POLICY REPORT . 2026

Bicycle Safety

Evidence-Based Governance from the SINERGI Project

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KEY MESSAGES

1. Bicycle safety is studied through two complementary perspectives. Bicycle safety on road segments is commonly assessed in two different ways: perceived stress and crash frequency. The first perspective focuses on how safe cyclists feel on a road segment, while the second examines past crashes and analyses their risk factors. These two perspectives are not contradictory; rather, they capture different dimensions of bicycle safety.

2. The Level of Traffic Stress framework measures perceived cyclist stress, but it is incomplete without traffic flow. The Level of Traffic Stress (LTS) framework classifies road segments according to how stressful they are for cyclists with different levels of proficiency. It is useful because it is simple, rule-based, and relies mainly on road design and infrastructure characteristics. However, more recent extensions show that traffic flow, especially motor-vehicle traffic, also affects cyclist stress. Congestion and mixed traffic can increase perceived stress and alter route choice, meaning that infrastructure alone does not provide a complete picture.

3. Incorporating vehicle traffic flow can change the stress classification of bicycle lanes. Our work in SINERGI shows that when traffic flow is included into the analysis, some road segments previously classified as low stress may no longer appear as safe as suggested by infrastructure-only measures. In other words, roads that look safe from their physical design alone may impose higher stress once motor-vehicle volumes are taken into account.

4. Bicycle crashes are substantially under-reported in official police data. A major limitation in bicycle safety statistical analysis is that crash data are incomplete. In Denmark, police records capture only a small share of the crashes. This means that current crash statistics likely understate the true scale of bicycle safety problems, particularly for less severe incidents.

5. In recorded non-solo bicycle crashes, collisions with motor vehicles are far more common than collisions with other cyclists. The Copenhagen crash dataset used in our study shows that most recorded non-solo bicycle crashes involve motor vehicles. Between 2017 and 2024, 4,546 recorded crashes involved a bicycle and a motor vehicle, whereas 633 involved two bicycles. This indicates that bicycle–vehicle conflicts remain the dominant crash type in the available data, even though bicycle–bicycle conflicts are also relevant for analysis.

6. The main risk factors differ by crash type. For bicycle–vehicle crashes, the most important risk factors are exposure to vehicle interaction and network complexity, especially a high number intersections. For bicycle–bicycle crashes, the main factors are bicycle volume and residential density concentration, meaning that conflicts are more likely where many cyclists use relatively short and densly populated links. These results suggest that the mechanisms behind bicycle–vehicle and bicycle–bicycle crashes are different and should not be treated as the same policy problem.

THE SINERGI PROJECT

Sustainable city-logistics in the age of digitization (SINERGI) is a research project funded by JPI Urban Europe, running from 2023 to 2026. The project is coordinated by TU Delft and Tongji University, with partners including Just Eat Takeaway, Gemeente Amsterdam, Vervoerregio Amsterdam, AMS Institute, Copenhagen Business School, Singapore Management University, Meituan, and Tsinghua University. The project operates across four pilot cities: Amsterdam, Copenhagen, Singapore, and Shanghai.

Within SINERGI, we investigate how large-scale data on bicycle traffic and motorized traffic can be used to improve routing, traffic management, and safety on bicycle networks. The central idea is to create a digital ecosystem in which data, models, and decision-support tools are integrated to support better routing and operational decisions for riders and planners. In this technical report, we focus on two contributions developed so far. The first contribution revises bicycle-lane stress classifications by incorporating traffic flow into the Level of Traffic Stress framework. The second contribution estimates bicycle crash probability and identifies the key factors associated with bicycle–vehicle and bicycle–bicycle crashes. Together, these studies provide the basis for future work on safety-oriented routing.

Context: SAFETY OF CYCLIST

Bicycle safety is not straightforward to interpret because the literature studies it from more than one angle. Some studies examine how cyclists perceived stress and comfort while cycling, whereas others focus on observed crashes and their severity or frequency. Both perspectives are important for policy.

There have been substantial efforts to increase cycling participation, for example through investments in cycling superhighways (Supercykelstier, 2019). Such initiatives have successfully increased cycling rates in several cities. At the same time, safety remains a major concern. A survey of approximately 2,000 residents in Copenhagen in 2017 found that 37 percent felt vulnerable while cycling on the road. Studies by von Stülpnagel & Binnig (2022) and Marshall & Ferenchak (2019) show that individuals are more likely to cycle in environments where they perceive higher levels of safety. Thus, despite its well-documented benefits, safety remains a primary concern.

At the European level, cyclist fatalities have not fallen as quickly as total road fatalities. Although the absolute number of cyclists killed on EU roads remained relatively stable between 2010 and 2024, the share of cyclist fatalities in total road fatalities increased from 7% in 2010 to 9% in 2019 (European Commission, 2024). This has strengthened the policy need to improve cyclist safety. One of the major challenges in road engineering is identifying traffic solutions that ensure both high objective road safety and high perceived safety for all road users (Danish Road Directorate, 2017).

WHAT SINERGI FOUND

Updating the Level of Traffic Stress with traffic flow

Farzadnia & Romero Morales (2025) developed an explainable clustering framework, to update prior road stress classifications while providing interpretability. The motivation is that the traditional Level of Traffic Stress framework, which is introduced by Mekuria et al. (2012), provides useful prior knowledge, but it does not fully reflect the effect of motor-vehicle traffic volume on cyclist stress. The LTS framework classifies road segments into four categories according to the level of stress they impose on cyclists: LTS 1 represents routes that are comfortable for almost all cyclists, including children and other vulnerable users; LTS 2 refers to routes that are acceptable for most adult cyclists; LTS 3 includes roads that are generally suitable only for more confident and experienced cyclists; and LTS 4 represents the highest-stress conditions, typically tolerated only by highly confident cyclists. The proposed method therefore updates existing LTS labels by combining prior knowledge with new information, while also explaining why a road segment changes class.

The method was applied to 1,083 bicycle-accessible road segments in Frederiksberg, Denmark. The initial labels came from an infrastructure-based LTS classification, and motor-vehicle Annual Average Daily Traffic (AADT) was added as a new feature. Since complete AADT coverage was not available, missing values were imputed using a Random Forest model before the clustering analysis was carried out.

The results show that adding traffic flow can change the classification of some road segments. This is important because it implies that infrastructure-only classifications may overestimate the safety of some links. In particular, roads that appear low stress based on speed limits, number of lanes, and bicycle facilities may impose greater stress when they also carry substantial motor traffic. The main contribution of this work is therefore not only to update LTS labels, but to do so in a way that remains transparent and explainable to planners and decision makers.

Data dependency. Updating LTS labels requires road-segment traffic-flow data, especially vehicle traffic volume.

Crash probability and risk factors

Farzadnia & Romero Morales (2026) examined bicycle crash probability in Copenhagen using an interpretable machine-learning approach. The objective is to rank road segments by the probability of bicycle crashes and identify the most important factors behind that risk for two crash types: bicycle–vehicle crashes and bicycle–bicycle crashes.

The crash analysis uses police-reported accidents from 2017 to 2024. Although these data are known to under-report the true number of crashes, they still provide a useful basis for identifying relative risk patterns. In total, the dataset contains 5,698 recorded crashes involving at least one cyclist. Of these, 4,546 involved a collision with a motor vehicle, 633 involved another bicycle, and the remaining cases involved other counterparts such as pedestrians, obstacles, or animals (Danmarks Statistik, 2023; Danish Health Data Agency, 2026).

One important result is that intersections are major safety hotspots. Approximately 74% of bicycle–vehicle crashes and 36% of bicycle–bicycle crashes occurred at intersections. Another important finding is that crash risk does not increase monotonically with the nominal LTS label. Surprisingly, LTS 2 road segments appear to be the safest group for both bicycle–vehicle and bicycle–bicycle crashes, while LTS 1 segments can exhibit unexpectedly high crash risk. This pattern is explained largely by exposure: low-stress routes tend to attract many cyclists, which increases the probability of cyclist encounters and conflicts.

The machine-learning results further show that the dominant risk factors differ across crash types. For bicycle–vehicle crashes, key factors include vehicle interaction exposure, intersection and crossing complexity, bus-route presence, and lane configuration. For bicycle–bicycle crashes, the most important factors are bicycle traffic volume and dense use of relatively short links. These findings imply that policy interventions should be tailored to the type of conflict being addressed.

Data dependency. Crash-risk modelling additionally requires reliable bicycle exposure data and better crash reporting across police and health records.

THE MISSING PREREQUISITE: DATA

A central conclusion from both studies is that better data are not merely helpful; they are a prerequisite for effective bicycle safety policy. Updated LTS classifications require traffic flow data, especially motor-vehicle counts, at the road-segment level. Crash probability models require not only crash records, but also reliable exposure measures for both bicycles and motor vehicles. Without these data, cities cannot identify where risks are highest, why they arise, or which interventions are most likely to work.

Study result	Main finding	Policy relevance
Updated LTS classification	Adding vehicle traffic flow can reclassify some road segments from lower to higher stress	Infrastructure-only safety assessment is incomplete
Crash probability model	LTS 2 appears safest overall, while some LTS 1 roads show unexpectedly high risk	Low-stress labels should not be treated as a guarantee of low crash risk
Bicycle–vehicle crashes	Risk is strongly associated with vehicle interaction, intersections, and complex crossings	Prioritise intersection redesign and mixed-traffic conflict points
Bicycle–bicycle crashes	Risk is strongly associated with bicycle volume and dense short links	Monitor crowding and design of high-volume bicycle corridors

Table 1: Summary of SINERGI findings and their policy relevance.

In practical terms, the missing prerequisite is systematic, regularly updated, and geographically complete data on bicycle and vehicle traffic flows at the road-segment level. Without such data, cities do not fully know how many cyclists and vehicles use each segment, where exposure is concentrated, which apparently safe roads are actually riskier than assumed, and where interventions would generate the greatest safety benefit.

RECOMMENDATION

For City Authorities

Build a road-segment safety data system. City authorities should establish a unified road-segment database that combines bicycle counts, motor-vehicle counts, road design characteristics, and crash records. This is the first condition for updating the Level of Traffic Stress framework and for estimating crash probability in a reliable way. Without this data infrastructure, cities cannot identify where exposure is concentrated, which roads are misclassified as low stress, or which segments should be prioritised for intervention.

Update bicycle network assessment beyond infrastructure-only LTS. Cities should not rely only on static infrastructure characteristics when classifying bicycle safety. The findings from SINERGI show that vehicle traffic flow can change how safe a road segment appears to cyclists. Municipalities should therefore incorporate traffic volume into their routine bicycle-network audits and use explainable methods when revising LTS labels so that changes remain transparent to planners and decision makers.

Prioritise intersections and complex mixed-traffic segments. The crash analysis shows that intersections and complex network structures are major contributors to bicycle risk, especially for bicycle–vehicle crashes. City authorities should prioritise junction redesign, conflict-point reduction, crossing treatment, and better separation on road segments where cyclist and vehicle interaction is high.

Address bicycle–bicycle conflicts on high-volume low-stress corridors. The report also shows that low-stress routes are not automatically low-risk routes. Some LTS 1 corridors attract large cyclist volumes and can therefore experience relatively high bicycle–bicycle conflict. Authorities should monitor crowding on protected and shared bicycle facilities and consider width, overtaking space, and local traffic management on corridors with very high bicycle demand.

Use explainable risk models for investment prioritisation. Cities should adopt interpretable modelling tools, such as explainable clustering and SHAP-based crash-risk analysis, when prioritising safety interventions. These tools make it possible not only to rank risky segments, but also to explain why they are risky, which is essential for policy legitimacy and communication.

For National and EU Regulators

Standardize traffic-flow data collection for bicycle planning. National and EU regulators should support a common standard for collecting and reporting bicycle and motor-vehicle traffic counts at the road-segment level. This would make bicycle safety assessments more comparable across cities and would support the wider use of data-driven planning tools.

Reform crash registration to reduce under-reporting. Current bicycle crash statistics are heavily constrained by under-reporting, especially when relying only on police data. National authorities should improve the integration of police, hospital, and emergency department data so that bicycle crashes are recorded more completely and can better support policy evaluation.

SUMMARY MATRIX

	City Authorities	National / EU Regulators
Data	Build road-segment traffic and crash database	Standardise traffic-flow and crash reporting
Safety Assessment	Update LTS with traffic flow	Support interoperable safety data standards
Crash Prevention	Prioritise intersections and high-conflict segments	Reform accident registration and under-reporting
Bicycle Network	Monitor crowding on high-volume bicycle corridors	Support risk-based bicycle network planning
Governance	Use explainable risk models in policy decisions	Require access to safety-relevant data

Table 2: Summary of recommended actions by governance level.

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ABOUT SINERGI

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About This Brief

This brief synthesises working-papers evidence from the SINERGI project (2023–2026). Results from Farzadnia & Romero Morales (2025) and Farzadnia & Romero Morales (2026) are derived from computational experiments on road networks in Denmark. External statistics are sourced from Denmark Statistic, Denmark Road Directory and Danish Health Data Agency; full references are provided above. Fact-checking was conducted against original sources in April 2026.