TRA

TRANSPORT
RESEARCH
ARENA
BUDAPEST
18-21/05/26

A Hybrid Extreme Value Theory Framework for Adaptive Pedestrian Crash Risk Estimation

Amir Hossein Kalantari*, Amna Chaudhry, Stella Roussou, Apostolos Ziakopoulos & Amir Pooyan Afghari

*Presenter

18/05/2026

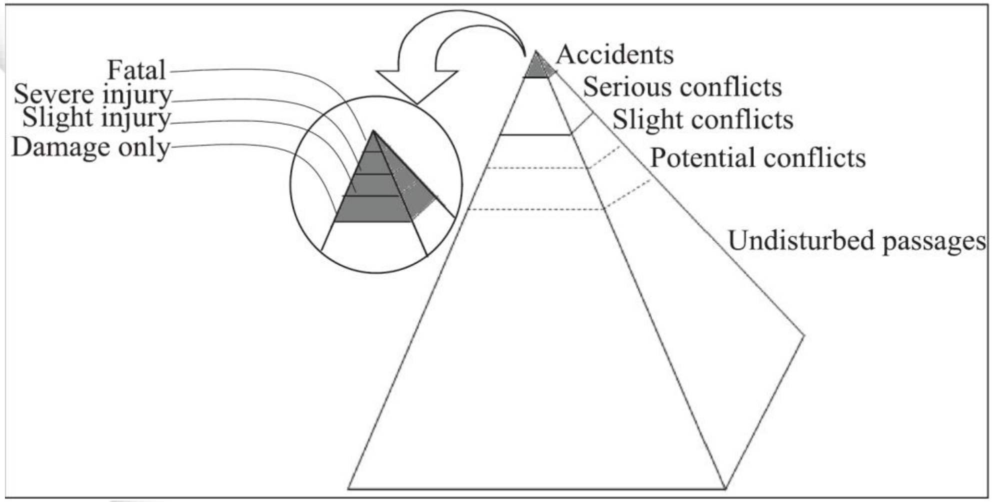
BACKGROUND

Motivation

- Despite advances in vehicles and infrastructure, **pedestrians remain highly vulnerable**
- **Serious crashes are rare and spatially dispersed**, limiting statistical reliability
- Crash-based models are **reactive, data-poor, and site-specific**
- ⇒ Need a **proactive, behavior-based safety approach**

Existing Approach

- **Traffic conflicts** capture behavioral precursors to crashes
- Enable proactive risk estimation via **SSMs (e.g. TTC)**
- Even among conflicts, **high-risk events remain rare**
- ⇒ **Extreme Value Theory (EVT)** for tail modelling
- **Standard EVT: GEV, GP — GP more stable; both sensitive under sparse extremes**



Hydén, C.: The development of a method for traffic safety evaluation: The Swedish Traffic Conflicts Technique. Bulletin Lund Institute of Technology, Department 70. Lund Institute of Technology, Lund (1987).

Key Challenges

- **Dependence**: clustered interactions violate EVT assumptions
- **Threshold sensitivity**: arbitrary choices → **different risk estimates (same data)**
- **Data limitations**: noise, uncertainty, small effective samples
- **Tail uncertainty**: **bounded and environment-dependent extremes**
- ⇒ EVT results become **sensitive, unstable, and poorly characterized in uncertainty**

Research Gap

- EVT is **theoretically sound but practically fragile**
- Results depend strongly on **modelling choices and thresholds**
- **High, poorly characterized uncertainty** limits decision-making
- No framework: **data-driven threshold selection, consistent tail behavior, robustness with limited data, etc.**
- ⇒ Missing a **unified, data-driven EVT workflow**

Current Study

Current Study

- Propose a **hybrid, data-adaptive EVT framework** for pedestrian safety
- Integrates:
    - *anomaly-based extreme-event identification*
    - *multi-criteria threshold diagnostics*
    - *flexible tail modelling strategies*
    - *systematic evaluation of EVT assumptions*
    - *enforcement of independence and tail consistency*

METHODS

The Framework

1: Safety Indicator

TTC_{min}

- Pairwise interaction (construction)
- Minimum over time (aggregation)
- Continuous surrogate (severity)
- Left-tail (extremes)

2: Exceedance sampling

- Prefiltering (relevance)
- EVT direction/support (tail)
- IForest / MCD / Hybrid (detection)

Best by post-declustering ESS (selection)

3: Declustering & threshold diagnostics

- Declustering (independence)
- Hybrid / ATSM-like sweep (robustness)
- KS + GOF p-value (fit)
- AIC / BIC (parsimony)
- CV Log (generalization)
- n_{exc}, π_{local}/π_{global} (tail support)
- MRL + (ξ, σ) stability (screening)

The Framework

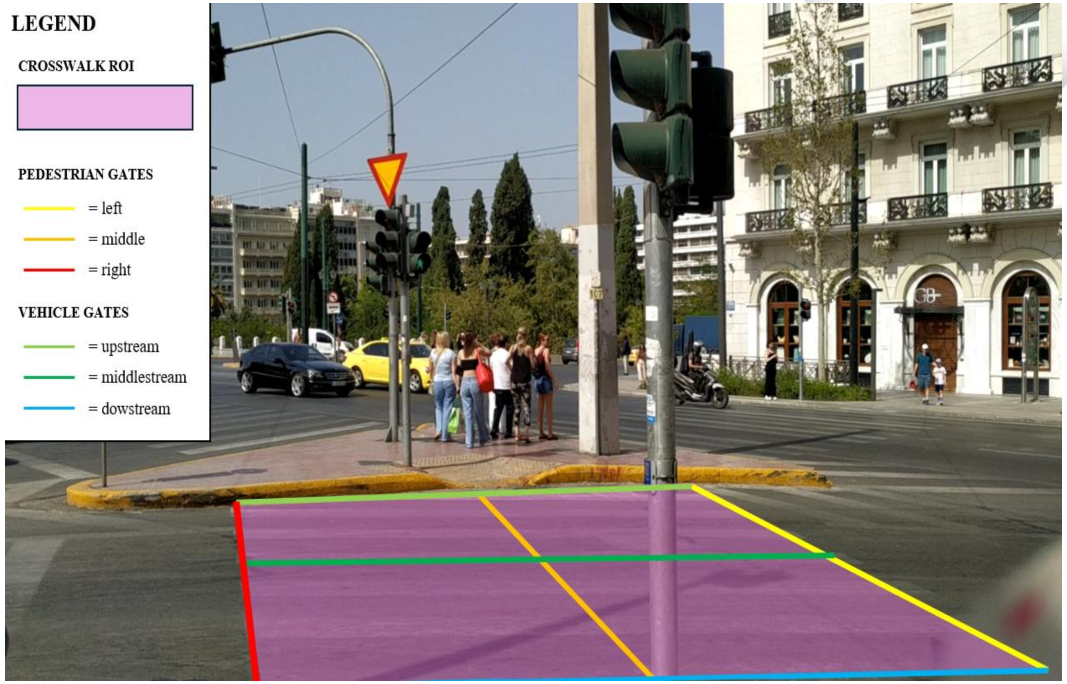
4: Model fitting and fallback strategy

- GEV / GP (baseline)
- Bayesian GP / GAMLSS (auxiliary)
- BM & POT (mode-aware)
- $Y = u - X$ (exceedance space)
- MLE / MCMC-NUTS (inference)

5: Crash risk & frequency estimation

- GEV (direct at x_c)
- GP: $\pi_{tail} P(Y \geq \delta)$ (tail risk)
- Bayesian GP (posterior uncertainty)
- GAMLSS (exceedance-based)
- ACCF (anchor-calibrated)

Case Study: Vasilissis Sofias–Panepistimiou, Athens

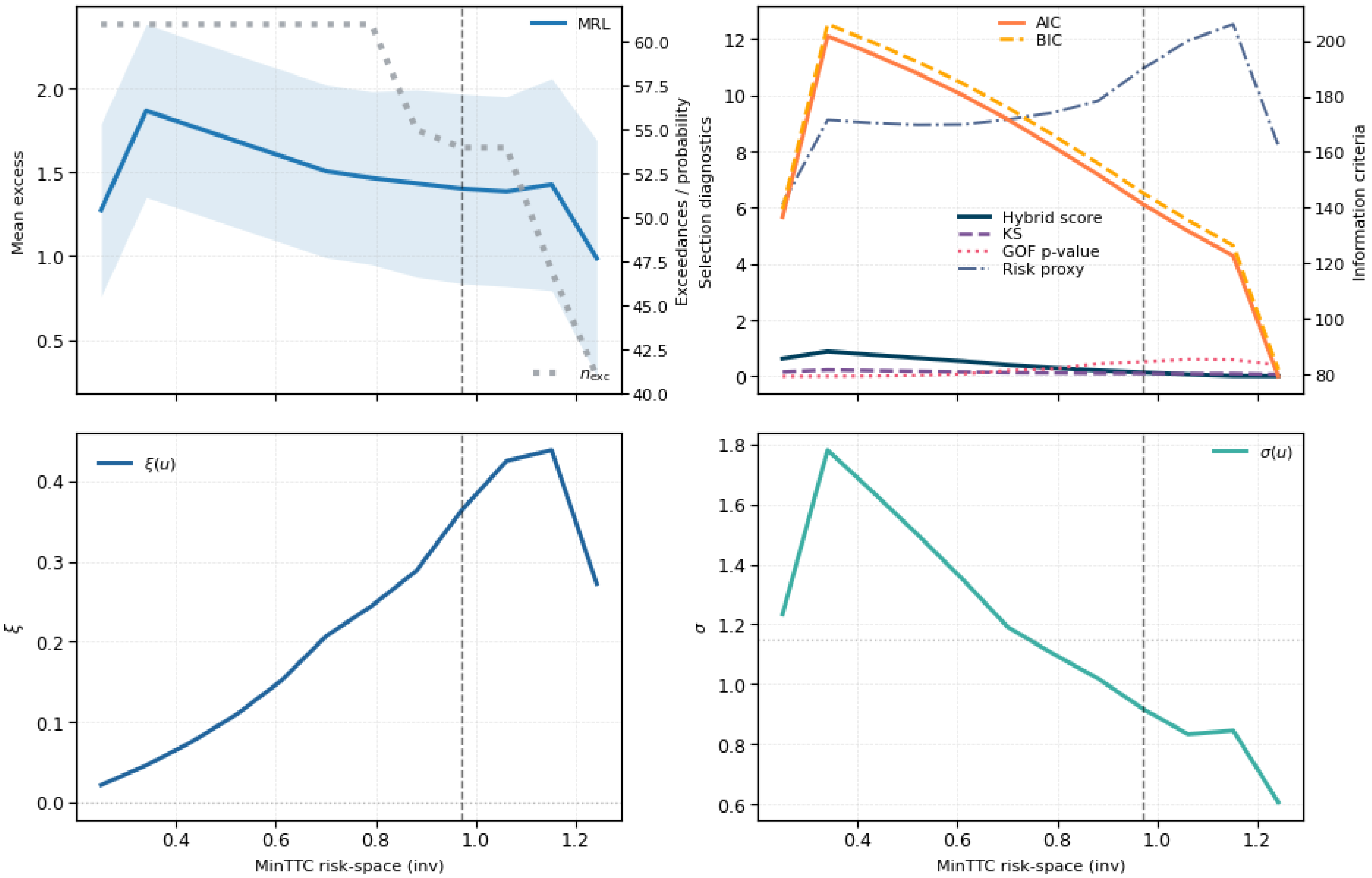


- YOLOv8 → Pedestrians & Vehicles
- ResNet-50 → feature embedding

Resutls

Threshold Diagnostics

$u = 1.013$ s

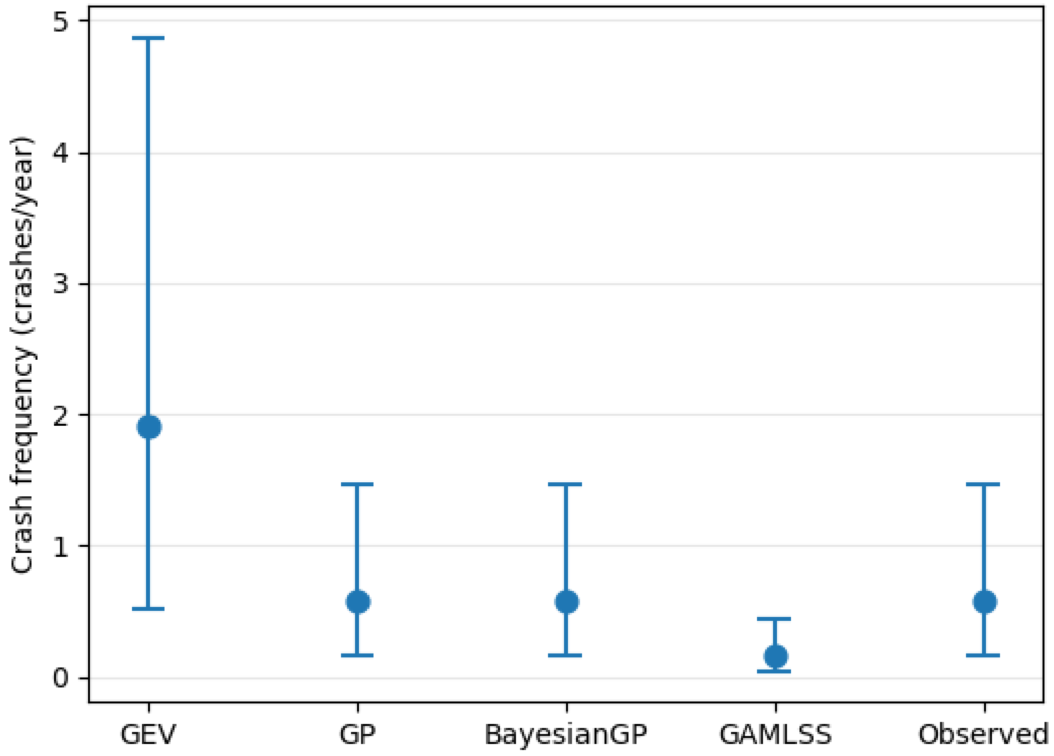


Models

	GEV	GP	Bayesian GP	GAMLSS
Threshold (s)	N/A	1.013	1.013	1.013
Shape	0.350	0.332	0.417	2.001
Scale	0.756	0.947	0.964	2.330
Location	1.094	N/A	N/A	N/A
KS Statistic	0.179	0.084	N/A	0.145
AIC*	80.104	141.908	N/A	142.003
Estimated risk	0.069	0.021	0.021	0.006
Risk Lower bound	0.045	N/A	0.020	N/A
Risk higher bound	0.100	N/A	0.021	N/A
ACCF	1.903	0.572	0.571	0.169

* GEV AIC is computed on the full sample, whereas tail-model AICs use exceedances only; they are not directly comparable across likelihood spaces.

Obs: 0.571 crashes/year (95% CI: 0.156–1.463)



Conclusions

Takeaways

- EVT reliability is a workflow problem, not a model choice
- Admissible, data-driven thresholds replace subjective tail definition
- POT aligns modelling with the operative (left) tail of conflict severity
- Bayesian regularization makes tail risk interpretable and decision-ready

Practical Safety Implications

- Identify which crossings to fix first
- Select the most effective intervention per site
- Evaluate whether interventions actually work
- Monitor crash risk continuously (near real-time)
- Estimate expected crashes for planning and funding

THANK YOU!

TRA TRANSPORT RESEARCH ARENA

BUDAPEST 18-21/05/26

Re-Generation in transport