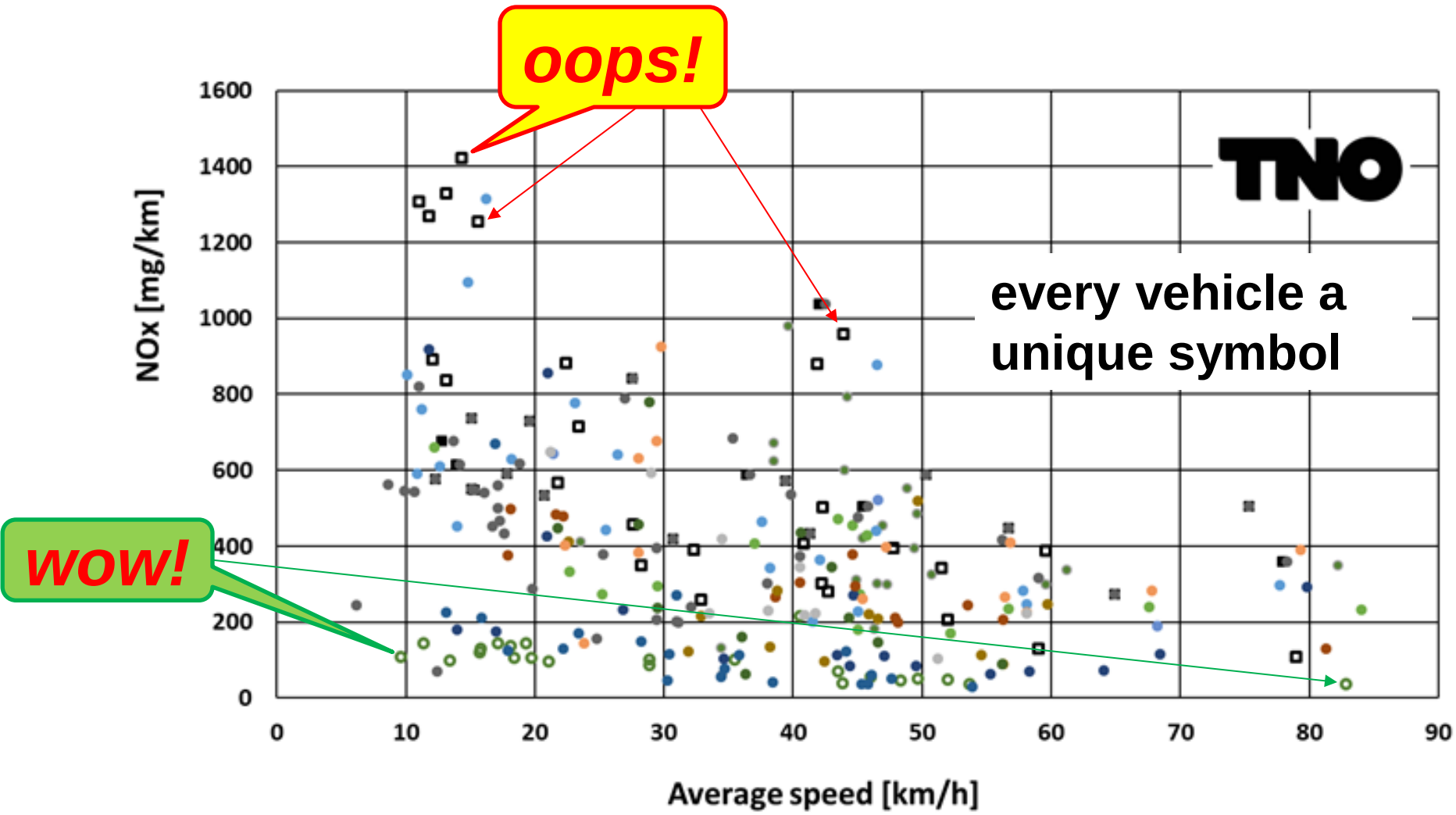
# ASSESSMENT OF RECENT CHANGES IN RDE LEGISLATION

guide for independent testing from surveillance to compliance | Ligterink, N.E. (Norbert)

# GETTING FAMILIAR WITH RDE
## *TNO RESEARCH & DEVELOPMENT PORTFOLIO*

- 2011-2015: (*from the archives*)
  - on-road testing for emission factors and assessments
  - developing RDE trips and assisting the Netherlands in RDE-LDV group
- 2016: (*all published: you can read about it*)
  - testing Euro-6 passenger cars in RDE and more (TNO 2016 report R11177)
  - strength and weaknesses of RDE (TNO 2016 report 11227)
- 2017: (*this talk, reports and papers due in November*)
  - **Understanding on-road variations in the RDE test**
  - **Testing Euro-6 light commercial vehicles in RDE and normal use**
  - **Review of the RDE evaluation methods on the basis of stakeholder data**
  - **Robust statistical methods in in-service conformity**
  - **Developing measurement equipment for monitoring (enhancing SEMS)**

# ALL TRIPS WITH EURO-6 LCVS IN 2017



# OBSERVATIONS FROM THE LCV TESTING

- **Large variations in the Euro-6 NOx emissions results:**
  - differences between different vehicle models ***(factor 10)***
  - differences between driving styles and payloads ***(factor 5)***
  - differences between different usages (RDE, package delivery, motorway)

- **RDE testing not trivial:**
  - Many invalid tests ***(RDE range: factor 2)***
  - Optimizing routes and instructions is essential
  - Payload adds to the complexity of testing LCVs in RDE

- **Major improvement of Euro-6 over Euro-5 vans**:
  - Dutch emission factors ~60% down from previous estimates based on Euro-5
  - weighing by sales numbers essential for the correct average

# RDE EVALUATION METHODS

## *"CORRECTING FOR DEVIATIONS"*

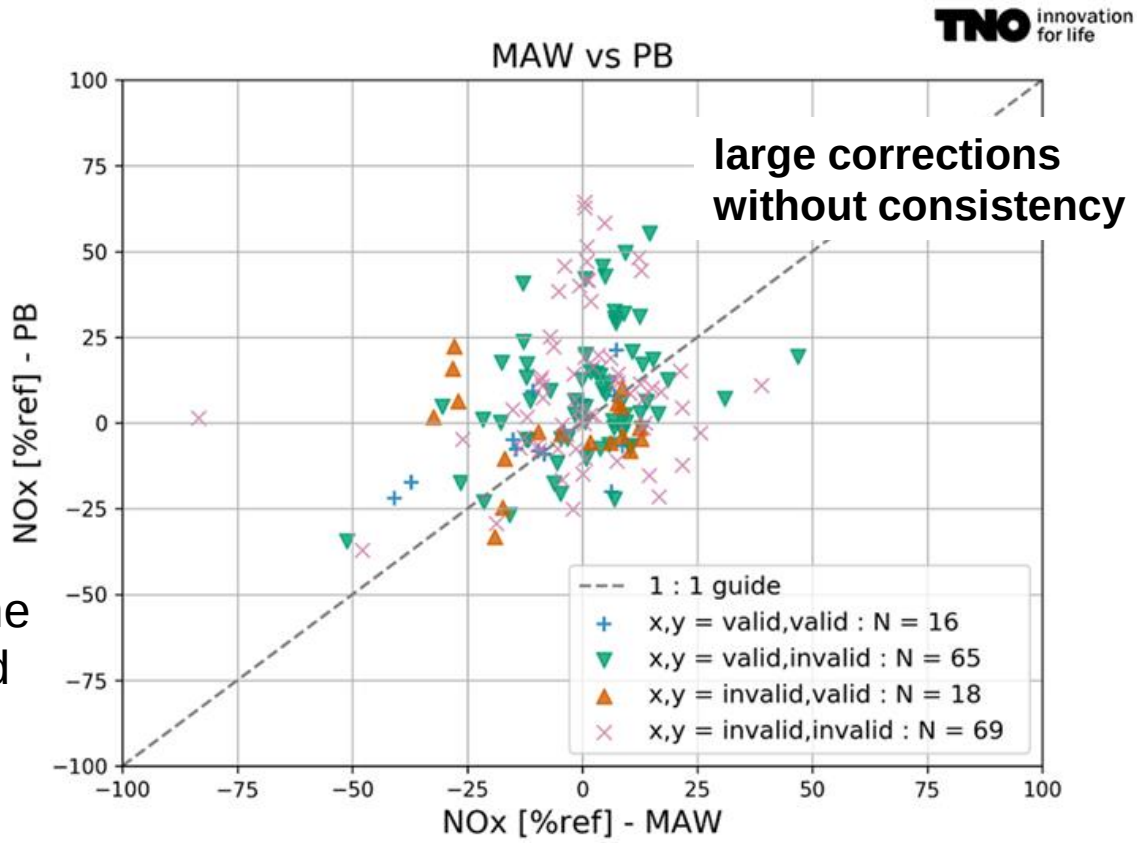
**Our working hypothesis**

Evaluation methods are intended to correct for deviations in test executions.

In particular aspects related to velocity and $CO_2$ emissions, since these aspects are the basis of the evaluation methods.

Varying conditions, vehicles, and text executions at the same time show a large uncorrelated scatter of the corrections.

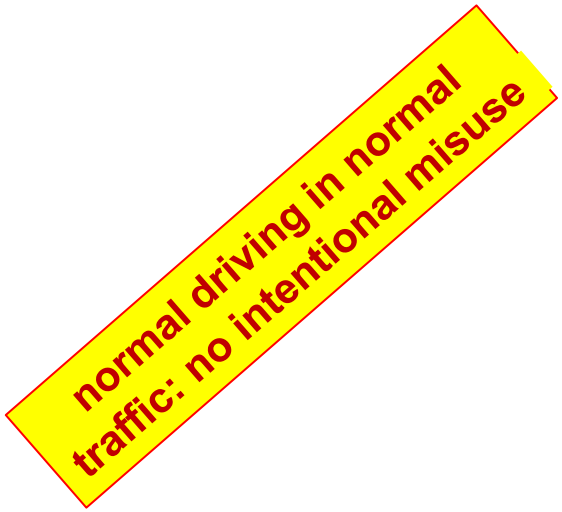
***randomization or some systematics?***



# DRIVING BEHAVIOUR AND PAYLOAD

## *SPECIAL TESTS WITH FOCUS ON EVALUATION METHODS*

- **keeping the same:**
  - vehicle
  - weather (i.e. tested in one period)
  - route (fixed RDE route)
  - conditioning (one RDE test after another)
  - driver
- **variation in:** *(relevant for evaluation methods)*
  - **driving instructions:**
    - gear shifting
    - stopping distance and time
    - headway
  - **payload**



# RDE RANGE IN THE FULL RANGE OF DRIVING BEHAVIOUR AND PAYLOAD

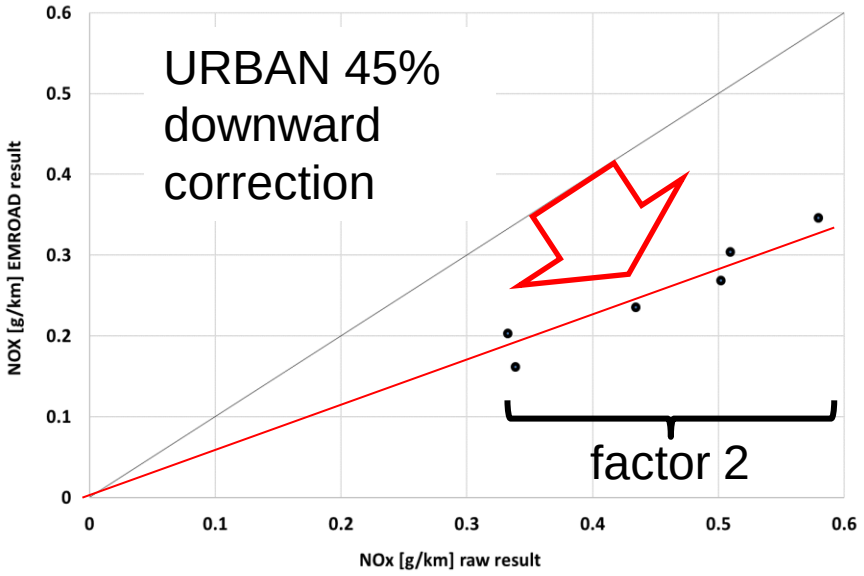
| RDE compliant? (N1 Class II) | ok | | Urban part too agressive | | | ok | skewed road type fractions | Urban part too agressive | 1% to much stop time in urban part | ok | | | Not sufficient dynamics on highway |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trip | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| **Style** | **normal** | **normal** | **sport** | **sport** | **sport** | **normal** | **eco** | **sport** | **sport** | **sport** | **normal** | **eco** | **eco** |
| Weight [kg] | **1482** | **1482** | 1940 | 1940 | 1960 | **1820** | 1660 | 1940 | 1940 | **1960** | **1820** | **1680** | 1700 |
| Average velocity [km/h] | **47.3** | **45.4** | 38.5 | 38.5 | 39.6 | **49.6** | 46.5 | 44.2 | 44 | **48.8** | **49.4** | **44.9** | 46.3 |
| Average velocity (v>0) [km/h] | **52.8** | **54.3** | 52.1 | 55.9 | 56.5 | **57.9** | 53.1 | 57.5 | 56.1 | **58.4** | **57.6** | **53.2** | 52.3 |
| CO2 [g/km] | **140** | **157** | 175 | 179 | 194 | **142** | 122 | 180 | 175 | **166** | **140** | **127** | 116 |
| EMROAD CO2 | **159** | **178** | | | | **159** | | | | **199** | **152** | **145** | |
| NOx [mg/km] | **280** | **392** | 579 | 623 | **908** | **452** | 281 | 734 | 557 | **513** | **367** | **291** | **172** |
| EMROAD NOx | **174** | **240** | | | | **291** | | | | **329** | **235** | **187** | |
| NOx/CO2 [g/kg] per second | **1.8** | **2.3** | 3.2 | 3 | 4.7 | **3.1** | 2.2 | 3.5 | 2.8 | **2.7** | **2.3** | **2.3** | 2.4 |
| NOx/CO2 [g/kg] from EMROAD total | **2** | **2.5** | | | | **3.1** | | | | **3** | **2.6** | **2.3** | |
| Urb CO2 [g/km] | **159** | **173** | | | | **160** | | | | **183** | **151** | **137** | |
| Urb EMROAD CO2 | **154** | **170** | | | | **159** | | | | **185** | **151** | **138** | |
| Urb NOx [mg/km] | **302** | **462** | | | | **504** | | | | **425** | **345** | **311** | |
| Urb EMROAD NOx | **162** | **269** | | | | **346** | | | | **304** | **235** | **203** | |
| Urb NOx/CO2 [g/kg] from EMROAD total | **2** | **2.7** | | | | **3.3** | | | | **2.5** | **2.6** | **2.3** | |

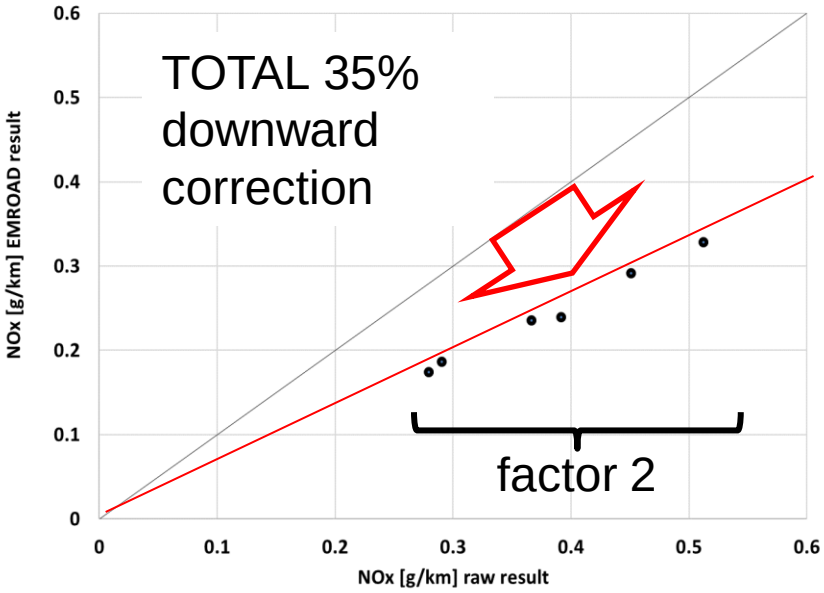
**factor 2 in RDE trips**

**factor 5 in all trips**

# THE EFFECT OF EMROAD* (MAW) ON VALID TRIPS WITH THE SAME VEHICLE

## *SYSTEMATIC!*



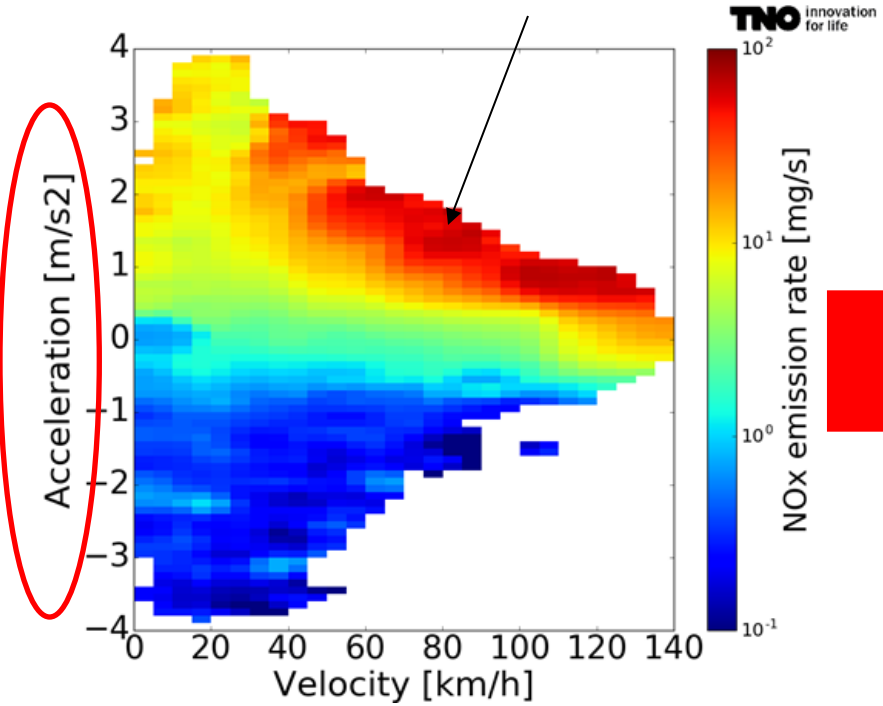

***there is no "reference", for which there is no correction***



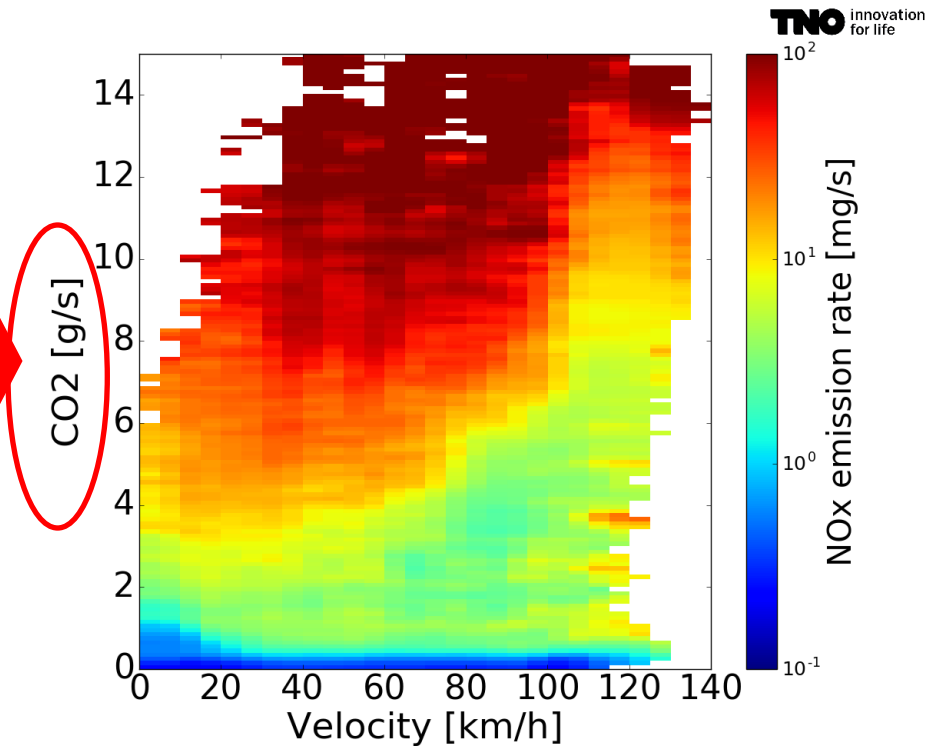
** only two valid tests for CLEAR (PB), no analysis possible*

# THE PROBLEM WITH TESTING VANS
## *WITH PAYLOAD UP TO 90% MAXIMAL WEIGHT*

power depends on test mass




invariant: power ~ $CO_2$ rate [g/s]

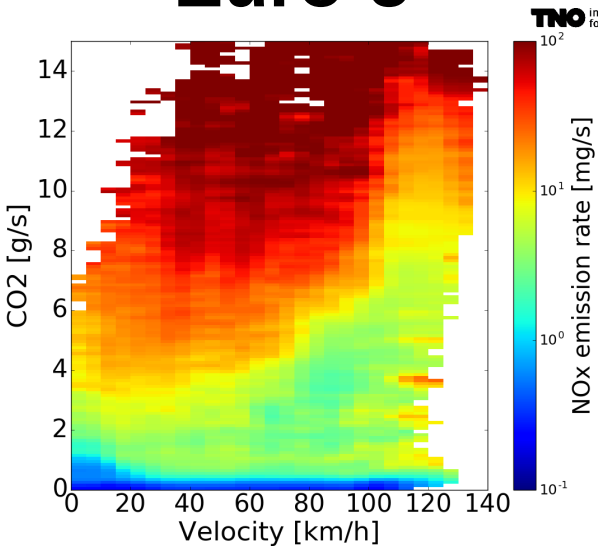


# SAME MAKE AND MODEL CLASS III VAN
## *DEVELOPMENT IN EMISSION PERFORMANCE*

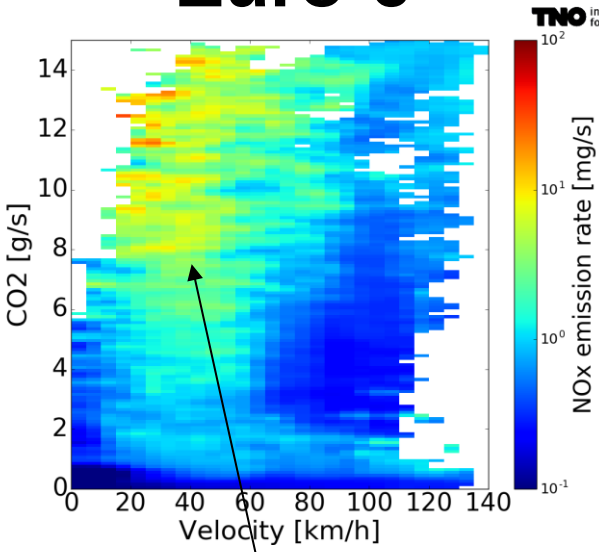
***also well-performing vehicles show variations in emissions***

"3.5 ton ← 5 ton GVW"

**Euro-5**

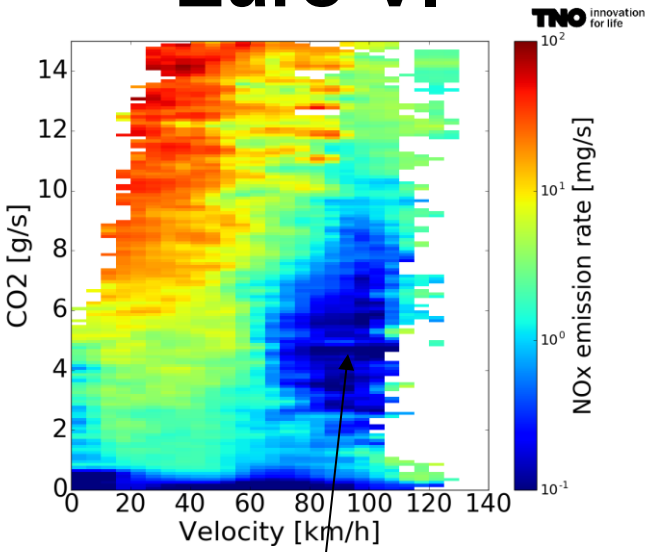



**Euro-6**



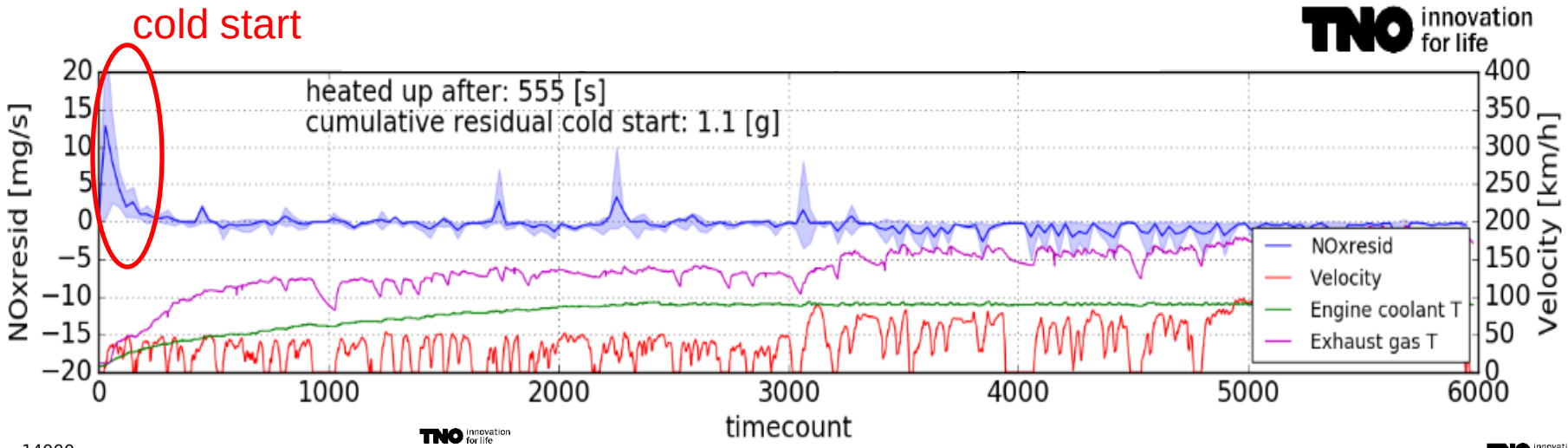

best urban

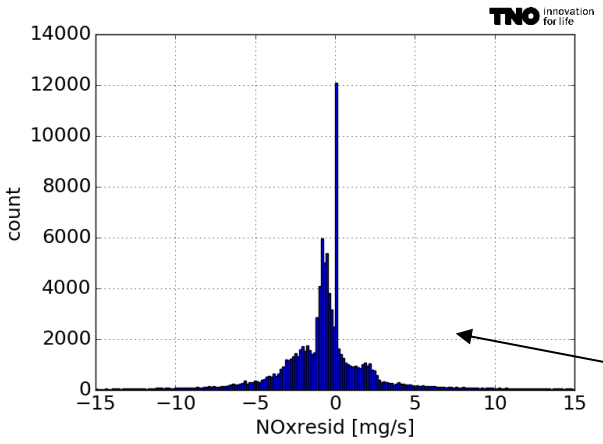
**Euro-VI**



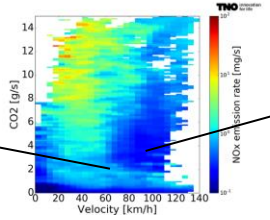

best motorway

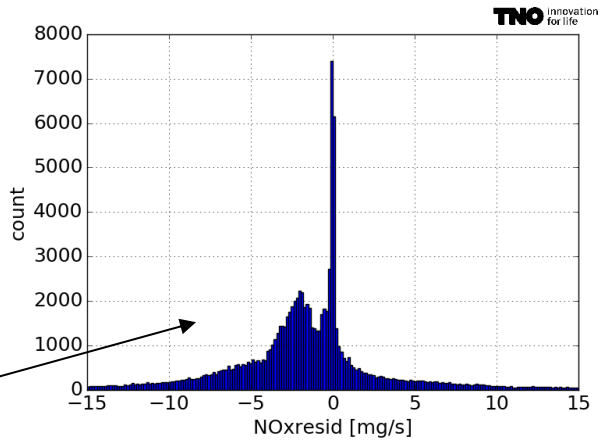
# ASSESSING COLD START AND CONTROL
## *STUDY OF RESIDUALS*
### *"DETECTING DIFFERENCES"*




deviations (residues) from average emission behaviour with (vel, CO2) shows specific optimizations

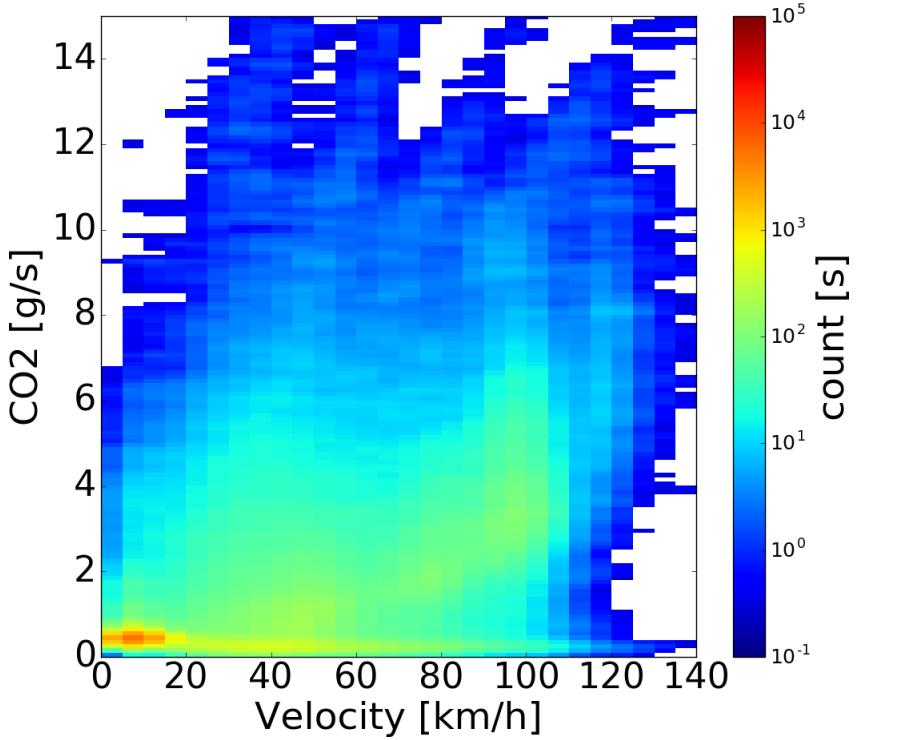


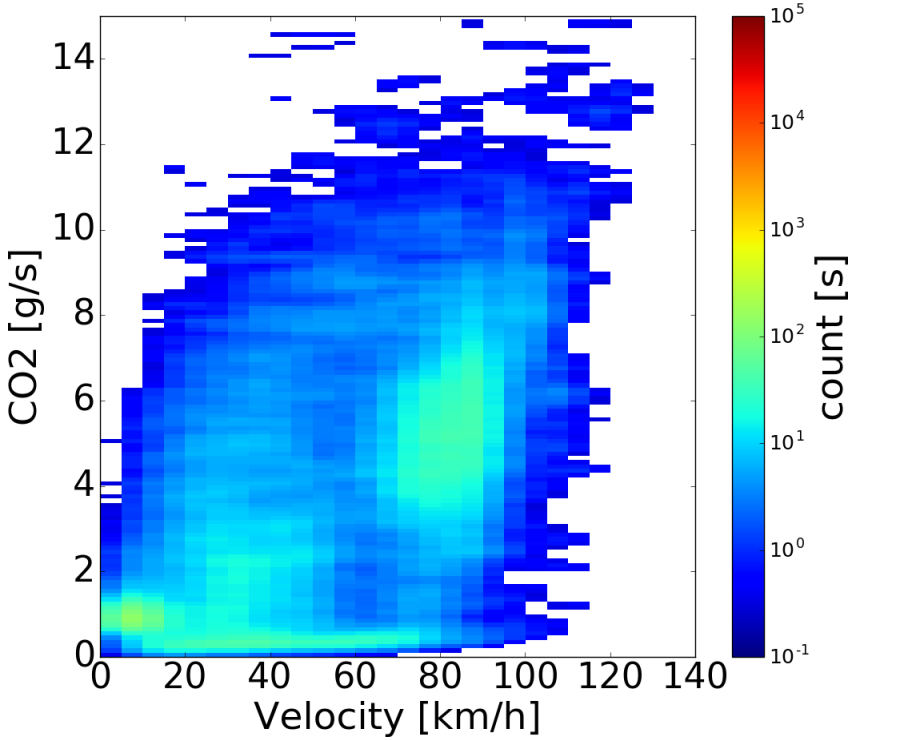
# THE PROBLEM WITH DRIVERS
## *"IT IS PERSONAL"*

***time spend at given speed and throttle position***

*the erratic test driver*




*the decisive test driver*

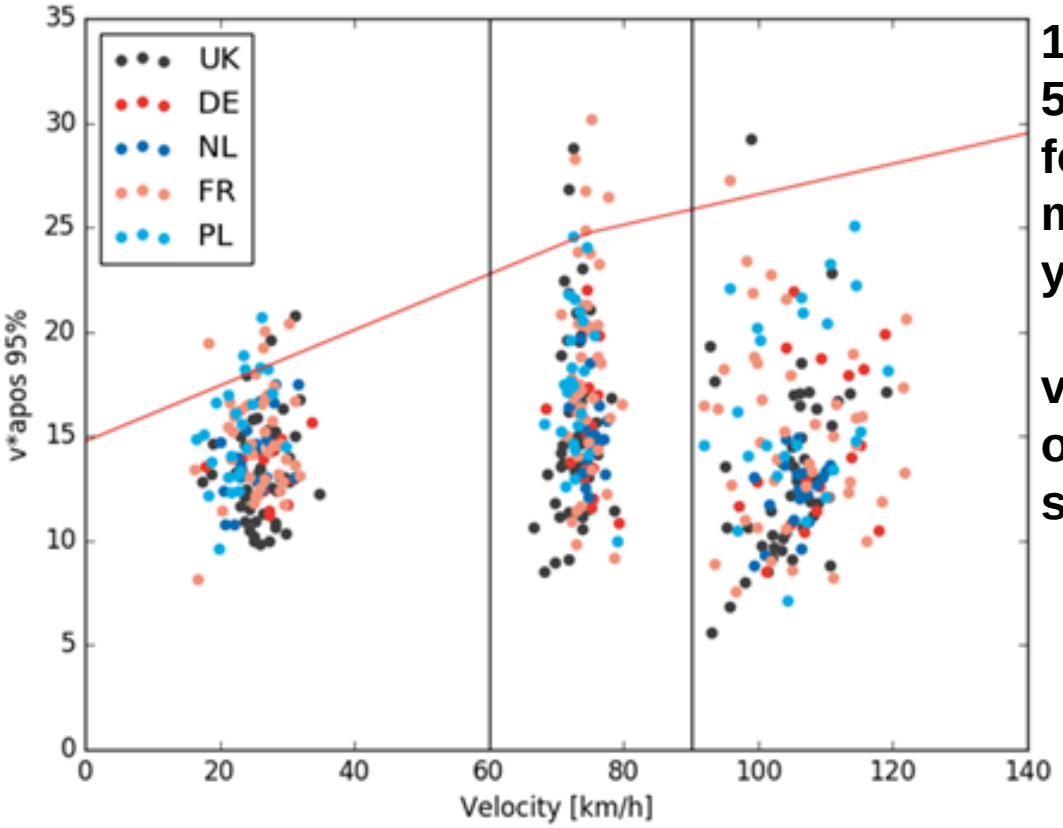


# EUROPEAN NATURALISTIC DRIVING

## UDRIVE V*$A_{POS}$[95%] PER DRIVER *(NOT JUST TRIPS!)*

Accurate velocity signal essential for v*$a_{pss}$[95%] determination.

Serious concerns with smart phone GPS for v*$a_{pos}$.




**150 drivers in 5 countries followed for months to years.**

**velocity based on wheel speed.**

# LIST OF ASSESSED METHODS

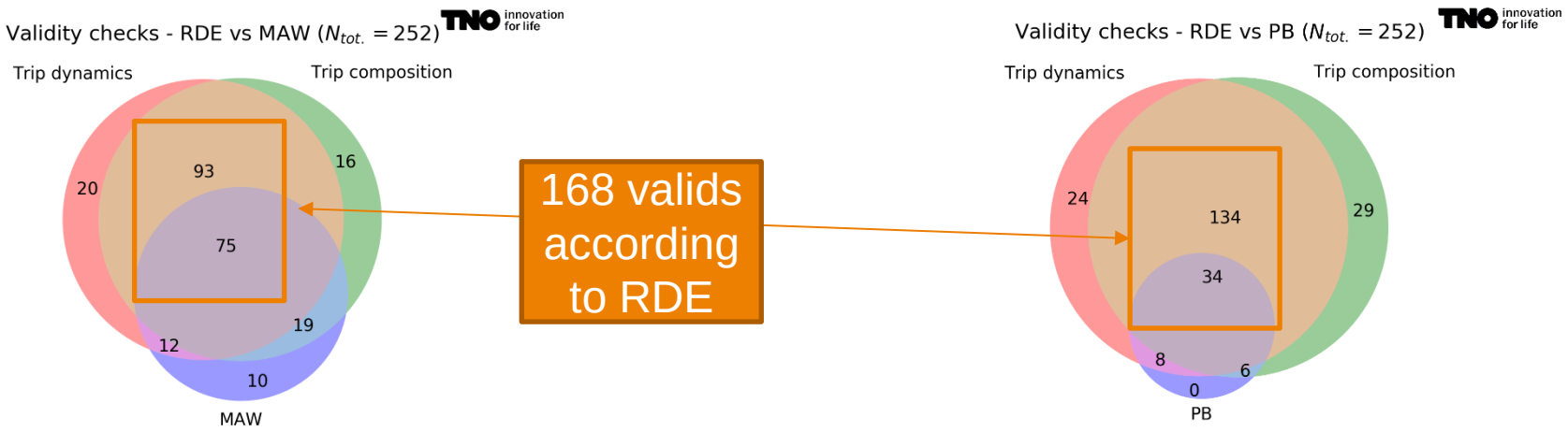
## *IN CONTRACT FOR THE COMMISSION*

| | Trip validity on RDE BCS | Trip validity on evaluation method BCS | Corrected emissions |
|---|---|---|---|
| Raw emissions, no BCS | NO | NO | NO |
| Raw emissions with test validity | YES | NO | NO |
| PB | YES | YES | YES |
| MAW + MAW looped | YES | YES | YES |
| $NO_X/CO_2$ | YES | NO | YES |
| $NO_X/CO_2$ MAW (ACEA) | YES | YES | YES |
| Raw emisisons MAW (T&E) | YES | YES | NO |

# INVALID TESTS MOST IMPORTANT ISSUE

## BOUNDARY CONDITIONS (BCS) OF THE EVALUATION METHODS (NOT DYNAMICS)

- Many invalid trips: 252 → 168 → 75 and 34
- BCS of evaluation methods have a greater impact than general RDE BCS → different principles of test normality
- For MAW, motorway share (not enough windows) and the urban part of the $CO_2$ band (positive and negative) are important factors for invalidity on MAW test normality. For PB, the power bins P1+2, P3 and P5 are important factors.

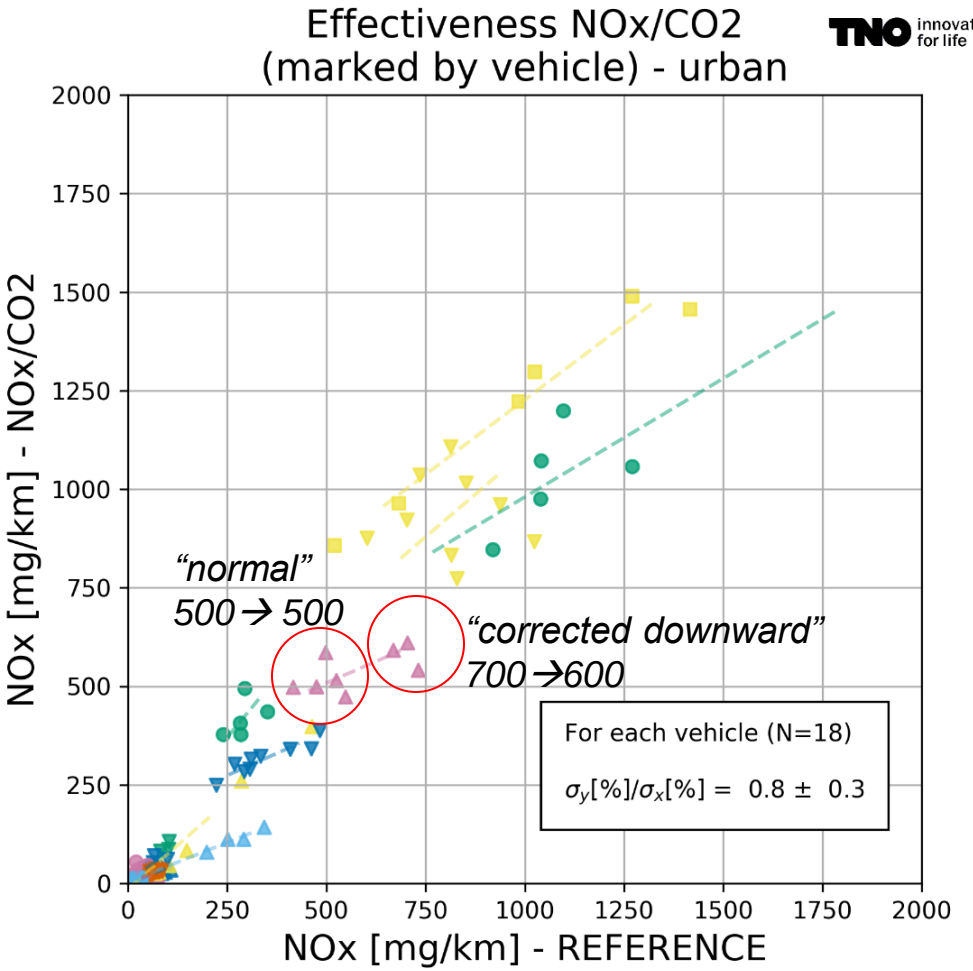



*Venn diagram without order: all BCS checked independently*

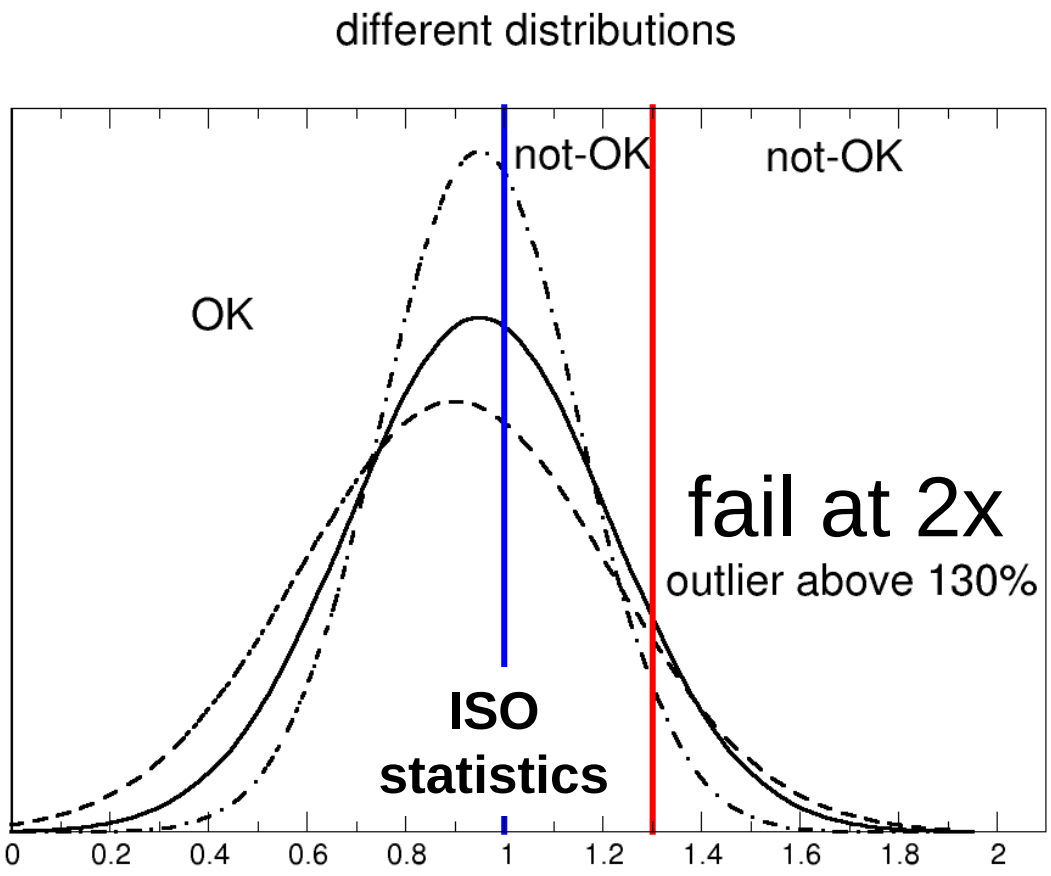
# EFFECTIVENESS: EMISSION RESULTS

Ratio of the average variation, or standard deviation, per vehicle in the evaluation result and the variation in the raw result:

- It was shown that none of the methods show a high correlation between raw results and evaluation results. (NOx/CO2 urban shows the most correlation: higher $CO_2$ gives a correction downward.)
- MAW even showed a slight increase in scatter on top of the variation observed in the raw test results with individual vehicles
- Some systematic effects per vehicle might exist in PB



# STATISTICAL PROCEDURE
## *FOR IN-SERVICE CONFORMITY*



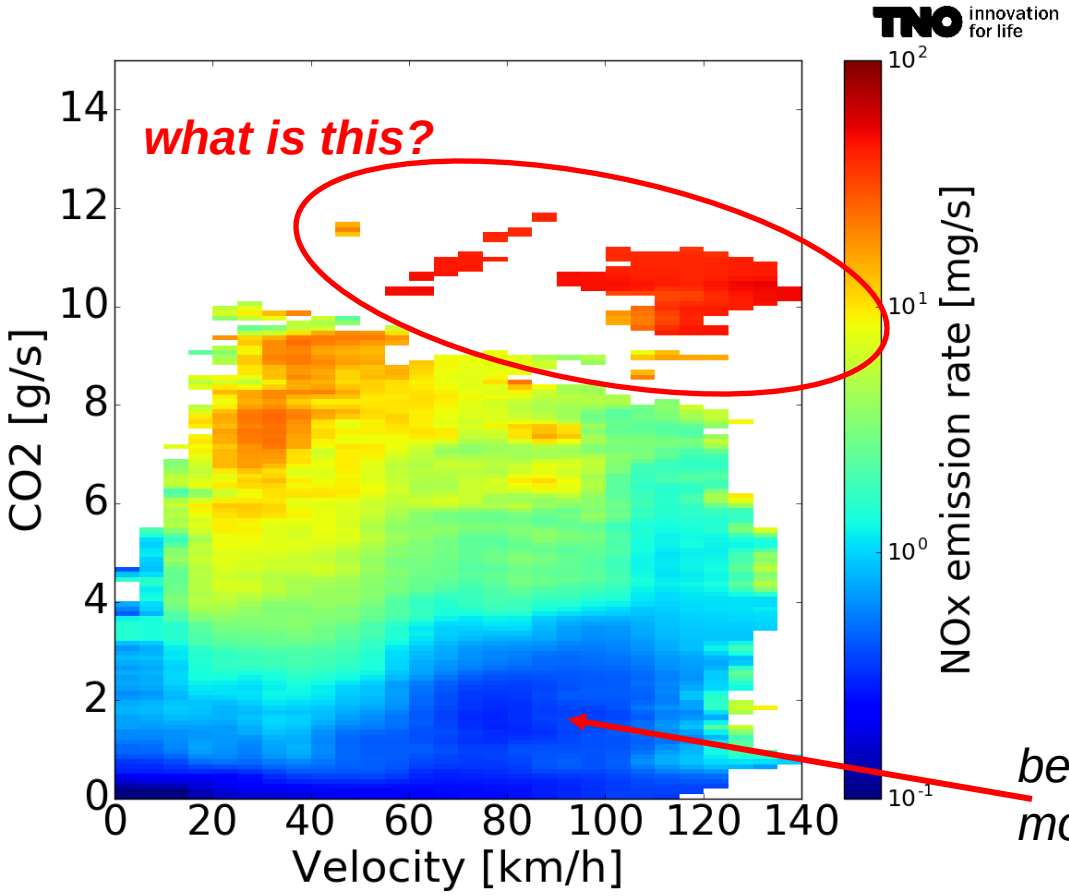

**For example**:
ISO statistics makes 25% faulty vehicles compliant with a minimal risk of incompliance.

Fail with two times a +30% outlier (in 10 tests maximal) ensures that the emission levels remain within bounds, for these 25% faulty vehicle.

simply said: in the worst case, 75% below 1 and 25% below 1.3 keeps the results still below 1.075 times the limit.

# MEET THE CLEANEST CAR, SO FAR

## *… STILL A REASON TO DRIVE DECISIVELY ECO*




*below 1 mg/s in moderate driving!*

# UNDERSTANDING ON-ROAD TEST RESULTS
## *REPRODUCIBILITY*

- **What if an (In-Service Conformity) test shows unexpected results?**
  - Can this result be reproduced?
  - If it cannot be reproduced, will it be ignored?
- **It is essential to understand the cause of on-road variations**
  - accurate signal for velocity, improving flow measurements *(inlet?)*
  - **development of measurement equipment:** *(ongoing)*
    - road slope *(altitude variations affect engine loads significantly)*
    - wind *(causing air drag variations up to 100%)*
    - road surface and dynamic rolling resistance *(unknown effects)*
    - battery, auxiliaries, and hybridization require new meters
- **Monitoring is essential to determine true risk/rate of high emissions**
  - In the “RDE era”, emissions will be more erratic and variations are larger
  - new ways of thinking and presenting results (no “one-number” nonsense)

# THANK YOU FOR YOUR ATTENTION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