



Technical & Traffic Assessment Results Urban ADF

L3Pilot Final Event

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Urban Evaluation

Introduction

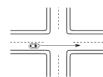
- Three pilot sites for urban ADF
- Similar process as for motorway
- Minor changes in the process



+ Additional Urban Indicators



+ Additional Database



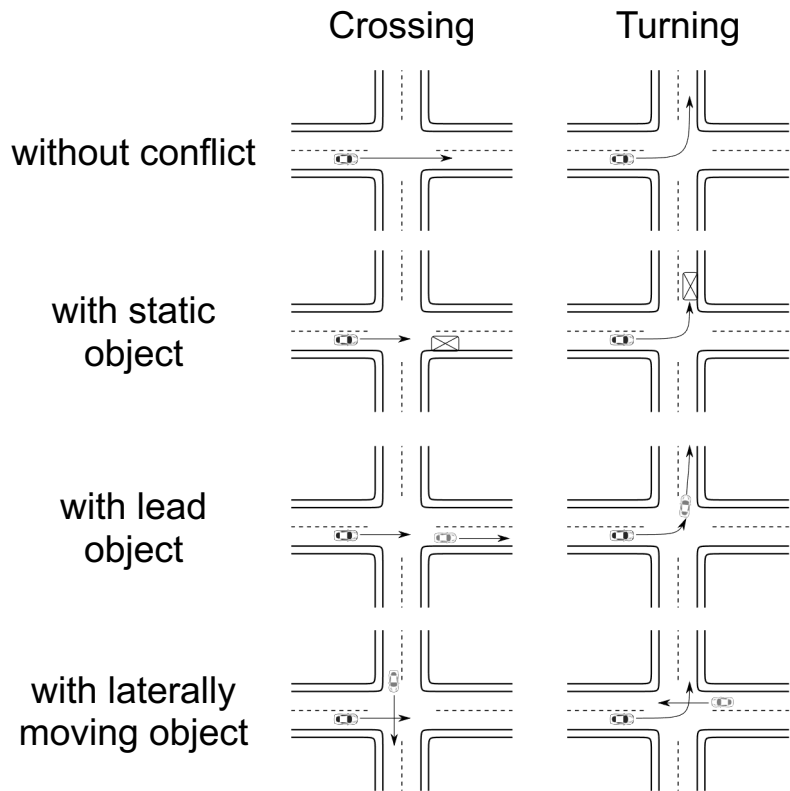
+ Additional Urban Scenarios



+ Bootstrapping

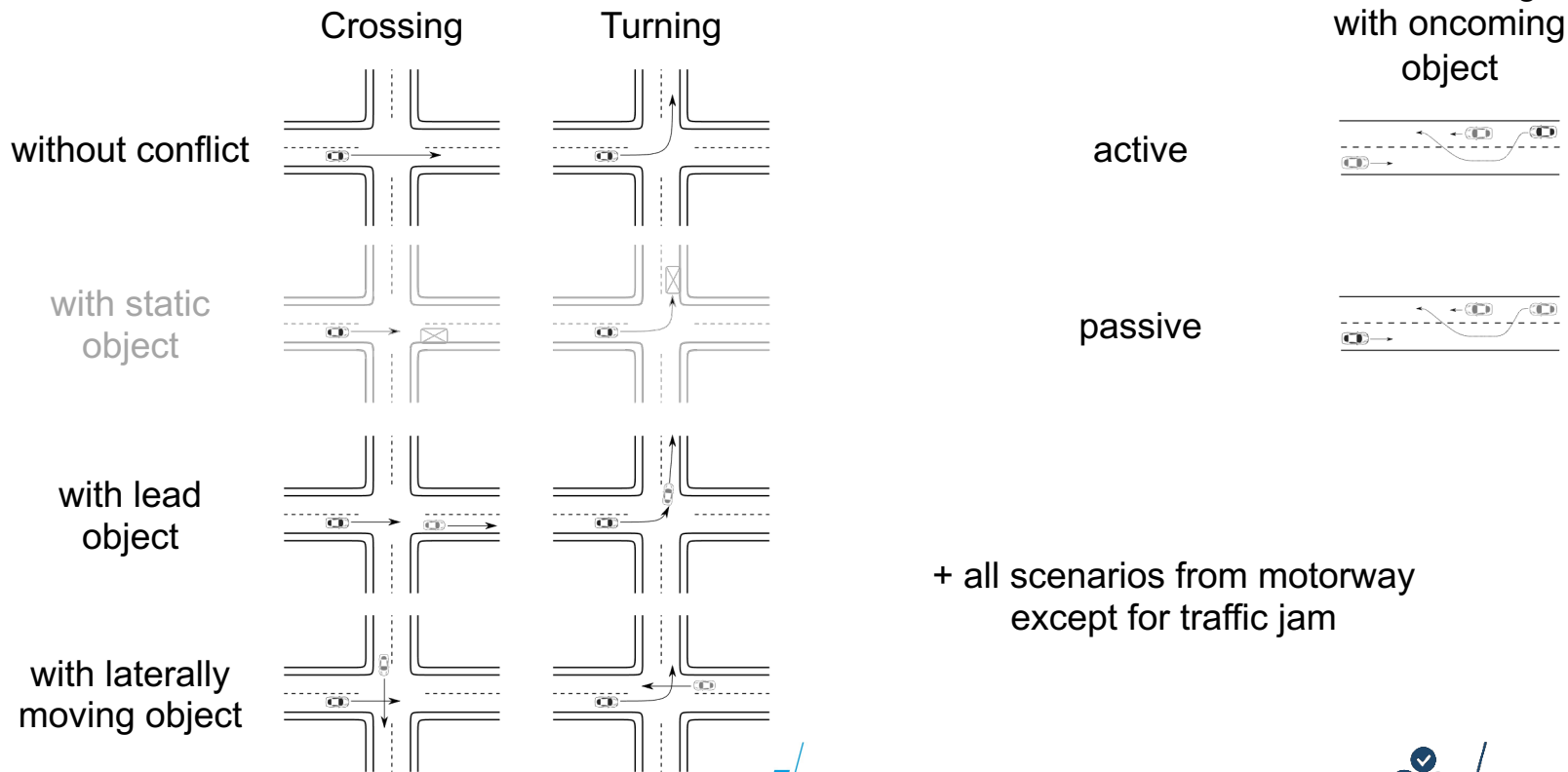
Urban Evaluation

Additional Urban Scenario Instances



Urban Evaluation

Additional Urban Scenario Instances

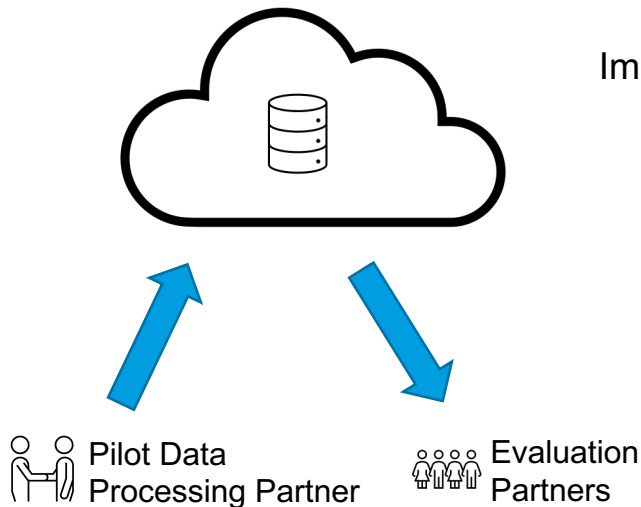


+ all scenarios from motorway except for traffic jam

Methods

Changes for the Urban ADF

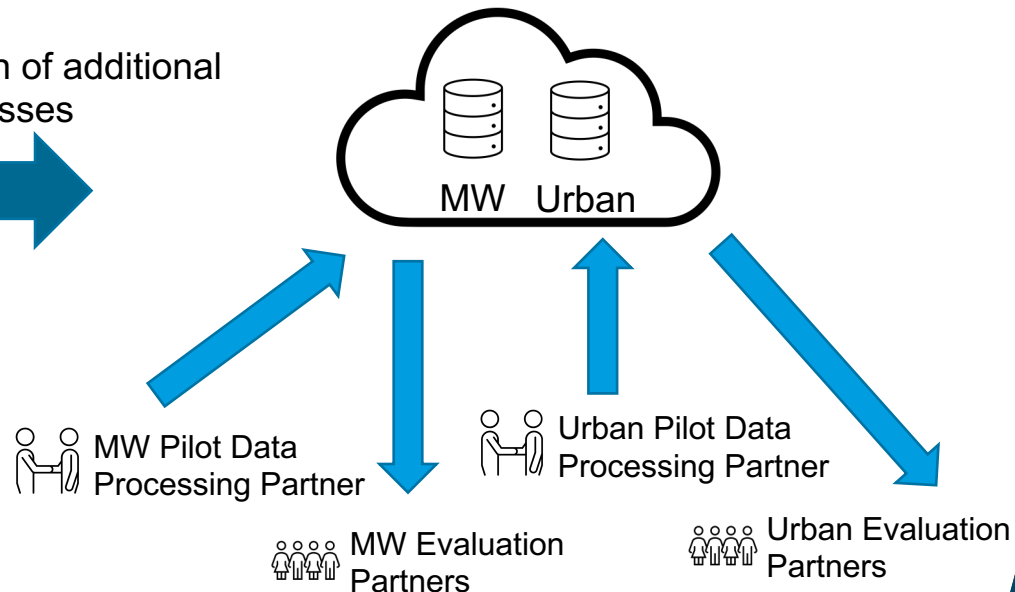
Status Motorway Only



Implementation of additional processes



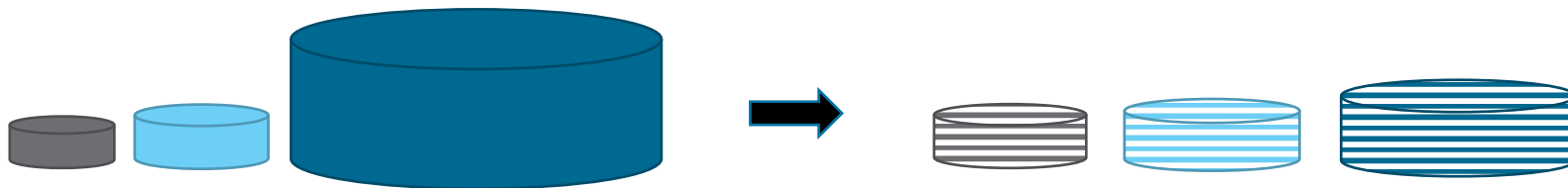
Status with Urban



No changes to motorway processes needed!

Data Imbalance Challenge

- There were three urban pilot sites
- One of the sites had > 10 times the amount of data in some scenarios
- Analysing the data as-is was not an option, as the results should reflect all the three pilot sites therefore
- The challenge was addressed by generating bootstrapped samples, but undersampling the majority site

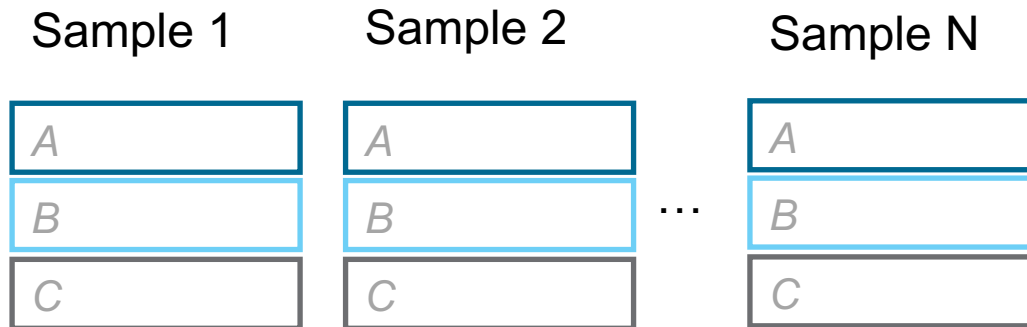


Bootstrapping Process

A			
	x1	x2	
Scenario 1		2	4
Scenario 2		4	2
...		1	7
	y1	y2	
Trip 1		2	1
Trip 2		4	5
...		2	8

B

C



- A random sample of the data was drawn for each pilot site
- The sample size was determined so that the data would be more balanced
- The samples were uploaded to Consolidated Database, and labelled to belong into the same sampling round
- Multiple sampling rounds were performed

Bootstrapping

Advantages and Disadvantages

Advantages

- Statistical indicators for ADF and baseline (e.g., mean, median, confidence intervals) and statistical tests can be performed with bootstrapped samples
- Distributions for ADF and baseline can be analysed
- Data source is not directly revealed but all the pilot site data can be utilised

Disadvantages

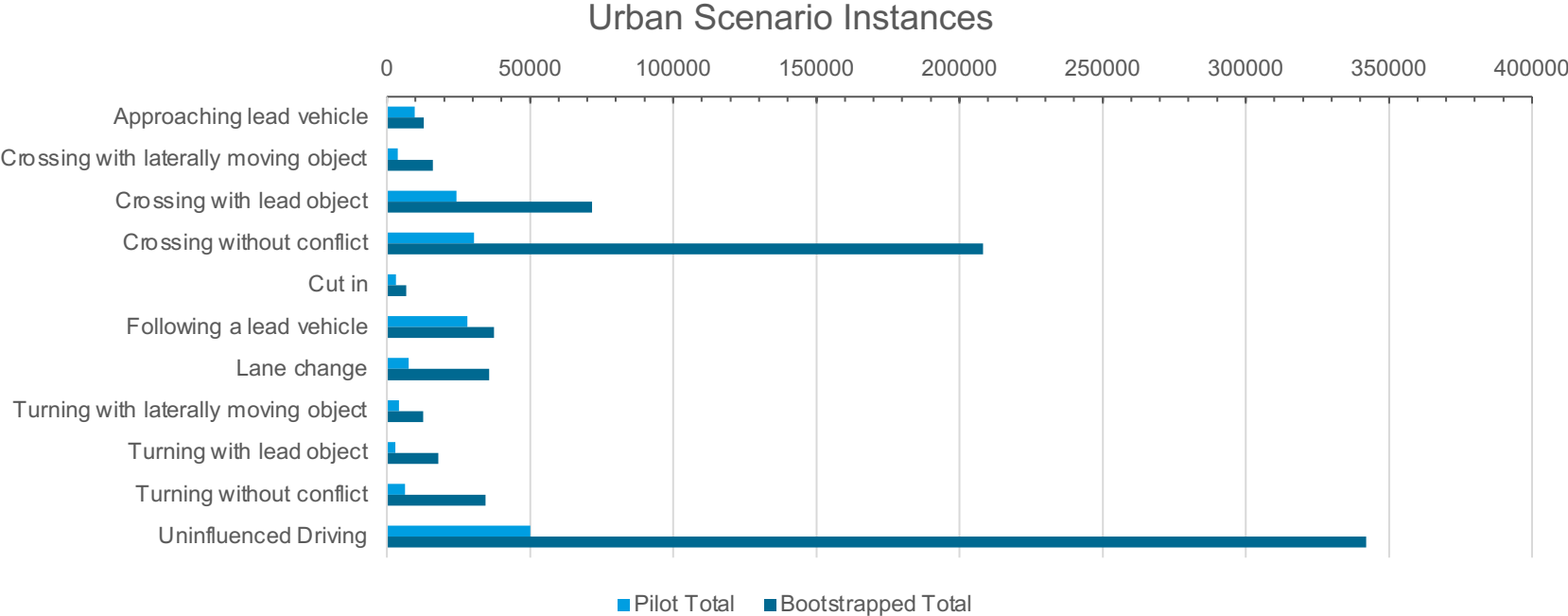
- Repeated observations could reveal the identity of the pilot sites
 - Random noise added: smooth bootstrap
- Undersampling influences the estimates of standard error
 - Compromise between balanced data and possibility to identify baseline-ADF differences

Bootstrapping

Procedure

- Pilot data processing partners
 - performed the analyses on the raw data and generated Trip performance indicators and Scenario performance indicators
 - created bootstrapped samples based on their own data with a small amount of noise added
- uploaded the bootstrapped samples to the Consolidated Database
- Required analyses were performed based on the data in the Consolidated Database

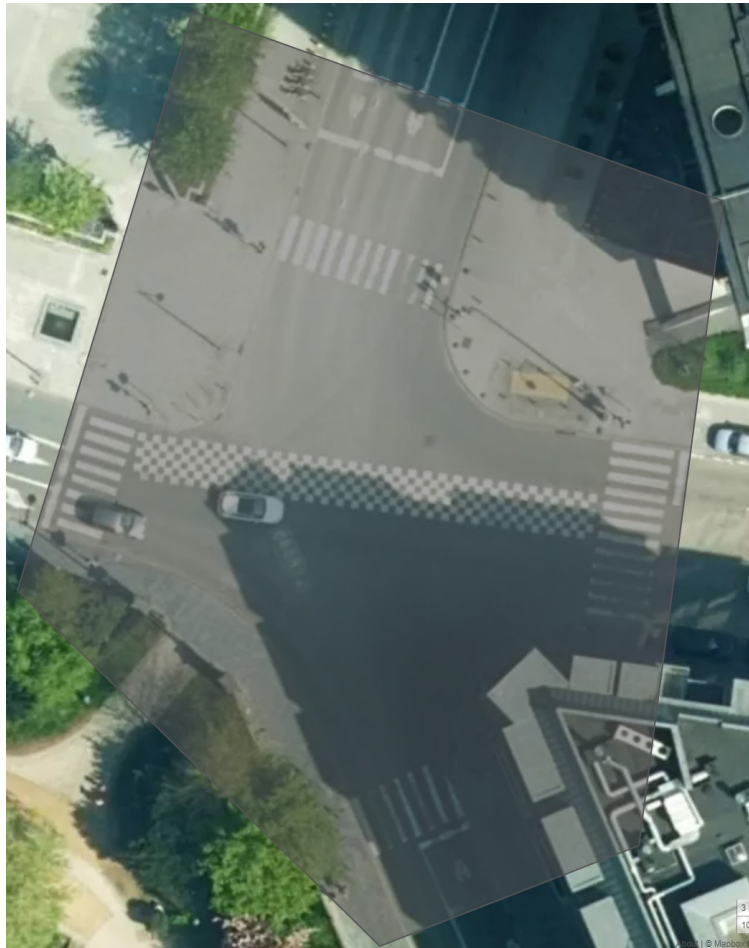
Bootstrapping Numbers



Intersections

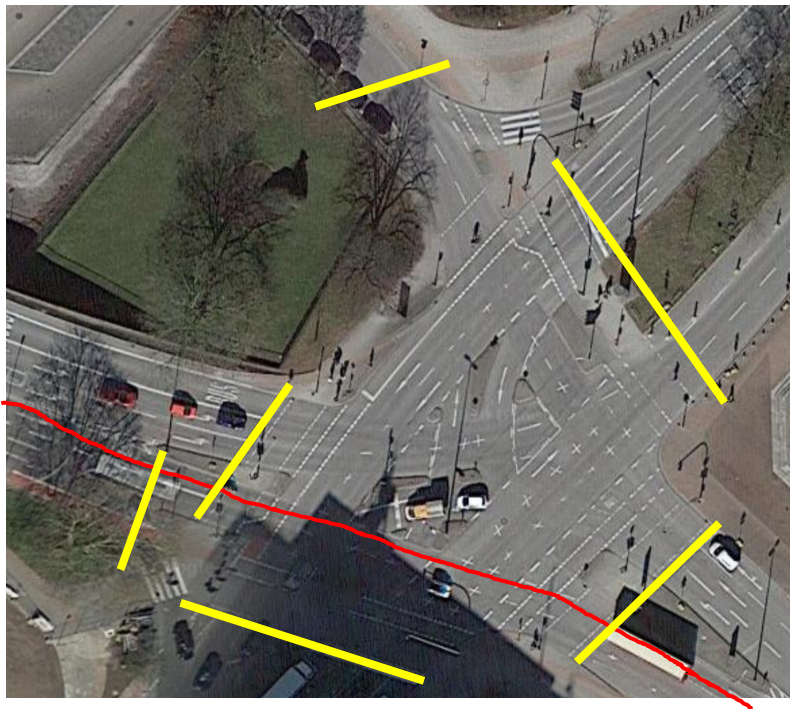
Brussels Example

- Agreed on how to draw intersection boundaries and on the types and rules
- Boundaries based on markings (stopping lines, pedestrian crossings, solid lines, ..) if available, otherwise on curve of the curb or width of the roads
- Added pedestrian crossings as an intersection type



Intersections

Hamburg Example

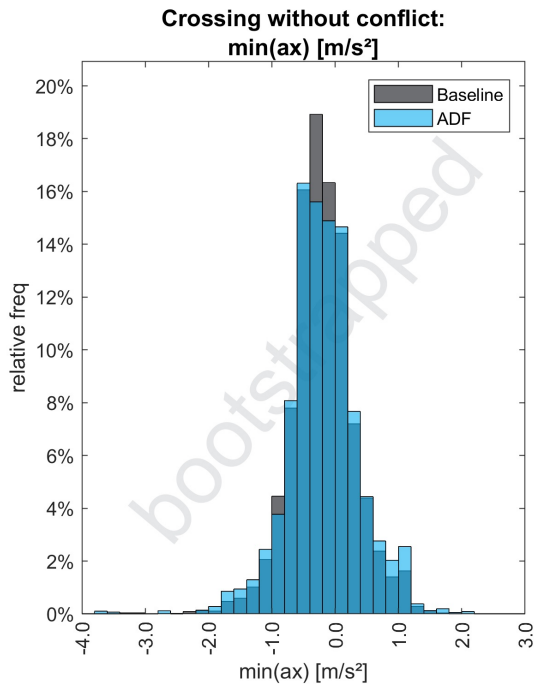
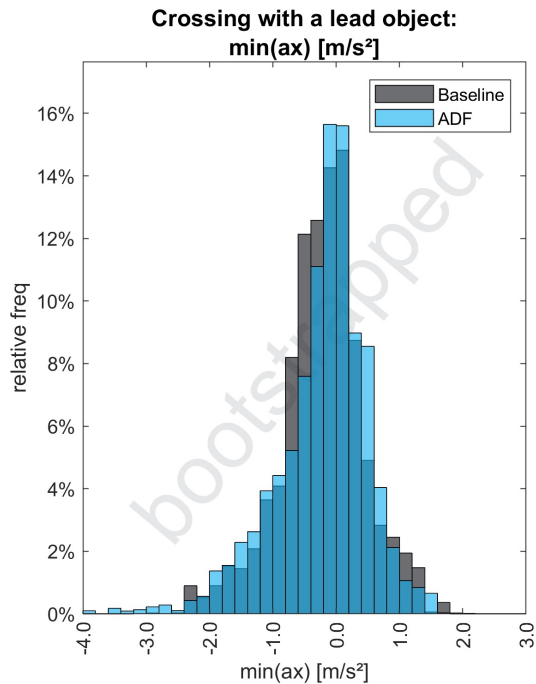


List of Research Questions Selection

Research Question	Performance Indicator(s)
What is the impact of ADF on longitudinal vehicle dynamics?	Longitudinal Acceleration (a_x)
What is the impact of ADF on the driven speed?	Speed (v)
What is the impact of ADF on lane keeping?	Position in Lane
What is the impact of ADF on the frequency of certain events?	Frequency of driving scenarios
What is the impact on car following behaviour?	Time Headway

What is the impact of ADF on longitudinal vehicle dynamics?

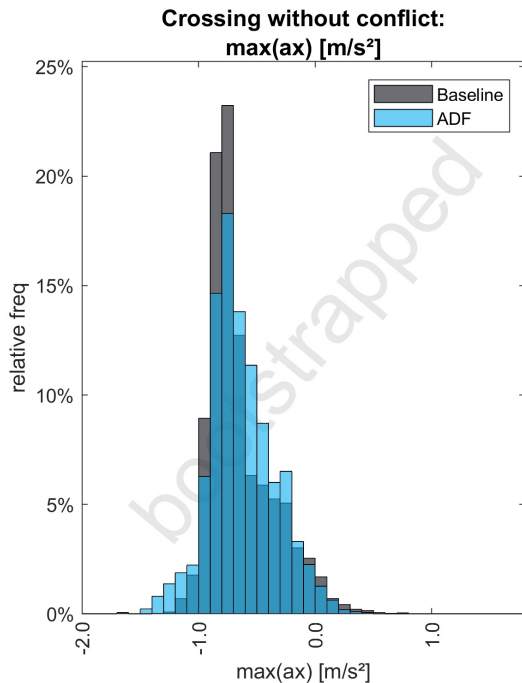
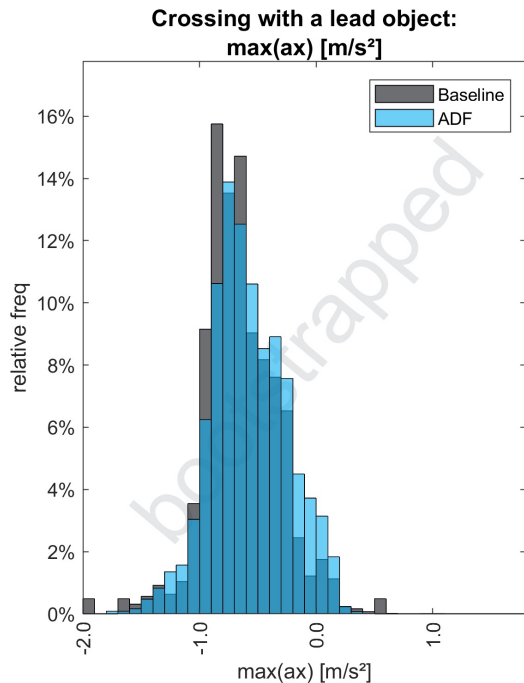
Minimum Longitudinal Acceleration



When travelling through intersections using ADF, only small differences in vehicle dynamics to a human driver are measurable.

What is the impact of ADF on longitudinal vehicle dynamics?

Maximum Longitudinal Acceleration



When travelling in urban areas, infrastructure and lead objects are similar limiting factors for humans and ADFs.

What is the impact of ADF on longitudinal vehicle dynamics?

Overview Effect Sizes

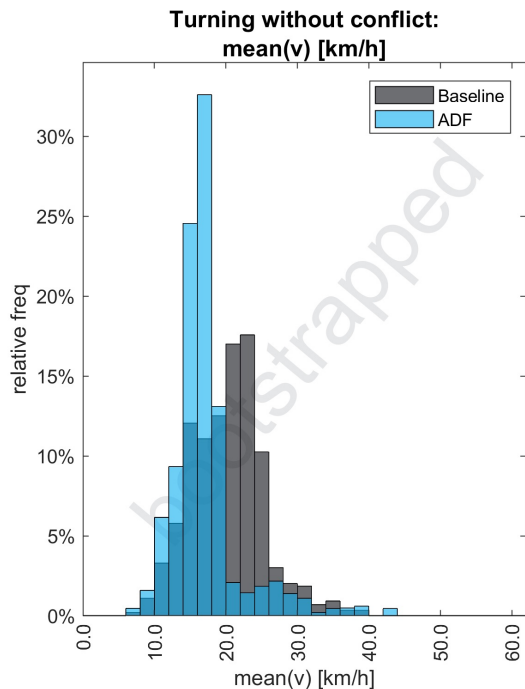
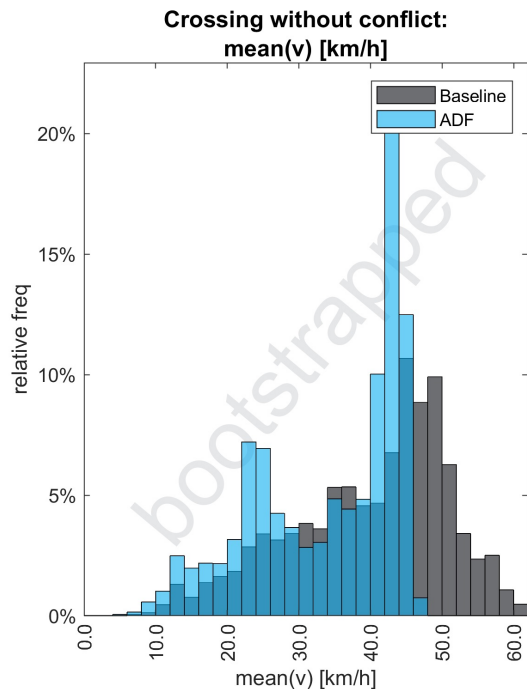
Research question	PI	Approaching lead vehicle	Crossing with laterally moving object	Crossing with lead object	Crossing without conflict	Cut in	Following a lead vehicle	Lane change	Turning with laterally moving object	Turning with lead object	Turning without conflict	Uninfluenced driving
What is the impact of ADF on longitudinal vehicle dynamics?	min(ax)	0	0	0	0.01		0.14		0	-0.09	0.24	0.53
	max(ax)	-0.1	0	0.21	0.04		-0.28		-0.39	-0.25	0.04	-0.65
	mean(ax)	-0.08	0.05	0.16	0.05		0		-0.21	-0.14	0.17	0.23
	sd(ax)	0	0	0.22	0.02		-0.06		-0.58	-0.18	-0.53	-0.4

Across all scenarios, decelerations and accelerations show a mixed picture.

In most scenarios, the variation of longitudinal acceleration is reduced.

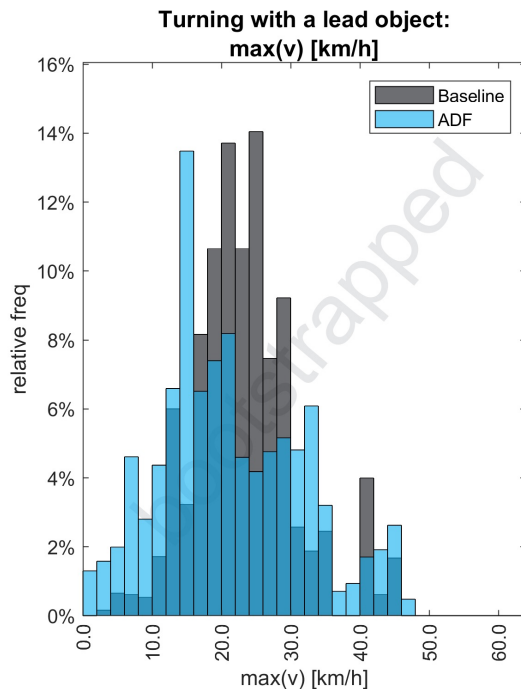
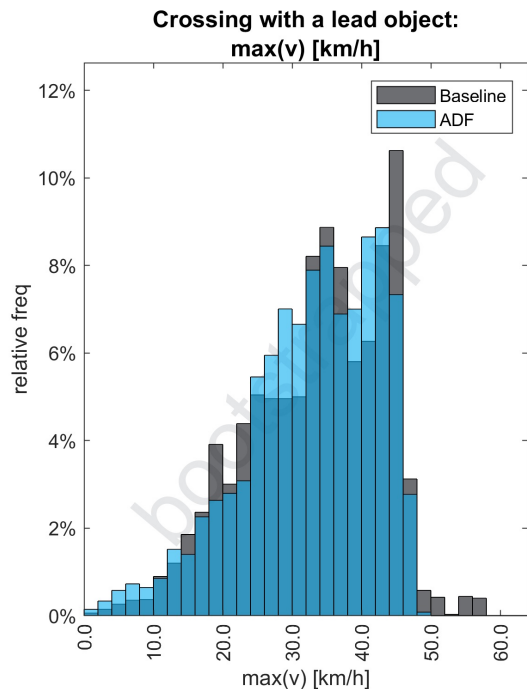
What is the impact of ADF on driven speed?

Mean Speed



When travelling through intersections using ADF, limitations in the speed limit can be clearly seen.

What is the impact of ADF on driven speed? Maximum Speed



When travelling through intersections using ADF, reduced speeds for turning become visible.

What is the impact of ADF on driven speed?

Overview Effect Sizes

Research question	PI	Approaching lead vehicle	Crossing with laterally moving object	Crossing with lead object	Crossing without conflict	Cut in	Following a lead vehicle	Lane change	Turning with laterally moving object	Turning with lead object	Turning without conflict	Uninfluenced driving
What is the impact of ADF on the driven speed?	mean(v)	-0.4	0.26	-0.16	-0.56	0.29	-0.31	-0.26	-0.1	-0.21	-0.63	-0.82
	max(v)	-0.38	0.29	-0.07	-0.58	0.35	-0.36	-0.12	-0.17	-0.2	-0.56	-0.91
	sd(v)	0.16	0.12	0.37	0.21	0.26	-0.22	0.4	-0.2	0	0.13	-0.24

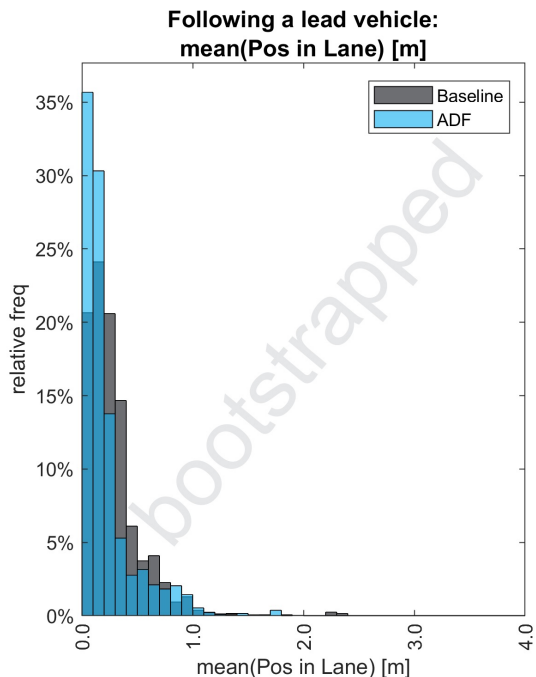
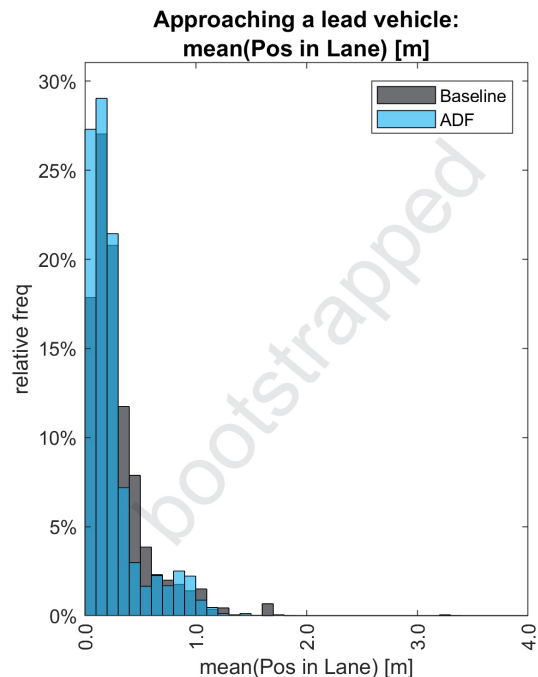
Across all scenarios, driven speeds show mixed effects.

Across all scenarios, effects of speed limit are visible.

In most scenarios, the variation of speed is increased.

What is the impact of ADF on lane keeping?

Mean Position in Lane



When travelling with ADF, lane keeping is slightly improved.

What is the impact of ADF on lane keeping?

Overview Effect Sizes

Research question	PI	Approaching lead vehicle	Crossing with laterally moving object	Crossing with lead object	Crossing without conflict	Cut in	Following a lead vehicle	Lane change	Turning with laterally moving object	Turning with lead object	Turning without conflict	Uninfluenced driving
What is the impact of ADF on lane keeping?	sd(Pos in Lane)	0.09					-0.05					0.06
	mean(Pos in Lane)	-0.2					-0.23					-0.02

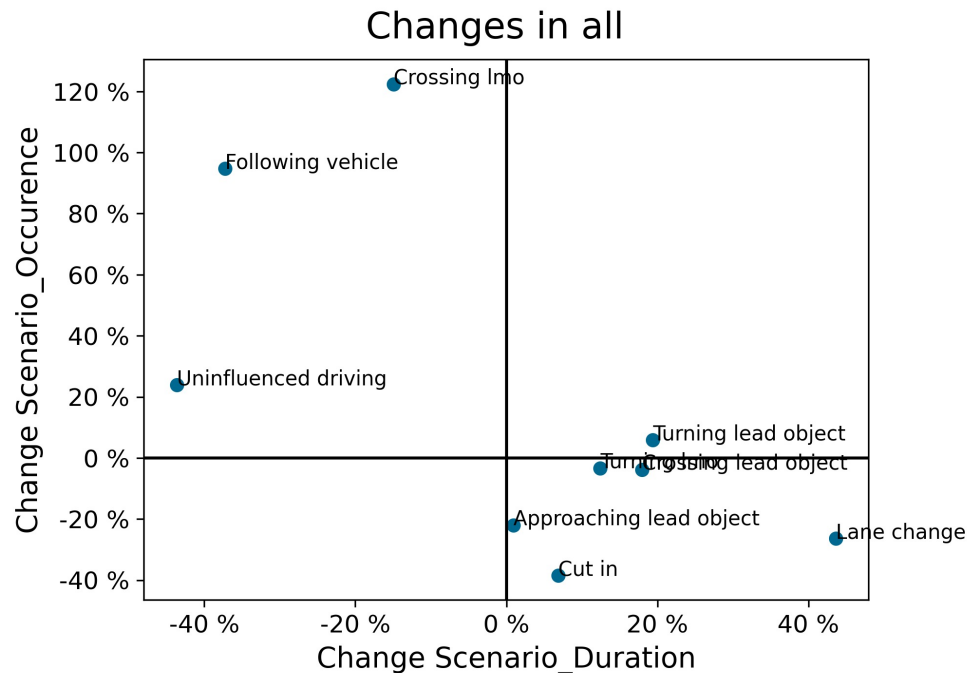
Across all scenarios, ADF keeps closer to the centre of the lane.

In most scenarios, the variation is slightly increased.

What is the impact of ADF on the frequency of certain events?

When scenarios are longer, they are mostly less frequent.

- Frequency of lane changes is reduced by over 20%, while they are over 40% longer.
- Frequency of Uninfluenced Driving is increased by over 20%.
- Frequency of following scenarios almost doubles with shorter instances.



What is the impact of ADF on the frequency of certain events?

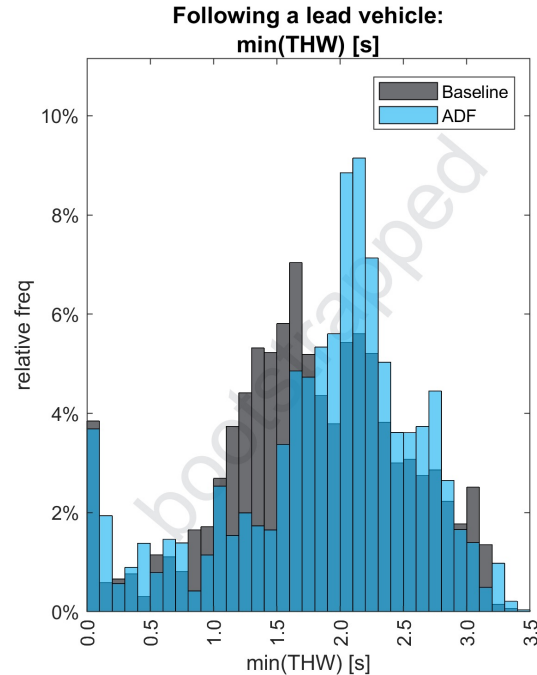
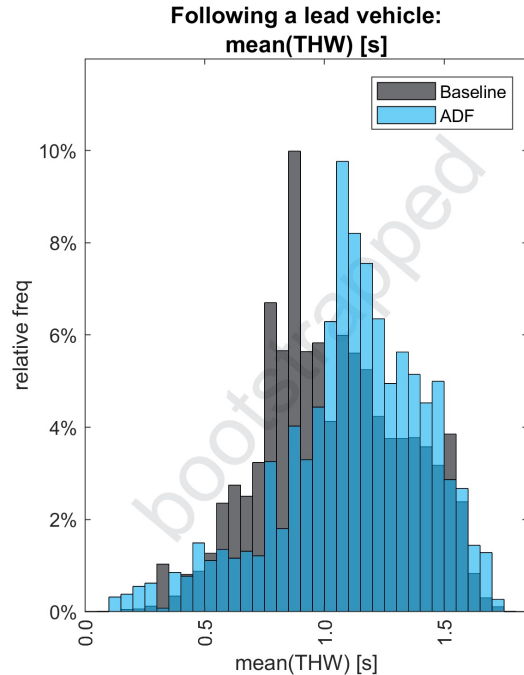
Research question	PI	Approaching lead vehicle	Crossing with laterally moving object	Crossing with lead object	Crossing without conflict	Cut in	Following a lead vehicle	Lane change	Turning with laterally moving object	Turning with lead object	Turning without conflict	Uninfluenced driving
RQ-T11	Frequency	-0.2	0.43	-0.13		-0.45	0.37	-0.43	-0.04	0.05		0.59
	Duration	0	-0.36	0.25	0.21	0.15	-0.57	0.8	0.38	0.39	0.48	-0.6

Changes in frequency and duration for lane changes and uninfluenced driving show clear effects.

For other scenarios, the changes have smaller effects.

What is the impact of ADF on car following behaviour?

Time Headway



During car following with ADF, minimum and mean THW are increased.

What is the impact of ADF on car following behavior?

Overview Effect Sizes

Research question	PI	Approaching lead vehicle	Crossing with laterally moving object	Crossing with lead object	Crossing without conflict	Cut in	Following a lead vehicle	Lane change	Turning with laterally moving object	Turning with lead object	Turning without conflict	Uninfluenced driving
What is the impact on car following behavior?	mean(THW)	0.05					0.27					
	min(THW)	0.25				0.08	0.14					

Across all scenarios, time headways (THW) are increased with small effects.

Conclusions

- **Results** are generated using
 - Piloting data from **three urban pilot sites** with **bootstrapping** and a large database
- **ADF behaviour similar** to that of human drivers in urban use-case
- Automated vehicles **adhere to the speed limit**
- Results for **vehicle dynamics** are scenario dependent in the urban use-case
- **Longer duration** of intersection scenarios
- Data from **more extensive environments** might be helpful for further evaluations
 - **Complexity** of urban environment as limiting factor for detailed evaluation



Thank you for your kind attention.

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FINAL EVENT

Hamburg 2021

ITS World Congress

Repeated observations: smooth bootstrap

- In balanced sampling, an observation from a minority pilot site is more likely to be selected: source of an observation could be revealed by the number it is repeated in the data
- A small amount of normally distributed noise will be added to the continuous measurement variables
- A small amount of uniform noise will be added to index variables
- This will make it very difficult to identify repeating observations from the dataset, without essentially affecting the distributions or variability in the data

Standard errors in under/oversampling

- When the bootstrap sample size == data size, the bootstrapped standard error properly estimates the true standard error
- At undersampling (bootstrap sample size < data size), the standard errors increase
- At oversampling (bootstrap sample size > data size), the standard errors decrease
- This influence statistical inferences
 - Undersampling is more conservative approach, and thus preferable

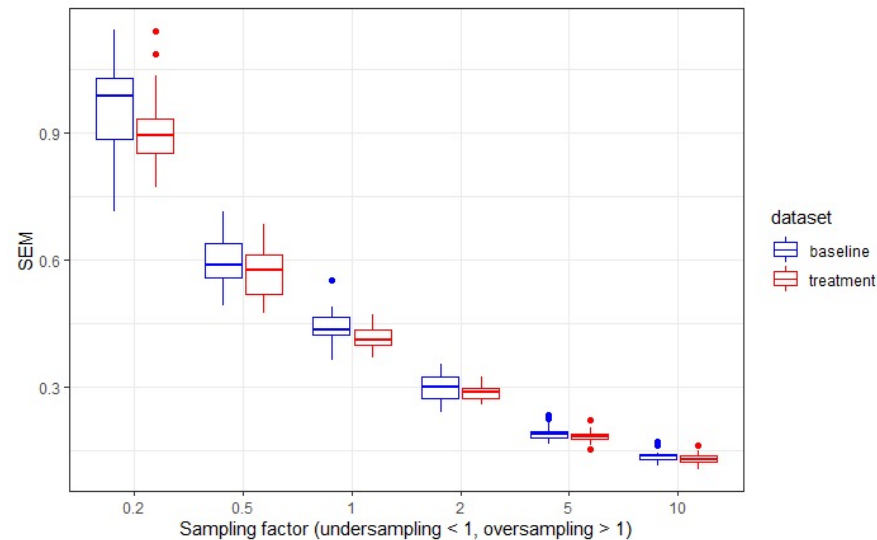


Figure. Simulation of the effect of under/oversampling on the standard error of mean (SEM). Exact values depend on the distributions and original data sizes.



Pilot Leader



Pilot Data Processing Partner



Evaluation Partners



Collect **raw data** from vehicle



Quality check on raw data ([l3pilot-cdf/quality-checker](#))



Conversion of raw data to L3Pilot **Common Data Format (CDF)** ([l3pilot-cdf/python](#), [l3pilot-cdf/matlab](#), [l3pilot-cdf/c_plusplus](#))



Quality check on converted data ([l3pilot-cdf/quality-checker](#), [matlab-viewer](#), [dm-pi-framework](#))



Pilot Leader transfers converted data to **Pilot Data Processing Partner**

Quality check on converted data ([matlab-viewer](#), [dm-pi-framework](#), [l3pilot-cdf/quality-checker](#))

Run **Derived measures (DM)** and **scenario scripts** ([dm-pi-framework](#))

Video annotation based on generated DMs and Scenarios ([dm-pi-framework](#), [matlab-viewer](#))

Run **Performance Indicators (PI)** scripts ([dm-pi-framework](#))

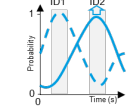
Aggregate enriched data ([con-db-aggregation](#))

Upload aggregated data to **consolidated database (CDB)** ([cdb-uploader](#))

Query aggregated data from consolidated database (CDB) ([cdb-uploader](#), [pc_db_ui](#))

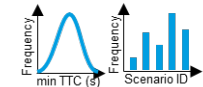


Perform evaluation and produce results for technical and traffic evaluation



Generate input for impact assessment

Calculate impact

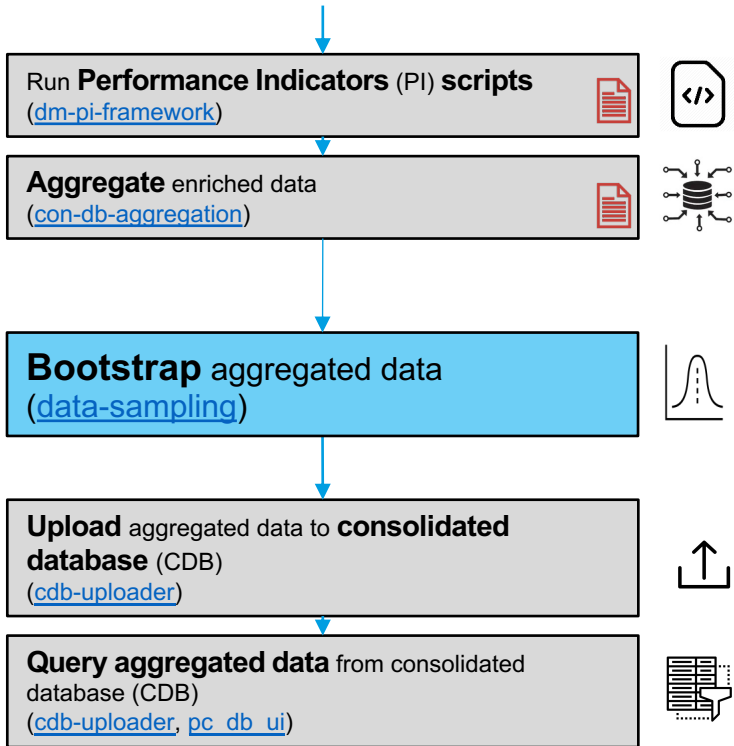




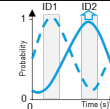
Pilot Data Processing Partner



Evaluation Partners



Perform evaluation and produce results for technical and traffic evaluation



Generate input for impact assessment

Calculate impact

