

# CYCLISTS' INTERACTION WITH INFRASTRUCTURE

## METHODS FOR RISK ASSESSMENT AND OBSTACLE DESIGN

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	Conceptualization	Data curation	Formal analysis	Funding acquisition	Investigation	Methodology	Project administration:	Resources	Software	Supervision	Validation	Visualization	Writing – original draft	Writing – review & editing
Carl Johnsson		X				X	X		X		X		X	X
Jenny Eriksson	X	X	X	X	X	X		X				X	X	X
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The authors report no competing interests.

## Declaration of generative AI use

Generative AI tools have been used to translate parts into Swedish and to improve the language in certain sections of the report. AI has also been used to produce the report's summary.

## Prior dissemination declaration

An early version of this work was presented at the International Cycling Safety Conference (ICSC) i Oslo, Norge, held on 4–6 November 2025.

## Ethics statement

The methods for data collection in the present study have been approved by the Swedish Ethical Review Authority (decision no. 2023-07649-01).

## Funding agency involvement

Representatives from the Swedish Transport Administration participated in several project meetings and provided valuable feedback. However, the funder had no influence on the study design, data analysis, or interpretation of the results.

## Data availability statement

The data used in this report is available online at the following link: <https://doi.org/10.5281/zenodo.19877991>. Note that this data only contains the trajectories of the road users and no video recordings.

## Code availability statement

The code used to analyse the data in this project is available at request from the authors.

## ABSTRACT

The overall objective of this project has been to increase knowledge regarding how infrastructure affects the risk of fall accidents and how to design safer cycling environments. The project is divided into two studies focusing on risk analysis and physical design, respectively.

**Study 1** focused on developing and testing a method for proactive risk assessment using video analysis and Extreme Value Theory (EVT). By analysing cyclists' movement patterns at three locations in Lund, the risk of two specific types of instability could be quantified: the risk of pitching over the handlebars (*pitch-over*) and the risk of skidding (*skidding*). The results demonstrate that the method can successfully identify risk-prone segments within the infrastructure, enabling targeted measures before accidents occur.

**Study 2** investigated the design of chicanes (bicycle barriers) through an experiment at VTI's cycle test track. A total of 37 cyclists with various types of bicycles (including cargo bikes and velomobiles) tested twelve different combinations of gate distances and overlaps. The study shows that current recommendations for chicanes force cyclists to slow down to speeds below 10 km/h, which is the threshold where a bicycle becomes unstable. Furthermore, larger bicycles have significant difficulties passing through the current standard design.

**Conclusions and recommendations.** The project concludes that bicycle infrastructure must be designed to maintain bicycle stability. For kissing gates intended for speed reduction, a new design with a longitudinal distance of 2.5 meters and an overlap of 0.5 meters is recommended. This configuration allows for a stable passing speed while still dampening the speed of fast cyclists. The report also highlights the potential of using video-based analysis as a tool to systematically evaluate and improve traffic safety for cyclists.

### På svenska

Det övergripande syftet med detta projekt har varit att öka kunskapen om hur infrastrukturen påverkar risken för fallolyckor och hur vi kan utforma säkrare cykelmiljöer. Projektet är uppdelat i två delstudier med fokus på riskanalys respektive fysisk utformning.

**Delstudie 1** fokuserade på att utveckla och testa en metod för proaktiv riskbedömning med hjälp av videoanalys och extremvärdesteori (EVT). Genom att analysera cyklisters rörelsemönster på tre platser i Lund kunde risken för två specifika typer av instabilitet kvantifieras: risken att slå över styret (*pitch-over*) och risken att få sladd (*skidding*). Resultaten visar att metoden framgångsrikt kan identifiera riskfyllda segment i infrastrukturen, vilket möjliggör riktade åtgärder innan olyckor inträffar.

**Delstudie 2** undersökte utformningen av cykelfällor genom ett experiment på VTI:s cykeltestbana. Totalt 37 cyklister med olika typer av cyklar (inklusive lådcyklar och velomobiler) fick testa tolv olika kombinationer av grindavstånd och överlapp. Studien visar att dagens rekommendationer för cykelfällor tvingar cyklister till hastigheter under 10 km/h, vilket är gränsen för när en cykel blir instabil och vinglig. Dessutom har större cykelekipage svårt att passera dagens standardutformning.

**Slutsatser och rekommendationer.** Projektet konkluderar att cykelinfrastruktur måste utformas för att bibehålla cykelns stabilitet. För cykelfällor som syftar till hastighetsdämpning föreslås en ny utformning med 2,5 meters längdavstånd och 0,5 meters överlapp, vilket tillåter en stabil passagehastighet samtidigt som det dämpar farten för snabba cyklister. Rapporten lyfter även potentialen i att använda videobaserad analys som ett verktyg för att systematiskt utvärdera och förbättra trafiksäkerheten för cyklister.

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# 1 INTRODUCTION

## 1.1 BACKGROUND

Cycling is increasingly promoted as a sustainable and healthy mode of transport, particularly in urban environments. However, despite its societal benefits, cycling safety remains a critical challenge. A large proportion of cyclist injuries do not involve collisions with other road users but instead occur as **single-bicycle accidents**, commonly referred to as fall accidents. These incidents constitute the majority of serious cyclist injuries in many countries. In Sweden, for example, approximately 80% of seriously injured cyclists are involved in single accidents, highlighting their significance as a public health and traffic safety concern.

Single-bicycle accidents are typically the result of complex interactions between the cyclist, the bicycle, and the surrounding infrastructure. Previous research has shown that infrastructure-related factors—such as uneven or slippery surfaces, sharp geometric transitions, obstacles, and constrained spaces—play a central role in the occurrence of these accidents. In addition, environmental conditions (e.g., weather, surface friction) and human factors (e.g., sudden maneuvers, distraction) often interact with infrastructure deficiencies, further increasing the likelihood of loss of balance.

A key challenge in addressing single-bicycle accidents lies in the **limitations of traditional safety analysis methods**. Conventional approaches rely heavily on reported accident data, which are inherently reactive and often incomplete. Many fall incidents go unreported, and even when data are available, they provide limited insight into the underlying mechanisms leading to instability. As a result, it is difficult to identify hazardous infrastructure elements before accidents occur or to evaluate the safety implications of new design interventions.

At the same time, common infrastructure measures intended to improve safety—such as speed-reducing devices or physical barriers—may have unintended consequences. For example, bicycle barriers (chicanes or kissing gates) are frequently implemented to reduce cyclist speed or restrict access. However, such designs may force cyclists into low-speed, high-instability conditions or create accessibility barriers for certain user groups, including older cyclists and users of larger bicycles (e.g., cargo bikes). This highlights the need for a more nuanced understanding of how infrastructure design affects cyclist behavior, stability, and safety outcomes.

## 1.2 RESEARCH AIM

Against this background, the present project aims to advance both the **measurement and design of cycling safety**. Specifically, the objectives are:

1. To develop and evaluate a **proactive method for assessing fall risk** based on observed cyclist behavior, using video analysis and statistical modeling.
2. To investigate how the **physical design of infrastructure elements**, particularly bicycle barriers, influences cyclist stability, safety, and user experience.

To achieve these objectives, the project is structured into two complementary studies. Study 1 focuses on methodological development for risk assessment using trajectory data and Extreme Value Theory, enabling the identification of high-risk locations without relying solely

on accident records. Study 2 focuses on the experimental evaluation of bicycle barrier design, examining how different geometric configurations affect cyclist performance and perceived safety.

By combining analytical modeling with controlled experimentation, the project seeks to provide a more comprehensive, evidence-based foundation for designing safer and more inclusive cycling infrastructure.

## STUDY 1: PROACTIVE RISK ASSESSMENT USING VIDEO ANALYSIS AND EXTREME VALUE THEORY

### 1.3 METHODOLOGICAL FRAMEWORK

Study 1 develops a methodology for estimating fall risk using video-based trajectory data. Cyclists were recorded at three locations in Lund, Sweden, and their movements were extracted as time-stamped trajectories describing position, speed, and acceleration. These data enable the derivation of physically grounded indicators related to cyclist stability.

The analysis focuses on two principal mechanisms of fall accidents:

- Pitch-over (forward overturning): Occurs when high deceleration or collision causes the rear wheel to lift, leading to forward rotation over the handlebars.
- Skidding (loss of traction in curves): Occurs when lateral forces during turning exceed the available tire–surface friction.

Both mechanisms are modeled using fundamental principles of mechanics. Stability thresholds are defined based on critical values of deceleration, velocity, turning radius, and friction conditions. These thresholds represent the limits beyond which a cyclist is likely to lose balance. To convert these indicators into probabilistic risk measures, the study applies Extreme Value Theory (EVT). EVT is well suited for modeling rare and extreme events and is used here to estimate the probability that observed cyclist behavior approaches or exceeds instability thresholds.

The approach involves: -Segmenting cyclist trajectories into short spatial intervals, -Extracting extreme values of instability indicators within each segment, -Fitting Generalized Extreme Value (GEV) distributions to estimate the probability of imbalance. This segment-based modelling enables the generation of spatially resolved risk maps, identifying locations where cyclists are most likely to experience instability.

### 1.4 RESULTS

The application of the method at three urban locations demonstrates that:

- Risk varies significantly at a fine spatial scale, often within short segments of infrastructure.
- Specific geometric features—such as curves, transitions, and constrained passages—are associated with elevated instability probabilities.
- The method can identify high-risk areas even in the absence of recorded accidents, supporting proactive safety assessment.

By incorporating cyclist flow data, the analysis also allows estimation of the expected frequency of instability events, providing a more comprehensive measure of exposure-adjusted risk.

### 1.5 LIMITATIONS

The method estimates instability events rather than actual accidents. While instability is a necessary precursor to falls, not all such events result in injury. The relationship between modelled instability and observed accident frequency remains to be validated.

Additionally, the analysis is sensitive to environmental conditions such as surface friction and weather. The empirical data used in this study were collected under relatively favourable conditions, and further research is required to generalize results to different contexts.

## 2 STUDY 2: EXPERIMENTAL EVALUATION OF BICYCLE BARRIER DESIGN

### 2.1 EXPERIMENTAL DESIGN

Study 2 examines how the design of bicycle barriers (chicanes) affects cyclist behavior, stability, and perceived safety. The study was conducted as a controlled experiment on a test track, where 37 participants navigated a series of barrier configurations.

Participants represented three user groups:

- Cyclists without mobility constraints,
- Cyclists with reduced confidence or physical capability,
- Users of larger or non-standard bicycles (e.g., cargo bikes, velomobiles).

A total of twelve configurations were tested, varying:

- Longitudinal distance between barriers,
- Degree of overlap between barrier elements,
- Effective path width.

Cyclist speed, behaviour, and subjective assessments were recorded and analysed.

### 2.2 RESULTS

The results indicate that current design recommendations for bicycle barriers present several challenges:

- **Speed reduction and instability.** Existing configurations force cyclists to reduce speed below approximately 10 km/h. This is a critical threshold below which bicycles become dynamically unstable, leading to increased wobbling and reduced control.
- **Accessibility limitations.** Larger bicycles experience significant difficulty navigating standard barrier designs, often requiring dismounting or complex manoeuvres.
- **User experience.** Many participants reported discomfort, difficulty, or perceived risk when passing through the barriers, particularly in configurations with shorter distances or greater overlap.

These findings suggest that conventional barrier designs may inadvertently increase fall risk by compromising stability, while also reducing accessibility for diverse user groups.

### 2.3 DESIGN IMPLICATIONS

Based on the experimental results, an alternative configuration is proposed:

- **Longitudinal spacing:** approximately 2.5 meters
- **Overlap:** approximately 0.5 meters.

This design allows cyclists to maintain a stable speed while still moderating excessive velocity. It also improves passability for larger bicycles, supporting more inclusive infrastructure design.

### 3 DISCUSSION AND CONCLUSION

The combined findings from both studies highlight the importance of considering **dynamic stability** in cycling infrastructure design. While traditional safety measures often prioritize speed reduction or collision avoidance, they may overlook the fundamental requirement that bicycles rely on forward motion for balance.

Study 1 demonstrates the feasibility of **proactive, data-driven risk assessment**, enabling identification of hazardous infrastructure features before accidents occur. Study 2 provides empirical evidence that certain design interventions—specifically bicycle barriers—can negatively affect stability and usability if not carefully designed.

Together, the studies suggest that infrastructure should be evaluated not only in terms of compliance with design standards, but also in terms of its impact on cyclist behaviour and physical stability.

#### 3.1 CONCLUSION

This project contributes to the understanding of cyclist safety by integrating analytical modeling and experimental design evaluation. The main conclusions are:

- Single-bicycle accidents are strongly influenced by infrastructure design and its interaction with cyclist stability.
- Video-based trajectory analysis combined with Extreme Value Theory offers a robust method for proactive risk assessment.
- Current bicycle barrier designs may introduce instability and accessibility issues, particularly at low speeds.
- Infrastructure design should prioritize maintaining cyclist stability while achieving safety objectives such as speed moderation.

The findings support a shift toward **evidence-based and behaviour-informed design principles** for cycling infrastructure, with the potential to reduce fall-related accidents and improve overall safety.

## ABOUT AUTHORS



**Carl Johnsson** is an Assistant Professor at Lund University. His research focuses on methods for traffic safety evaluation, mainly through observations from video recordings, with a particular emphasis on unprotected road users.



**Jenny Eriksson** is a statistician and investigator at the Swedish National Road and Transport Research Institute (VTI). She is involved in traffic safety work, primarily focusing on pedestrian and bicycle traffic.



**Zhankun Chen** is a PhD student in traffic safety at Lund University. His current research focuses on proactive methods for traffic safety analysis, particularly the application and interpretation of extreme value theory in the analysis of microscopic traffic interactions.



**Kevin Gildea** was a postdoctoral researcher at Lund University until 2025. His research focuses on the combination of computer vision, deep learning, and multi-object dynamics. In particular, it emphasizes the use of these technologies for studies of injury biomechanics, with a special focus on unprotected road users.



**Aliaksei Lareshyn** is an Associate Professor of Traffic Safety at Lund University. His main expertise lies in the theory and practical application of proactive (non-accident-based) methods for traffic safety analysis. His other research interests include methods for traffic data collection, unprotected road users, and policy and practice in traffic safety work.