Assessing the Speed Impact of Traffic Calming Devices Using Functional Data Analysis

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Outline

- Motivation
- Types of traffic measures
- Real dataset
  - Description
  - Preparation
- Statistical methods
- Results
- Conclusion and future work

Motivation

Outside / inside urban area in the Czech Republic in 2021

1. [1.] How many traffic accidents occur? 34,279 / 65,053 traffic accidents
2. [2.] How many persons are killed as a result of traffic accidents? 345 (65%) / 186 (35%) persons
3. [3.] How many persons are hurt as a result of excessive speed in villages? 4,128 (69%) / 1,871 (31%) persons

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Traditional traffic calming measures

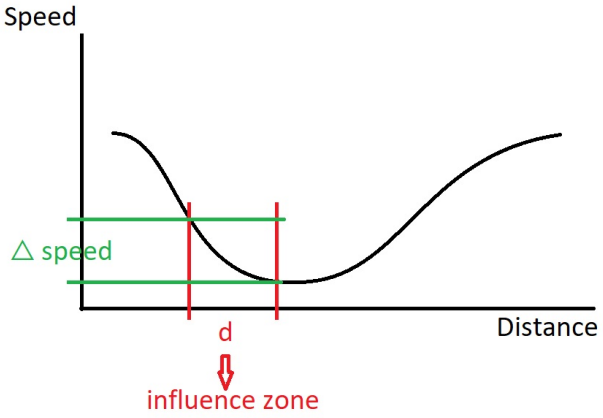
- Speed Hump
- Median island
- Speed Table / Raised Crosswalks
- CVT (dynamic speed control system)

Sardon's special case

- only existing through road in 40-kilometer single carriage way $\rightarrow$ dual carriage way $\rightarrow$ a complication in traffic calming
- Since 2020 there is a draft of a new road marking norm
- Some of the new marks included are:
  - Longitudinal road markings of a color other than white
  - Broken border lines
  - Dragon's teeth

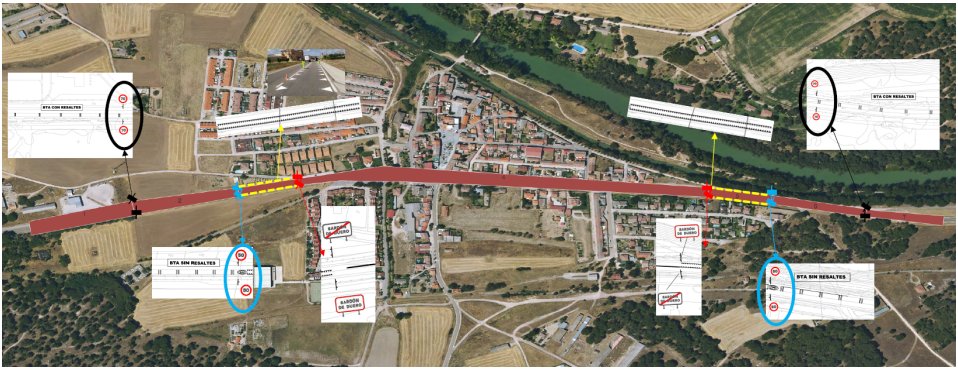
Objectives

- Is there a decrease in speed due to installation of measures?
- Which location shows a significant difference in speed profiles?



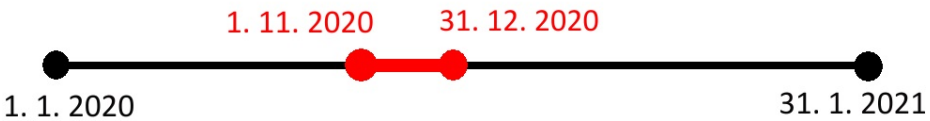
Data description

- location: Sardón de Duero (Spain)

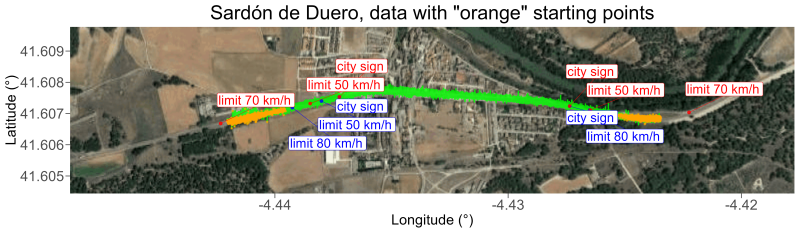


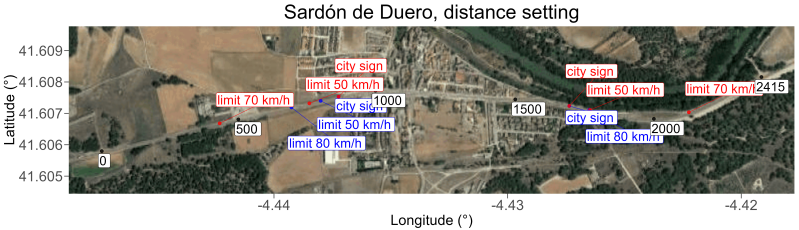
Data description

- **Data collection:** 1. 1. 2020 – 31. 12. 2021
- **Instalation of restrictions:** 1. 11. 2020 – 31. 12. 2020
- GPS records (source: Xouba Ingenieria SL)
- **Data registration:** spatiotemporal data with period 1 record per 3 – 60 seconds
- **cleaned data:**
  - 1 record per max 15 seconds
  - Direction 1: 1,066 drives
  - Direction 2: 1,129 drives



Data preparation





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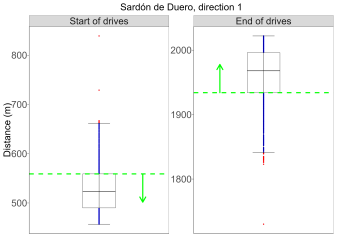
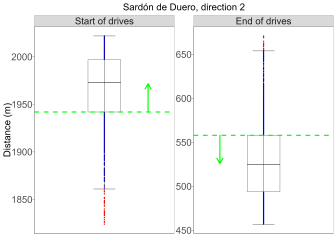
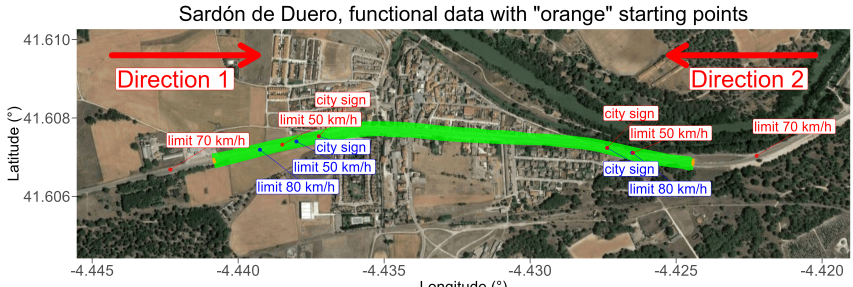






Functional observations

- **Speed profiles as functional observations**
  - speed as a function of distance from origin
  - approximation by a cubic B-spline basis function

$$y_{ij}(t) = \sum_{k=1}^{p} c_{ij}^{k} \phi^{k}(t)$$

t ... distance
i ... curve index
j ... population index
k ... index of basis component
p ... number of basis functions

Presumptions

- **Let's suppose**
  - independence of random sample elements
- **Not necessary suppose**
  - ! independence of basis coefficients
  - ! joint or marginal normality of basis coefficients
  - ! orthogonality of bases
- **Nonparametric permutation tests**

Global testing

- **Global test**
  - let's suppose two independence random samples of elements in L^2

$$H_0 : \mu_1(t) = \mu_2(t), \forall t \in T \text{ against } H_1 \; \exists t \in T : \mu_1(t) \neq \mu_2(t)$$

$\mu_j(t)$ ... functional mean

- reject $H_0 \rightarrow$ **interval testing**

Algorithm

- **Algorithm of interval testing**
  1. interval testing
  2. correction for multiple comparison

Interval testing

1. **Interval testing** interval testing on all open interval $\mathcal{I} \subseteq T$ and its supplement $T \setminus \mathcal{I}$

$$H_0^{\mathcal{I}} : \mu_1^{\mathcal{I}} = \mu_2^{\mathcal{I}} \text{ against } H_1^{\mathcal{I}} : \mu_1^{\mathcal{I}} \neq \mu_2^{\mathcal{I}}$$

$\mu_i^{\mathcal{I}}$ . . . restriction on $\mathcal{I}$

test statistics:

$$\mathcal{F}^{\mathcal{I}} = \frac{1}{|\mathcal{I}|} \int_{\mathcal{I}} (\overline{y}_1(t) - \overline{y}_2(t))^2 dt$$

$$\mathcal{F}^{T \setminus \mathcal{I}} = \frac{1}{|T \setminus \mathcal{I}|} \int_{T \setminus \mathcal{I}} (\overline{y}_1(t) - \overline{y}_2(t))^2 dt$$

p-values $\Rightarrow p^{\mathcal{I}} = lim_{\mathcal{I} \to t} \sup \left(p^{\mathcal{I}} \right); p^{T \setminus \mathcal{I}}$

Interval testing

2. **Correction for multiple comparison**

adjusted p-value:

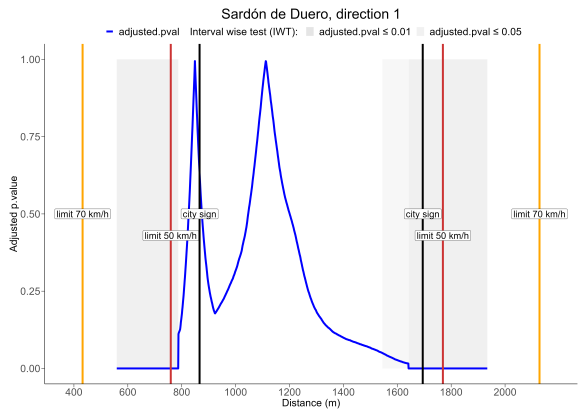
$$\tilde{p}(t) = \sup_{\mathcal{I}:\, t \in \mathcal{I}} \left(p^{\mathcal{I}}(t), p^{T \setminus \mathcal{I}}(t) \right)$$

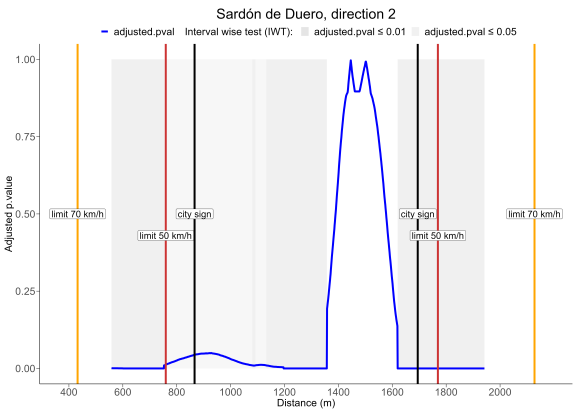
Control of Type I error:

- control of supplement interval $\rightarrow$ subintervals are equally represented
- Interval-wise error rate (IWER) $\forall \mathcal{I} \subseteq T$:

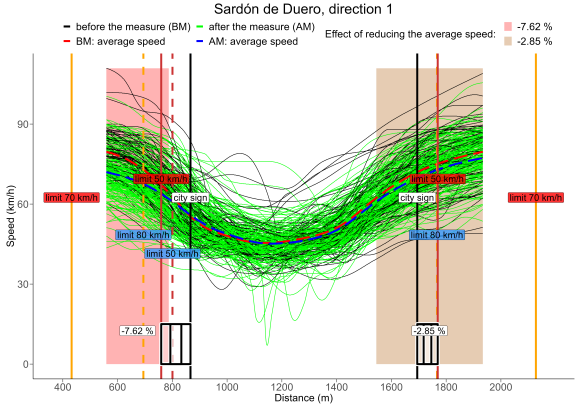
$$H_0^{\mathcal{I}} \text{ hold } \Rightarrow \mathbb{P}[\forall t \in \mathcal{I}, \tilde{p}(t) \leq \alpha] \leq \alpha, \ \forall \alpha \in (0,1)$$

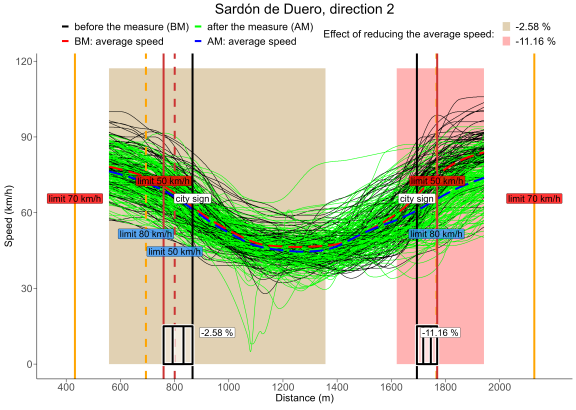
Results


Sardón de Duero, direction 1
adjusted.pval
Interval wise test (IWT):
adjusted.pval ≤ 0.01
adjusted.pval ≤ 0.05
Adjusted p.value
1.00
0.75
0.50
0.25
0.00
limit 70 km/h
city sign
limit 50 km/h
city sign
limit 50 km/h
limit 70 km/h
400
600
800
1000
1200
1400
1600
1800
2000
Distance (m)


Sardón de Duero, direction 2
adjusted.pval
Interval wise test (IWT):
adjusted.pval ≤ 0.01
adjusted.pval ≤ 0.05
Adjusted p.value
1.00
0.75
0.50
0.25
0.00
limit 70 km/h
city sign
limit 50 km/h
city sign
limit 50 km/h
limit 70 km/h
400
600
800
1000
1200
1400
1600
1800
2000
Distance (m)

Results


Sardón de Duero, direction 1
before the measure (BM)
after the measure (AM)
BM: average speed
AM: average speed
Effect of reducing the average speed:
-7.62 %
-2.85 %
Speed (km/h)
Distance (m)
limit 70 km/h
limit 50 km/h
city sign
limit 80 km/h
limit 50 km/h
-7.62 %
-2.85 %


Sardón de Duero, direction 2
before the measure (BM)
after the measure (AM)
BM: average speed
AM: average speed
Effect of reducing the average speed:
-2.58 %
-11.16 %
Speed (km/h)
Distance (m)
limit 70 km/h
limit 50 km/h
city sign
limit 80 km/h
limit 50 km/h
-2.58 %
-11.16 %

Conclusion and Future Work

- Conclusion
  - speed profiles of individual drives differ after traffic measures realization in both directions
  - difference mainly before entry to village
    (vertical and horizontal road markings)

- Future work
  - Examination various traffic measures for similar locations
  - Rating of homogenity changes for speed profiles
    (IWT for variances)
  - Speed profiles modelling through functional data analysis

Thank you for your attention

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References

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