# Development and Calibration of Safety Performance Functions for Urban Roads in Flanders, Belgium


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UHasselt


20/09/2024

Web Page: https://twin-safe.com/


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# Introduction

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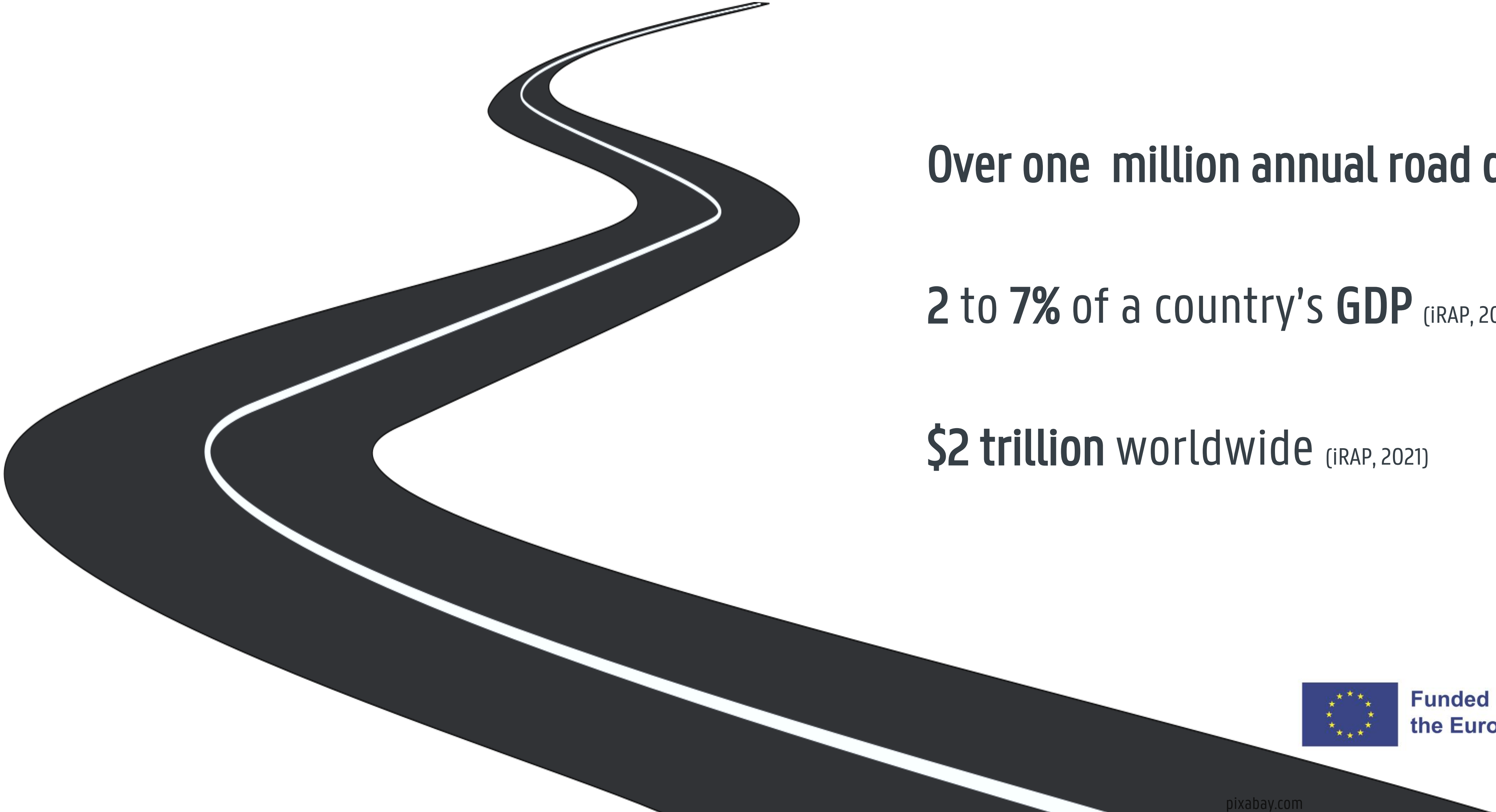
# INTRODUCTION


pixabay.com

Over one million annual road deaths

2 to **7%** of a country's **GDP** (iRAP, 2021)

**$2 trillion** worldwide (iRAP, 2021)

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# INTRODUCTION


Source: FHWA

## Sustainable Development Goals (SDG) (UN, 2015)

- **Target 3.6:** 50% reduction in road injuries and fatalities by 2030
- **Target 11.2:** Inclusive, safe, cost-effective, resilient, and sustainable transportation systems

## **Safe System Approach** and **Vision Zero**

## Decade of Action for Road Safety 2021-2030 (UN, 2020)

## EU Directives on Road Safety (European Commission, 2018, 2019, 2020)

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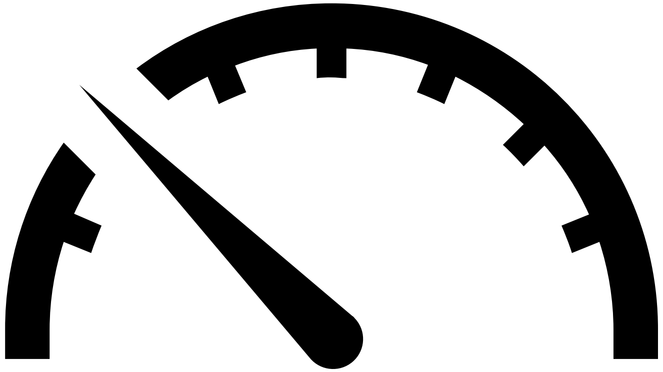
# INTRODUCTION



- **Insufficient decrease** in road deaths
- **Stagnated progress** or increase

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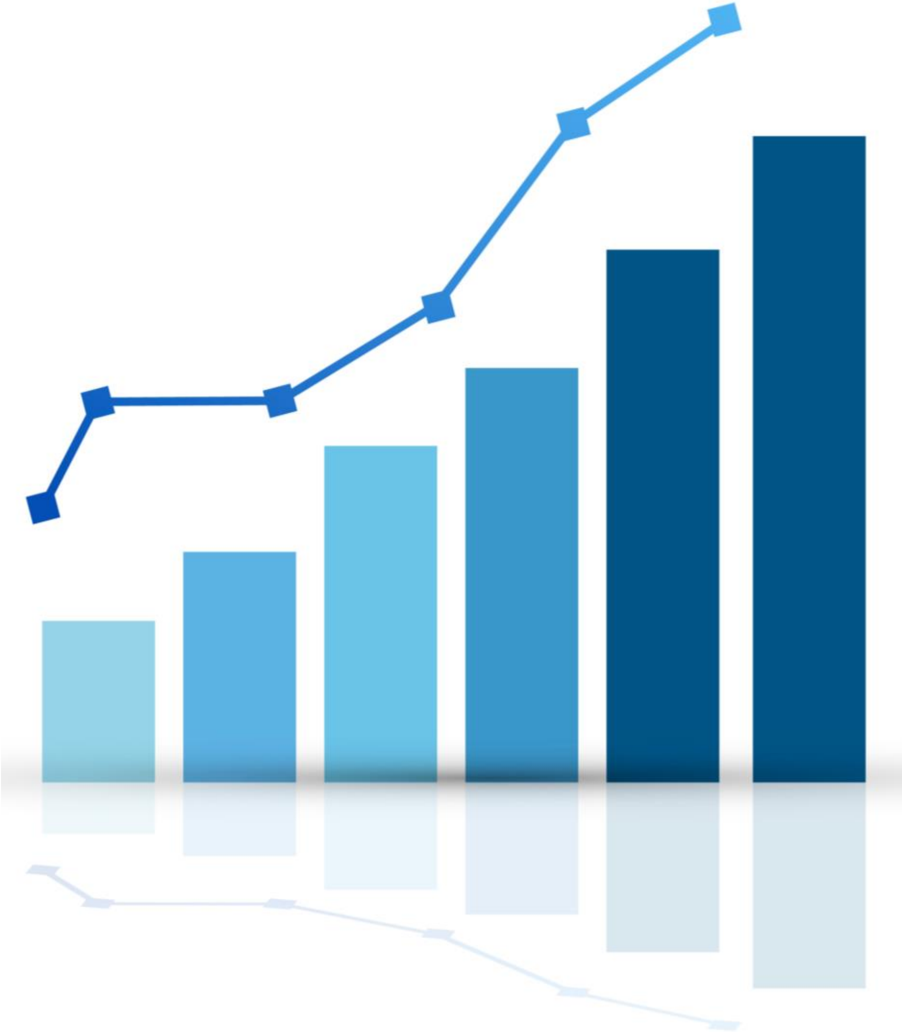
# INTRODUCTION



## Road Safety Research

- Identification and analysis of crash hotspots
- Causal analysis of crashes

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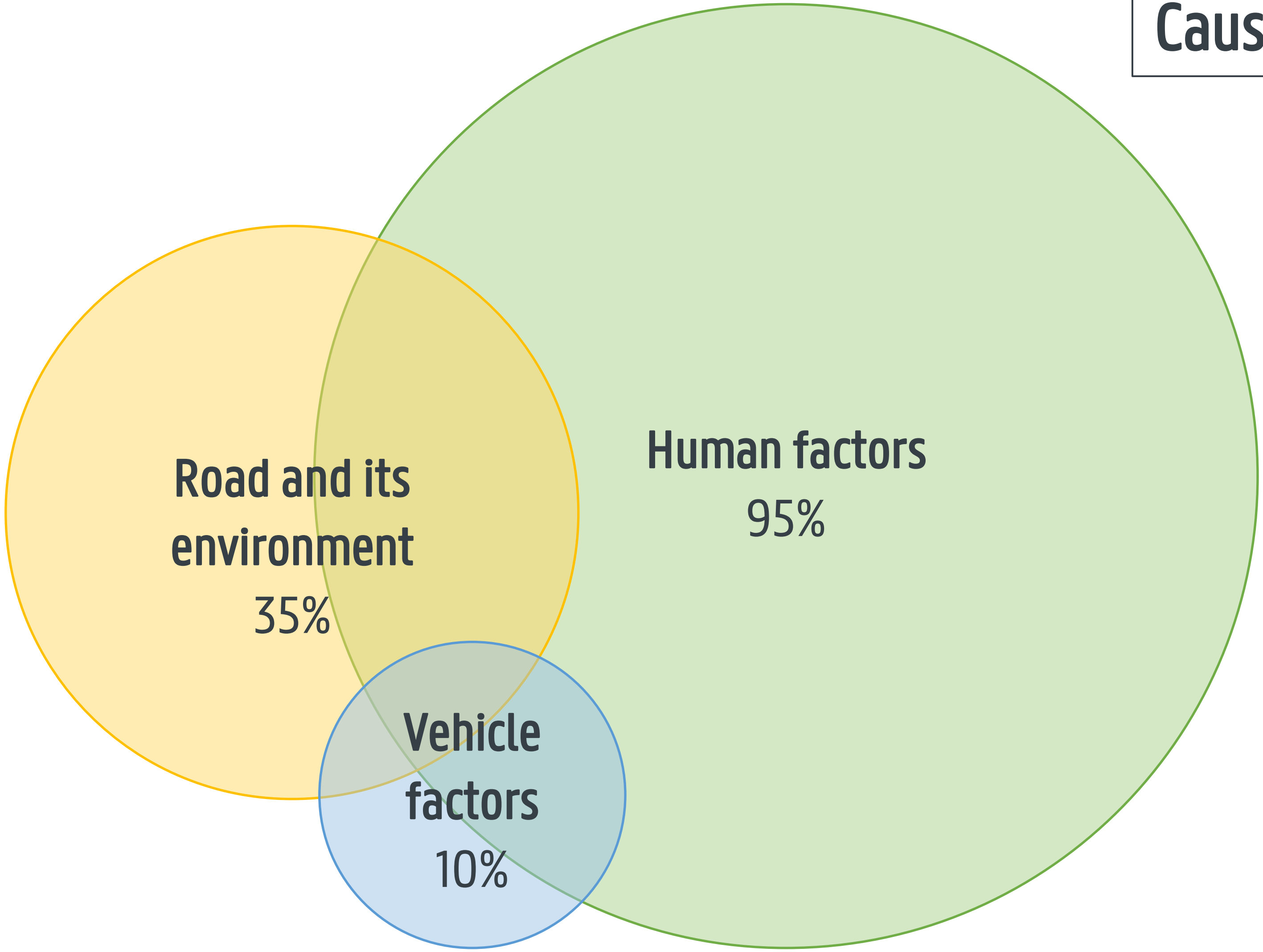
# INTRODUCTION

Causal analysis of crashes




Source: KornAcKi et al., (2017)

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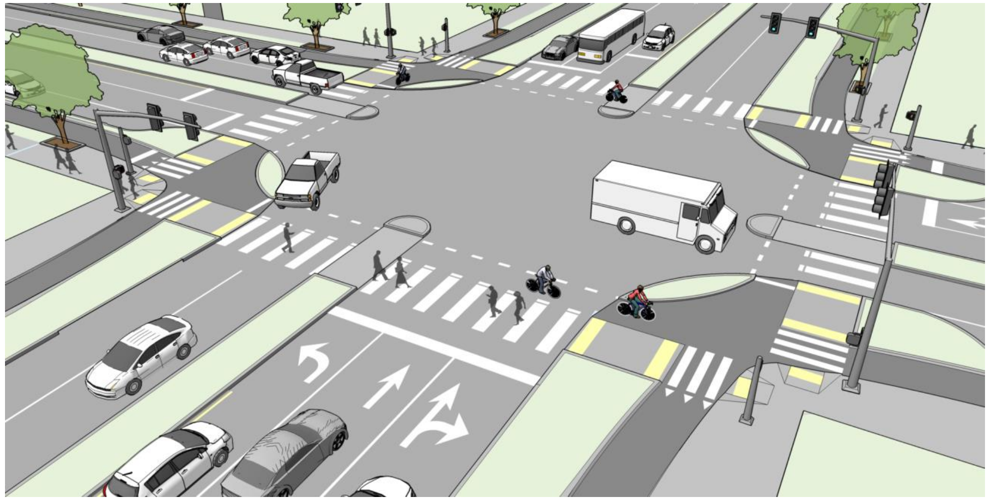
# INTRODUCTION



Source: altago.com

## Role of Road in Traffic Safety

- Direct role (e.g., faulty geometry, unforgiving roads)
- Indirect role via road user behaviour (self-explaining roads)
- Controllable unlike other factors

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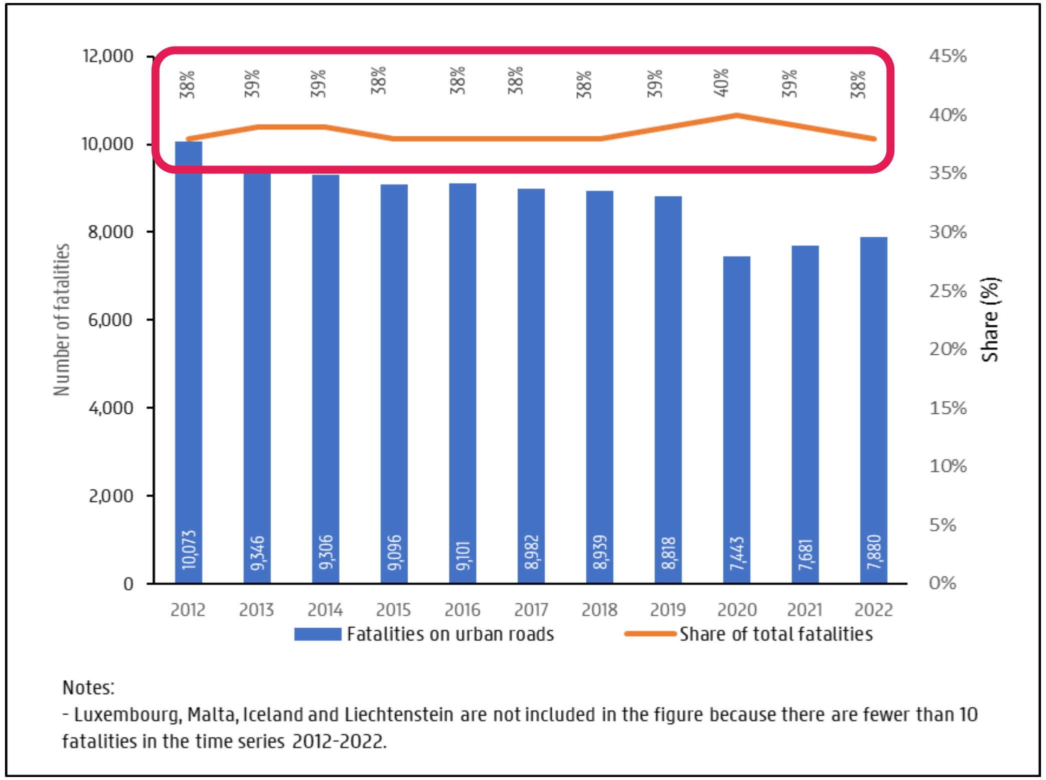
# INTRODUCTION




## Traffic Safety in Urban Areas (EU)

- **38%** road fatalities in the EU in 2022 (European Commission, 2024)
- **56%** severe injuries in the EU in 2022 (European Commission, 2024)
- **31** of **32** EU cities did not meet the SDG targets (ITF, 2022)

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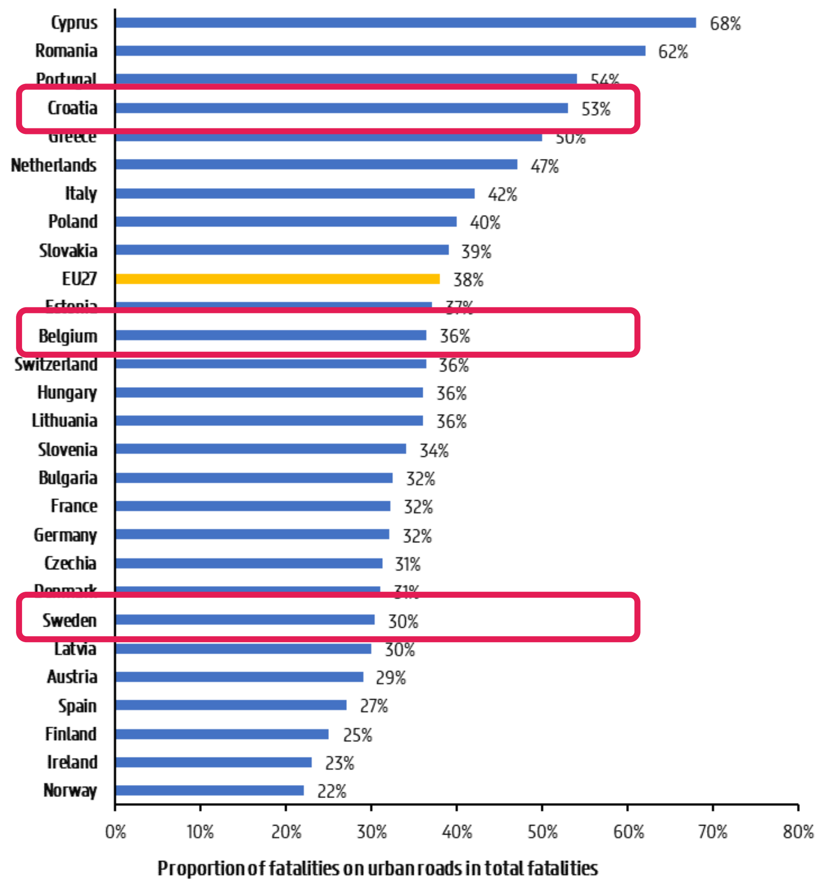
# INTRODUCTION




Notes:
- Luxembourg, Malta, Iceland and Liechtenstein are not included in the figure because there are fewer than 10 fatalities in the year 2022.
- For Ireland, Greece, Latvia, Finland and Sweden the missing value for 2022 was imputed with the last known value in the series.

## Traffic Safety in Urban Areas (EU)

- **High crashes** in **Eastern/Central** Europe
- **Relative low** crashes in **Scandinavia**
- **36%** road fatalities in **BE** in **2022** (European Commission, 2024)

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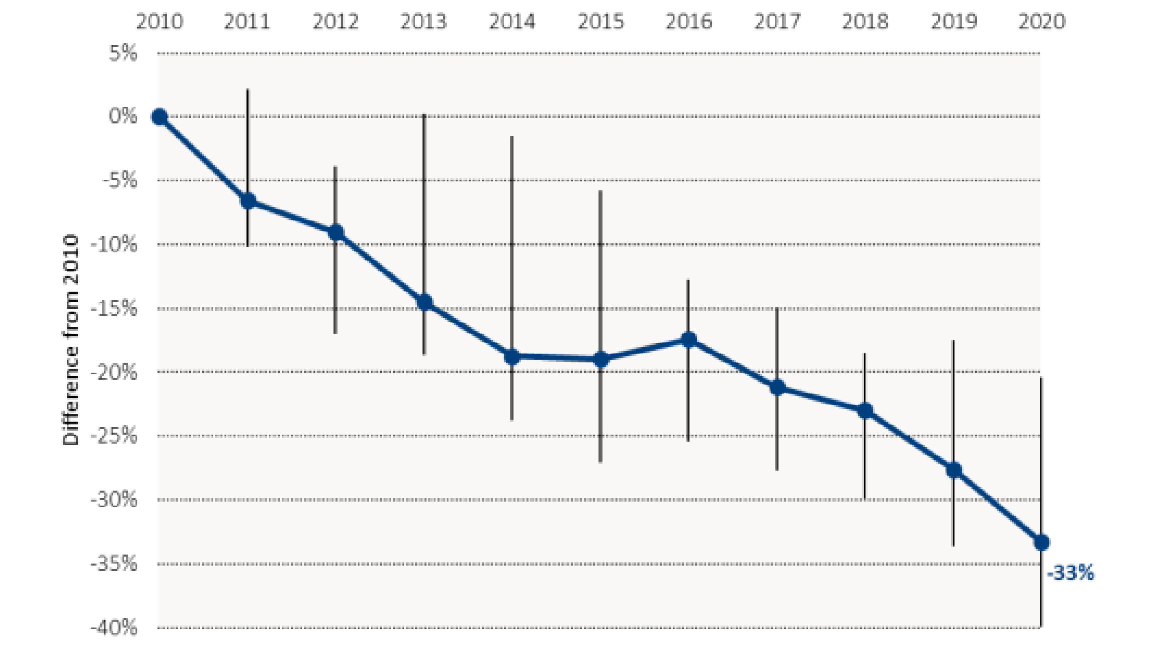
# INTRODUCTION




Note: for each year, the dot represents the median percentage change since 2010 across 26 cities. Vertical bars represent the inter-quartile range: observations between the 25th and the 75th percentiles. The number of deaths is captured by a three-year average – for instance, a 2010 value represents the 2008-2010 average.

Source: ITF Safer City Streets database.

## Traffic Safety in Urban Areas (EU)

- **4%** of the median annual reduction rate from **2010 to 2020** (ITF Safe City Streets database, 2022)
- **2.3% & 5%** reductions are most common (ITF Safe City Streets database, 2022)

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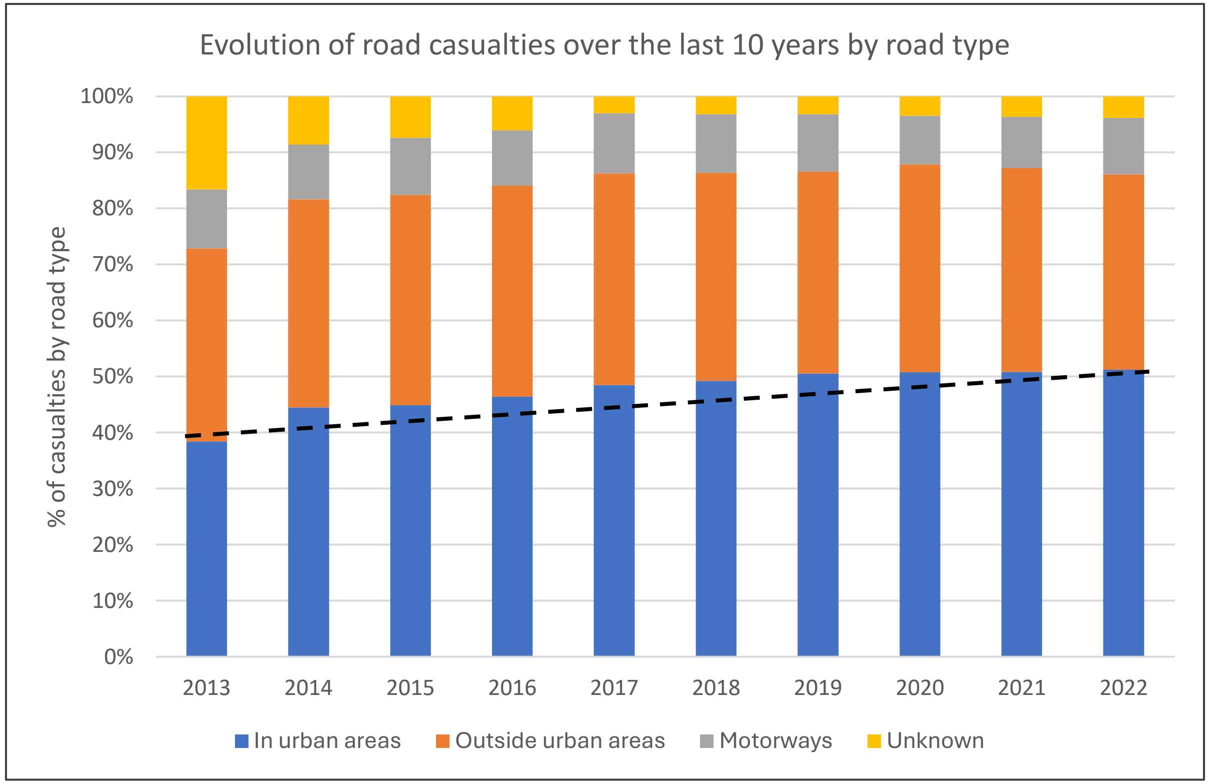
# INTRODUCTION




Source: Vias Institute, 2024

## Traffic Safety in Flanders

- Urban crashes: **increasing trend** compared to other crashes (Vias Institute, 2024)
- Car occupants **(36%)** suffered the highest proportion, followed by cyclists at **33%** in 2022 (Vias Institute, 2024)

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# Problem Statement

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# PROBLEM STATEMENT

**Numerous factors** contribute to urban roads (un)safety

**Lack of the granularity** needed in **current approaches**

**Reactive strategies** are **insufficient**

**Pressing need for a different approach which can anticipate potential risks and inform targeted interventions**

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# Objectives

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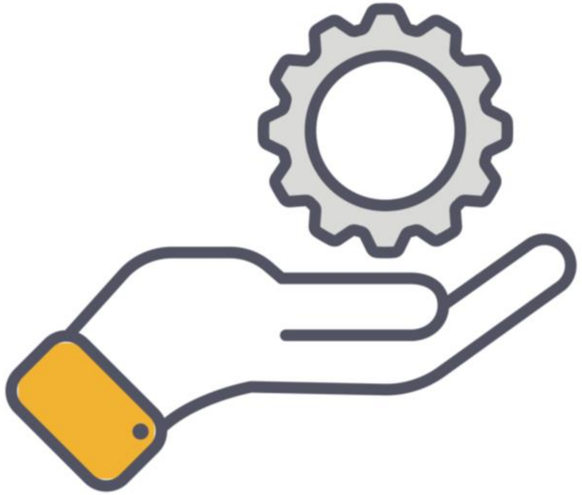
# OBJECTIVES



Safety Performance Functions → **Compelling solution**

- Analyse multifaceted interactions of variables via statistical techniques
- Provide predictive framework for anticipating potential hazards

**Develop comprehensive crash prediction models specifically designed for urban areas**

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# OBJECTIVES

1. To estimate **safety performance functions (SPFs)** for urban **road segments** and **intersections** by applying **advanced statistical** techniques to acquire **higher accuracy** and **reliability**

2. To explore the **applications** of the estimated SPFs in crash **hotspot identification** and SPFs' **transferability**


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# Research Questions

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# RESEARCH QUESTIONS

| | |
|---|---|
| **Research Question 01** | What factors influence crash frequency on urban road segments and intersections? |
| **Research Question 02** | How do different alternatives to the traditional modelling approach perform regarding statistical fit and predictive performance? |
| **Research Question 03** | What are the best models for hotspot identification? What is the best HSID method when the modelling technique remains the same? |
| **Research Question 04** | Can applying the Bayesian model (with informative priors) help develop better SPF for areas with limited data? |

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# Methodology

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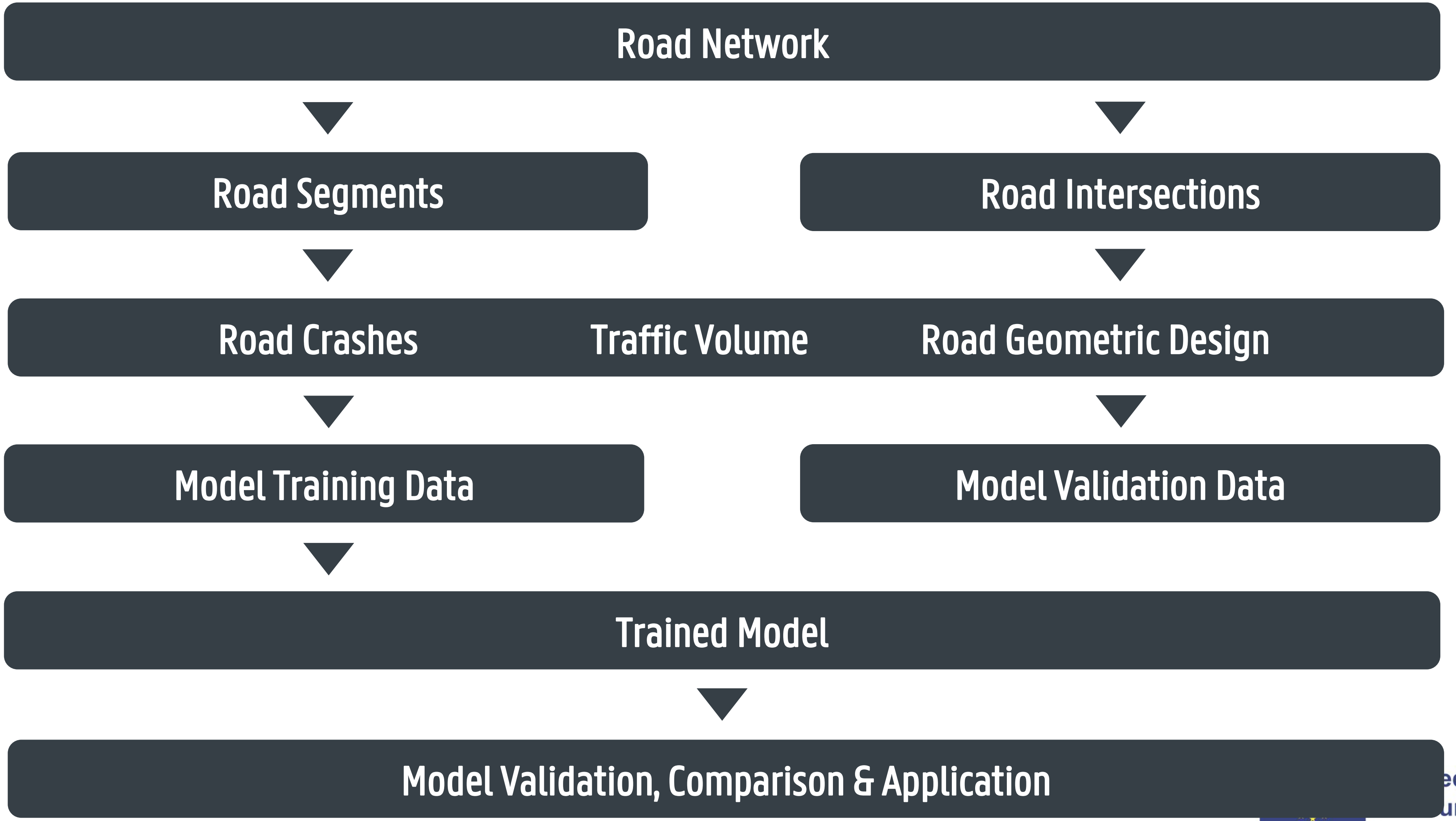
# STUDY FRAMEWORK



# Data preparation

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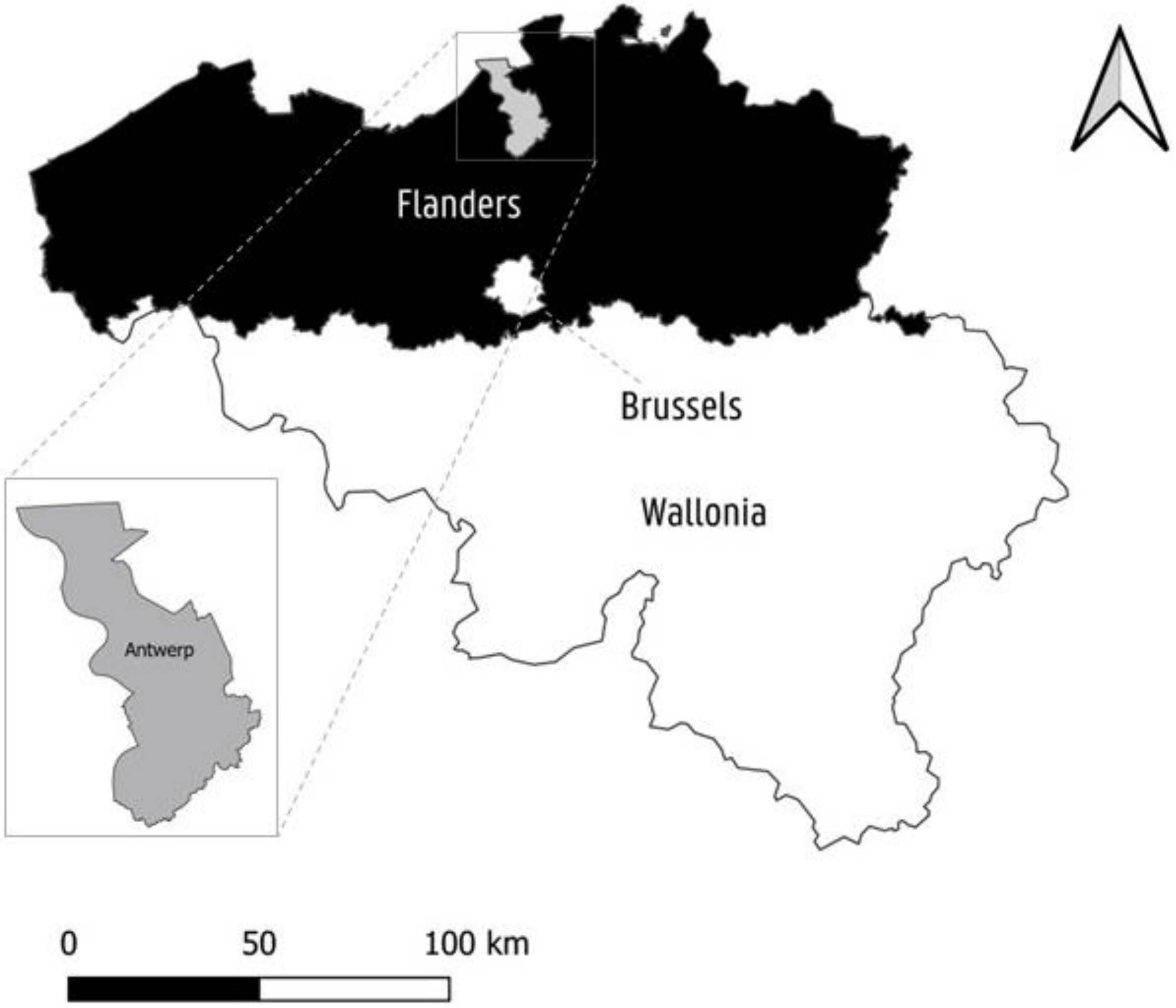
# STUDY AREA

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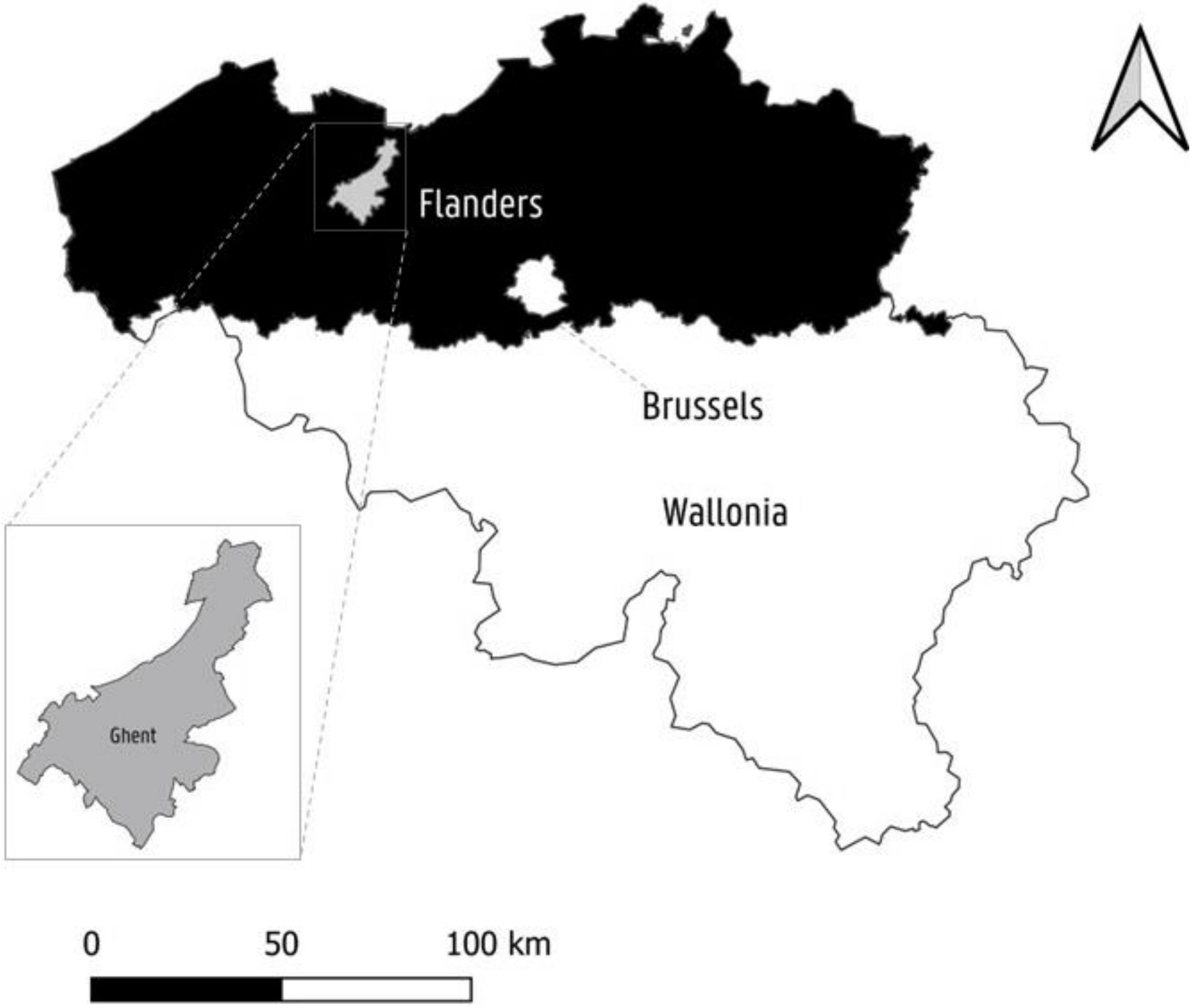
# STUDY AREA

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# DATA SOURCES

Police

Town government

Mobility agencies

Regional Government (Dept)

Flanders
State of the art

lantis bouwen aan verbinding

Politie

STAD ANTWERPEN

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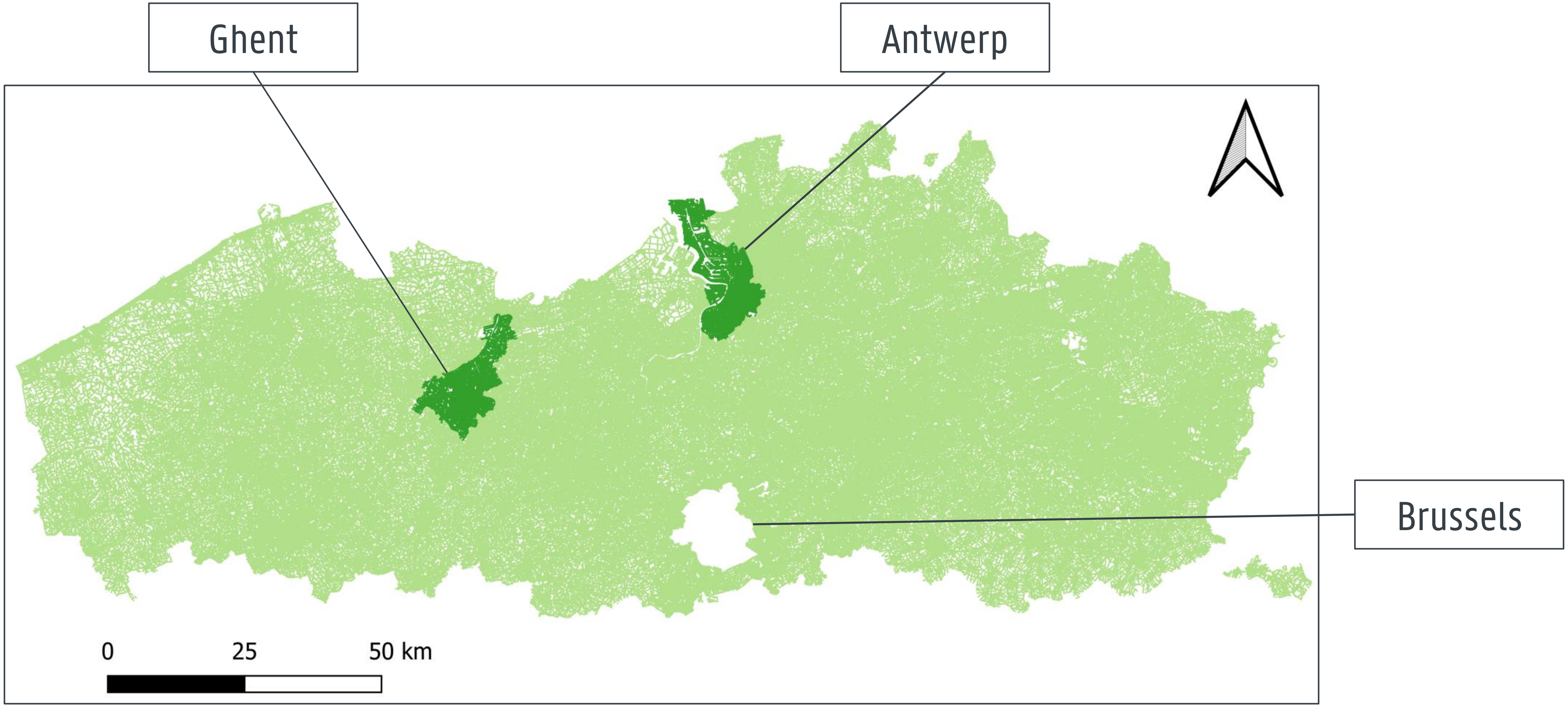
# FLANDERS ROAD NETWORK




Antwerp and Ghent road network within Flanders

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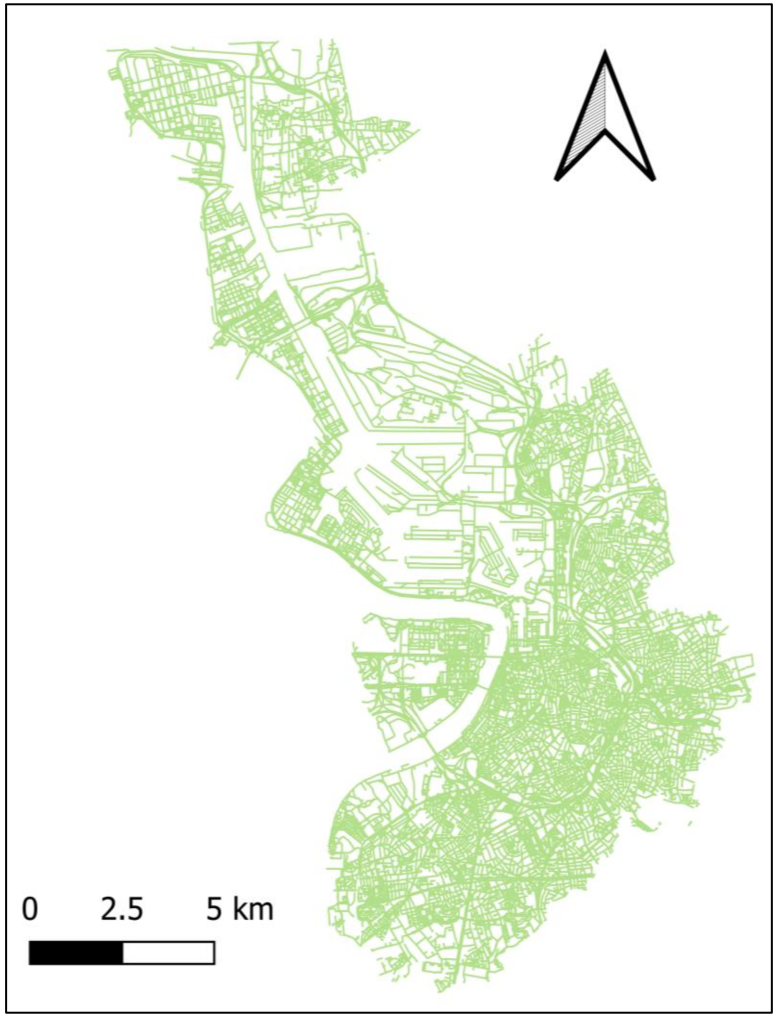
# ANTWERP ROAD NETWORK




Map of Antwerp city with all public roads from Flanders' roads register

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# CRASH LOCATIONS


Buffering operation for defining a selection area

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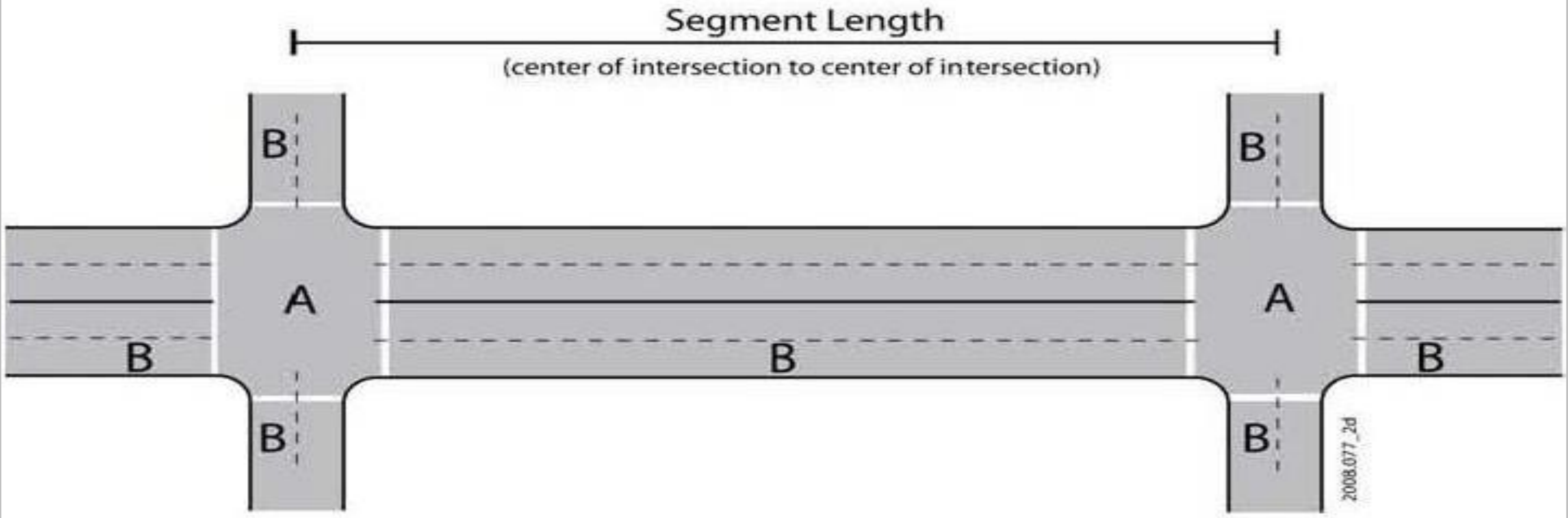
# SEGMENT & INTERSECTION




A All crashes that occur within this region are classified as intersection crashes.

B Crashes in this region may be segment or intersection related, depending on on the characteristics of the crash.

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# CRASH DATA

| Year | Site types | Injury | Fat. Plus Inj. | PDO | Total |
|---|---|---|---|---|---|
| 2010 | Intersection | 427 | 428 | 581 | 1009 |
| | Road segment | 764 | 773 | 2324 | 3097 |
| | **Total** | 1191 | 1201 | 2905 | 4106 |
| 2011 | Intersection | 535 | 535 | 623 | 1158 |
| | Road segment | 790 | 795 | 2379 | 3174 |
| | **Total** | 1325 | 1330 | 3002 | 4332 |
| | . | . | . | . | . |
| | . | . | . | . | . |
| | . | . | . | . | . |
| 2015 | Intersection | 415 | 418 | 373 | 791 |
| | Road segment | 749 | 751 | 1993 | 2744 |
| | **Total** | 1164 | 1169 | 2366 | 3535 |
| 2010-2015 | Intersection | 2494 | 2504 | 2936 | 5440 |
| | Road segment | 4667 | 4702 | 13422 | 18124 |
| | **Total** | 7161 | 7206 | 16358 | 23564 |

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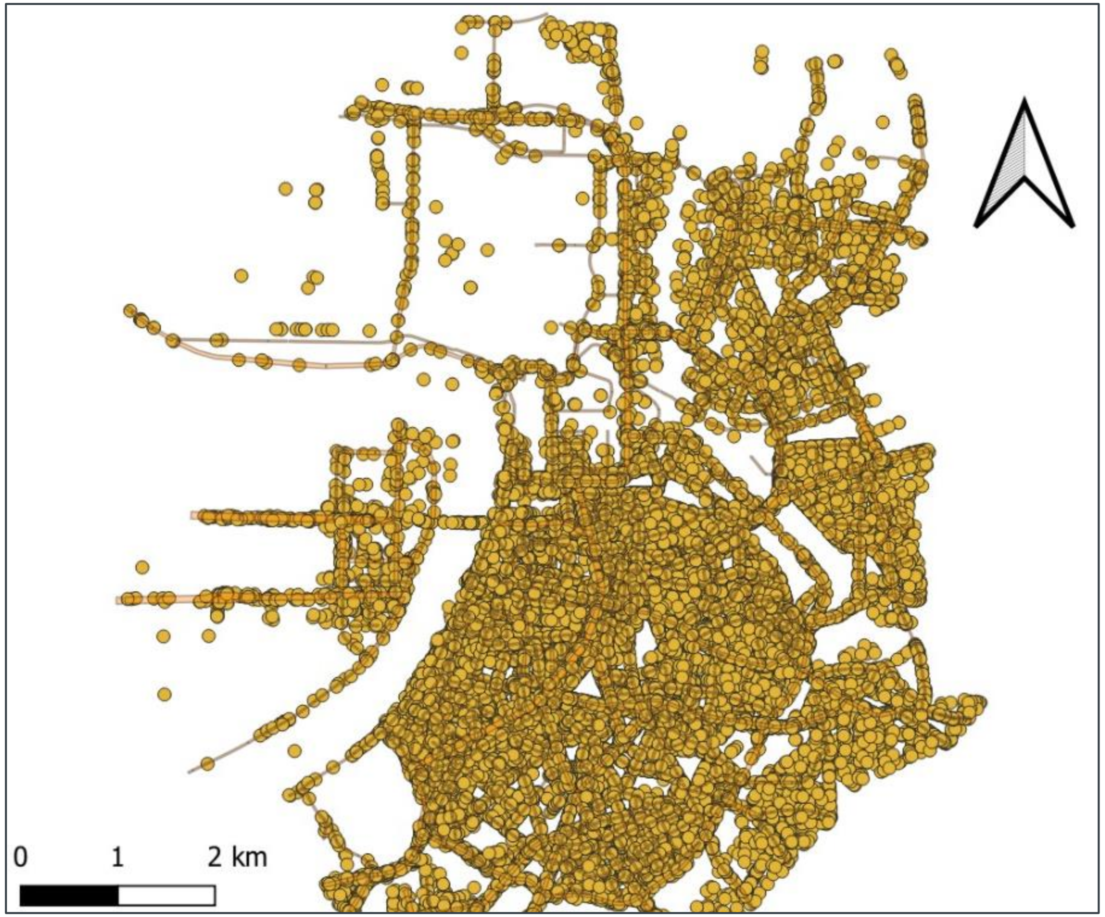
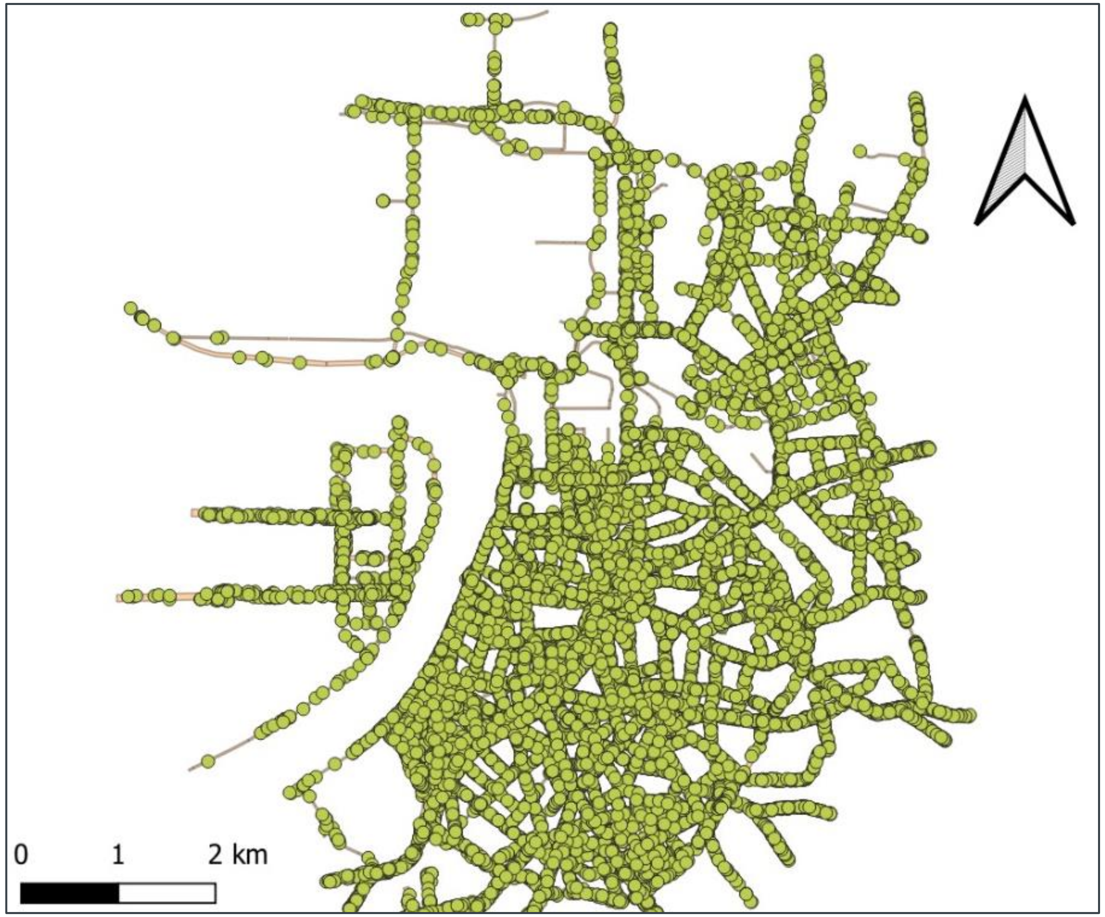
# FINAL DATA




Raw data




Cleaned data

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# SEGMENTS DATA-EXAMPLE

| Variable | Min | Max | Mean | Standard Deviation (SD) |
|---|---|---|---|---|
| **(a) Crash frequency** | | | | |
| All crashes | 0 | 90 | 7.54 | 10.29 |
| PDO crashes | 0 | 67 | 5.51 | 6.94 |
| Injury crashes | 0 | 43 | 1.99 | 4.40 |
| Injury and fatal crashes | 0 | 43 | 2.01 | 4.42 |
| **(b) Traffic and roadway cross-section variables** | | | | |
| Segment length (km) | 0.05 | 1.557 | 0.123 | 0.102 |
| Traffic volume (AADT) | 35 | 31,783 | 4894.09 | 6715.03 |
| Lane width (m) | 2.5 | 5 | 3.51 | 0.53 |
| **Number of lanes** | 1 = 748 sites (30.39%),<br>2 = 1051 sites (42.71%),<br>3 and 3+ = 662 sites (26.90%) | | | |
| **Parking type** | No parking = 733 sites (29.78%),<br>Parallel parking = 1564 sites (63.55%),<br>Perpendicular & angle parking = 164 sites (6.66%) | | | |
| **Parking arrangement** | No parking = 733 sites (29.78%)<br>One-sided parking = 719 sites (29.22%)<br>Two-sided parking = 949 sites (38.60%)<br>Two-sided parking on each road = 59 sites (2.40%) | | | |
| **Divide/ Undivided** | Divided sites = 566 sites (23.00%),<br>Undivided = 1895 sites (77.00%) | | | |
| **Speed** | 30 km/h or below = 493 sites (20.03%),<br>50 km/h = 1768 sites (71.84%),<br>70 km/h and above = 200 sites (8.13%) | | | |

Crash data and road infrastructure and geometric design characteristics

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# INTERSECTION DATA EXAMPLE

| Variable | Min | Max | Mean | Standard Deviation (SD) |
|---|---|---|---|---|
| **Signalised Intersection (N=198)** | | | | |
| **(a) Crash frequency** | | | | |
| All crashes | 0 | 87 | 13.90 | 13.85 |
| PDO crashes | 0 | 50 | 6.98 | 7.76 |
| Injury & fatal crashes | 0 | 39 | 6.92 | 7.22 |
| **(b) Traffic and roadway cross-section variables** | | | | |
| AADT on Major Approach | 183 | 41,915 | 14,559 | 9,424 |
| AADT on Minor Approach | 31 | 26,837 | 5,225 | 4,906 |
| **Skewness** | No skewness = 143 (72.22%)<br>Skewness = 55 (27.78%) | | | |
| **Number of approaches/legs** | 4 legs = 121 (61.11%)<br>3 legs =77 (38.89%) | | | |
| **Presence of stop sign on minor approach** | No = 187 (94.45%)<br>Yes = 11 (5.55%) | | | |
| **Presence of stop line on minor approach** | No = 19 (9.60%)<br>One side= 96 (48.48%)<br>Each side= 83 (41.92%) | | | |
| **Left Turn Lane on Major Approach** | No = 92 (46.47%)<br>One side= 56 (28.28%)<br>Each side= 50 (25.25%) | | | |

Crash data and road infrastructure and geometric design characteristics

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# Four Studies

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# 1

**Site type**

- Intersection:
  - Signalised
  - Unsignalised

**Method**

- Functional forms of the NB model

**Results**

- Crash prediction
- Model performance

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# STUDY 1 – INTERSECTIONS

1

Study 1 – Intersections

**Study Area**
- Antwerp

**Aim**
- Improving accuracy of crash prediction modelling

**Method**
- Functional forms of the NB model

**Results**
- Crash prediction
- Model performance

**Signalised intersections:**

- Traffic volume of major approach (+)
- Traffic volume of minor approach (+)
- Presence of a crosswalk on the minor approach (+)
- Intersection skewness: high skewness (+)

2 Study 2

3 Study 3

4 Study 4

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# STUDY 1 – INTERSECTIONS

1

Study 1 – Intersections

**Study Area**
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- Model performance

2

Study 2

3

Study 3

Study Area

- Crash prediction
- Model performance

4

Study 4

Study Area
- Antwerp
- Ghent

Aim
- Applying locally developed informative priors for the estimation of Bayesian models for transferability of SPFs

Method
- Bayesian NB

Results
- Model performance

**Unsignalised intersections:**

- Traffic volume of major approach (+)
- Traffic volume of minor approach (+)
- Presence of a crosswalk on the minor approach (+)
- Number of through lanes on the minor approach (+)
- Number of legs (+)

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# STUDY 1 – INTERSECTIONS

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1

Study 1 – Intersections

**Study Area**
- Antwerp

**Aim**
- Improving accuracy of crash prediction modelling

**Method**
- Functional forms of the NB model

**Results**
- Crash prediction
- Model performance

2

Study 2

3

Study 3

Study Area

Results
- Crash prediction
- Model performance

4

Study 4

Study Area
- Antwerp
- Ghent

Aim
- Applying locally developed informative priors for the estimation of Bayesian models for transferability of SPFs

Method
- Bayesian NB

Results
- Model performance

**Other results:**

Insignificant variables included:

- Exclusive left turn lanes
- Exclusive right turn lanes
- Size of intersection

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# STUDY 1 – INTERSECTIONS

Study 1 – Intersections

1

Study Area
- Antwerp

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- Improving accuracy of crash prediction modelling

Method
- Functional forms of the NB model

Results
- Crash prediction
- Model performance

2

Study 2

3

Study 3

4

Study 4

**Signalised intersections:**

- NB-P
- NB-2

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# STUDY 1 – INTERSECTIONS

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1

Study 1 – Intersections

**Study Area**
- Antwerp

**Aim**
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**Method**
- Functional forms of the NB model

**Results**
- Crash prediction
- Model performance

2 Study 2

3 Study 3

4 Study 4

**Unsignalised intersections:**

- GP model for all & PDO crashes
- NB-P model for injury and injury & fatal crashes

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# 1

**Site type**

- Intersection:
  - Signalised
  - Unsignalised

**Method**

- Functional forms of the NB model

**Results**

- Crash prediction
- Model performance

# 2

**Site type**

- Road segments

**Method**

- Application of GP and NB models

**Results**

- Crash prediction
- Model performance

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# STUDY 2 – ROAD SEGMENTS

1

Study 1

Study Area
- Antwerp

Aim
- To improve the accuracy of crash prediction modelling

Method
- Functional forms of the NB model

Results
- Crash Prediction
- Model performance

2

Study 2 – Road segments

**Study Area**
- Antwerp

**Aim**
- Improving accuracy of crash prediction modelling

**Method**
- Application of GP and NB models

**Results**
- Crash prediction
- Model performance

3

Study 3

4

Study 4

**Significant predictors:**

- Traffic volume (+)
- Number of lanes and lane width (-)
- On-street parking (+)
- Speed limits (-)
- Median divider (-)

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# STUDY 2 – ROAD SEGMENTS

1

Study 1

Study Area
- Antwerp

Aim
- To improve the accuracy of crash prediction modelling

Method
- Functional forms of the NB model

Results
- Crash Prediction
- Model performance

2

Study 2 – Road segments

**Study Area**
- Antwerp

**Aim**
- Improving accuracy of crash prediction modelling

**Method**
- Application of GP and NB models

**Results**
- Crash prediction
- Model performance

3

Study 3

Study Area

Method
- RBNB & VDPNB models in crash hotspot identification
- Empirical Bayes and PSI methods

Results
- Crash prediction
- Model performance

4

Study 4

Study Area

models for transferability of SPFs

Method
- Bayesian NB

Results
- Model performance

**Best models:**

- NB model for all & multi-vehicle crashes
- GP model for single- & parked-vehicle crashes

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## 1

**Site type**

- Intersection:
  - Signalised
  - Unsignalised

**Method**

- Functional forms of the NB model

**Results**

- Crash prediction
- Model performance

## 2

**Site type**

- Road segments

**Method**

- Application of GP and NB models

**Results**

- Crash prediction
- Model performance

## 3

**Site type**

- Road segments

**Method**

- RBNB and VDPNB models in crash hotspot identification
- Empirical Bayes and PSI methods

**Results**

- Modelling approach
- HSID method performance

# STUDY 3 – HOTSPOTS IDENTIFICATION

- EB method with RPNB performed better than the EB method with the VDPNB model
- PSI method with the VDPNB model showed poor performance in all methods

Study 3 – Hotspots Identification

3

**Study Area**
- Antwerp

**Aim**
- Determining accurate hotspot identification method

**Method**
- RBNB and VDPNB models in crash hotspot identification
- Empirical Bayes and PSI methods

**Results**
- Modelling approach
- HSID methods performance

Study 1

Study 2

Study 4

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# STUDY 3 – HOTSPOTS IDENTIFICATION

- EB method performed better than the PSI method

**1** Study 1

Study Area

- Functional forms of the NB model

Results

- Crash Prediction
- Model performance

**2** Study 2

Study Area

- Application of GP and NB model

Results

- Crash prediction
- Model performance

**3** Study 3 – Hotspots Identification

**Study Area**

- Antwerp

**Aim**

- Determining accurate hotspot identification method

**Method**

- RBNB and VDPNB models in crash hotspot identification
- Empirical Bayes and PSI methods

**Results**

- Modelling approach
- HSID methods performance

**4** Study 4

Study Area

- Antwerp
- Ghent

Aim

- Applying locally developed informative priors for the estimation of Bayesian models for transferability of SPFs

Method

- Bayesian NB

Results

- Model performance

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# 1

**Site type**

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**Results**

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- Model performance

# 2

**Site type**

- Road segments

**Method**

- Application of GP and NB models

**Results**

- Crash prediction
- Model performance

# 3

**Site type**

- Road segments

**Method**

- RBNB and VDPNB models in crash hotspot identification
- Empirical Bayes and PSI methods

**Results**

- Modelling approach
- HSID method performance

# 4

**Site type**

- Road segments

**Method**

- Bayesian NB

**Results**

- Model performance

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# STUDY 4 - TRANSFERABILITY

1

Study 1

Study Area
- Antwerp

Aim
- To improve the accuracy of crash prediction modelling

Method
- Functional forms of the NB model

Results
- Crash Prediction
- Model performance

2

Study 2

Study Area

Method
- Application of GP and NB models

Results
- Crash prediction
- Model performance

3

Study 3

Study Area

Method
- RBNB & VDPNB models in crash hotspot identification
- Empirical Bayes and PSI methods

Results
- Crash prediction
- Model performance

4

Study 4 – Transferability

**Study Areas**
- Antwerp
- Ghent

**Aim**
- Applying locally obtained informative priors for the estimation of Bayesian models for transferability of SPFs

**Method**
- Bayesian NB

**Results**
- Model performance

- The Bayesian models with locally obtained informative priors improved model performance (goodness of fit & precision) compared to Bayesian models with non-informative priors

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# Discussion

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# RECOMMENDATIONS

1 & 2

Road design characteristics

→ Significantly influence crash frequency at segments & intersections

↓

Using findings to **guide** the **design of intersections & segments in urban areas**

- **Intersection & segments safety forecasting and evaluation**
- **Informing planning initiatives**

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# RECOMMENDATIONS

3

Accurate hotspot identification

→ EB method > PSI method

↓

Methodology **choice** → significant **implications**

- **Accuracy and Reliability**
- **Evidence-Based Decision-Making**

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# RECOMMENDATIONS

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4

Model performance

→ With (locally obtained) informative priors > with non-informative priors

↓

Model **choice** → significant **implications**

- **Enhanced Parameter Estimation**
- **Improved Model Fit**

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# LIMITATIONS & FUTURE RESEARCH

- Different statistical approaches were not applied simultaneously to analyse each entity type separately
- Studies focused on either crash severity levels or crash types when developing SPFs
- Multiple variables could be useful predictor variables

  (e.g., driveway density, presence of bike lanes, and the proportion of bike and pedestrian volumes at intersections)
- HSID methods were examined using actual data

  → Difficulties in identifying false positives without prior knowledge of the true safety status

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# Conclusions

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# CONCLUSIONS

- Understanding of the association between **traffic** & **road geometric design-related** variables & **crash frequency** on the **urban** roads
- Focus → **Reliability and accuracy** of crash prediction
- Applications in **crash hotspot identification** & models (**Bayesian**) for areas with **insufficient data**
- Targeting road (un-)safety via outcomes closely aligned with the **Safe System Approach** & **Vision Zero principles**

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Web Page: https://twin-safe.com/

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