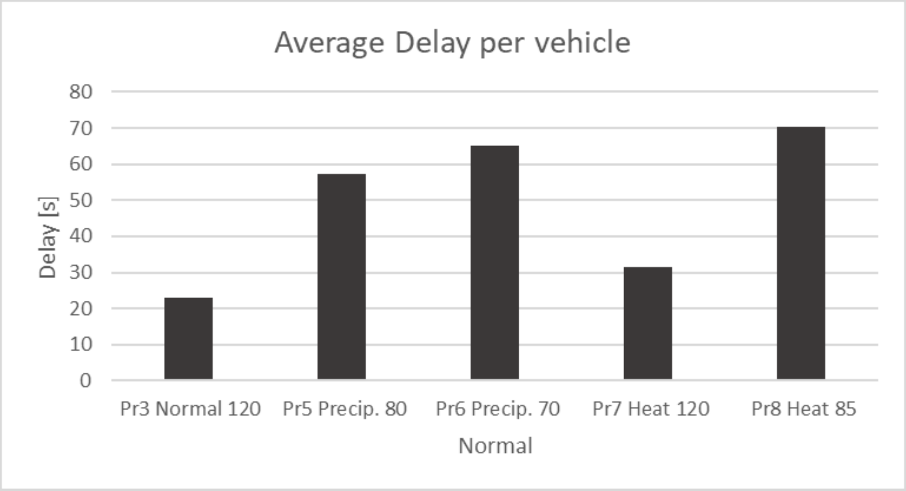
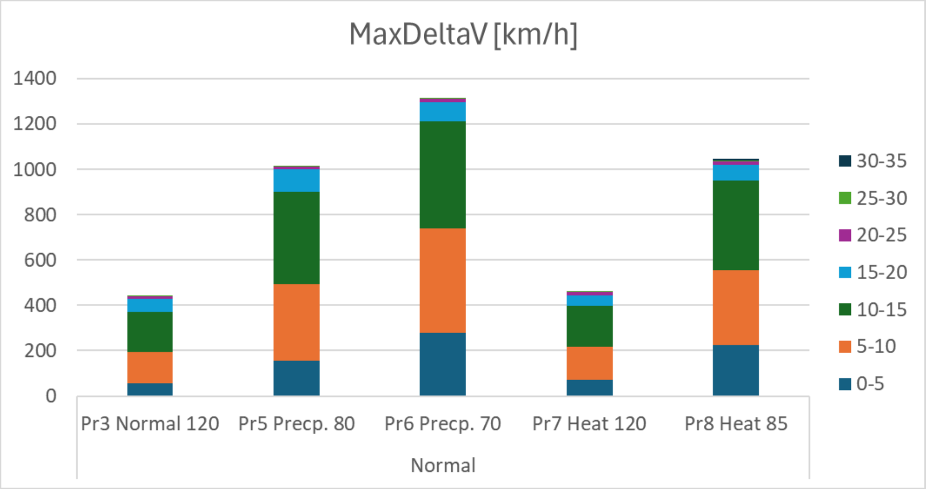
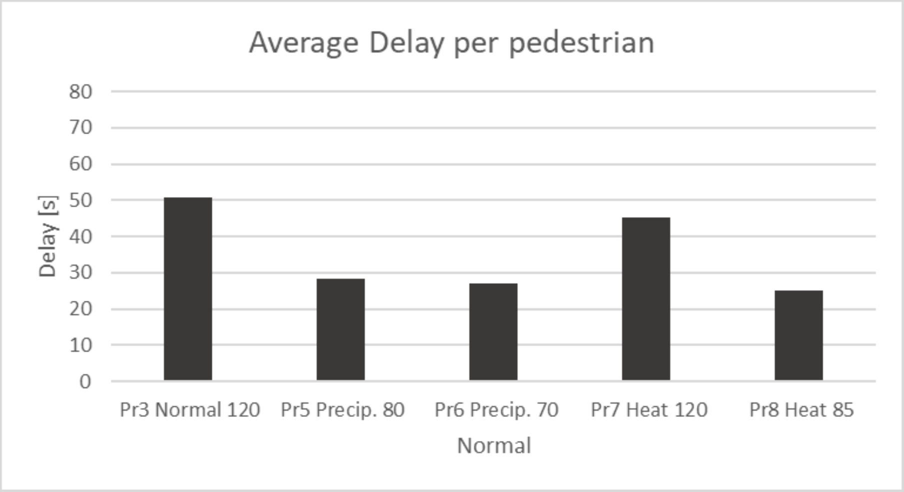
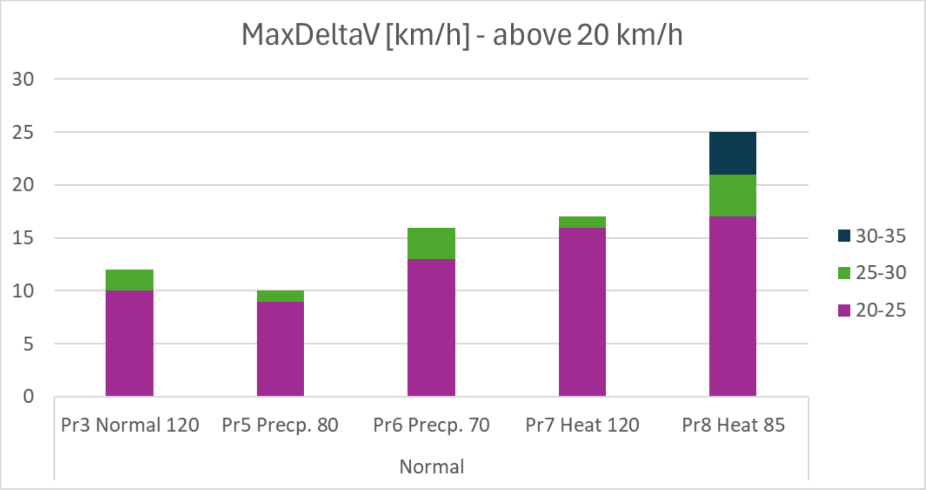
- Results – Normal conditions









ITS Services for Pedestrians - Weather-Responsive Signal Timing

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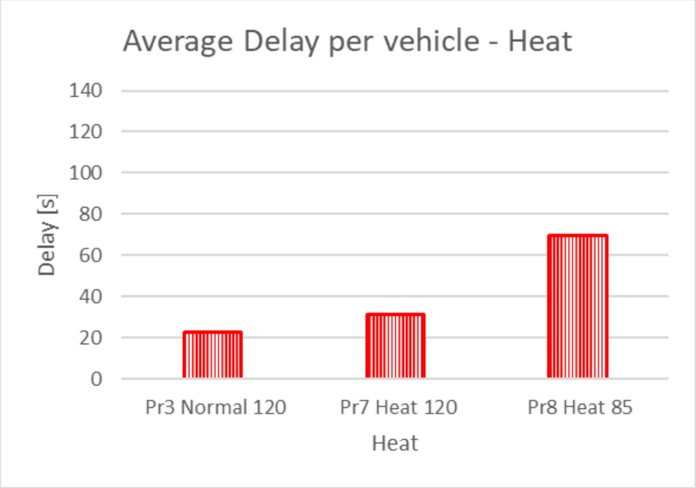
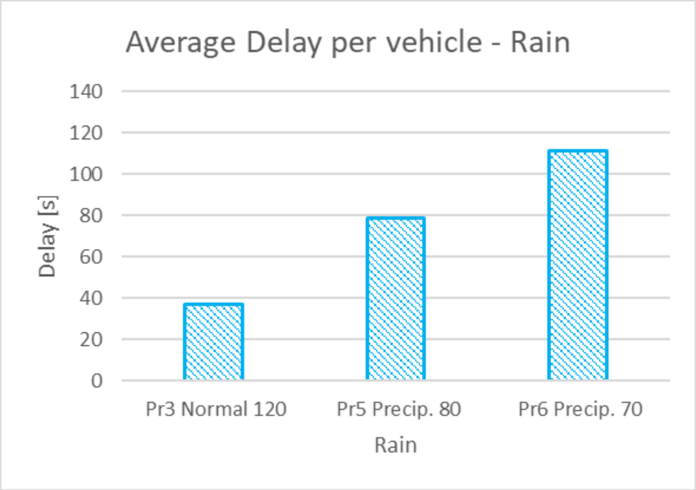
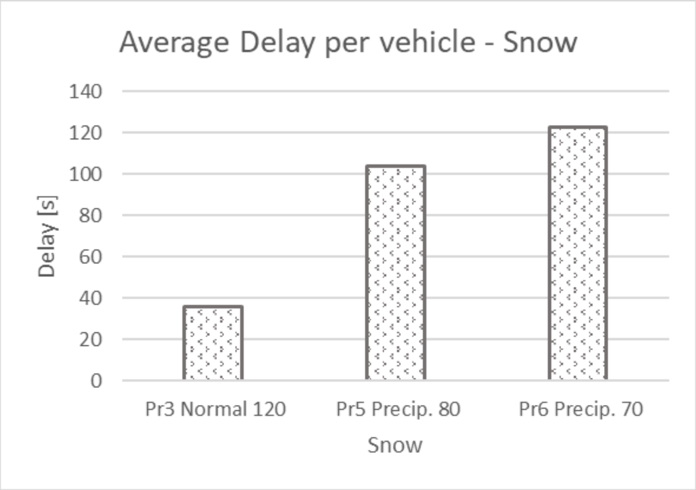
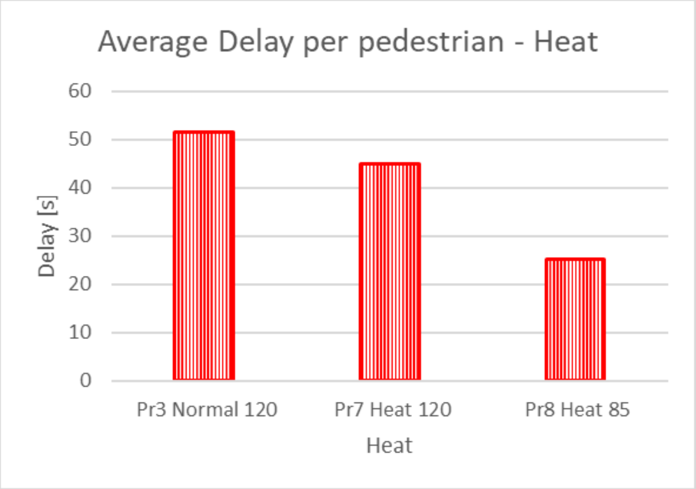
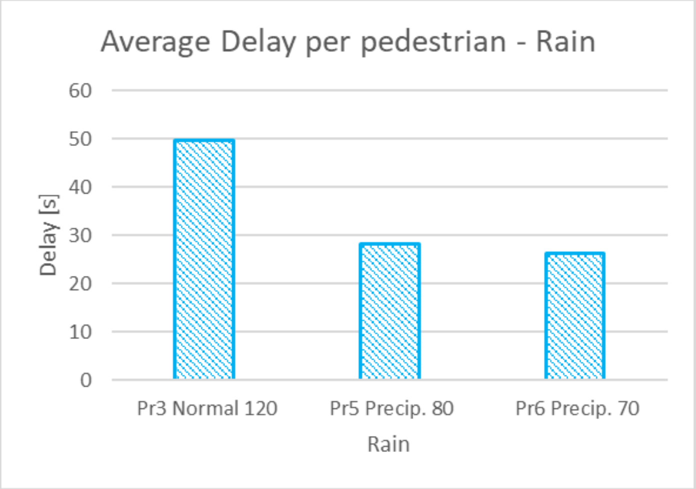
- Results - delays

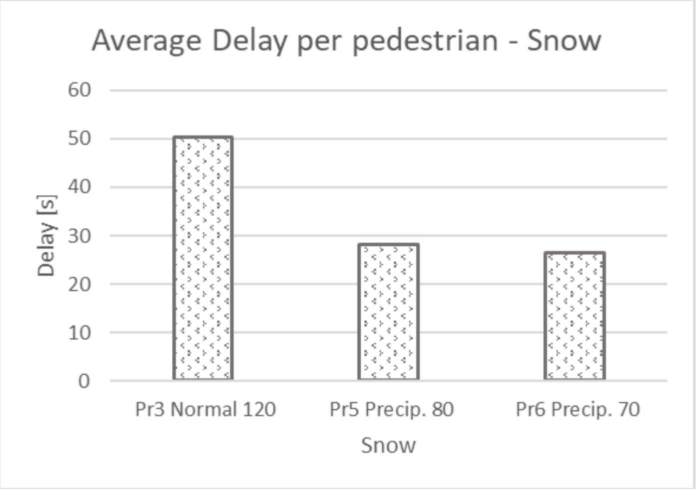












ITS Services for Pedestrians - Weather-Responsive Signal Timing

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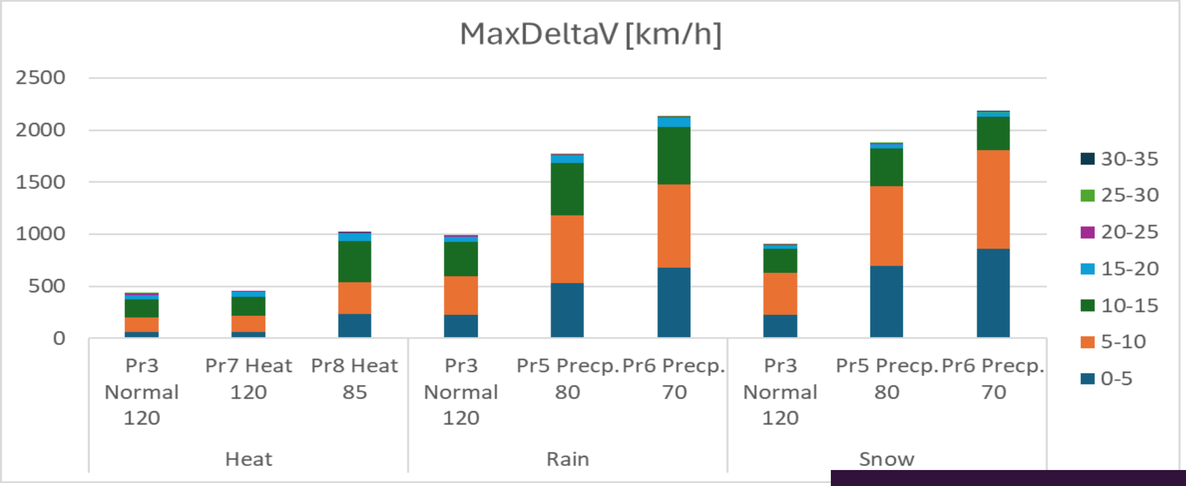
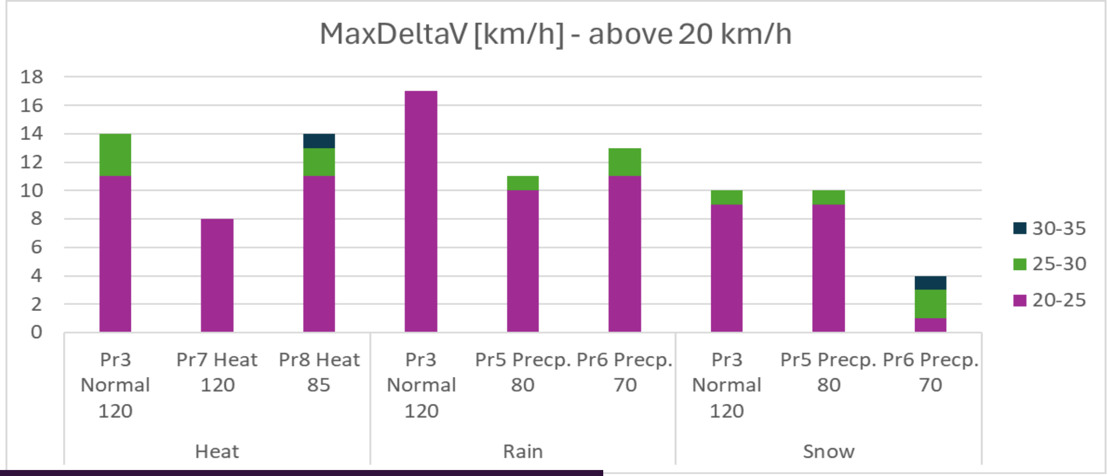
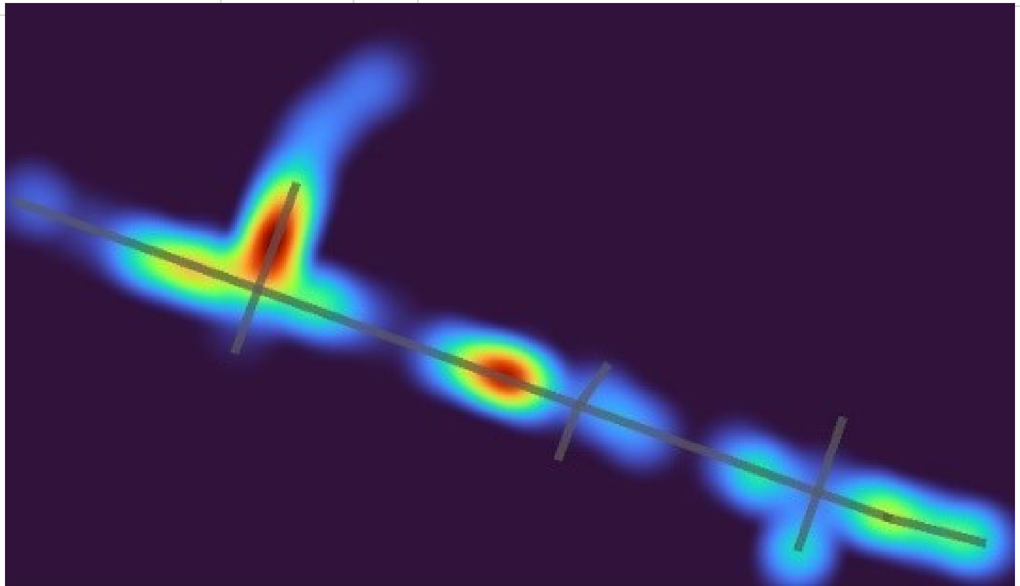
- Results – surrogate safety measures







ITS Services for Pedestrians - Weather-Responsive Signal Timing - Summary

- Weather conditions significantly influence the behaviour of road users, including both drivers and pedestrians. Active mobility users (such as pedestrians and cyclists) are especially vulnerable to adverse weather, including rain, snow, and heat.
- Conventional traffic control strategies are typically optimised for vehicular traffic, while pedestrian and cyclist phases are often treated as secondary and inconvenient necessities within the signal programme.
- Simulation-based analyses and surrogate safety measures indicate that traffic signal adjustments can improve both efficiency and safety, particularly for vulnerable road users, under adverse weather conditions.

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ITS Services for Pedestrians - Weather-Responsive Signal Timing - Recommendations

- Pedestrian speeds are affected differently depending on the type of adverse weather: during rainfall, pedestrians often walk faster to avoid getting wet, while in conditions such as heat, they tend to slow down due to discomfort. These variations should be considered when designing signal timings.
- It is recommended that signal cycle lengths and green light durations for pedestrians be adapted dynamically in response to prevailing weather conditions. This approach can reduce delays for pedestrians and enhance safety for all users.
- Implementing weather-dependent signal control strategies including adjustment of signal parameters based on temperature, precipitation, or pavement conditions has shown promising results. Such measures may play a key role in supporting and encouraging active mobility in challenging weather.

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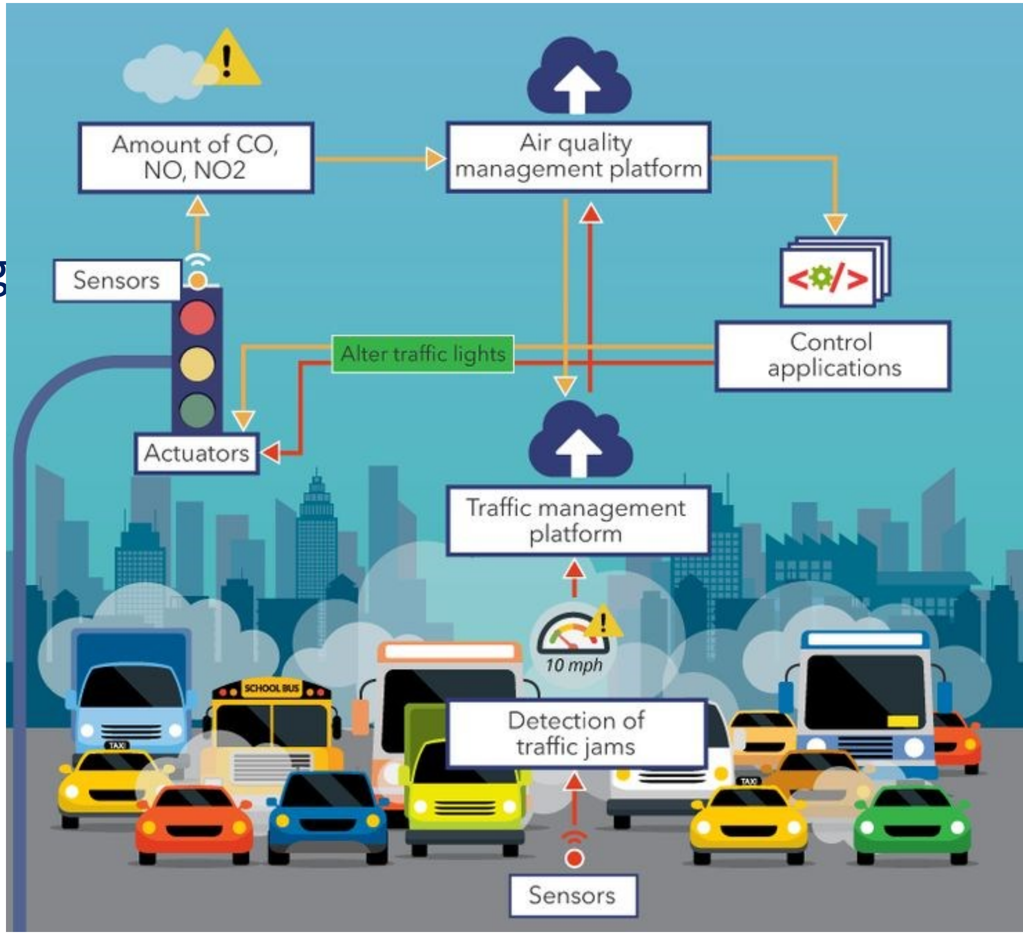
ITS Services for Cyclists

- **Data-driven decision-making** – leveraging traffic data from sensors, GPS, connected vehicles, and mobile devices to guide strategic and operational planning. Data-driven decision-making means cities no longer rely only on periodic traffic counts or surveys; instead, they use continuous streams of data to detect patterns and optimize network performance.
- **Real-time operations management** – enabling dynamic control of traffic lights, lane usage, speed limits, and public transport scheduling. Real-time operations management ensures that the transport system reacts instantly to incidents, congestion, or demand changes—keeping traffic flowing and improving reliability.
- **Enhancing user experience** – providing travelers with accurate, real-time information on travel times, routes, and disruptions via apps, websites, and digital displays. Enhancing user experience is critical for encouraging modal shift. When travelers have access to real-time, accurate, and reliable information, they are more likely to choose public transport or active modes.



Source: "IoT for Smart Cities: Use Cases and Implementation Strategies" via Pinterest

ITS Services for Cyclists

- **Cyclist-focused ITS improves safety, efficiency, and attractiveness of cycling as a daily transport mode.**
- **Bicycle detection at traffic signals** – automatic detection (induction loops, cameras, thermal sensors) enables signal adjustment, reduced waiting time, and priority for cyclists. Bicycle detection supports signal priority, making cycling more competitive with motorised traffic.
- **Green wave corridors for bikes** – signal coordination based on cycling speed (18–20 km/h) to improve flow and reduce stops.
- **GLOSA for cyclists (Green Light Optimal Speed Advisory)** – mobile apps or roadside displays advising the optimal speed to catch the next green light, reducing unnecessary stops and energy use.
- Green waves and GLOSA are key innovations: Green waves support continuous flows on major cycling corridors. GLOSA provides individualised speed advice to optimise energy, safety, and comfort.

https://copenhagenize.com/2014/08/the-green-waves-of-copenhagen.html

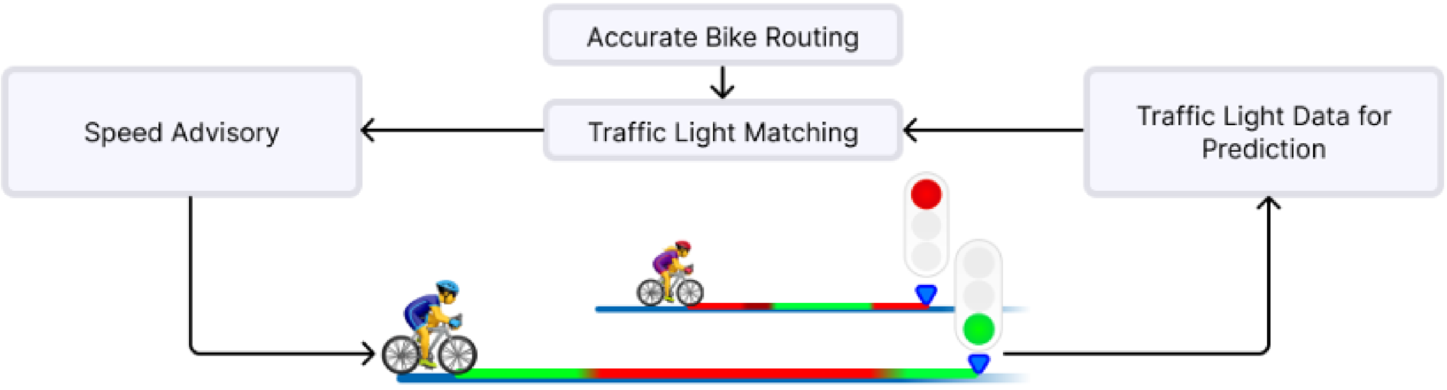
ITS Services for Cyclists

- **Green wave corridors for bikes** – signal coordination based on cycling speed (18–20 km/h) to improve flow and reduce stops. Some cities (e.g., Copenhagen) implement cyclist-specific green waves by linking traffic signals on main cycling arteries, enabling smoother, continuous flow at moderate cycling speeds. green waves ensure synchronized signal progression for groups of cyclists.

https://copenhagenize.com/2014/08/the-green-waves-of-copenhagen.html

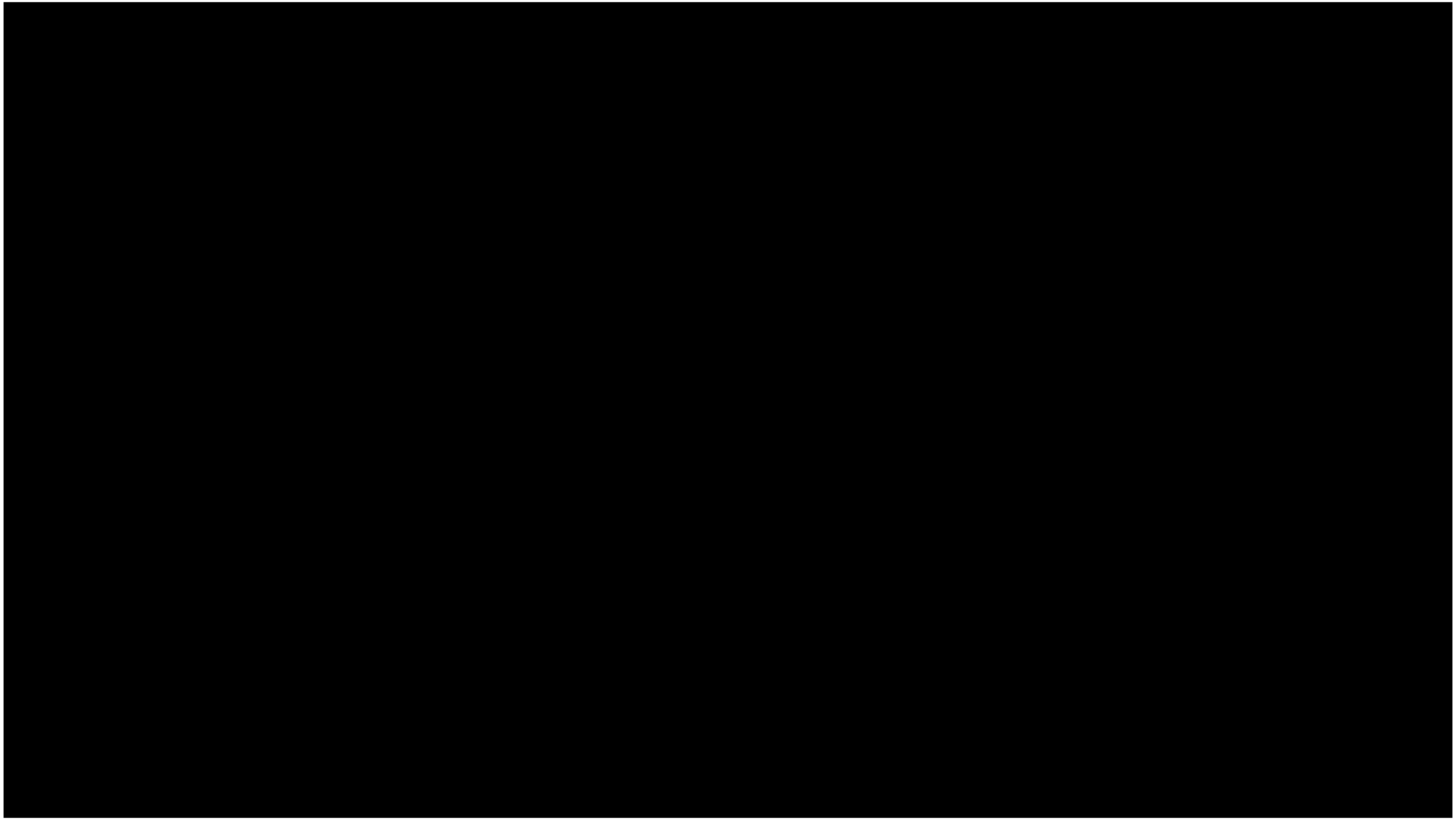
ITS Services for Cyclists

- **GLOSA for cyclists** (Green Light Optimal Speed Advisory) – mobile apps or roadside displays advising the optimal speed to catch the next green light, reducing unnecessary stops and energy use. GLOSA systems use infrastructure-to-vehicle communication to predict traffic signal phases and provide cyclists with optimal speed guidance to hit successive greens, enhancing ride comfort and flow. GLOSA offers personalized, real-time speed recommendations to minimize stops, smooth journey dynamics, and potentially reduce environmental impact



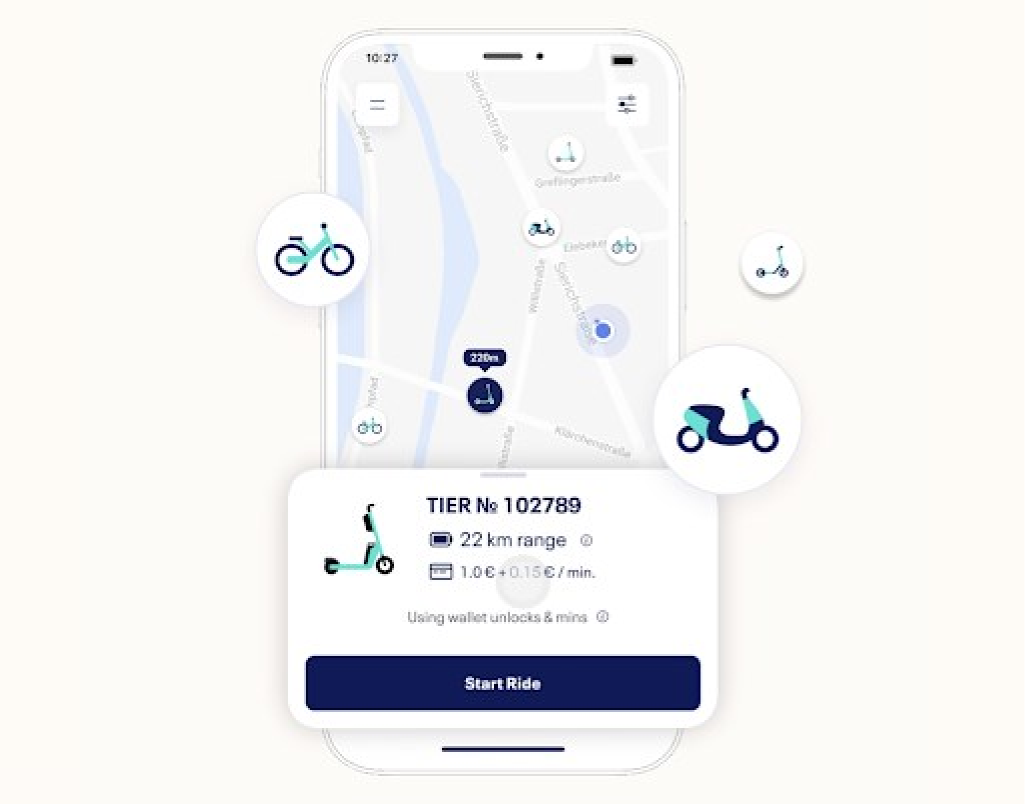
Source: https://tud.qucosa.de/api/qucosa%3A92544/attachment/ATT-0/

ITS Services for Cyclists



ITS Services for Cyclists

- **Digital bike counters & real-time parking availability** – displays that count cyclists and provide parking space availability at hubs (e.g., stations, interchanges). Digital counters and parking information increase both policy monitoring and user motivation by showing the visibility of cycling.
- **Integration with MaaS & navigation apps** – real-time data on cycle routes, weather, bike-sharing availability, and infrastructure conditions .
- **Safety-enhancing ITS tools** – warning lights for cars at bike crossings, smart path lighting activated by cyclists, collision detection at intersections. MaaS integration positions cycling as a fully integrated element of the multimodal transport system.



Source: *https://www.mapbox.com/insights/mobility-as-a-service-maas*

ITS Services for Cyclists

- **Digital bike counters & real-time parking availability** – displays that count cyclists and provide parking space availability at hubs (e.g., stations, interchanges). Digital counters and parking information increase both policy monitoring and user motivation by showing the visibility of cycling.
  - Electronic bicycle counters (also called “bike barometers”) detect and display cyclist numbers and often encourage cycling by raising awareness; they aid planning and serve as public-facing, persuasive urban visualizations.
  - Smart digital kiosks linked to sensor systems can display real-time counts of cyclists (and pedestrians), promoting active travel and illustrating usage trends Future Systems.
  - Some systems—like in Münster, Germany—simultaneously recognize and count incoming bicycles and report available parking spaces, improving user convenience.

Source: *https://www.futuresystems-inc.com/news/digital-cycle-counters*

https://youtu.be/nh_jgdYlwJc

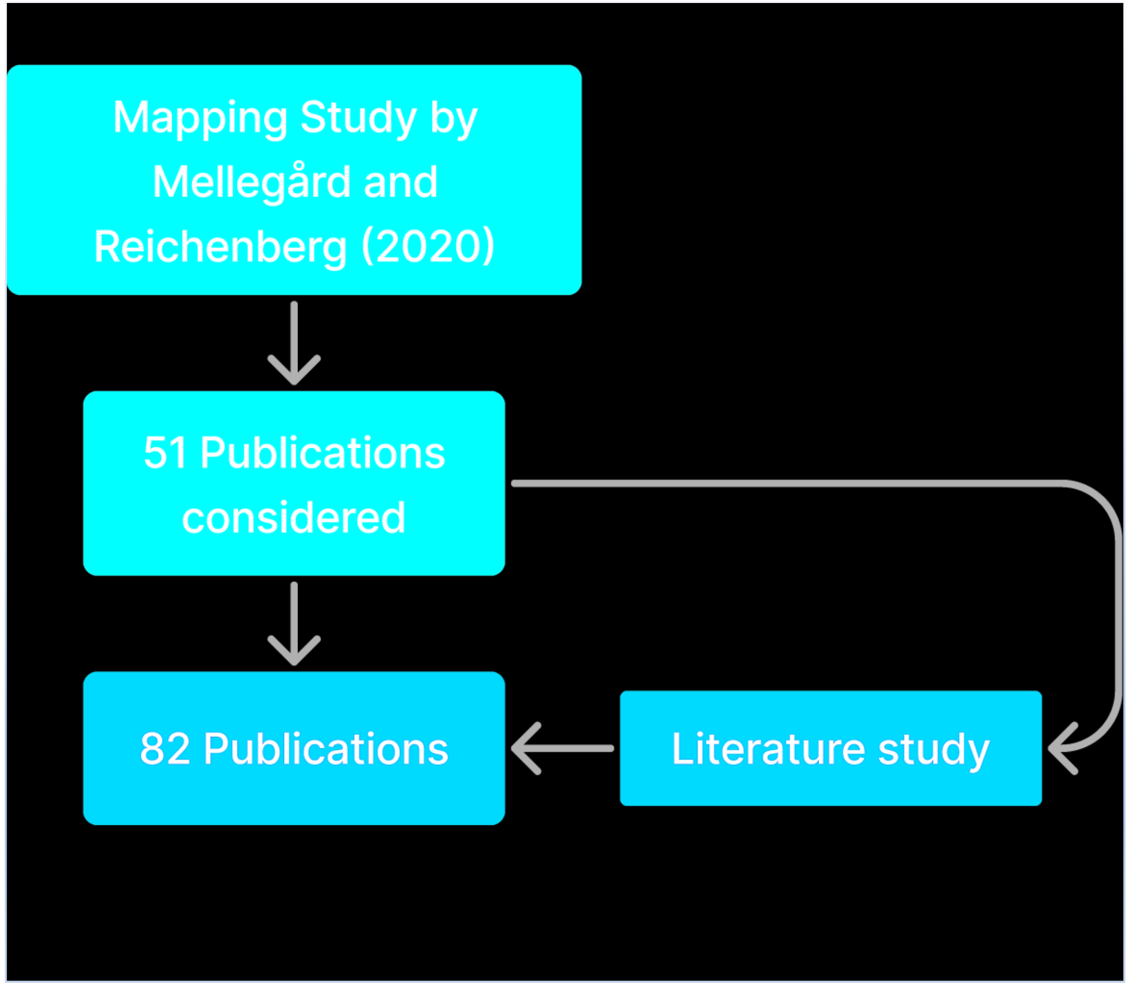
ITS Services for Cyclists

- **Example Cities:**
  - Amsterdam – traffic lights detecting bike platoons to extend green.
  - Copenhagen – green waves at 20 km/h on main corridors.
  - San Francisco – digital counters on Market Street.
  - Hamburg – real-time bike parking availability at rail stations.
  - Vienna (pilot) – GLOSA for cyclists tested via roadside displays and apps.

The Market Street bicycle counter. Photo: Aaron Bialick https://sf.streetsblog.org/2013/05/10/market-bike-counter-3231-cyclists-in-a-day-and-thats-an-underestimate

ITS Services for Cyclists - Motivation & Research Objectives

- **Cycling is key for sustainable mobility. ITS can reduce barriers such as waiting at signals, unsafe crossings, and lack of integration.**
- **Objectives:**
  - Test ITS services (Bike-GLOSA, Green Waves, Digital Counters)
  - Evaluate effects on efficiency, safety, and comfort.



$$B\_ITS = \alpha \cdot \Delta T + \beta \cdot \Delta S + \gamma \cdot \Delta C$$

where:

ΔT – reduction in travel time,

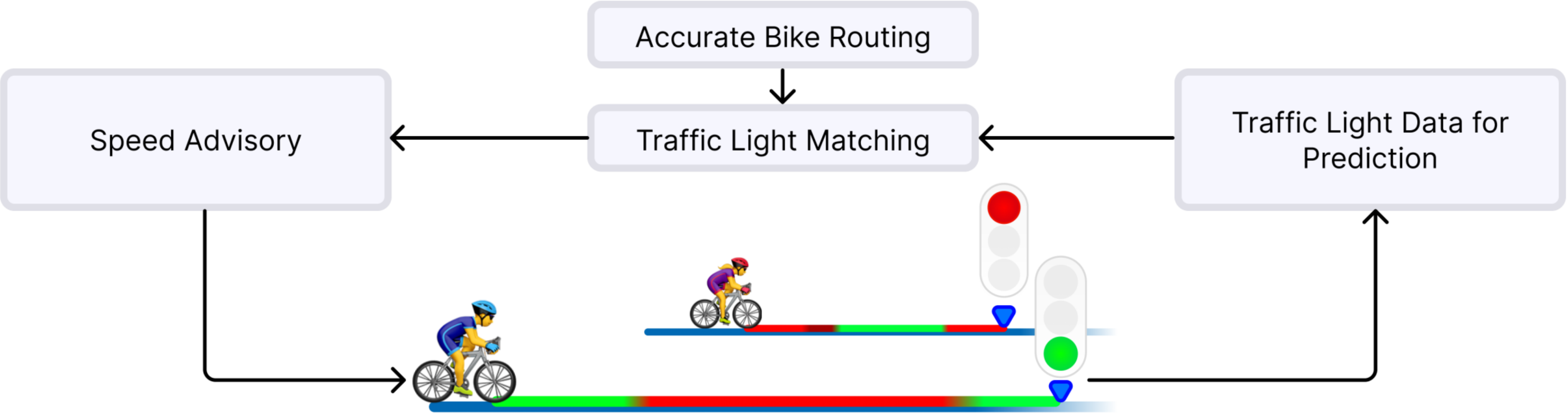
ΔS – increase in safety metrics,

ΔC – increase in comfort/acceptance,

α, β, γ – weights from surveys & policy priorities.

ITS Services for Cyclists - Methodology: Mixed Approach

- **Methods:**
  - Field pilots: Hamburg (PrioBike), Münster (Leezenflow), Vienna (bike-GLOSA).
  - Microscopic simulation (VISSIM/AIMSUN) to evaluate delays and stops.
  - Surveys on perceived comfort and acceptance.
  - Data analysis - Indicators: Stop frequency (fs), Travel time (t), Perceived comfort score (Likert scale).
- **Formula:**
  - $Q_{cycle}=(t_{free}-t_{actual})/t_{free}$
  - **Cycling quality indicator as ratio of free-flow to actual travel time.**



Green Light Optimal Speed Advisory for Bikes
Dipl.-Inf. Philipp Matthes
Dissertation

ITS Services for Cyclists - Perceived comfort score (Likert scale)

- **Definition:** The perceived comfort score is a subjective evaluation of a cyclist's riding experience, measured using a Likert scale (typically 5- or 7-point). It captures the psychological and experiential dimension of using cycling infrastructure or ITS interventions, beyond purely technical metrics like travel time or stop frequency.
- **Methodology:** Respondents (cyclists) are asked to rate their perceived comfort when using infrastructure or services such as bike-GLOSA, green waves, or smart detection systems.
- **Example Likert scale (5-point):**1 = Very uncomfortable; 2 = Uncomfortable; 3 = Neutral; 4 = Comfortable; 5 = Very comfortable
- **Surveys are conducted before and after interventions to measure changes in perception.**

ITS Services for Cyclists - Perceived comfort score (Likert scale)

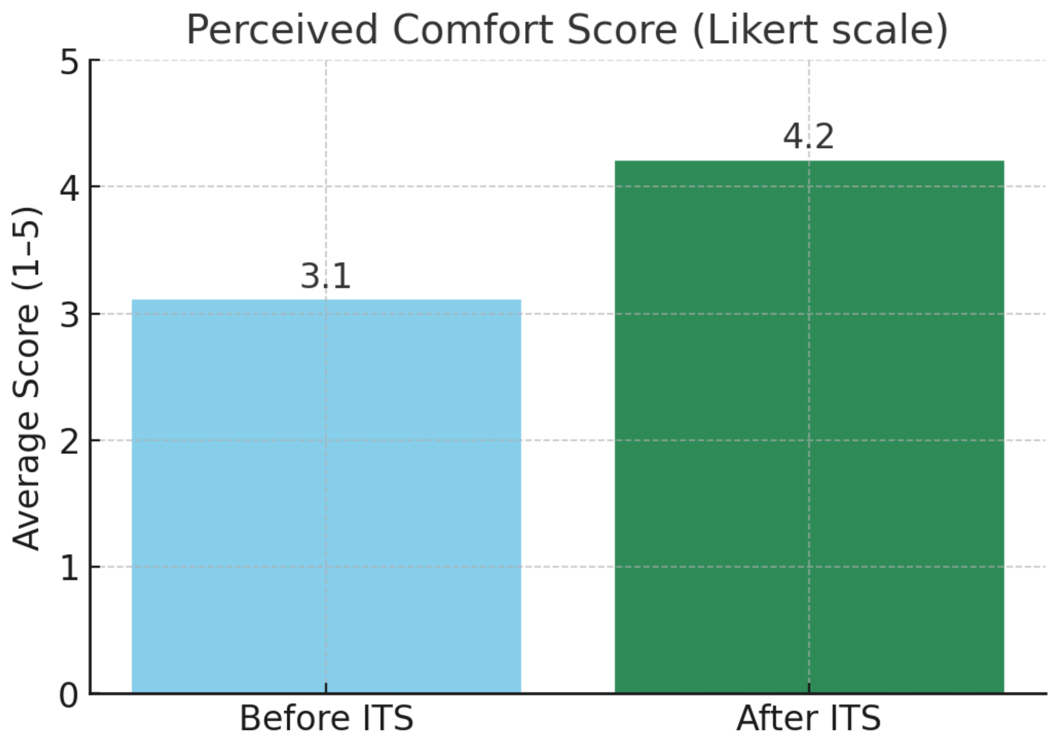
- **Application in Research:** Used in pilot projects (e.g., Münster Leezenflow and Hamburg PrioBike).
- In Münster, 75.9% of respondents reported an increased comfort score after implementation of the green wave system.
- Comfort scores are often correlated with **willingness to cycle more frequently**, making them a proxy for modal shift potential.
- Formula (aggregation):

$$CS = \frac{1}{N}\sum_{i=1}^{N} L_i$$

- where: CS = average comfort score, Li= Likert response of participant i, N = total number of respondents.

ITS Services for Cyclists - Perceived comfort score (Likert scale)

- **Extended Analysis:**
  - Changes in comfort score can be analysed using paired t-tests or Wilcoxon signed-rank tests to test significance.
  - Comfort score can be included in multi-criteria decision analysis (MCDA) alongside technical indicators.



ITS Services for Cyclists - Results: Bike-GLOSA

- **Findings (Hamburg pilot):**
  - Reduced average stops by 15–20%.
  - Increased travel time reliability (σ reduced by ~12%).
  - Users reported +22% comfort improvement.
  - Smartphone-based detection reduces costs.
  - Challenge: cyclist speed diversity.
- Equation:

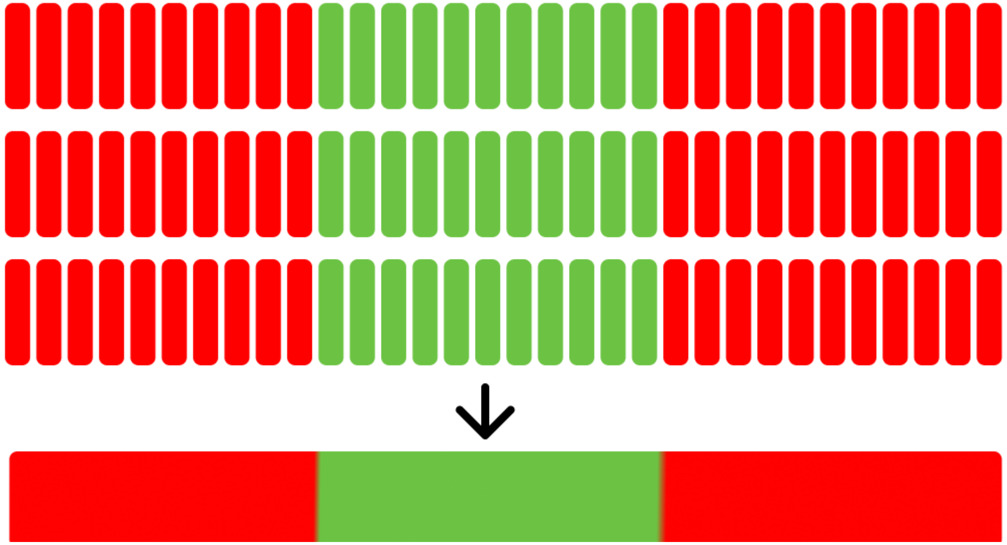
$$E[D] = \sum_{i=1}^{n} p_i \cdot d_i$$

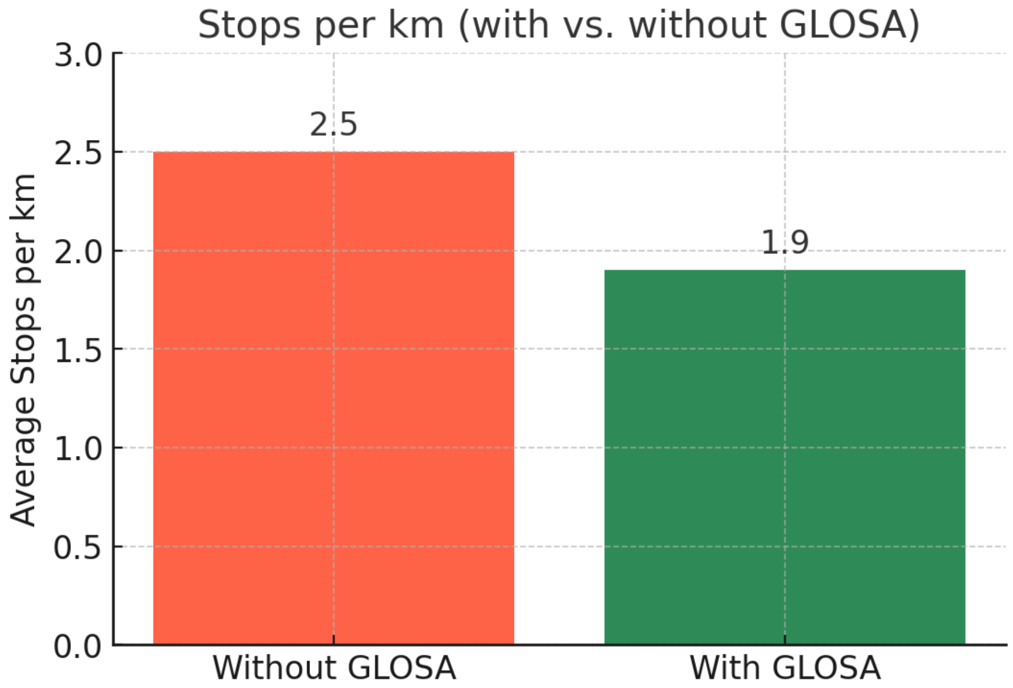
- Expected delay without GLOSA:
- where pi = probability of red light at intersection i, di = average delay.

- With GLOSA

$$E[D_{GLOSA}] = E[D] \cdot (1 - r)$$

- r = reduction factor





ITS Services for Cyclists - Results: Green Waves

- **Findings:**
- Copenhagen, Amsterdam, Münster pilots: Signal progression set at 20 km/h.
- Münster Leezenflow results: 6.6% fewer stops. 75.9% users reported higher comfort.
- Strong link between perceived comfort and mode attractiveness.
    - Formula:

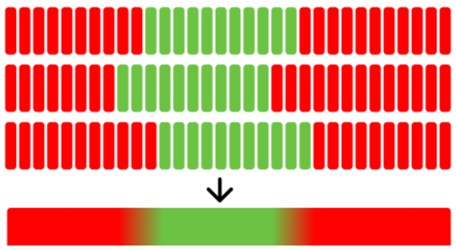
$$N_{stops} = \sum_{j=1}^{m} I(v_c \neq v_{gw})$$

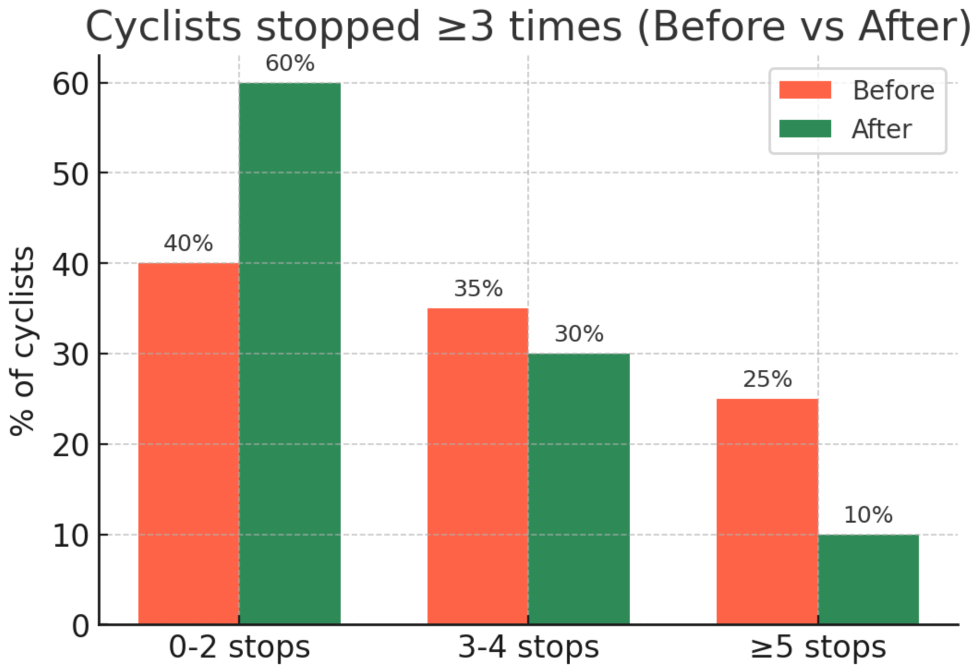
where Nstops– total number of stops a cyclist makes along a signalised corridor.

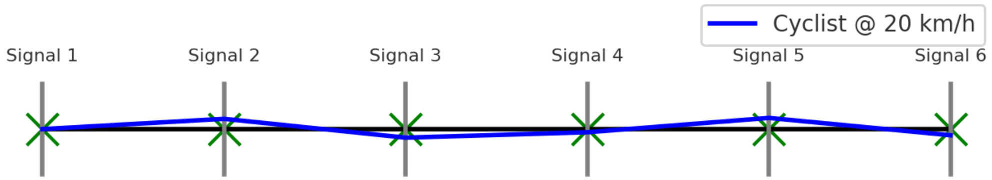
- mm – number of signalised intersections (or segments) in the corridor.

- v_c – actual cycling speed, v_{gw} – green wave progression speed (the speed needed to pass consecutive intersections during green, e.g. 20 km/h in Copenhagen).

- I(·) – indicator function, which takes the value: 1 if the condition $v_c \neq v_{gw}$ is true (cyclist does not match the green wave speed → a stop is likely) or 0 if $v_c = v_{gw}$ (cyclist rides at the green wave speed → no stop is required).





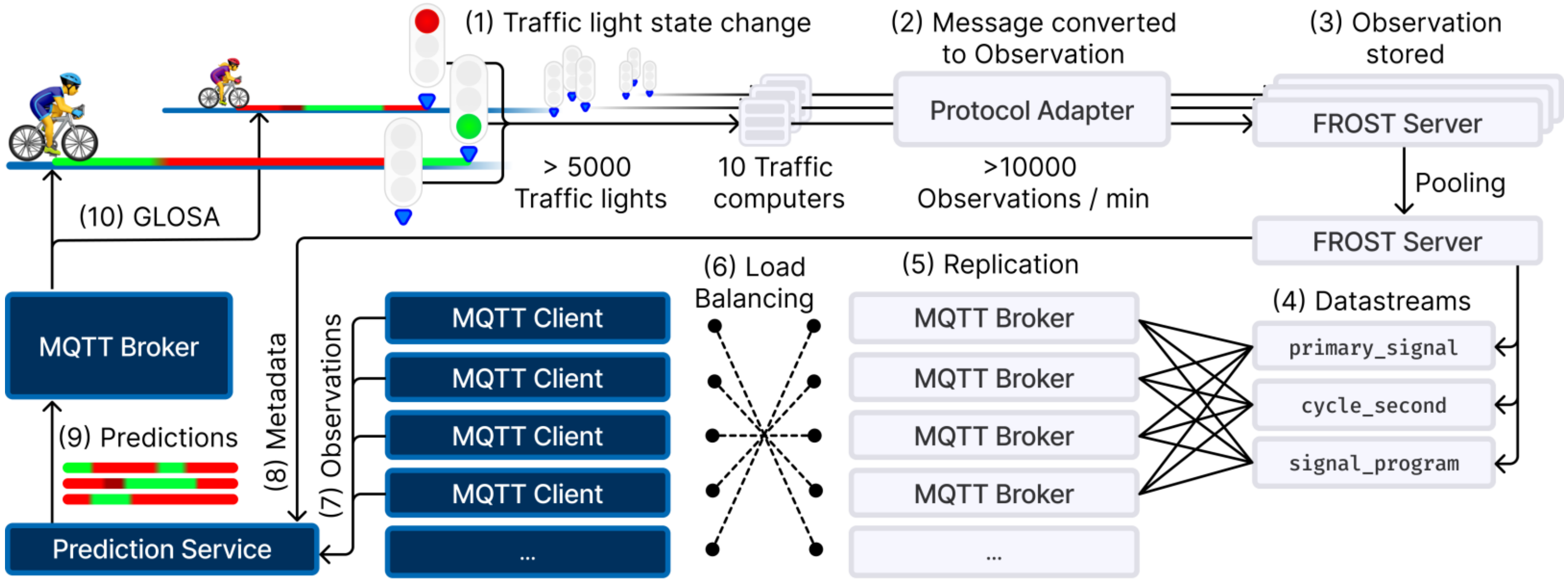


ITS Services for Cyclists - Discussion & Policy Implications

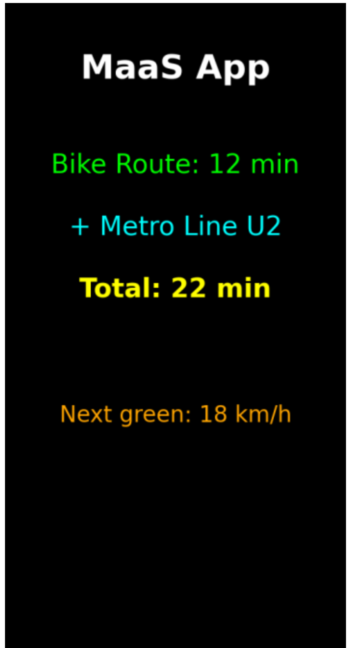
- **Triangulated methods** (pilots + simulation + surveys) confirm ITS effectiveness.
- **Key benefits:** Lower travel time variability. Improved subjective comfort & safety. Increased cycling attractiveness in MaaS systems.
- **Challenges:** Large-scale scalability. Speed diversity of cyclists. Integration with cooperative ITS and public transport.
- Equation (integration into MaaS utility):

$$U_{MaaS} = \sum_{k=1}^{K} \delta_k \cdot A_k$$

where Ak = accessibility gain of mode k, δk = user preference weight.

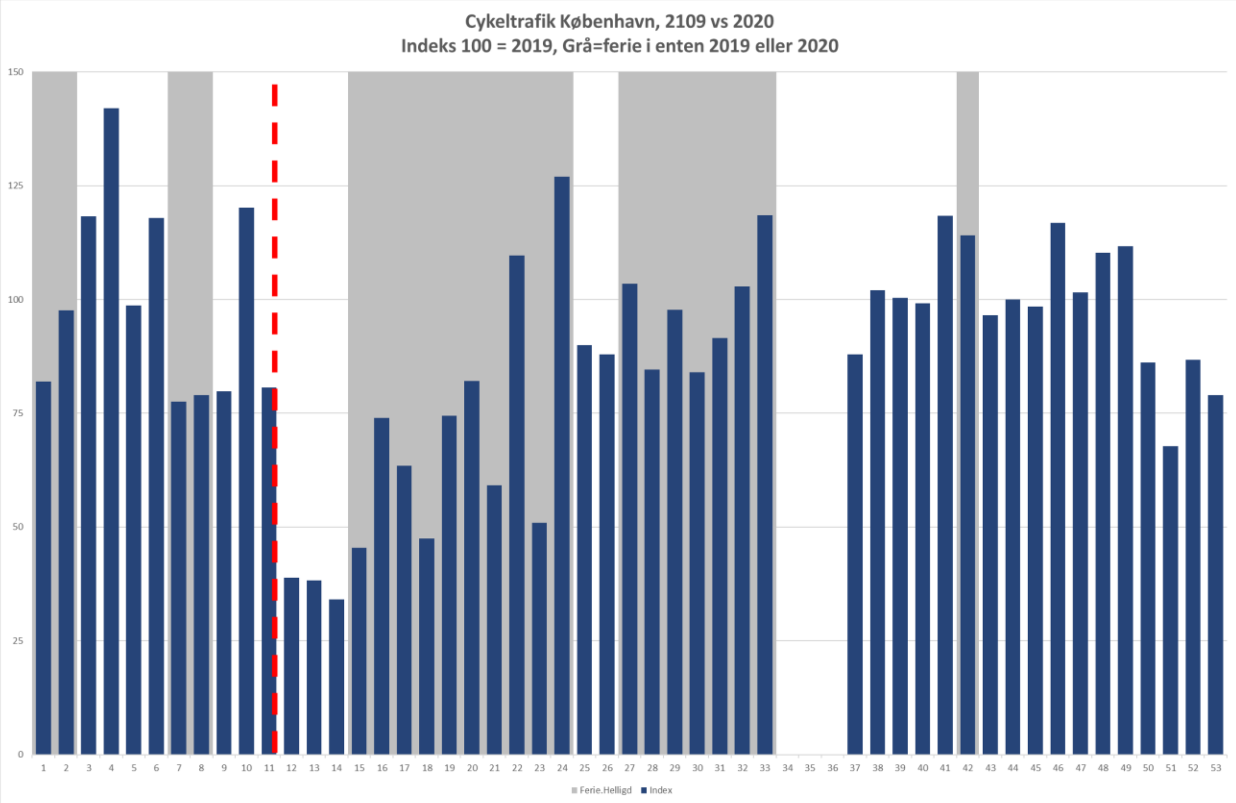


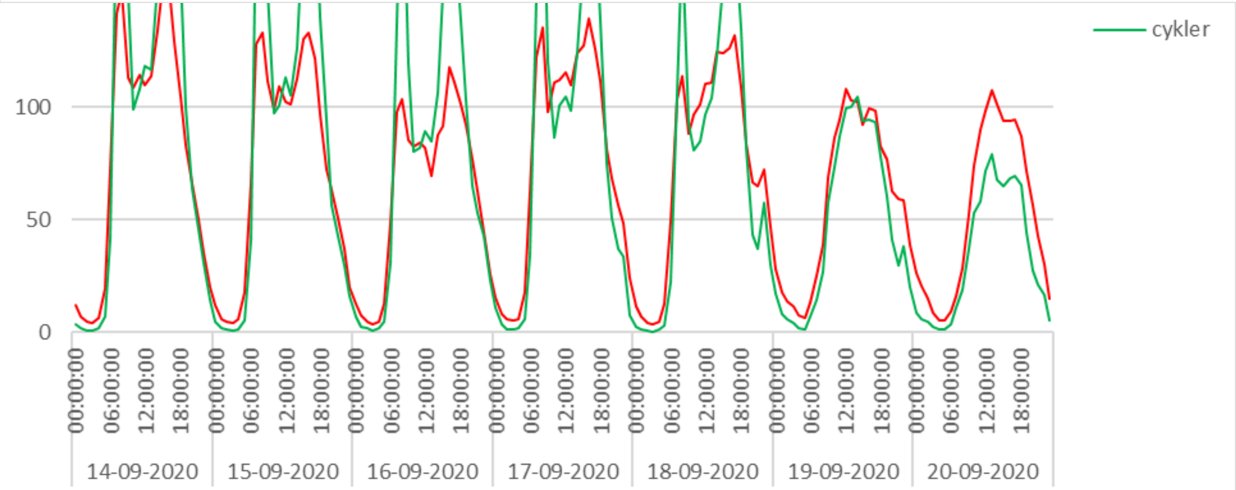
Green Light Optimal Speed Advisory for Bikes
Dipl.-Inf. Philipp Matthes
Dissertation

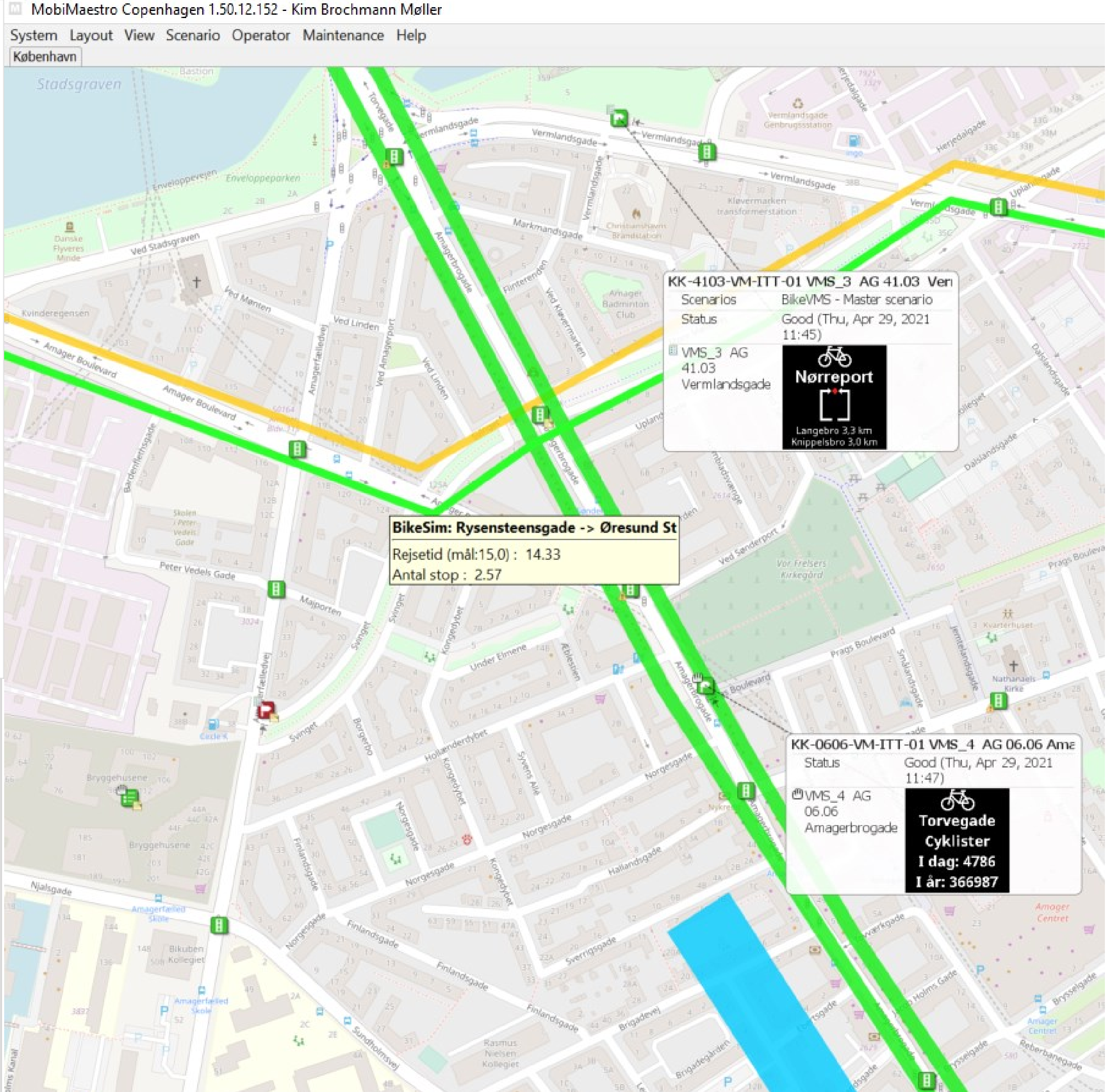


ITS Services for Cyclists - Copenhagen

Source: City of Copenhagen

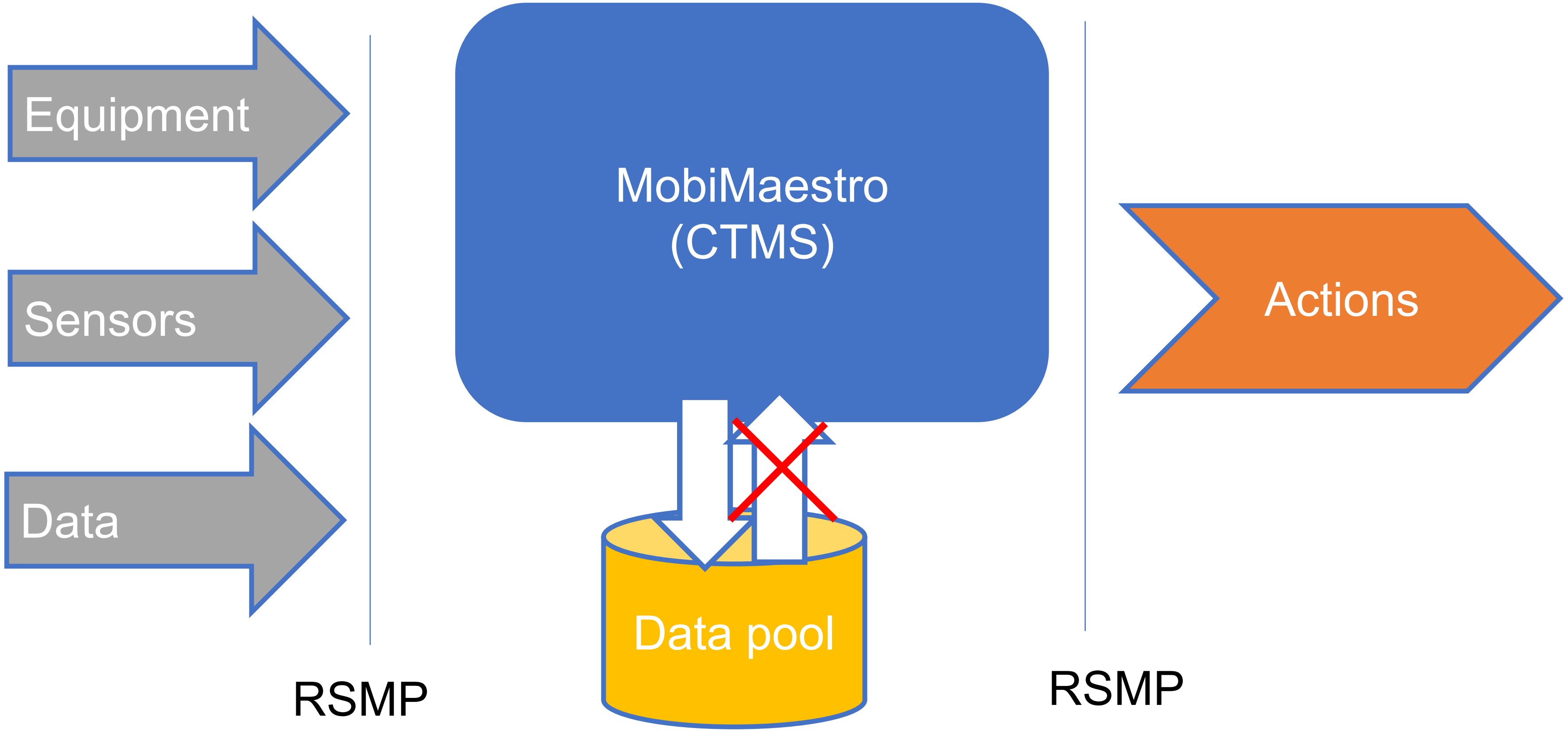






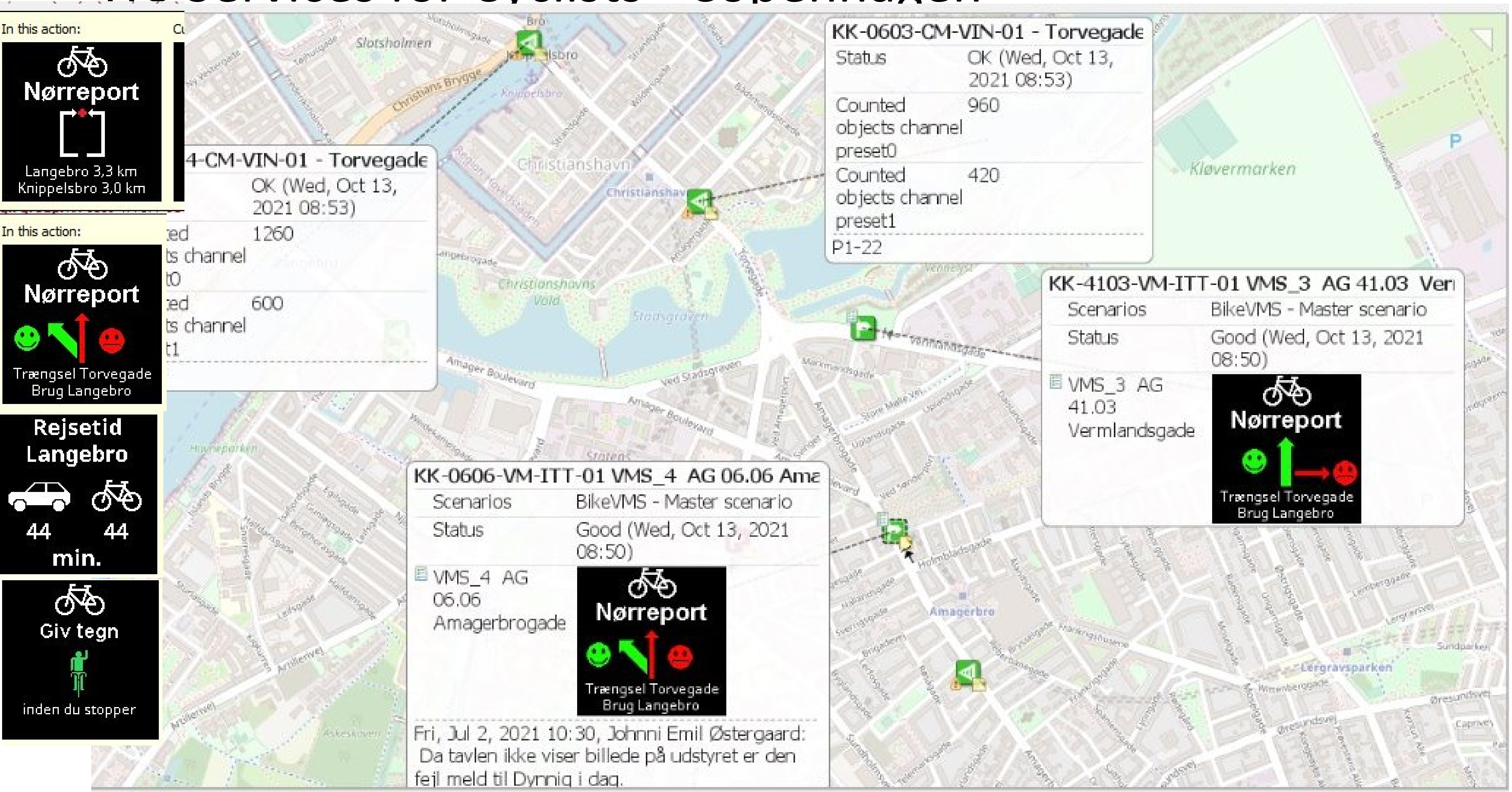
ITS Services for Cyclists - Copenhagen

Source: City of Copenhagen



ITS Services for Cyclists - Copenhagen

Source: City of Copenhagen



ITS Services for Cyclists - Copenhagen

Source: City of Copenhagen

ITS Services for Cyclists - Copenhagen

Source: City of Copenhagen

ITS Services for Cyclists - Hamburg

Source: City of Hamburg

Gefördert durch:
Bundesministerium für Digitales und Verkehr
aufgrund eines Beschlusses des Deutschen Bundestages

From Vision to Goals

Duration

- 01.01.2021 - 31.12.2024 – Budget of 7.8 Mio €, 50% reimbursement rate

Partner

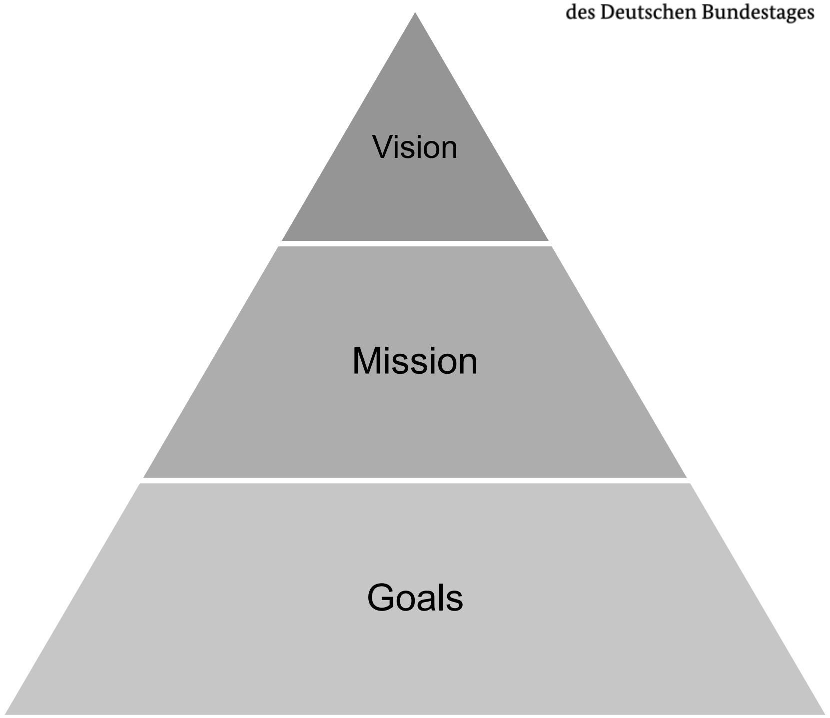
- Free and Hanseatic City of Hamburg, Technical University of Dresden, INAVET GmbH

Vision for Hamburg:

- To support the mobility transition, Hamburg is a pioneer in the digitization of cycling in Germany in 2025.

Mission for PrioBike-HH:

- Use of digital technologies to increase comfort and safety in bicycle traffic.



ITS Services for Cyclists - Hamburg

Source: City of Hamburg

Bicycle traffic counting will be expanded to provide more data for the PrioBike-HH services.

Adjustment of the traffic signal control to prioritize bicycle traffic at selected intersections.

Realization of green wave for cyclists.

Implementation of a cycling information app to provide a GLOSA and routing service to enable a digital green wave.

Development of innovative forms of interaction and their provision through various media for different fields of application of micro-mobility.

Visualization of speed recommendations or remaining green times in the infrastructure along selected bike lanes.

Warning the car driver about cyclists in the intersection area to increase the safety of cyclists.

Collection of dynamic cycling-related data and use of data from other projects to enrich the database of the PrioBike-HH services.

Ensuring permanent functioning of specific PrioBike-HH solutions and transferability to other cities.

ITS Services for Cyclists - Hamburg

Source: City of Hamburg

Green waves

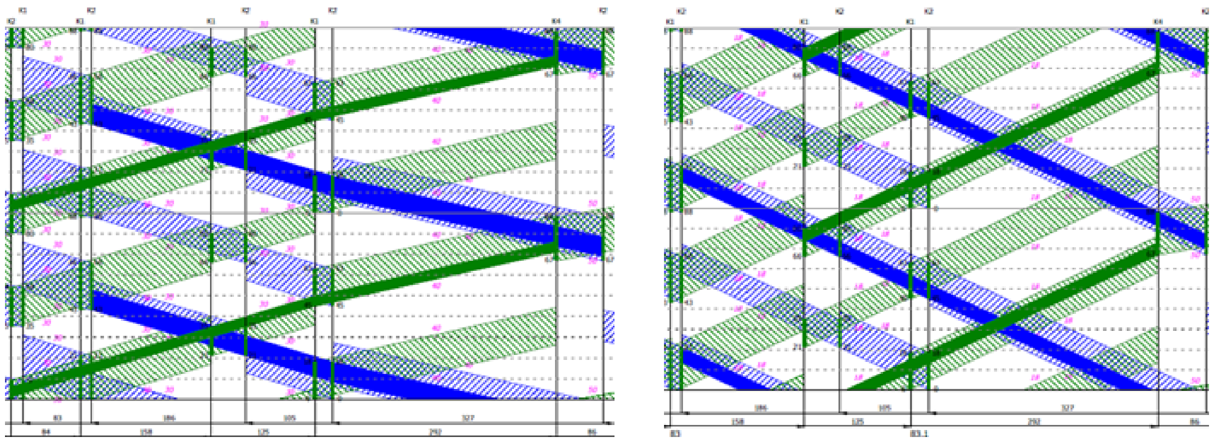
A green wave implemented for cyclists

- Five traffic lights are coordinated in a row
- For cyclists a speed of 18 km/h or 20 km/h, depending on topology

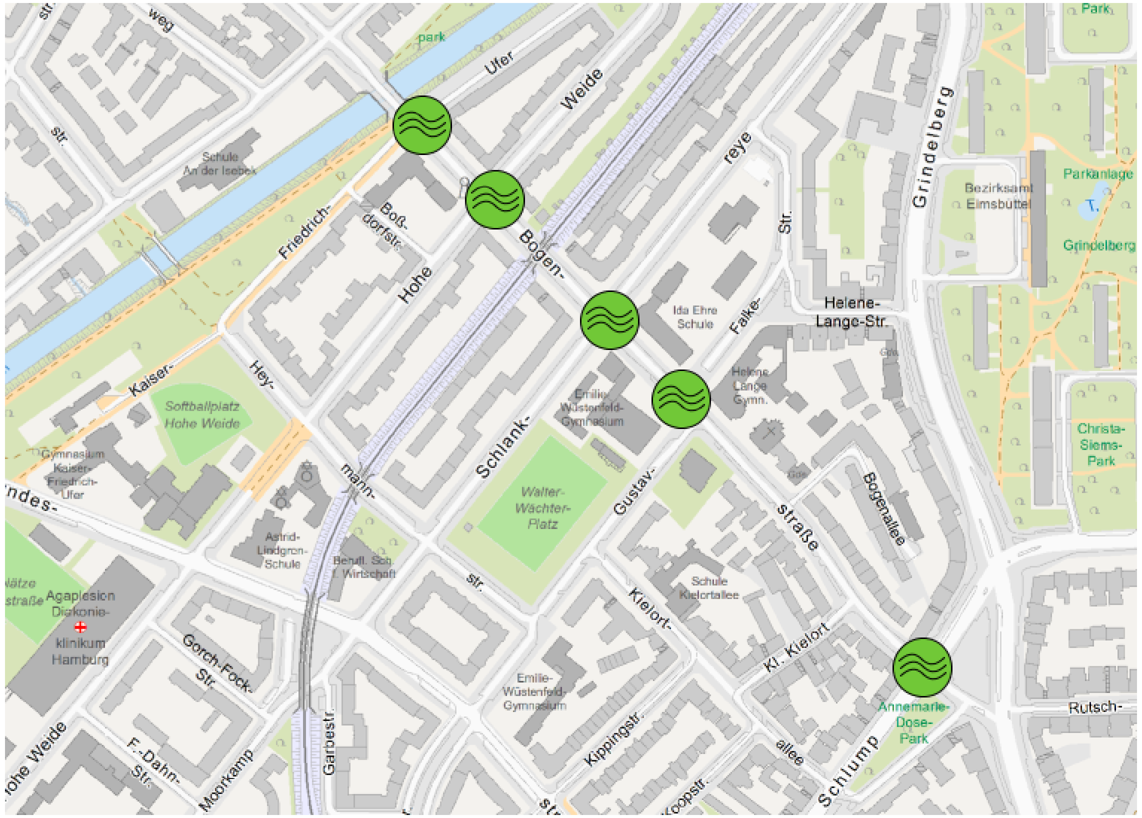
Evaluation

- Floating Car Data is used as well as simulations

(1) vehicles (2) cyclists



Time-space diagrams for vehicles and cyclists

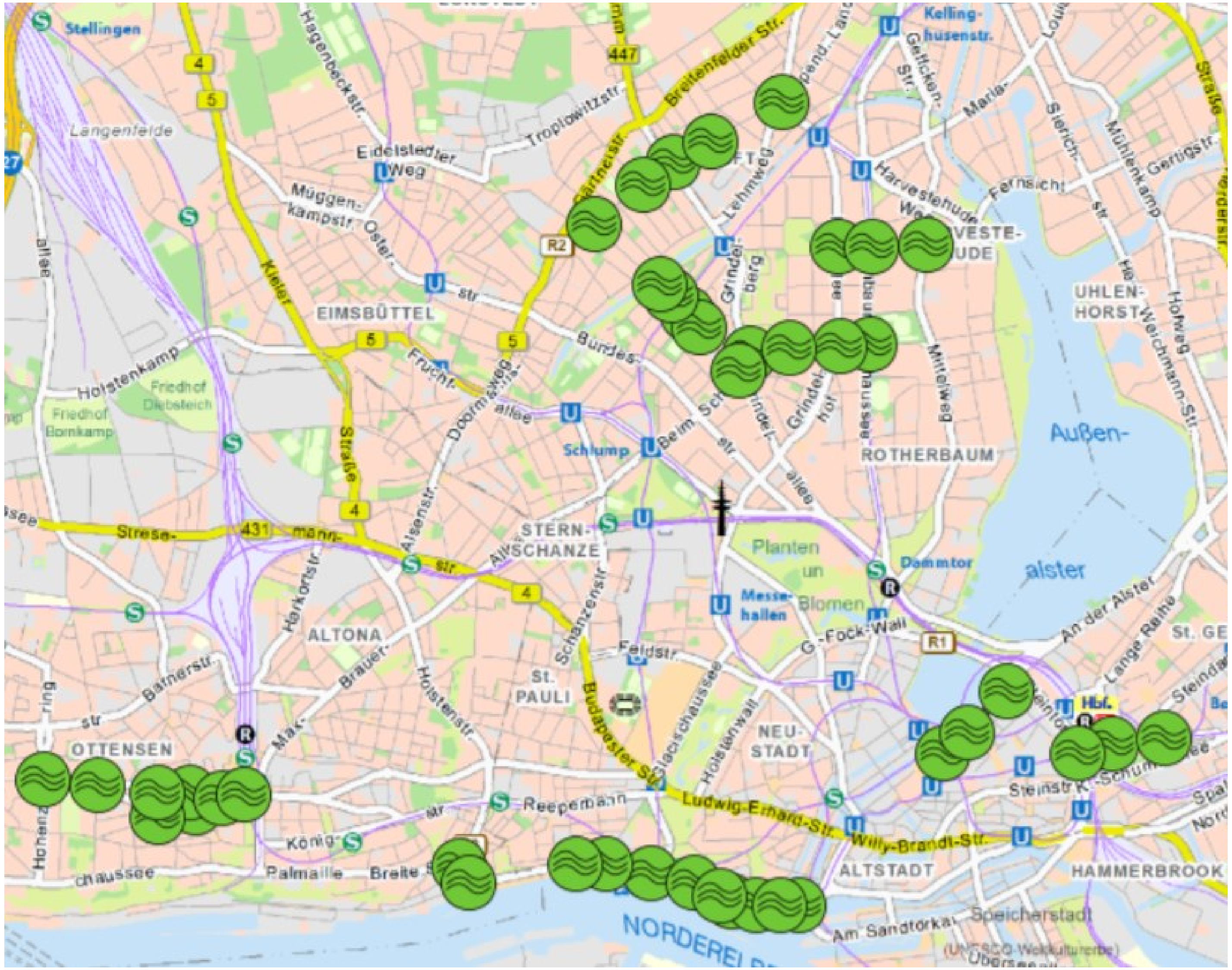


PrioBike-HH

ITS Services for Cyclists - Hamburg

Source: City of Hamburg

Green waves



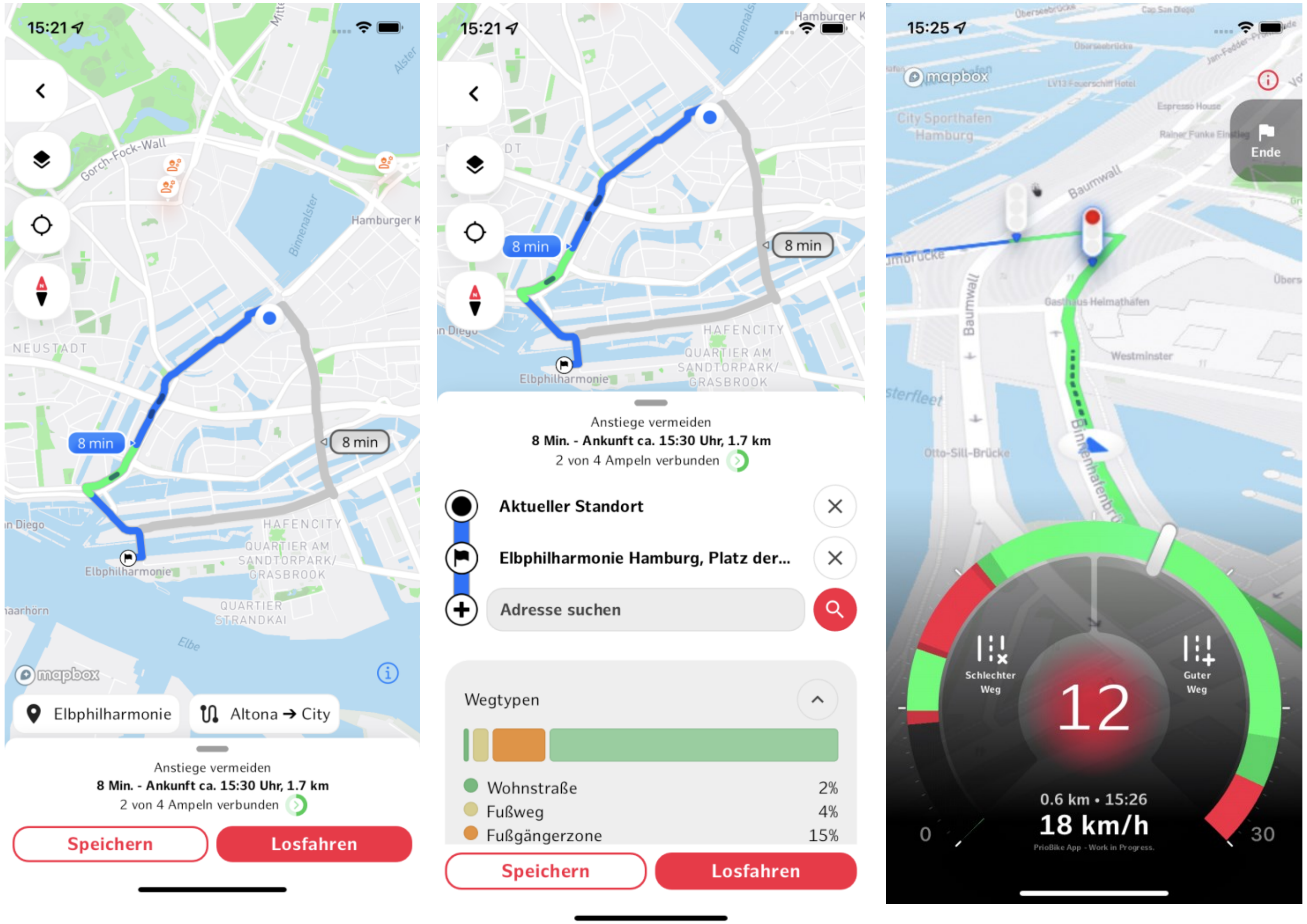
PrioBike-HH

ITS Services for Cyclists - Hamburg

Source: City of Hamburg

Glosa Smartphone App to increase comfort

Development of an app, for use on smartphones, that provides a GLOSA for cyclists as well as optimized bicycle traffic routing.



PrioBike-HH

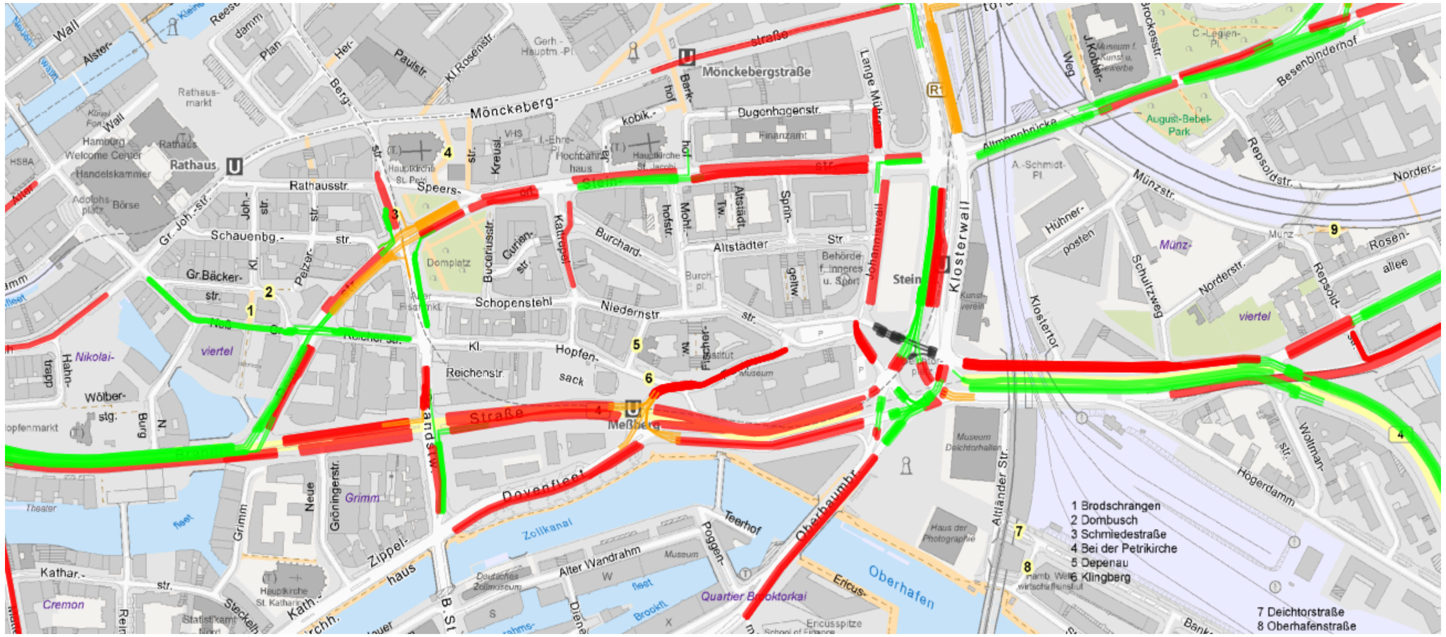
ITS Services for Cyclists - Hamburg

Source: City of Hamburg

Glosa Smartphone App to increase comfort

Data

- Traffic light process data
  (as SensorThingsAPI Objects)
- MAP – Data (intersection topology)
- Detector data (cars, pedestrians, cyclists, bus request points)
- Number of the running signal program



Masterportal Visualisation

Data can be accessed via:

MQTT-Broker: tld.iot.hamburg.de
Topic: v1.1/Datastreams({id})/Observations

Increasing comfort – Speed advisory pillar

1

Digital signaling of remaining green times or driving recommendations for cyclists at the roadside, for example by a pillar.

2

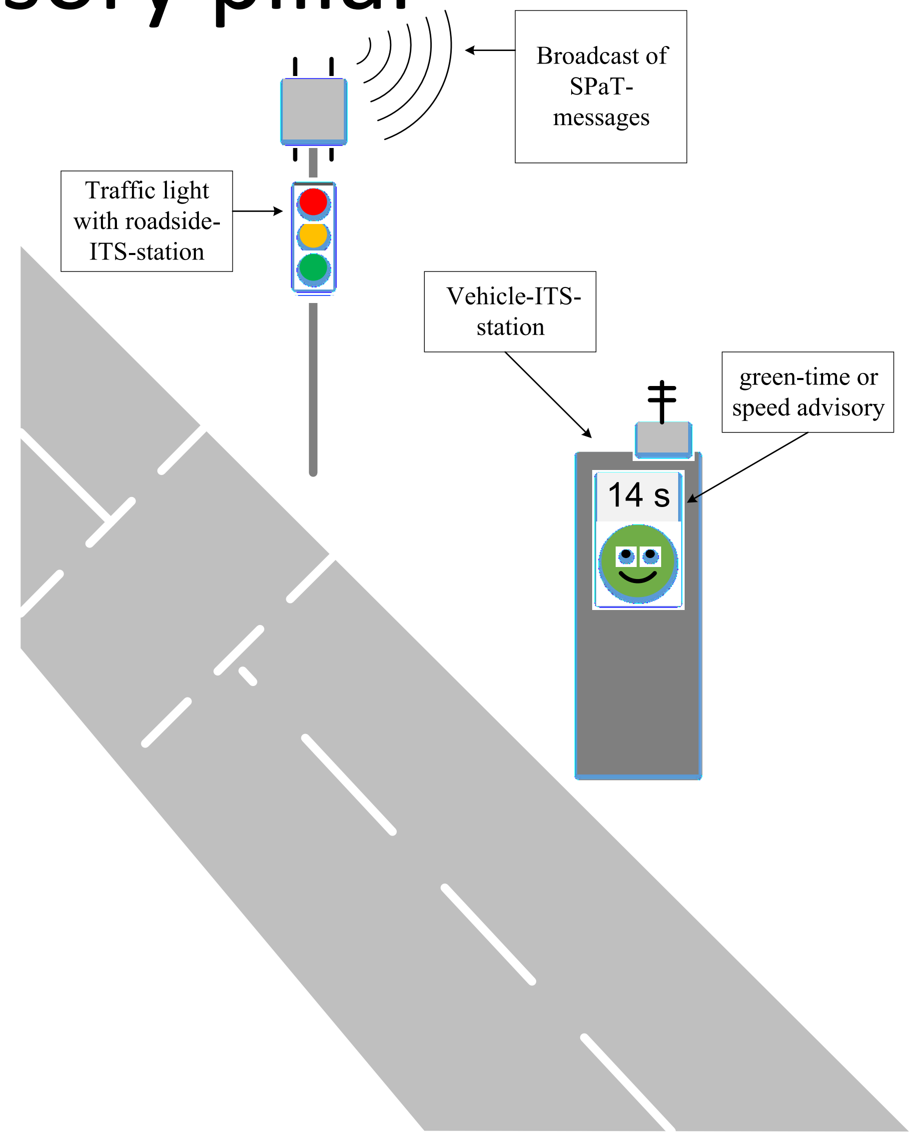
Dynamic lights on the ground indicate whether to ride faster or slow down.

© BVM

ITS Services for Cyclists - Hamburg

Source: City of Hamburg

Increasing comfort – Speed advisory pillar



First pilot

- Signal light including roadside-ITS-station
- Broadcast of SPaT-messages (signal phase and timing)
- Speed advisory pillar including vehicle-ITS-station
- Display with remaining green-time and speed advisory

PrioBike-HH

Source: City of Hamburg

Increasing comfort – Speed advisory pillar Evaluation

Findings:

- Average speed **increase** by 10% from 2.99 m/s to 3.30 m/s
- Average speed **decreased** near the intersection by 8% from 4.84 ms/s to 4.49 m/s
- Relative frequency of stops near the intersection **decreased** by 7%

PrioBike-HH

HAW HAMBURG

Analyse der Wirkung einer Geschwindigkeitsempfehlung für Radfahrer im Projekt PrioBike-HH

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2. April 2023

Zusammenfassung

Das Ziel dieser Studie besteht in der Entwicklung und Implementierung einer Methode zur Bewertung der Wirksamkeit einer Informationssäule für Radfahrer zur Verbesserung des Verkehrsflusses und Minimierung der Wartezeiten an einer Lichtsignalanlage sowie in der Bewertung der Wirkung in Hamburg an der Kreuzung Rothenbaumchaussee / Edmund-Siemers-Allee. Als Datengrundlage werden Messdaten aus einem Sensorsystem mit zwei LIDAR Sensoren und nachgeschalteter Objektklassifikation genutzt. Zur Analyse werden die bereitgestellten Datensätze zunächst in der Größe reduziert und gefiltert. Im Anschluss daran erfolgt die Analyse durch den Vergleich von Geschwindigkeiten in geographisch begrenzten Segmenten und im Vergleich des Zeitraumes vor der Installation der Informationssäule mit dem nach der Installation. Die hier vorgestellten Methoden liefern konsistente und reproduzierbare Ergebnisse und erscheinen daher geeignet, um die Wirksamkeit zu bewerten. Die Ergebnisse belegen eine Erhöhung der mittleren Geschwindigkeiten der Radfahrer nach der Installation in der Nähe der Lichtsignalanlage um etwa 10 % von 2,99 m/s auf 3,30 m/s. Gleichzeitig sinkt die mittlere Geschwindigkeit in größerem Abstand vor Erreichen der Kreuzung um etwa 8 % von 4,84 m/s auf 4,49 m/s. Eine Abschätzung zeigt, dass die relative Häufigkeit eines Stopps an der Lichtsignalanlage nach der Installation der Informationssäule um etwa 7 % zurückgeht. Die Studie schließt mit einer Übersicht möglicher Verbesserungsmaßnahmen.

1 Einführung

Im Rahmen des Projektes PrioBike-HH [3] entwickelt und untersucht die Behörde für Verkehr und Mobilitätswende der Freien und Hansestadt Hamburg unterschiedliche Verfahren zur Erhöhung der Attraktivität des Radverkehrs. Dieser soll, insbesondere durch die Reduzierung von Wartezeiten, beschleunigt werden. Gleichzeitig soll die Sicherheit im Radverkehr erhöht werden. Zum Einsatz kommen Methoden zur intelligenten Informationsweitergabe und -Lenkung. Im Rahmen des Projektes wurde in Hamburg am 9.12.2022 im Bereich der Kreuzung Rothenbaumchaussee / Edmund-Siemers-Allee eine Informationssäule [4] aufgestellt, die jedem Radfahrer eine Geschwindigkeitsempfehlung anzeigt. Diese Empfehlung wird abhängig von der jeweiligen Geschwindigkeit für jeden einzelnen Radfahrer berechnet. Dieser soll, wenn möglich, ohne Wartezeit die folgende Kreuzung passieren können. Die installierte Informationsäule ist in Abbildung 1 dargestellt. Zur Untersuchung der Wirksamkeit wurde eine Kombination aus zwei LIDAR Sensoren [5] mit angebundener Objekterkennung [6] aufgestellt. Das Urban Mobility Lab an der HAW Hamburg wurde beauftragt, ein Verfahren zur Analyse gesammelten Daten zu entwickeln, die Analyse durchzuführen

1

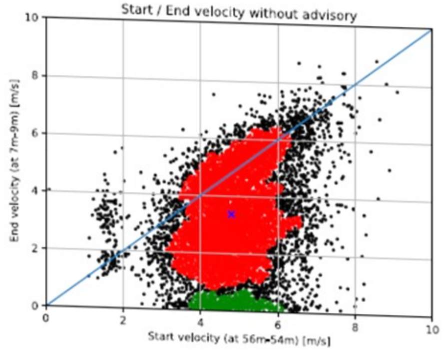


Abbildung 19: Clusteranalyse vor Installation der Säule

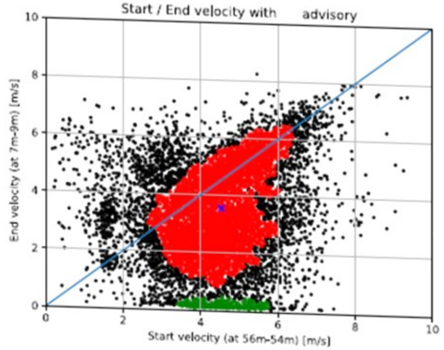


Abbildung 20: Clusteranalyse nach Installation der Säule

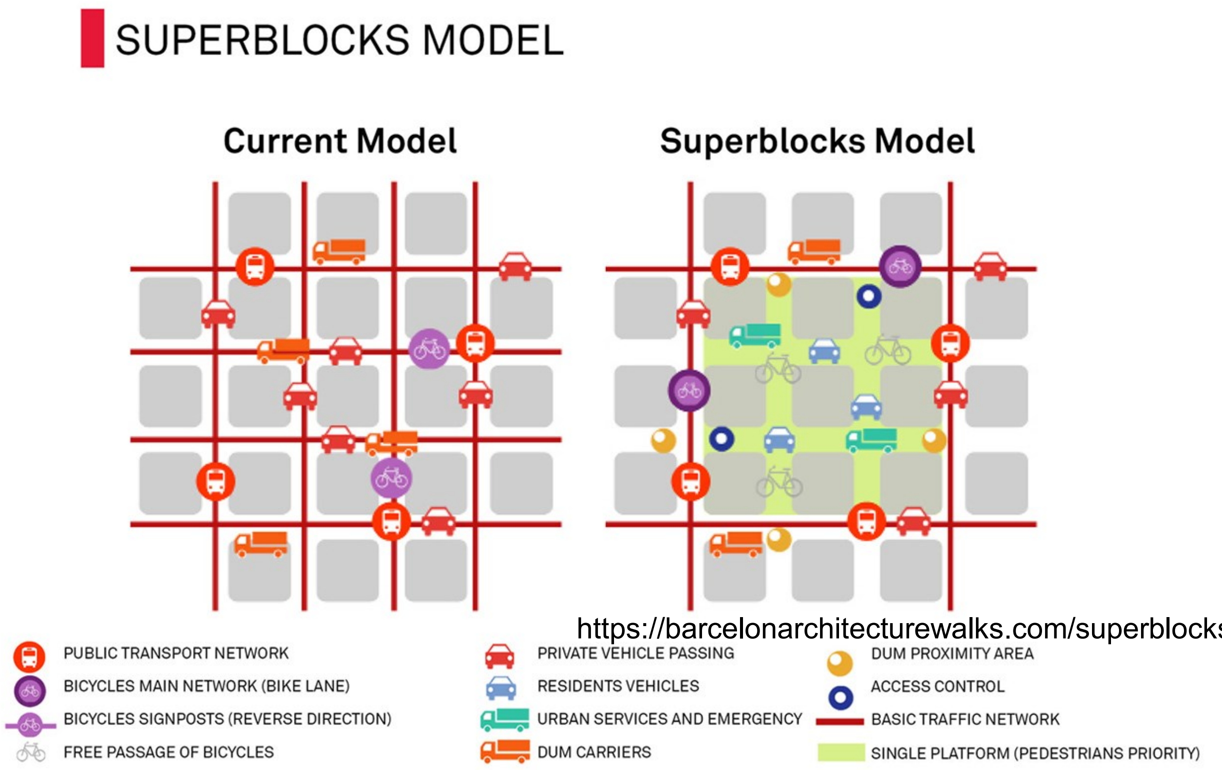
16

Adaptive Traffic Signals for Non-Motorized Users

- Sensor-based extension of green time for pedestrians – thermal cameras, radar, or pressure sensors detect slower-moving pedestrians (e.g., elderly, disabled), automatically extending green phases for safe crossing.
- AI-based queue length estimation for bikes – computer vision and machine learning estimate the number of waiting cyclists, dynamically adjusting green time allocation.
- Integration with pedestrian priority zones – adaptive signals aligned with policies such as Superblocks (Barcelona), school zones, and shared spaces, ensuring safety and comfort for non-motorized users.
- Multimodal coordination – adaptive controllers balance delays between pedestrians, cyclists, and vehicles, based on real-time demand.
- Pedestrians benefit from safer crossings and fewer conflicts, especially vulnerable groups with slower walking speeds.
- Cyclists gain efficiency through reduced waiting times and fairer signal allocation in mixed traffic contexts.
- AI-based detection allows for proactive, demand-responsive management instead of fixed signal plans.
- Integration with urban policies (e.g., Barcelona Superblocks, Melbourne CBD pedestrian-first zones) shows how adaptive systems support liveability and sustainability goals.

Adaptive Traffic Signals for Non-Motorized Users

- Barcelona’s Superblocks (or Superilles) model is a prime example of urban planning that accords priority to pedestrians and cyclists by curbing through-traffic and reshaping public spaces. This supports the deployment of adaptive traffic signals for non-motorized users, as these zones emphasize slow, flexible, and demand-responsive signal controls.
- The model restricts motor traffic to perimeter streets and converts internal areas into low-speed, shared-use spaces—making it ideal for pedestrian-priority signals.
- Evaluations highlight benefits: reduced noise, improved air quality, enhanced walkability, public health, and social interaction.

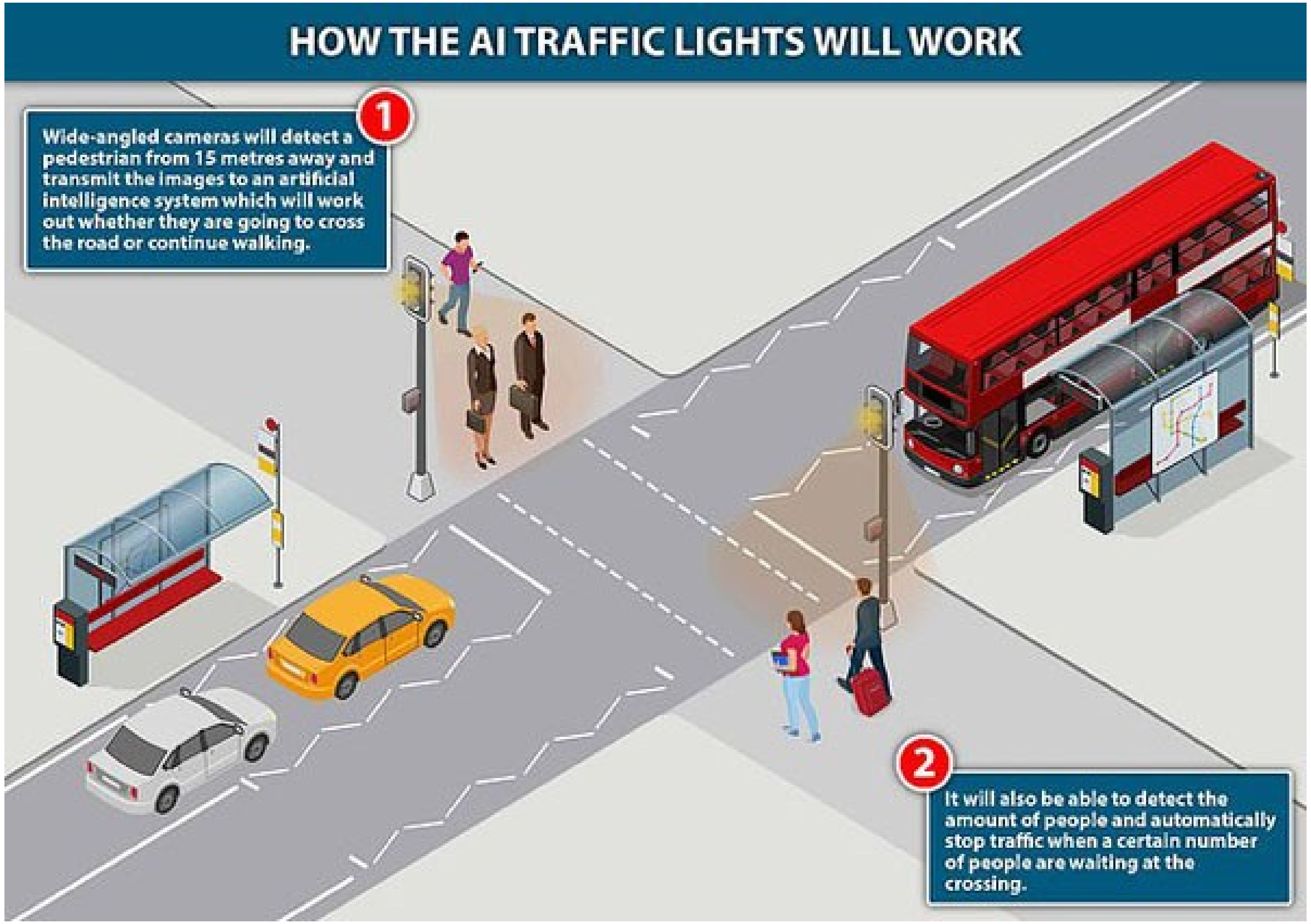


https://barcelonarchitecturewalks.com/superblocks

https://www.barcelona.cat/surveyfotografic/en/project/superilla_sant_antoni

Adaptive Traffic Signals for Non-Motorized Users

- AI-equipped traffic lights detect pedestrian presence and dynamically adjust signal phases—ideal for conveying Melbourne's smart adaptive signal concept. A relevant project is the Intelligent Corridor on Nicholson Street, Carlton. It uses sensors, AI, and real-time data to improve safety and traffic flow for all users, including pedestrians, cyclists, and vehicles.



https://doi.org/10.1016/j.trc.2022.103991

Adaptive Traffic Signals for Non-Motorized Users

- Singapore's "Green Man +" system, where elderly pedestrians or persons with disabilities tap their concession card on a sensor at the traffic signal to receive extended green time—from 3 up to 13 seconds—enabling safer, more comfortable crossings.
- The image captures a pedestrian at a user-activated crossing equipped with a card reader. Once the user taps their eligible card, the crossing phase is extended, giving vulnerable users more time to cross without feeling rushed.

https://theindependent.sg/lta-1500-more-gm-card-readers-at-traffic-lights-to-give-seniors-people-with-disabilities-more-time-to-cross-roads/

Smart Lighting for Safety & Comfort

- Motion-activated LED lighting on bike paths – sensors detect approaching cyclists or pedestrians, automatically increasing brightness to improve visibility and save energy.
- Color temperature adjustment based on time of day – warmer light in the evening to reduce glare and improve comfort; cooler white light at night to maximize visibility and alertness.
- Integration with CCTV for security monitoring – lighting infrastructure linked with surveillance systems to enhance safety perception and provide forensic support in case of incidents.
- Energy efficiency & sustainability – adaptive dimming reduces unnecessary energy consumption compared to static lighting.
- Smart lighting improves both objective safety (reducing accidents, improving obstacle visibility) and subjective safety (lowering perceived risk, especially for women and vulnerable users at night).
- Adaptive systems balance comfort, safety, and sustainability, using real-time data to provide the right lighting level at the right time.
- Research shows that better night-time lighting increases path usage by up to 30% in some pilot projects.
- Integration with CCTV and IoT systems allows multi-functionality: lighting, safety, and monitoring in a single infrastructure.

Smart Lighting for Safety & Comfort - Example Cities

- Eindhoven (Netherlands) – Van Gogh-Roosegaarde cycle path and cycle highways with dynamic LED lighting, responding to cyclist presence and weather conditions.
- Seoul (South Korea) – smart pedestrian and cycle path lighting integrated with motion sensors and adaptive brightness control.
- Copenhagen (Denmark) – experiments with intelligent dimming on cycle superhighways.

https://www.holland.com/global/tourism/get-inspired/current/van-gogh/van-gogh-roosegaarde-cycle-path

https://www.powerkoream.co.kr/news/articleView.

https://supercykelstier.dk/blog/2016/03/21/about-old/

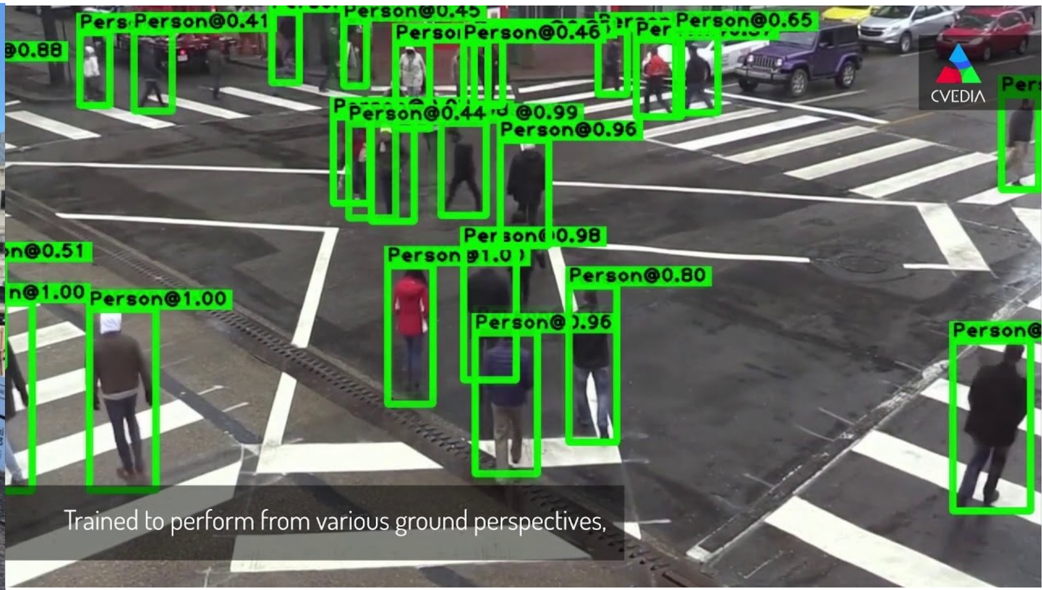
Hazard Detection & Alerts

- Automatic detection of wrong-way cycling or jaywalking – use of AI-enabled cameras and computer vision to detect unsafe or illegal movements in real time; warnings issued via signals, roadside displays, or mobile apps. Hazard detection is crucial for Vision Zero policies, protecting pedestrians and cyclists in dense urban areas. Wrong-way cycling and jaywalking detection reduces conflicts at intersections and mid-block crossings.
- Weather condition sensors triggering route alerts – integration of road weather stations (temperature, humidity, slipperiness, snow/ice) with MaaS platforms to inform cyclists and pedestrians about hazardous conditions. Road weather sensors extend safety beyond infrastructure monitoring, giving cyclists real-time advice to avoid icy routes or reroute.
- Real-time hazard reporting via MaaS apps – users can receive and provide hazard reports (e.g., obstacles, flooding, construction works), creating a crowdsourced layer of safety information. MaaS integration ensures accessibility of warnings: instead of static signs, information reaches users where they need it — on their mobile devices.
- Integration with C-ITS – hazard detection feeds shared with central traffic management systems to inform both vulnerable users and drivers. Crowdsourced reporting enables bottom-up hazard identification, complementing sensor-based systems.

Hazard Detection & Alerts- Example Cities

- Helsinki – road weather sensors connected with cyclist information boards and online platforms, issuing alerts on slippery conditions and recommended detours.
- Singapore – AI camera networks monitoring pedestrian crossings, detecting jaywalking or risky behaviours, triggering automatic alerts and enforcement.
- Oslo (pilot) – integration of road hazard detection with MaaS-based bicycle navigation apps.

https://sedimark.eu/transforming-urban-city-lidar-sensors-and-the-evolution-of-smart-cities/



https://www.cvedia.com/people-detection

https://flatironbike.com/best-bicycle-navigation-app/

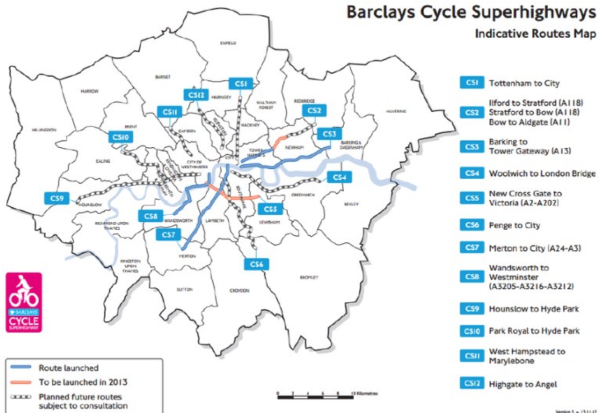
Data Collection & Analytics for Active Mobility

- IoT counters for pedestrians & cyclists – sensor-equipped counting stations using radar, thermal, or computer vision to record flows continuously and anonymously. IoT counters ensure long-term trend monitoring at strategic points (bridges, corridors).
- GPS tracking from shared mobility fleets – real-time data from shared bikes, e-scooters, and e-bikes provide granular trip patterns, speeds, and demand distribution. GPS-based data offers high spatial coverage and insights into route choice, speed, and travel behaviour.
- Big data analytics for infrastructure planning – combining multimodal datasets (counters, GPS, apps, weather, incidents) enables predictive modelling, network performance evaluation, and prioritisation of investments. Big data platforms (e.g., Strava Metro, Telraam, Eco-Counter, MaaS APIs) allow city planners to analyse behaviour in relation to time of day, weather, and events.
- Data fusion – integration of sensor and user-generated data ensures a more holistic picture of mobility flows and safety issues.
- Predictive analytics can model future demand and hazard risks, supporting evidence-based policy.

Data Collection & Analytics for Active Mobility- Example Cities

- Oslo (Norway) – deployed a city-wide network of cyclist counters, producing open datasets on daily, seasonal, and long-term flows.
- London - Integrated Strava Metro GPS data into city planning, identifying underserved areas and prioritising bike lane construction.
- London (UK) – combines TfL's permanent counters with crowdsourced GPS data to optimise cycle superhighways.

https://bikerumor.com/new-strava-metro-feature-shows-government-how-cyclists-are-using-city-streets//



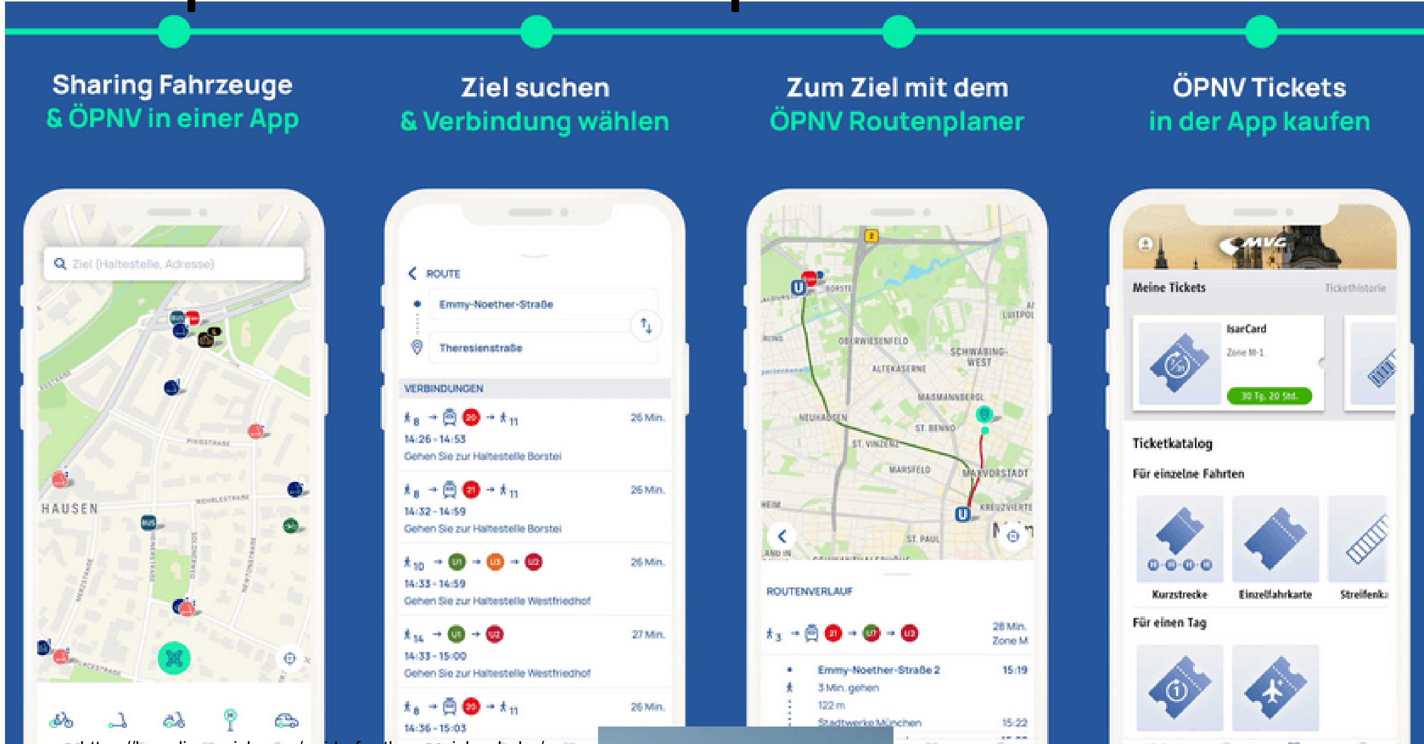
https://lcc.org.uk/news/where-are-all-the-cycleways//

Integration with Public Transport ITS

- Coordinated bike parking at transit hubs – dynamic information on parking availability at train and metro stations, integrated with journey planners to ensure seamless transfers. Bike parking & sharing at transit hubs directly supports the first/last-mile connection, extending catchment areas of rail and bus networks. Real-time ITS integration (bike capacity, parking availability) increases convenience, reduces barriers, and builds trust in multimodal solutions.
- Pedestrian routing within multimodal trip planning – routing algorithms incorporate walking and cycling links as part of first/last-mile solutions (e.g., shortest safe walking route from station exit to destination).
- Bike-on-bus and bike-on-train capacity info – real-time data on available bicycle slots on trains and buses, reducing uncertainty and improving reliability of multimodal trips.
- Fare & MaaS integration – single platform enabling booking, payment, and real-time updates for both active and public transport modes. Cities experimenting with integrated data platforms demonstrate that combining cycling, walking, and PT information leads to measurable mode shift.

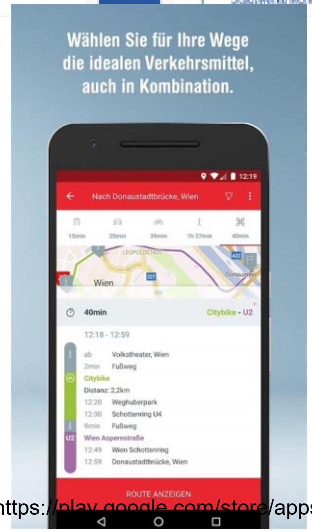
Integration with Public Transport ITS-Example Cities

- Munich (Germany) – S-Bahn journey planner integrates bike-sharing availability, allowing users to combine trains with shared bikes in one application.
- Portland (USA) – TriMet provides real-time information on bike rack availability on buses, allowing cyclists to plan trips with confidence.
- Vienna (Austria) – multimodal routing apps (e.g., WienMobil) integrate walking, bike-sharing, and PT in one platform.
- Helsinki (Finland) – Whim MaaS app supports seamless bike + PT combinations with single ticketing.



https://boredinmunich.com/guide-for-the-munich-s-bahn/


https://bikeportland.org/2019/04/25/trimets-new-buses-come-with-three-bike-



https://play.google.com/store/apps/details?id=at.wienerlinien.wienmobillab&pli=1

Geofencing & Micro-Mobility Control

- Geofencing is a technology that uses GPS, cellular signals, or Bluetooth to create a virtual boundary (a “geofence”) in the real world.
- When a device (e.g., e-scooter, shared bike, fleet vehicle, or smartphone) enters or leaves this defined area, the system automatically triggers an action, such as:
- limiting vehicle speed,
- blocking the ability to end a trip,
- sending a notification or alert,
- applying a fine or charge,enabling specific features (e.g., monitoring, location-based ads, reminders).

https://blog.beeswax.com/geofencing-101

Geofencing & Micro-Mobility Control

- Geofencing ensures orderly integration of micro-mobility in cities, reducing conflicts with pedestrians and preventing misuse of public space.
- Speed limiting for e-scooters in pedestrian zones – e-scooter operators integrate GPS-based speed caps (e.g. max 6–10 km/h) in sensitive areas like pedestrian plazas, promenades, and school zones. Speed reduction zones improve safety in crowded areas, while digital enforcement prevents blocking sidewalks and access points.
- No-parking enforcement using GPS geofencing – users cannot end a trip outside designated areas; app-based locks require parking inside virtual boundaries, with fines for violations.
- Dynamic curb allocation for bike/scooter parking – curb space reallocated in real time based on demand; ITS back-end communicates with operators to distribute fleet parking more evenly. Dynamic curb allocation represents the next step: data-driven management of urban space to balance the needs of scooters, bikes, delivery, and transit.
- Integration with city management platforms – geofencing data shared with municipalities for compliance monitoring and planning.
- Cities like Stockholm and Paris demonstrate that clear rules + digital enforcement are essential for long-term acceptance of shared micro-mobility.

Geofencing & Micro-Mobility Control

- Stockholm (Sweden) – established “slow zones” for e-scooters in the historic center; scooters automatically reduce speed to 6 km/h when entering geofenced areas.
- Paris (France) – pioneered strict geofenced no-parking rules; operators are fined if scooters are left outside approved zones.

https://www.motion-mag.com/articles/its-getting-serious-e-scooters-in-paris-yes-or-no

https://www.schweden-kompass.de/mit-dem-e-scooter-durch-stockholm/

Future Innovations for Active Mobility ITS

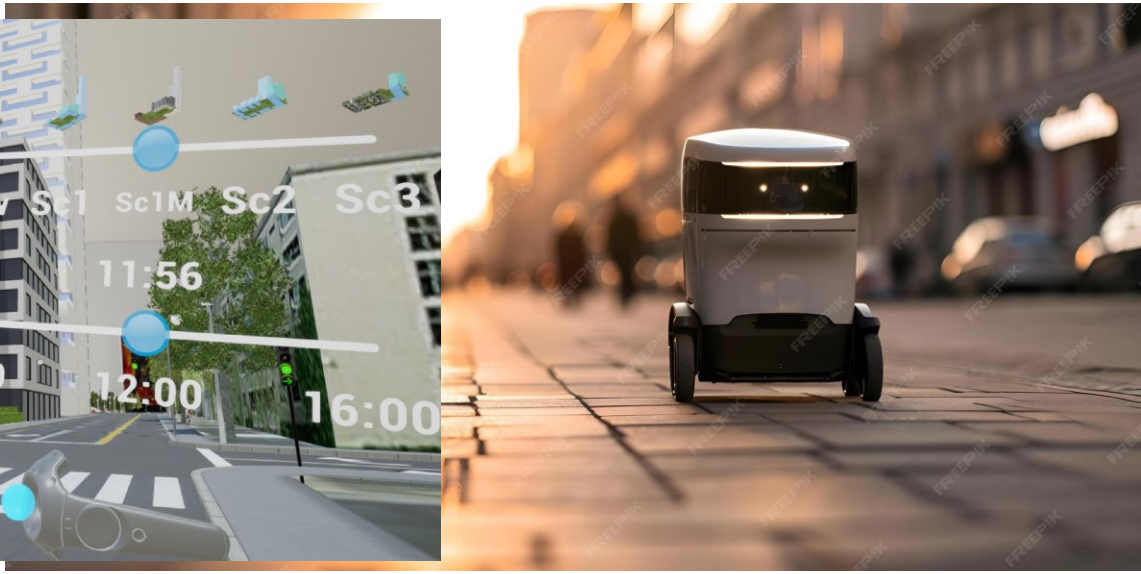
- Active mobility ITS is evolving towards proactive and predictive tools, not just reactive controls.
- AI-based personal safety scoring for routes – algorithms evaluate routes for pedestrians and cyclists using real-time data (traffic density, lighting, crash history, crime data, weather). Output: “safety score” provided via MaaS or navigation apps, guiding users to safer routes. AI safety scoring could transform personal mobility apps by recommending not only the shortest or fastest routes, but also the safest.
- VR pedestrian simulators for planning – immersive virtual reality environments allow planners, researchers, and citizens to “experience” proposed pedestrian zones or intersections before construction. This supports participatory planning and data-driven design validation. VR simulation has been tested in Vienna, allowing planners to design pedestrian spaces that reflect real human perception of comfort and safety.
- Integration with autonomous delivery robots – coordination between micromobility (pedestrians, bikes) and small-scale autonomous delivery robots. ITS ensures safe navigation on sidewalks, priority rules at crossings, and real-time incident alerts. Autonomous delivery robots (e.g., in Shanghai, Milton Keynes, and pilot projects in Hamburg) highlight the coming need for integration of humans and robots in shared pedestrian space.
- Predictive modelling with digital twins – urban “digital twins” simulate future interactions between active mobility users, robots, and vehicles, enabling proactive design.

Geofencing & Micro-Mobility Control

- Vienna (Austria) – VR pedestrian simulation projects for redesign of urban squares and crossings, involving citizen participation.
- Shanghai (China) – widespread pilot of autonomous sidewalk delivery robots, coordinated with traffic management platforms.
- Hamburg (Germany) – tests of delivery robots interacting with cyclists and pedestrians.
- These robots are being tested within an integrated ITS system, where synchronization with traffic signals and traffic management ensures safe coexistence with pedestrians and cyclists.

https://www.esri.com/arcgis-blog/products/city-engine/design-planning/ce-ue4-vr-experience

https://youtu.be/UWNzgSF6Wcs



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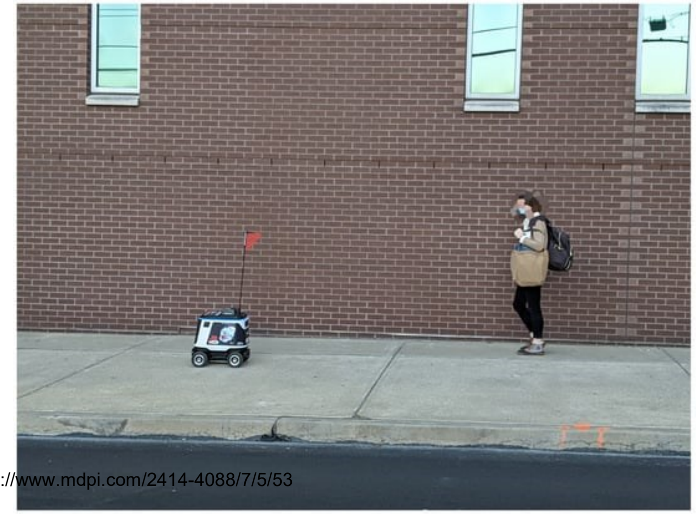

https://www.mdpi.com/2414-4088/7/5/53