ASSESSMENT OF RECENT CHANGES IN RDE LEGISLATION

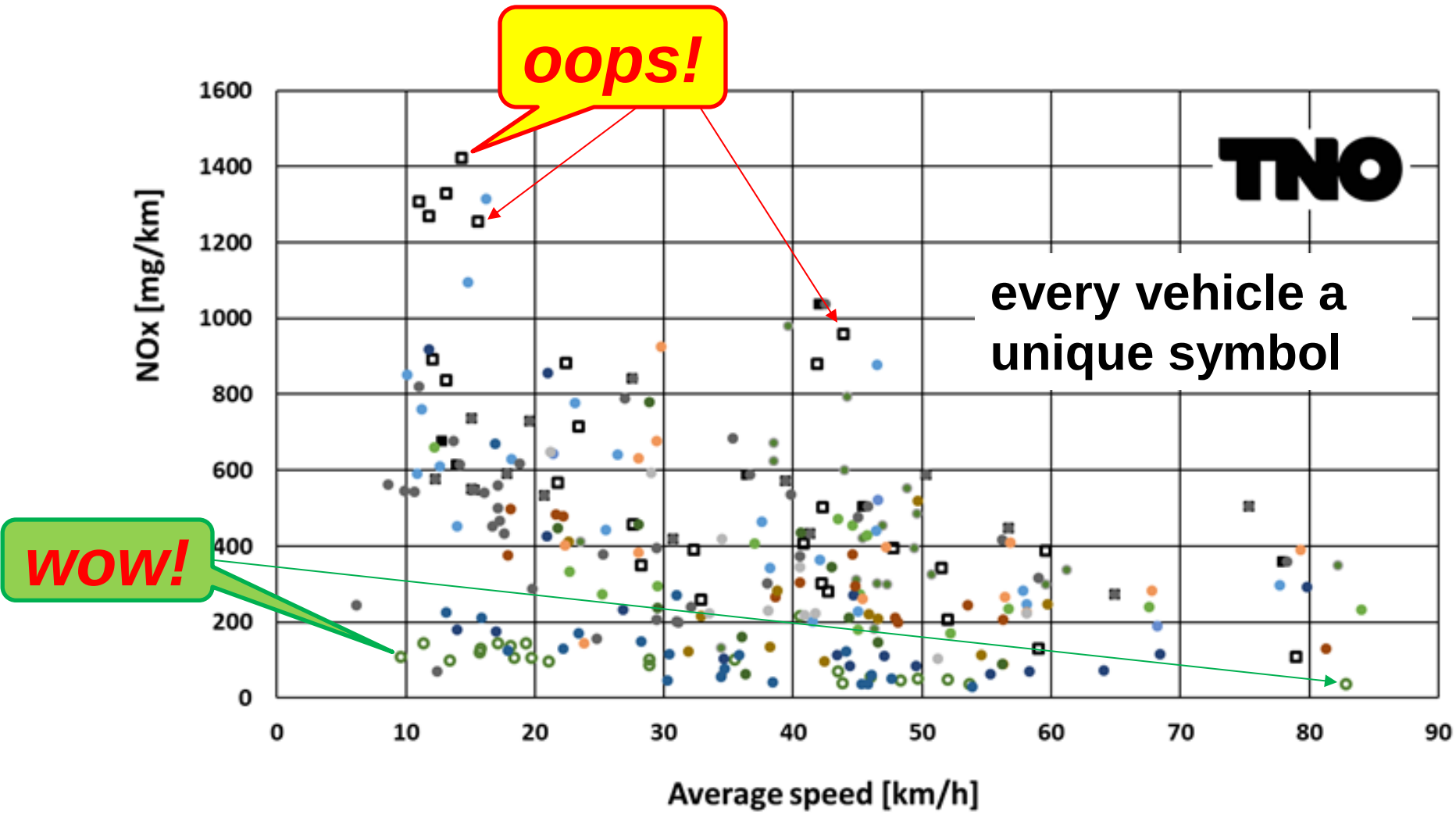
guide for independent testing from surveillance to compliance | Ligterink, N.E. (Norbert)



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"

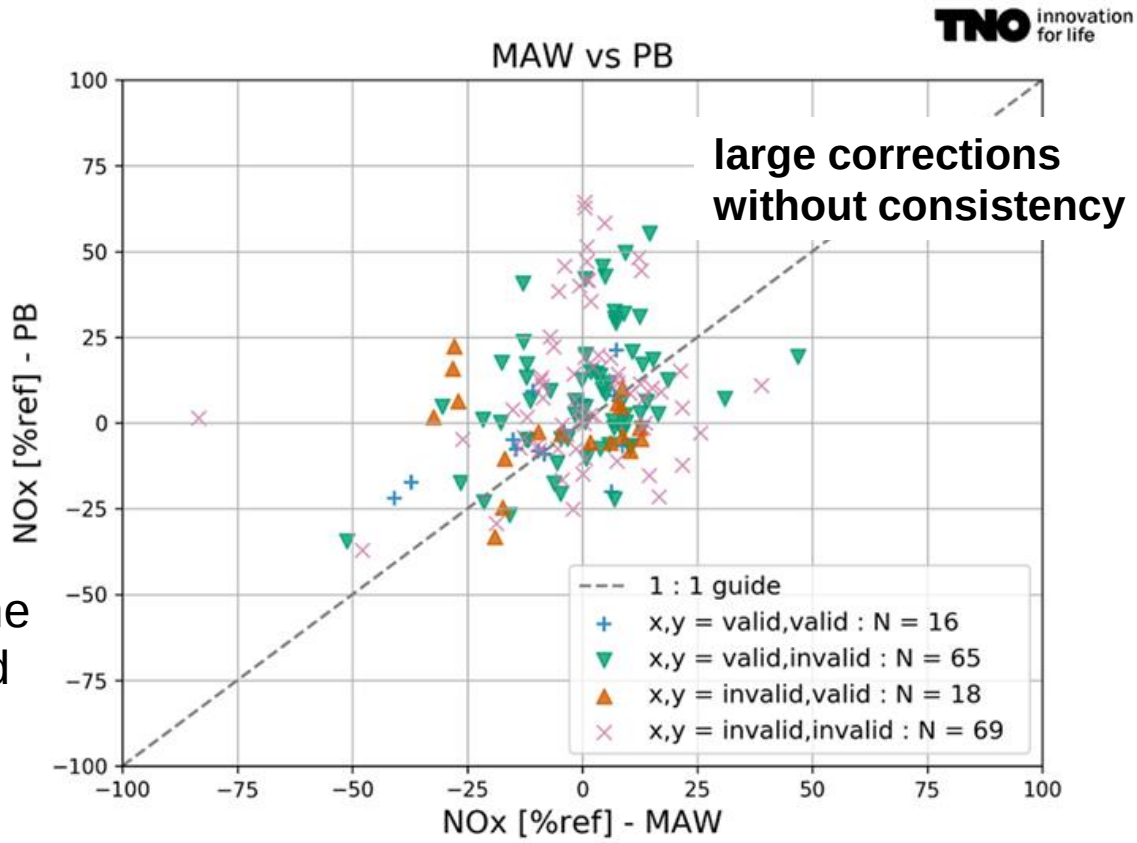
Our working hypothesis

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.

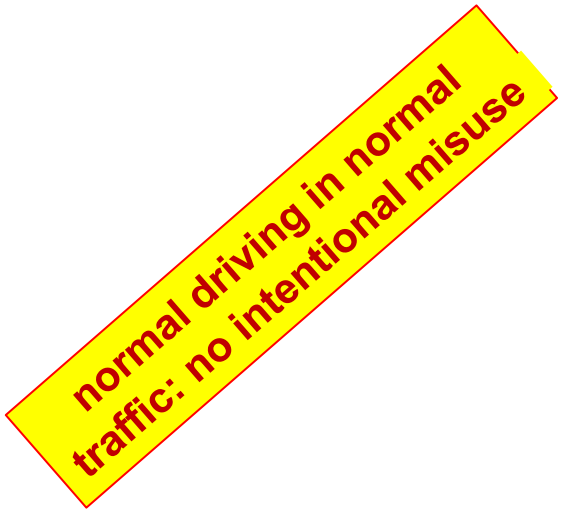
randomization or some systematics?



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

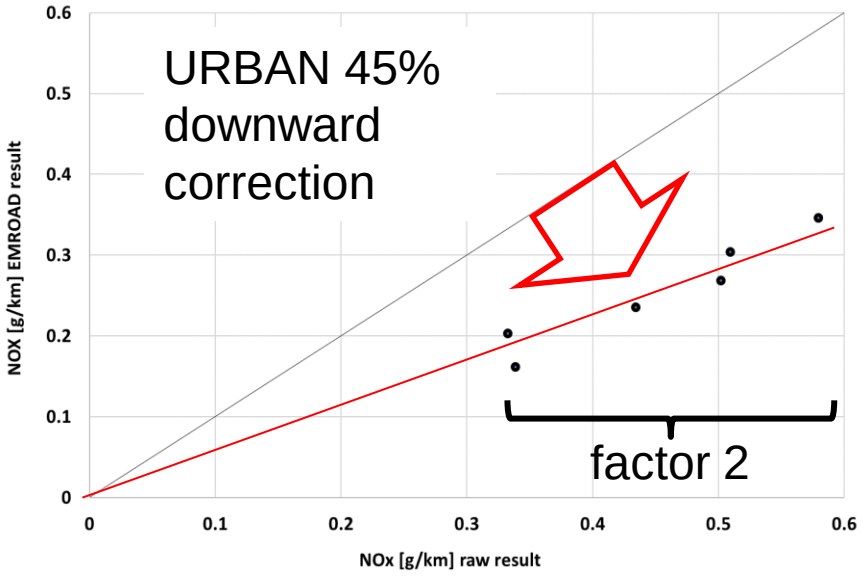
RDE compliant? (N1 Class II)	ok		Urban part too agressive			ok	skewed road type fractions	Urban part too agressive	1% to much stop time in urban part	ok			Not sufficient dynamics on highway
Trip	1	2	3	4	5	6	7	8	9	10	11	12	13
Style	**normal**	**normal**	**sport**	**sport**	**sport**	**normal**	**eco**	**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**	

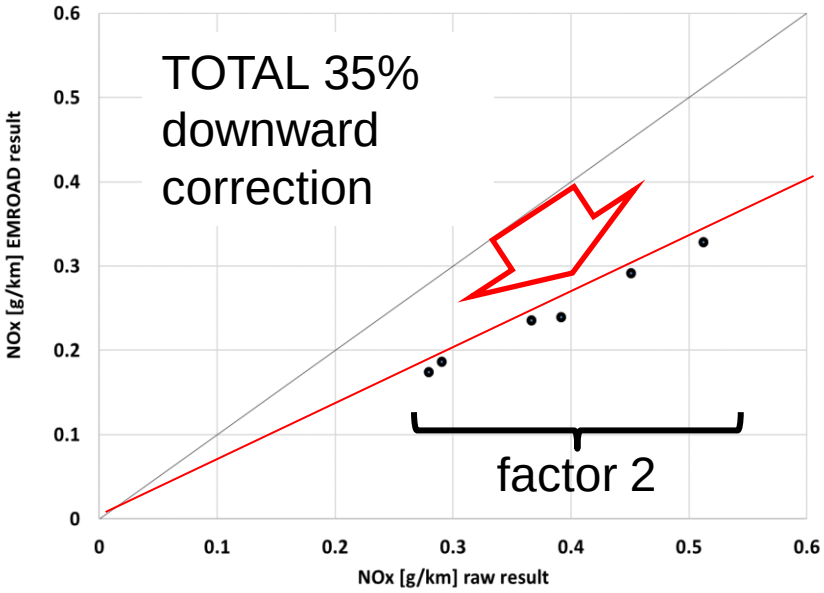
factor 2 in RDE trips

factor 5 in all trips

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

SYSTEMATIC!



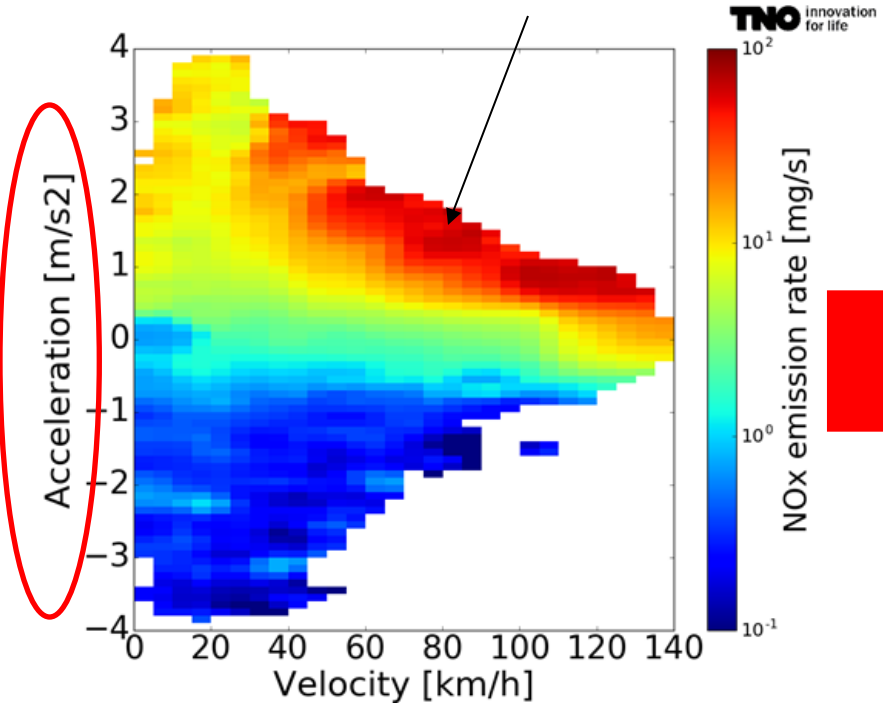


there is no "reference", for which there is no correction

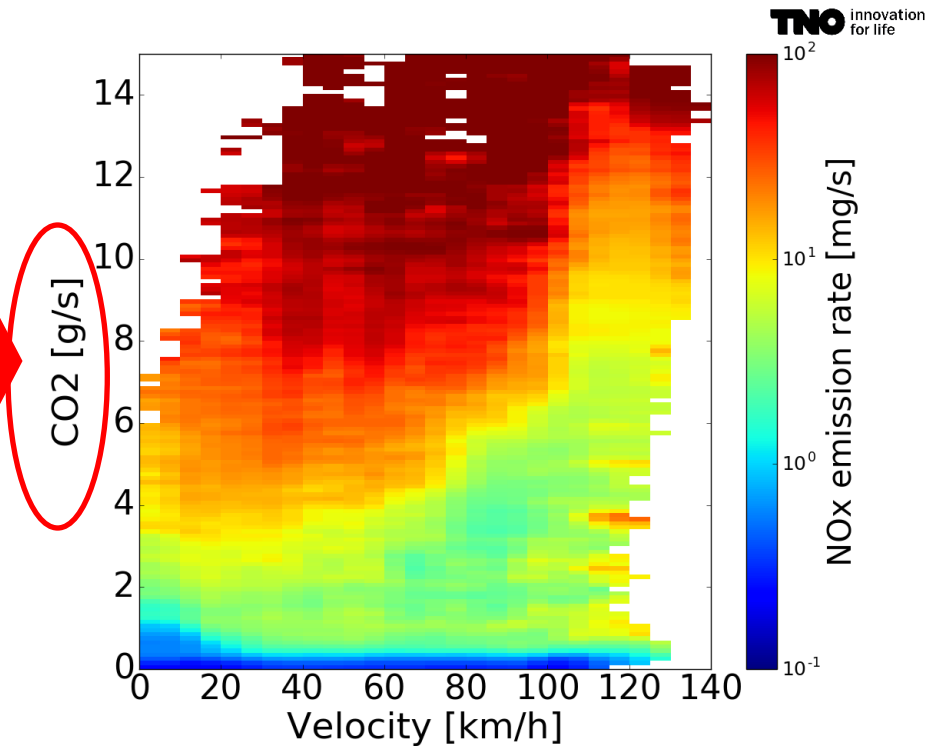
** only two valid tests for CLEAR (PB), no analysis possible*

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

power depends on test mass



invariant: power ~ CO_2 rate [g/s]

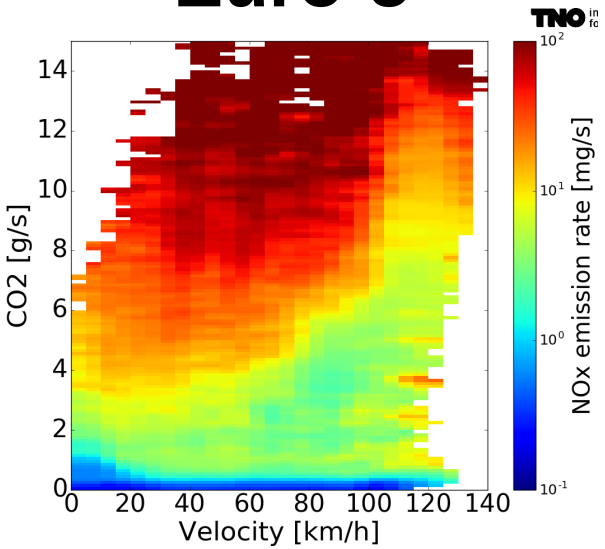


SAME MAKE AND MODEL CLASS III VAN
DEVELOPMENT IN EMISSION PERFORMANCE

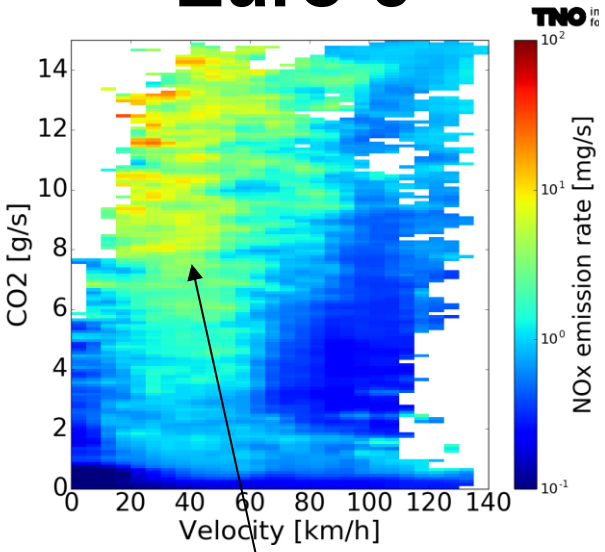
also well-performing vehicles show variations in emissions

"3.5 ton ← 5 ton GVW"

Euro-5

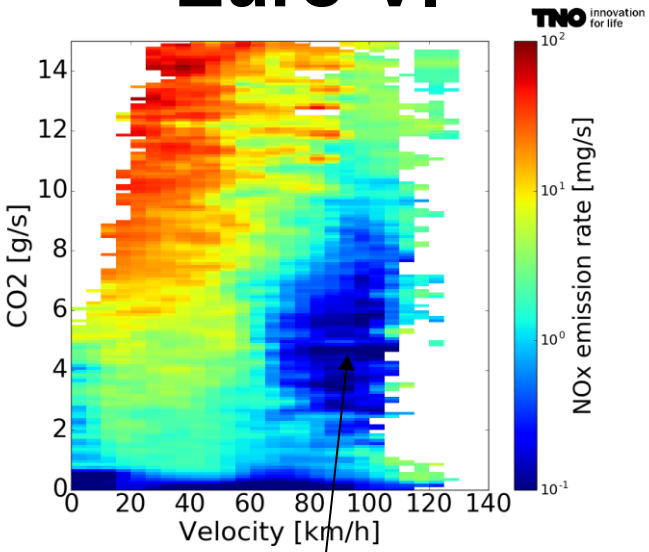


Euro-6



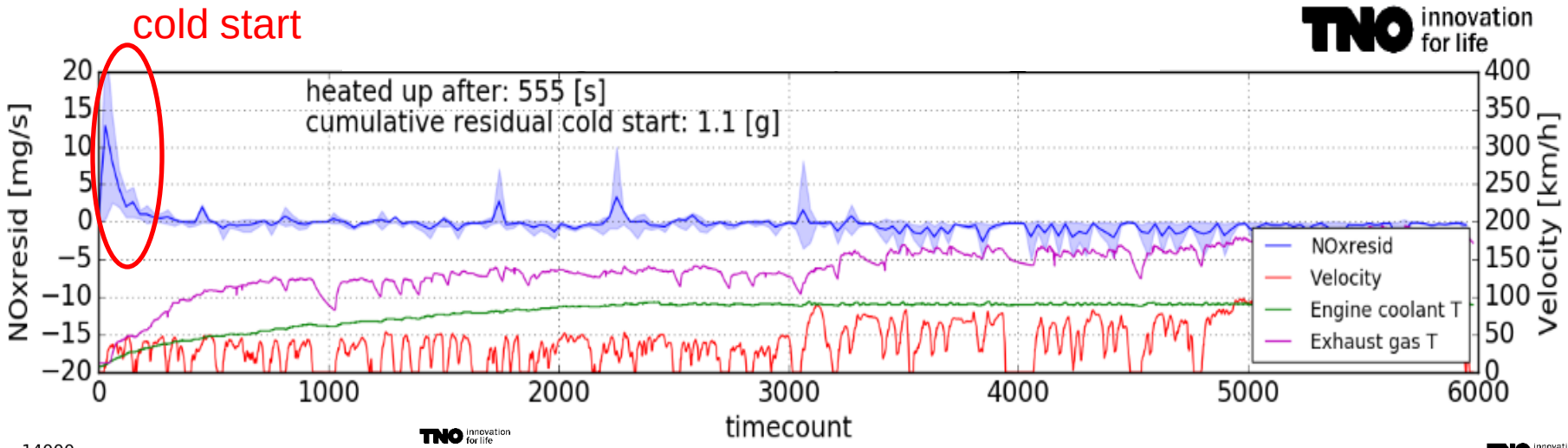
best urban

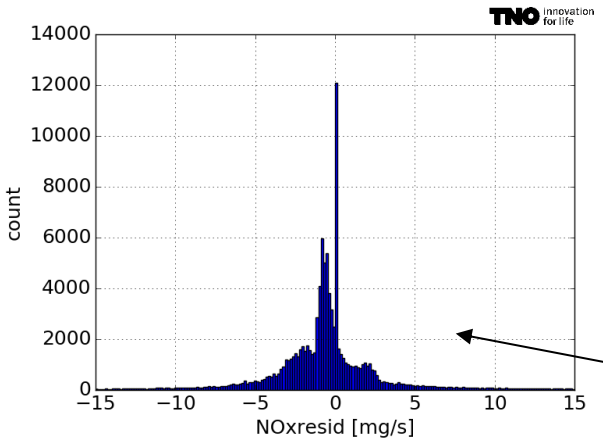
Euro-VI



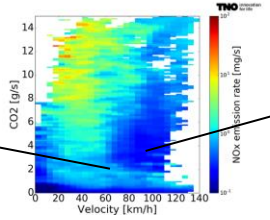
best motorway

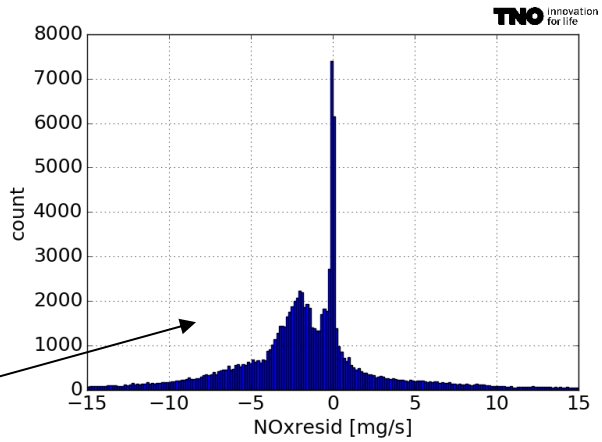
ASSESSING COLD START AND CONTROL
STUDY OF RESIDUALS
"DETECTING DIFFERENCES"





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

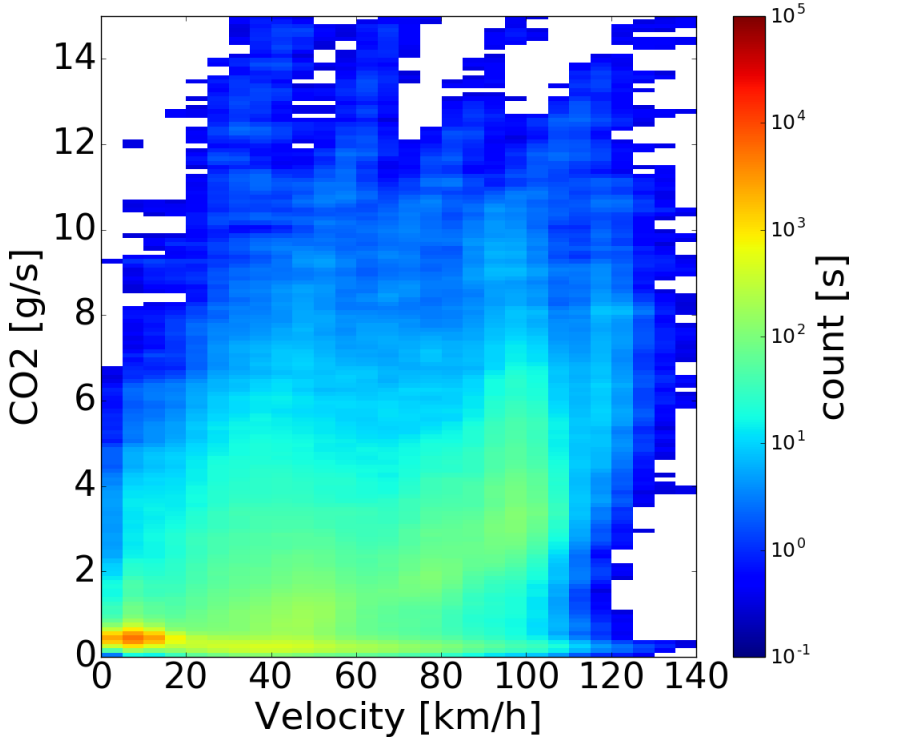




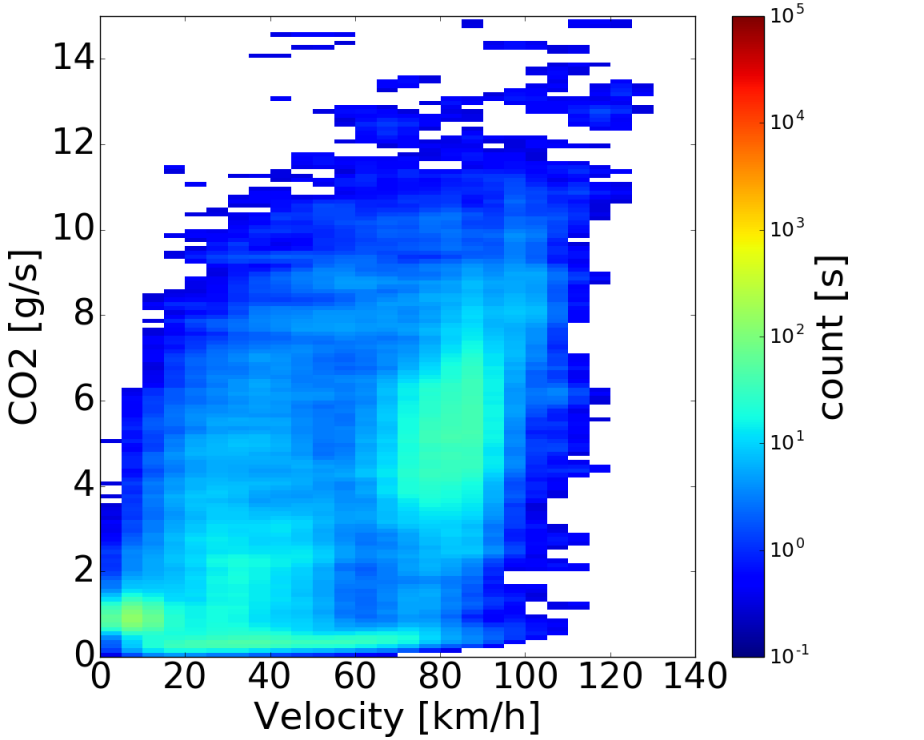
THE PROBLEM WITH DRIVERS
"IT IS PERSONAL"

time spend at given speed and throttle position

the erratic test driver



the decisive test driver

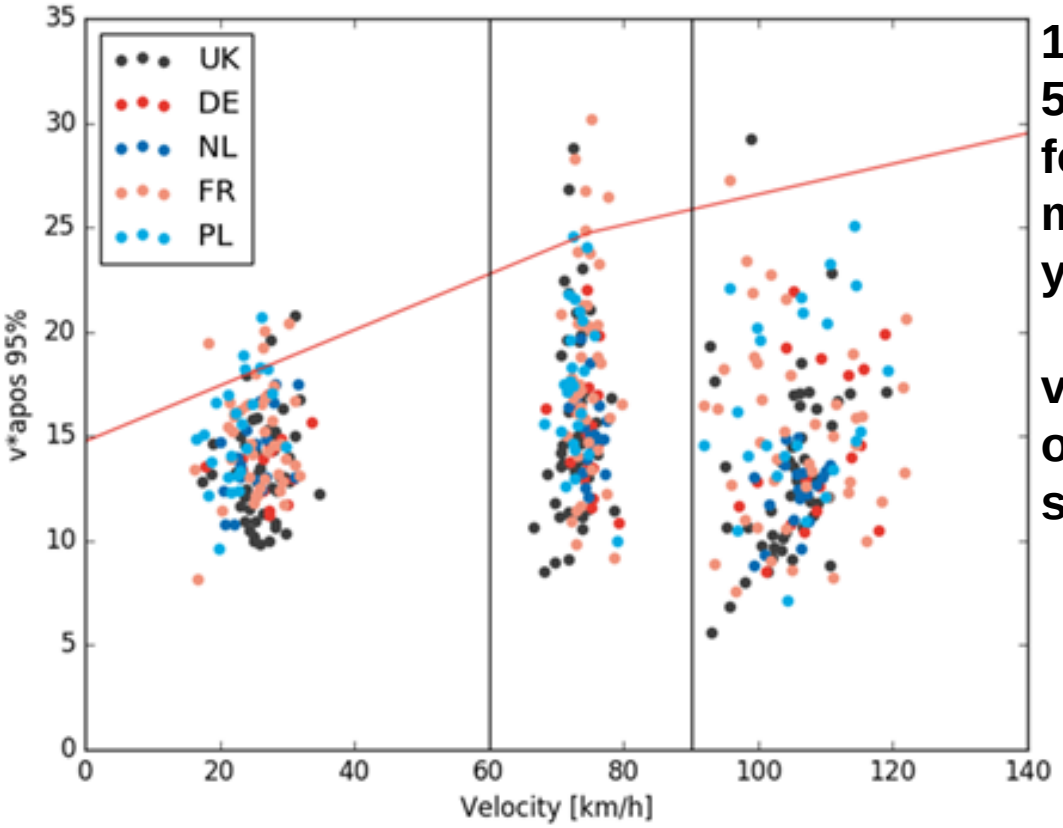


EUROPEAN NATURALISTIC DRIVING

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

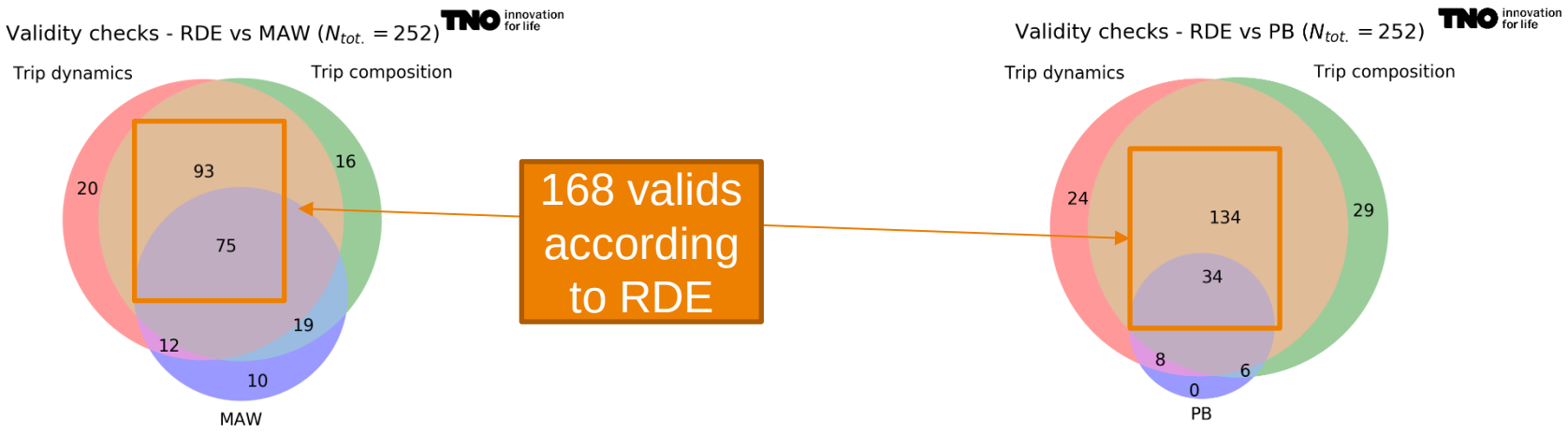
IN CONTRACT FOR THE COMMISSION

	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.

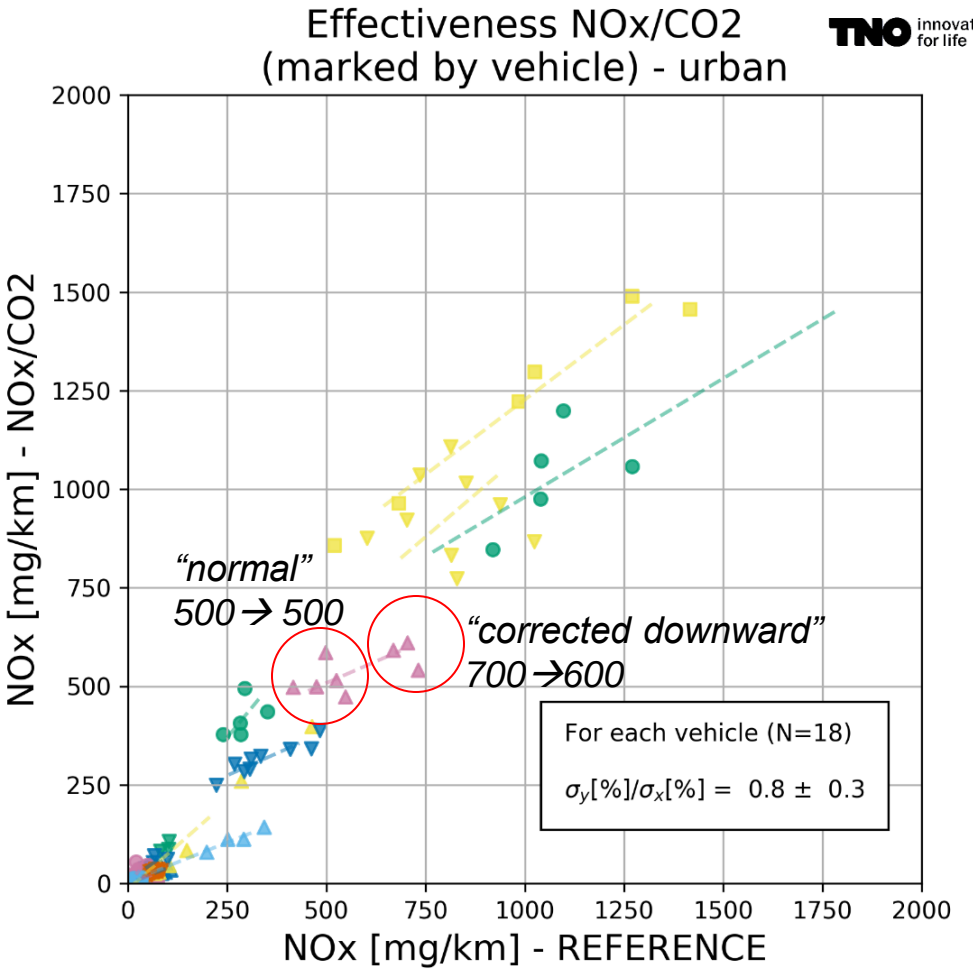


Venn diagram without order: all BCS checked independently

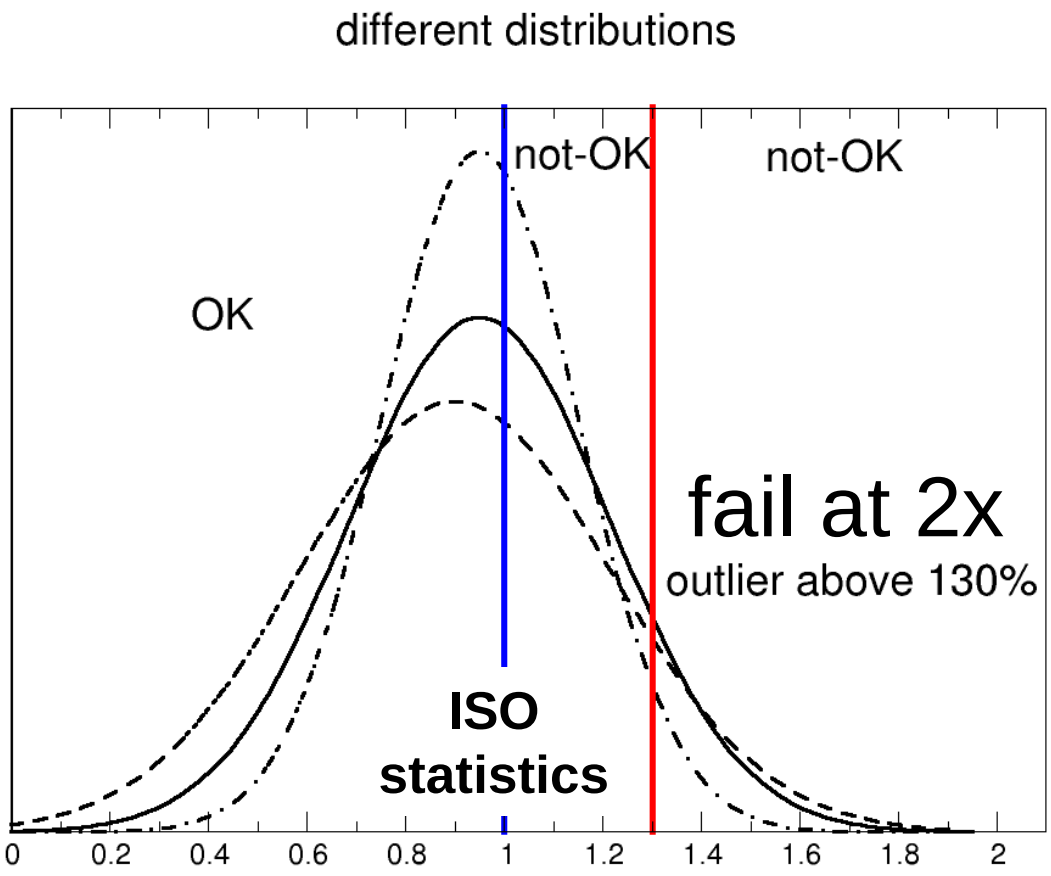
EFFECTIVENESS: EMISSION RESULTS

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



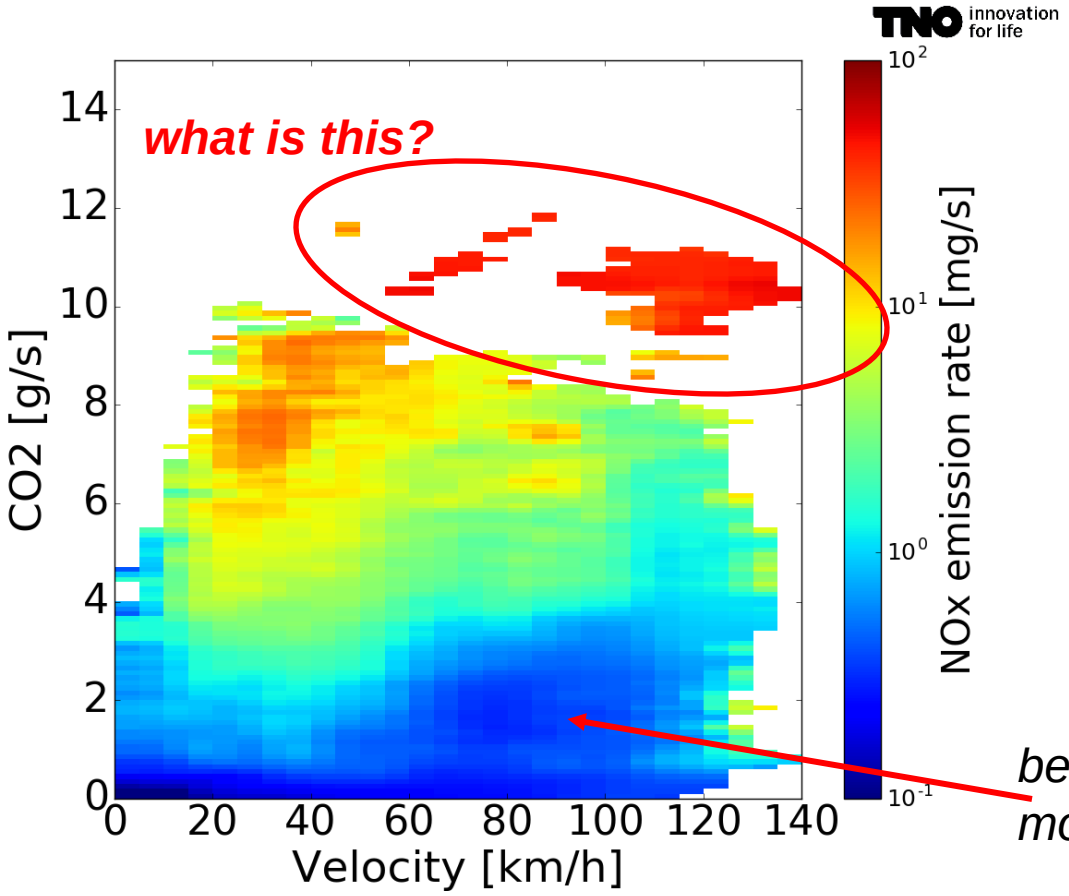
For example:
ISO statistics makes 25% faulty vehicles compliant with a minimal risk of incompliance.

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



norbert.ligterink@tno.nl