

# Testfield „OBD“ and massive data analysis

A PTE success story ready to take off

## Testfield „OBD“ and massive data analysis



## Anomaly Detection in Test Fields

# Anomaly Detection in Test Fields

**Data science** claims to **revolutionize** your test field efficiency.

Let's compare. This is your testfield **without** data science:



And this will be your testfield **with** data science:



...like if your doc diagnoses a slipped disk, but you still refuse your daily exercise

## Anomaly Detection in Test Fields

Ok, that was a little provocative, but what does it really mean?

**„Technology can be bought in – we need to develop people!“**  
*Phil Lawson, JLR*

So, you want to step into first league? Then you need....

# Anomaly Detection in Test Fields

...an awesome race car!



...which means without self-adulation, an AVL testfield of course



**BUT!...**

# Anomaly Detection in Test Fields

## BUT also...

...an awesome pilot!

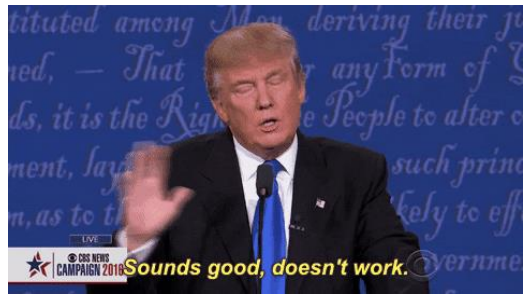
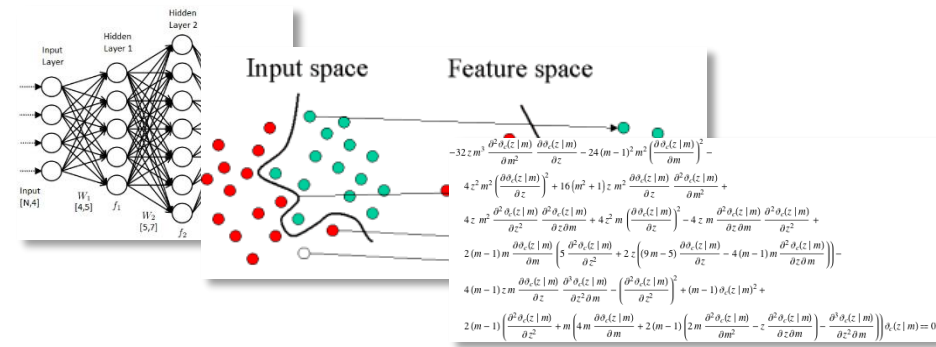
...which means a lot of pilots to be lead in your testfield contributing to maximize your test field output with meaningful data.



# Anomaly Detection in Test Fields

So, what is the best approach to integrate data science to improve your testfield output?

Hire a mathematical genius!



...who communicates with

Automation technician



Comissioning technician



Facility Management



Service technician



Testbed operator



**OMG, this person has no clue, what he is talking about....**

## Testfield „OBD“ and massive data analysis



## The Evolution of a not planned PTE concept tool



# The Evolution of a not planned PTE concept tool

## Validation loop in 2011

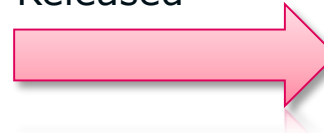


Performing the test



Generating Report and checking suspicious data manually

Released



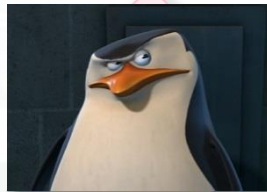
Calibration Engineer

Released

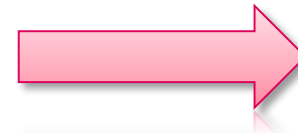


**Then, massive increase of chassis dyno projects.**

**Embrace yourself, 3rd shift is coming**



suspicious



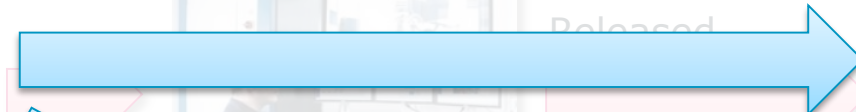
Data Validation Engineer

# The Evolution of a not planned PTE concept tool

## Validation loop in 2011



Performing the test



...chassis dyno Nr. 3 arrived

3 Chassis Dynos in 3 shifts



Calibration Engineer



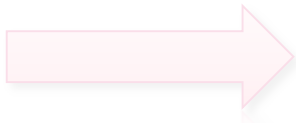
Info if failed



suspicious



Data Validation Engineer



# The Evolution of a not planned PTE concept tool

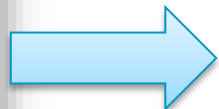
## Validation loop in 2011 – first automation step – daily analysis



**HOST**



**Concerto Script**



Test Name: 20111215\_1842\_TB402\_NEDC.1

Exhaust Massflow: TRACER - CVS Flow: 15,534

Test Name: 20111215\_1842\_TB402\_NEDC.1

1	2	3	SS_CO2_BAG	SSCO2DIL	SS_CO2TP	SS_CO2EO	Dev_CO2_DIL	Dev_CO2_TP	Dev_CO2_EO
g/km	g/km	g/km	g/km	g/km	g/km	%	%	%	
1	2	3	166,86	169,46	170,93	168,12	1,55	2,44	0,75
2	2	2	218,01	214,18	214,46	199,88	-1,76	-1,63	-8,32
3	3	3	199,08	197,63	198,34	188,12	-0,73	-0,37	-5,50

Test Name: 20111215\_1842\_TB402\_NEDC.1

1	2	3	SS_CO_BAG	SS_CO_DIL	SS_CO_TP	SS_CO_EO	Dev_CO_DIL	Dev_CO_TP	Dev_CO_EO
g/km	g/km	g/km	g/km	g/km	g/km	%	%	%	
1	2	3	1,1393	1,1476	1,1989	2,2225	0,73	5,24	95,07
2	2	2	0,0237	0,0270	0,0305	4,4345	14,15	28,63	18613,55
3	3	3	0,4367	0,4418	0,4630	3,6157	1,19	6,04	728,03

Test Name: 20111215\_1842\_TB402\_NEDC.1

1	2	3	SS_THC_BAG	SSTHC_DIL	SS_THCTP	SS_THCEO	Dev_THC_DIL	Dev_THC_TP	Dev_THC_EO
g/km	g/km	g/km	g/km	g/km	g/km	%	%	%	
1	2	3	0,1447	0,1491	0,1844	0,5693	3,06	23,76	282,18
2	2	2	0,0565	0,0660	0,0746	1,1203	16,71	13,07	1589,90
3	3	3	0,0892	0,0967	0,1152	0,9164	8,51	19,17	847,85

Test Name: 20111215\_1842\_TB402\_NEDC.1

1	2	3	SS_NOX_BAG_S	SSNOXDIL_S	SS_NOXTP_S	SS_NOXEO_S	Dev_NOX_DIL	Dev_NOX_TP	Dev_NOX_EO
g/km	g/km	g/km	g/km	g/km	g/km	g/km	%	%	%
1	2	3	0,1752	0,1850	0,2026	0,2208	5,53	15,62	25,94
2	2	2	0,2846	0,2809	0,2913	0,2706	-1,82	1,82	-5,44
3	3	3	0,2441	0,2454	0,2585	0,2522	0,13	5,49	2,91

Test Name: 20111215\_1842\_TB402\_NEDC.1

1	2	3	SS_NO_BAG_S	SS_NO_DIL_S	SS_NO_TP_S	SS_NO_EO_S	Dev_NO_DIL	Dev_NO_TP	Dev_NO_EO
g/km	g/km	g/km	g/km	g/km	g/km	g/km	%	%	%
1	2	3	0,1142	0,1187	0,1272	0,0410	3,88	11,28	-64,13
2	2	2	0,1839	0,1808	0,1876	0,1494	-2,24	1,66	-19,26
3	3	3	0,1581	0,1578	0,1652	0,1093	-0,60	4,09	-31,28

Test Name: 20111215\_1842\_TB402\_NEDC.1

1	2	3	SS_NHHC_BAG	SS_NHHC_DIL	SS_NHHC_TP	SS_NHHC_EO
g/km	g/km	g/km	g/km	g/km	g/km	g/km
1	2	3	0,1330	0,1373	0,1691	0,5546
2	2	2	0,0369	0,0463	0,0544	1,0840
3	3	3	0,0724	0,0800	0,0969	0,8880

Test Name: 20111215\_1842\_TB402\_NEDC.1

1	2	3	SS_CH4_BAG	SS_CH4_DIL	SS_CH4TP	SS_CH4EO
g/km	g/km	g/km	g/km	g/km	g/km	g/km
1	2	3	0,0134	0,0132	0,0174	0,0169
2	2	2	0,0225	0,0223	0,0231	0,0416
3	3	3	0,0191	0,0189	0,0210	0,0324

Test Name: 20111215\_1842\_TB402\_NEDC.1

1	2	3	SS_PM_SS_Soot_MSS
g/km	g/km	g/km	g/km
1	2	3	0,043208
2	2	2	0,018061
3	3	3	0,027369

Test Name: 20111215\_1842\_TB402\_NEDC.1

1	2	3	FC_BAG	SS_FCDIL	SS_FC_TP	SS_FC_EO
l/100km	l/100km	l/100km	l/100km	l/100km	l/100km	l/100km
1	2	3	6,3958	6,4948	6,5578	6,5581
2	2	2	8,2534	8,1100	8,1215	7,9561
3	3	3	7,5658	7,5121	7,5427	7,4386

Test Name: 20111215\_1842\_TB402\_NEDC.1

1	2	3	FC_BAG	SS_FCDIL	SS_FC_TP	SS_FC_EO
l/100km	l/100km	l/100km	l/100km	l/100km	l/100km	l/100km
2	2	2	8,2534	8,1100	8,1215	7,9561
3	3	3	7,5658	7,5121	7,5427	7,4386

**Manual check of all reports every morning... every day**

# The Evolution of a not planned PTE concept tool

## Validation loop in 2011 – first automation step – daily analysis

Test Name: 20111215\_1842\_TB402\_NEDC.1

Exhaust Massflow: FRACER - CVS Flow: 15,534

Test Name: 20111215\_1842\_TB402\_NEDC.1

SS_CO2_BAG	SS_CO2DIL	SS_CO2TP	SS_CO2BO	Dev_CO2_DIL	Dev_CO2_TP	Dev_CO2_BO
166,86	169,46	170,93	168,12	1,55	2,44	0,75
218,01	214,18	214,46	199,88	-1,76	-1,63	-8,32
199,08	197,63	198,34	188,12	-0,73	-0,37	-5,50

Exhaust Massflow: FRACER - CVS Flow: 15,534

Test Name: 20111215\_1842\_TB402\_NEDC.1

SS_CO_BAG	SS_CO2DIL	SS_CO2TP	SS_CO2BO	Dev_CO2_DIL	Dev_CO2_TP	Dev_CO2_BO
1,1393	1,1476	1,1989	2,2225	0,73	5,24	95,07
0,0237	0,0270	0,0305	4,4345	14,15	28,63	18613,55
0,4367	0,4418	0,4630	3,6157	1,19	6,04	728,03

Exhaust Massflow: FRACER - CVS Flow: 15,534

Test Name: 20111215\_1842\_TB402\_NEDC.1

SS_THC_BAG	SS_THCDIL	SS_THCTP	SS_THCBO	Dev_THC_DIL	Dev_THC_TP	Dev_THC_BO
0,1447	0,1491	0,1844	0,5693	3,06	23,76	282,18
0,0565	0,0460	0,0746	1,1203	16,71	13,07	1598,90
0,0892	0,0967	0,1152	0,9164	8,51	19,17	847,85

Exhaust Massflow: FRACER - CVS Flow: 15,534

Test Name: 20111215\_1842\_TB402\_NEDC.1

SS_NOX_BAG_S	SSNOXDIL_S	SS_NOXTP_S	SS_NOXBO_S	Dev_NOX_DIL	Dev_NOX_TP	Dev_NOX_BO
0,1752	0,1850	0,2026	0,2208	5,53	15,62	25,94
0,2846	0,2809	0,2913	0,2706	-1,82	1,82	-9,44
0,2441	0,2454	0,2585	0,2522	0,13	5,49	2,91

Exhaust Massflow: FRACER - CVS Flow: 15,534

Test Name: 20111215\_1842\_TB402\_NEDC.1

SS_NO_BAG_S	SS_NODIL_S	SS_NO_TP_S	SS_NO_BO_S	Dev_NO_DIL	Dev_NO_TP	Dev_NO_BO
0,1142	0,1187	0,1272	0,0410	3,88	11,28	-64,13
0,1839	0,1808	0,1876	0,1494	-2,24	1,46	-19,26
0,1581	0,1578	0,1652	0,1093	-0,60	4,09	-31,28

Exhaust Massflow: FRACER - CVS Flow: 15,534

Test Name: 20111215\_1842\_TB402\_NEDC.1

SS_NMHC_BAG	SS_NMHC_DIL	SS_NMHC_TP	SS_NMHCBO
0,1330	0,1373	0,1691	0,5546
0,0369	0,0463	0,0544	1,0840
0,0724	0,0500	0,0369	0,8880

Exhaust Massflow: FRACER - CVS Flow: 15,534

Test Name: 20111215\_1842\_TB402\_NEDC.1

SS_CH4_BAG	SS_CH4_DIL	SS_CH4TP	SS_CH4BO
0,0134	0,0132	0,0174	0,0169
0,0225	0,0223	0,0231	0,0416
0,0191	0,0189	0,0210	0,0324

Exhaust Massflow: FRACER - CVS Flow: 15,534

Test Name: 20111215\_1842\_TB402\_NEDC.1

SS_PM	SS_Soot_MSE
0,043208	
0,018061	
0,027369	

Exhaust Massflow: FRACER - CVS Flow: 15,534

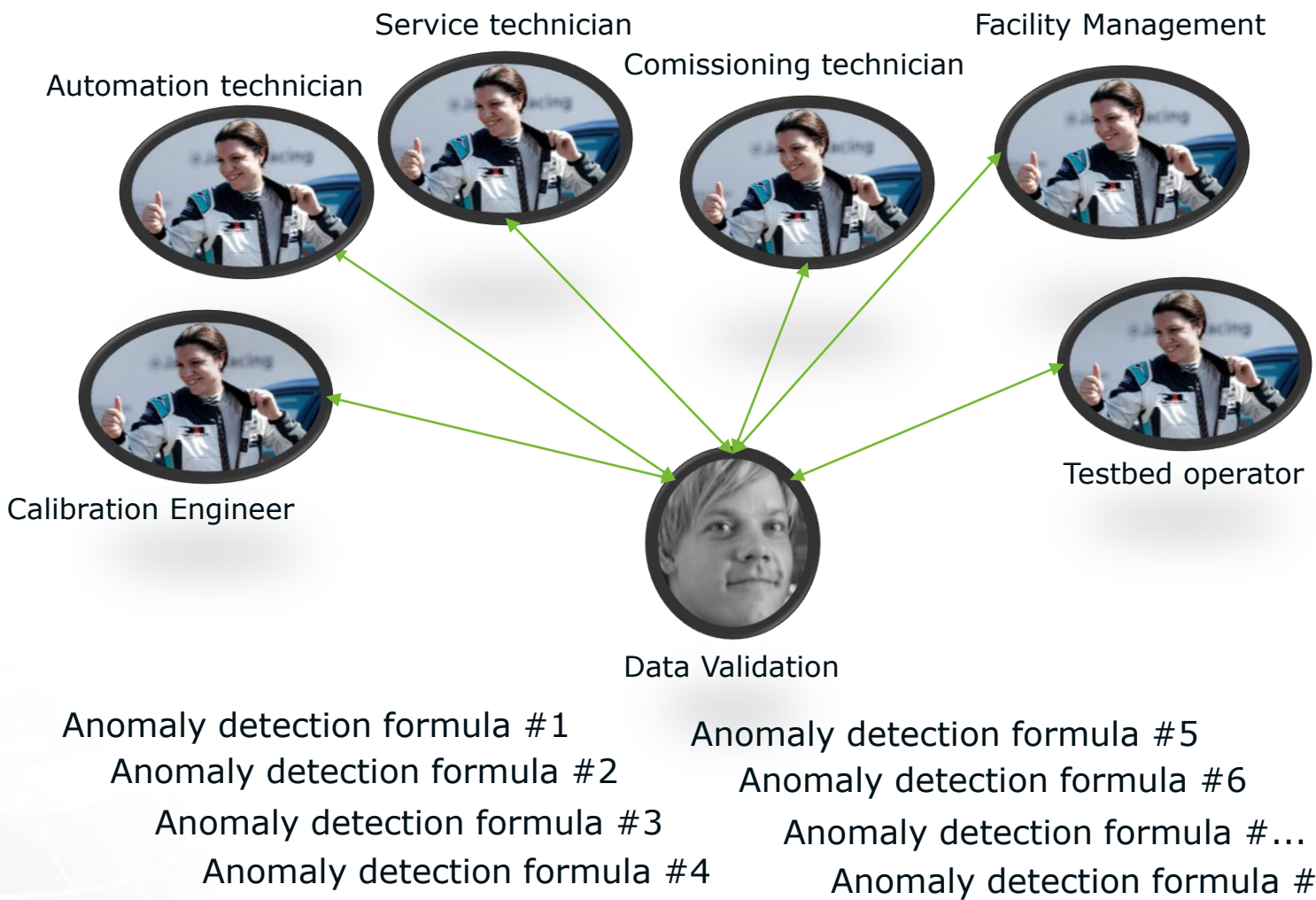
Test Name: 20111215\_1842\_TB402\_NEDC.1

FC_BAG	SS_FCDIL	SS_FC_TP	SS_FC_BO
6,3958	6,4948	6,5578	6,5581
8,2534	8,1100	8,1215	7,9561
7,5658	7,5121	7,5427	7,4386

Exhaust Massflow: FRACER - CVS Flow: 15,534

Test Name: 20111215\_1842\_TB402\_NEDC.1

FC_BAG	SS_FCDIL	SS_FC_TP	SS_FC_BO
8,2534	8,1100	8,1215	7,9561
7,5658	7,5121	7,5427	7,4386

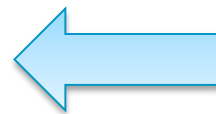


## The Evolution of a not planned PTE concept tool

Validation loop in 2011 – further automation steps

So, you managed to get through all data from the previous day and the ongoing shifts, heading home at 18:41...

Next day an applied anomaly detection detects an error at **18:42**. Which was an systematic error and all tests were broken until next morning.



...this is how i felt

## The Evolution of a not planned PTE concept tool

Validation loop in 2011 – further automation steps

Furthermore, if an faulty measurement has been detected still a deep dive through the data via data analytics in concerto had to be done.

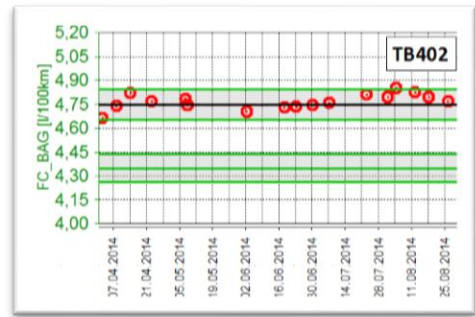
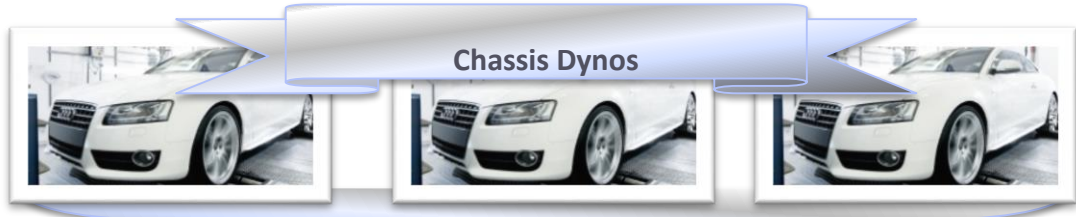
...but issues started being repetitive. It cristalized more and more a standard data analytics report.

Next steps were obvious.

**Mail notification of a standard data validation layout as PDF right after tests had been finished.**

# The Evolution of a not planned PTE concept tool

## Review of Status 2014



**Plausibility Task**

All needed **signals** (flow, pressure, temperature, humidity, all gas species) for the modal analysis, the final **test results** and **chassis dyno parameter** are checked.

**Signals:**

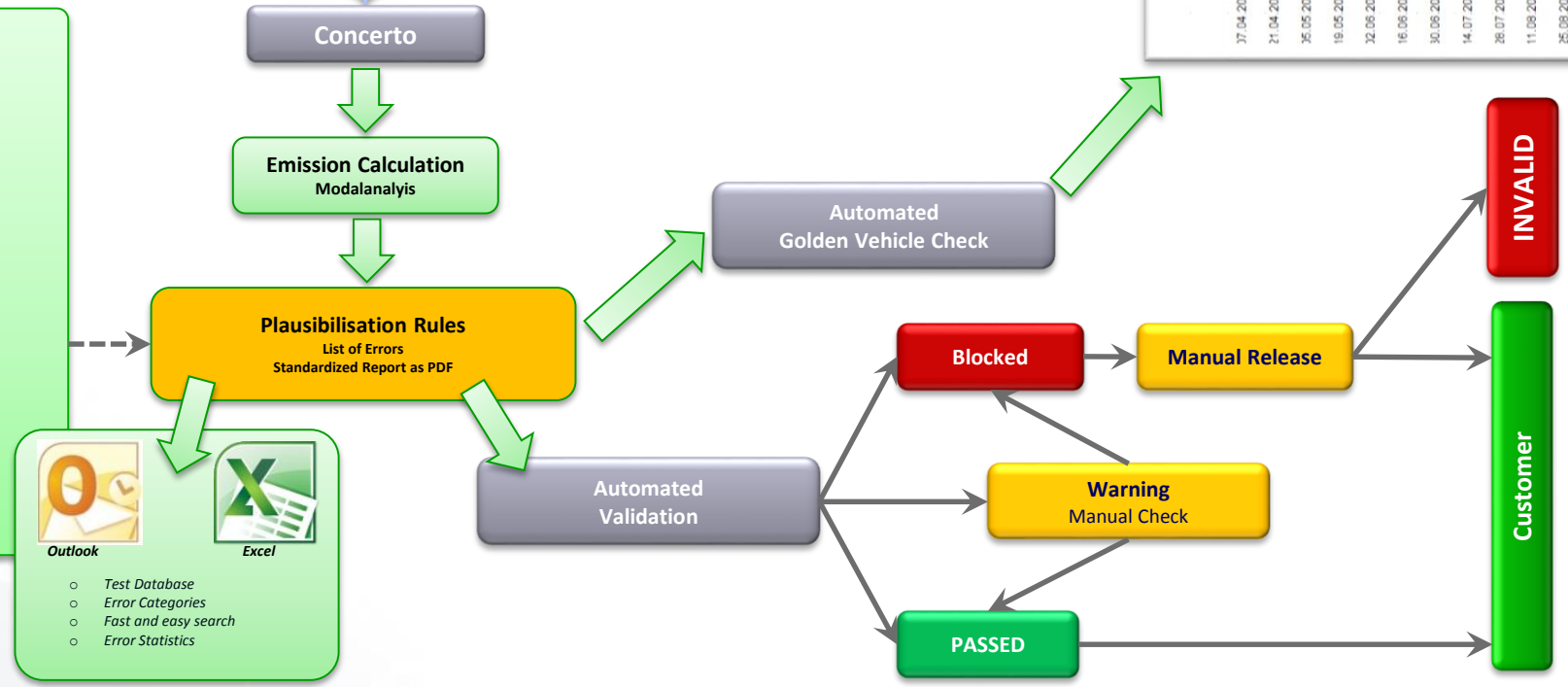
- Validation check
- Limit monitoring
- Statistical analysis, Measuring range violation

**Test results:**

- Deviations BAG/DIL/TP
- Carbon balance BAG/DIL/TP/EO

**Chassis dyno parameter:**

- Parameter check (Removal rates, Coast down parameter etc.)



**Outlook**

- Test Database
- Error Categories
- Fast and easy search
- Error Statistics

**...still only concerto scripts**

## The Evolution of a not planned PTE concept tool

### Next Steps: Including INCA Files

Service/Maintenance/Commissioning processes have been improved. Total failure rate with 7% in 2011 only regarding emission measurement could be reduced to an **overall** failure rate of lower than 2%.

...but data validation job remained „hard“. Still complains like: “ECU Dataset has been changed, but change is not reflected in the measurement data.”

More and more single complains took several days of analysis to prove whether measurement equipment or UUT being the root cause.

**ECU data started to play a significant role in anomaly detection. But INCA files were stored project specific.**



## The Evolution of a not planned PTE concept tool

### Next Step: Including INCA Files



**Santorin HOST**



- Same storage hierarchy
- Automated, meaningful naming
- Algorithm for automated syncing PUMA and INCA data
- Linked → easily open them together



**INCA HOST**



**...Whats missing? A GUI**

## Testfield „OBD“ and massive data analysis



**CalRep is born...**

# CalRep

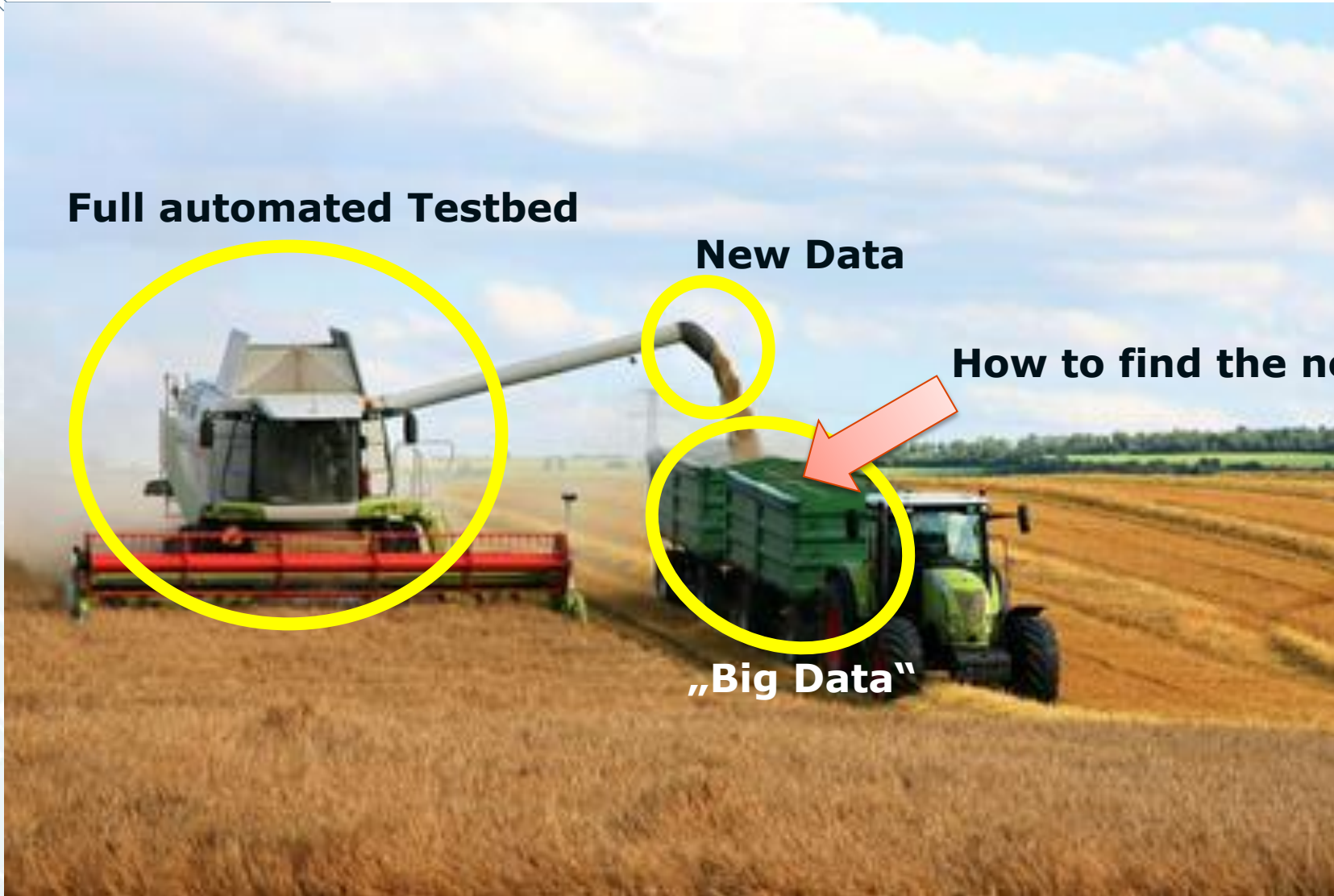
Looking for the needle in a haystack

**Full automated Testbed**

**New Data**

**How to find the needle?**

**„Big Data“**



# CalRep

Looking for the needle in a haystack



**Full automated Testbed**

**New Data**

**How to find the needle?**

**„Big Data“**

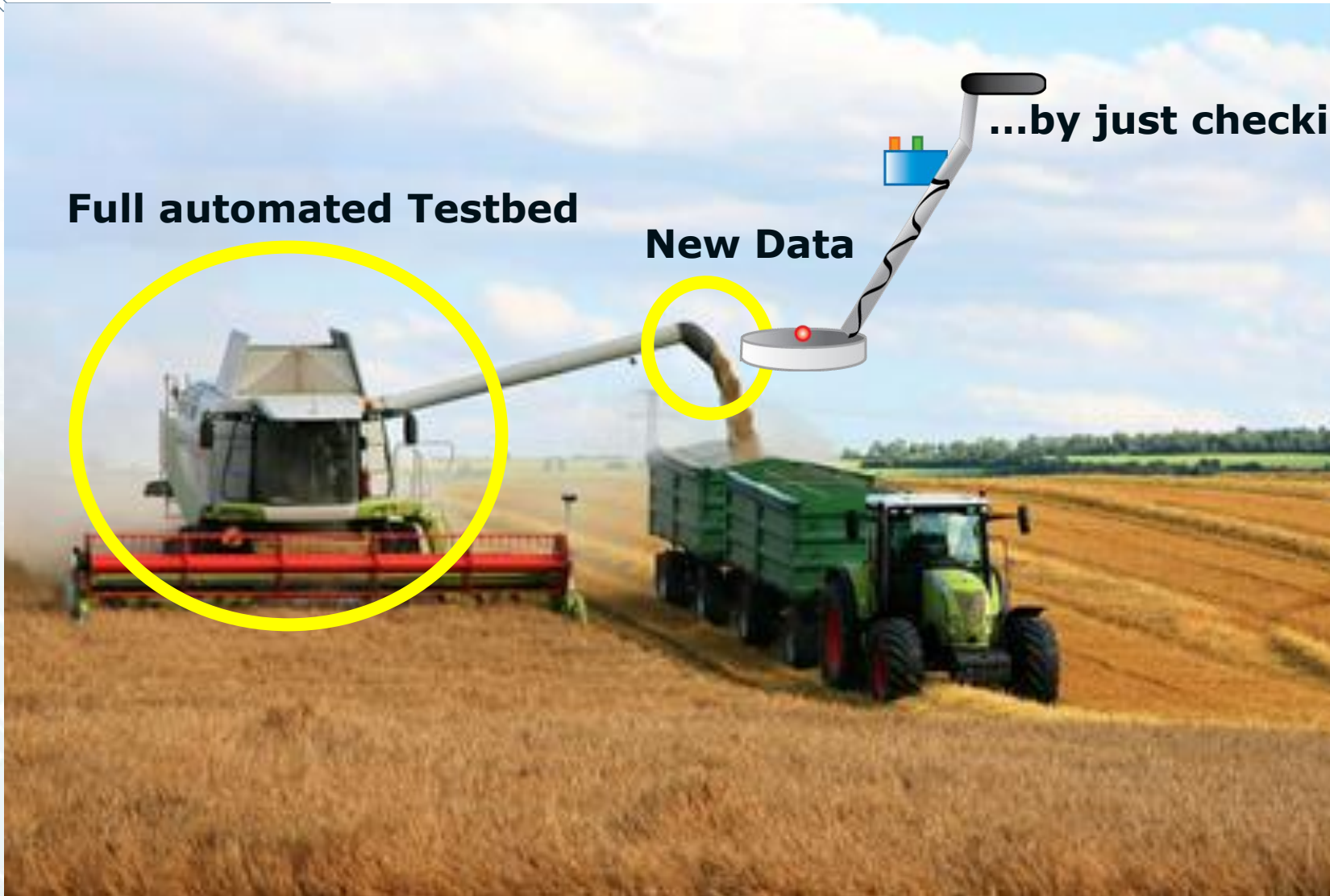


**Not checking every straw (misunderstood Big Data Analysis), but with a metal detector.**

**But where?**

# CalRep

Looking for the needle in a haystack



...by just checking new data with detector

Full automated Testbed

New Data



## AVL PTE Concept Tool

- Validation of all new test field data in a definable period e.g.: every 15min
- Applying plausibility checks = Testfield OBD
- Instant mail notification with definable analytics (layouts)
- And many more features

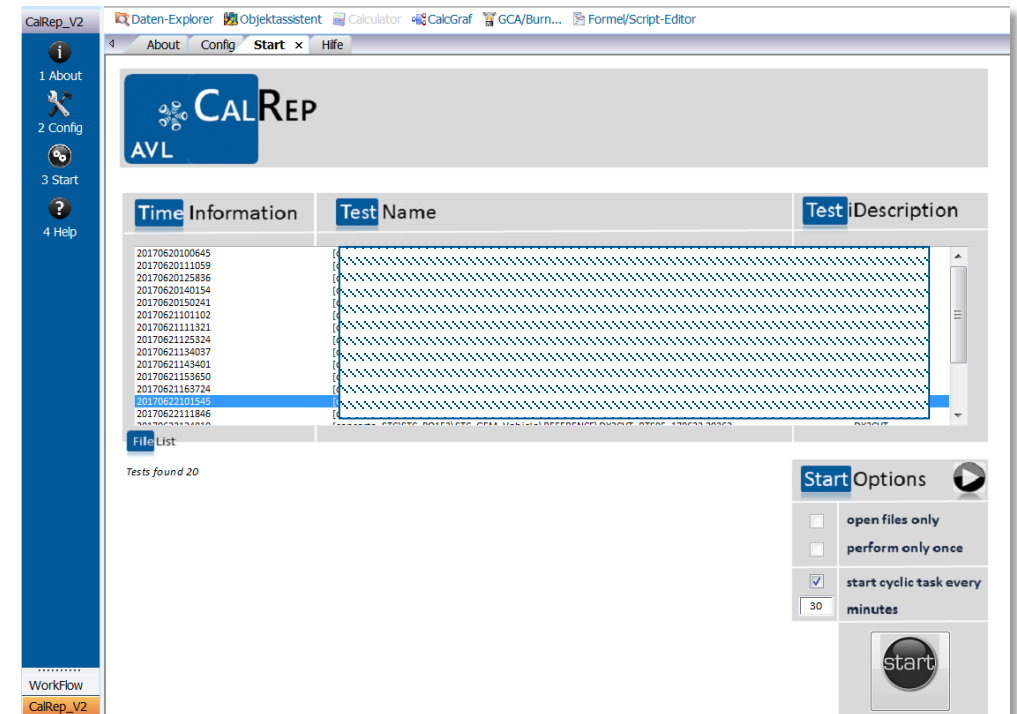
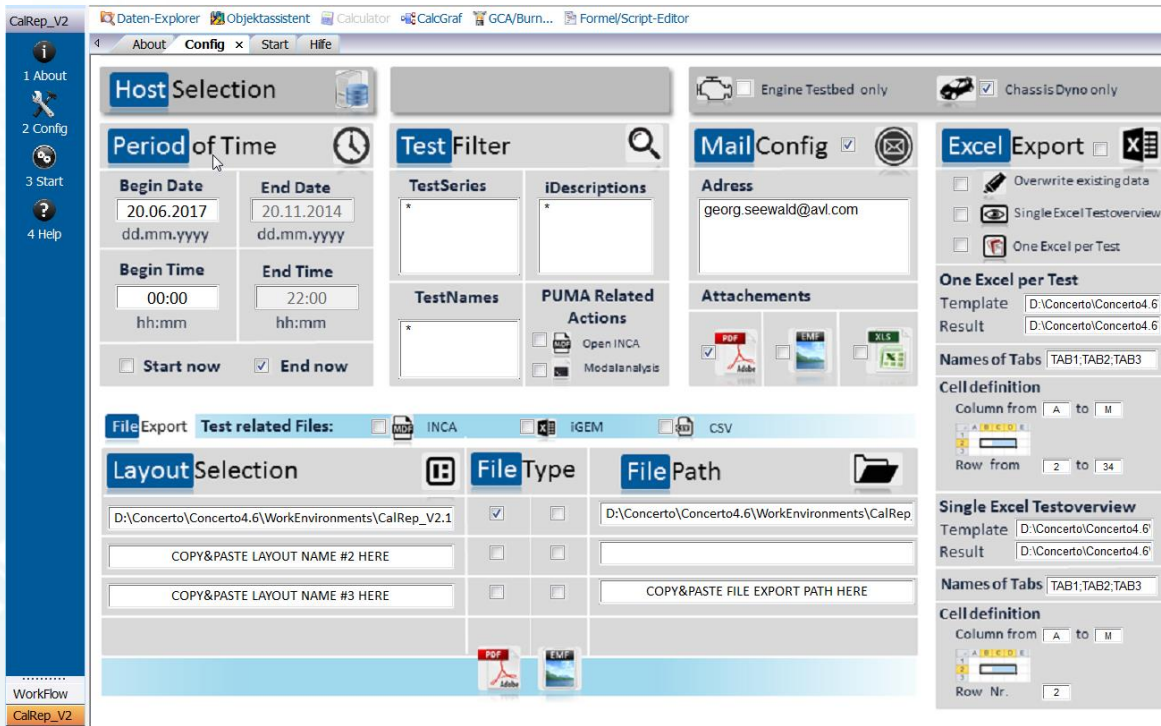
# CalRep

## Looking for the needle in a haystack



### CalRep V2.0 – with graphical user interface

CalRep is an AVL Concerto based application for **Testfield „OBD“**, generating automated testing and validation reports for PUMA and linked INCA tests



# CalRep

## Looking for the needle in a haystack

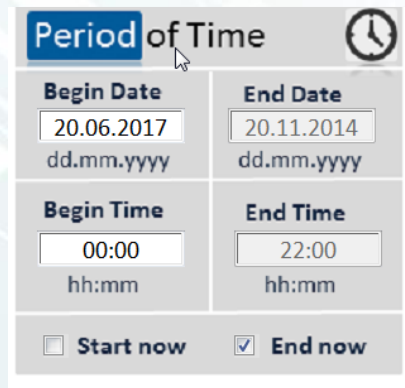
### CalRep V2.0 – with graphical user interface

What can you do with CalRep?

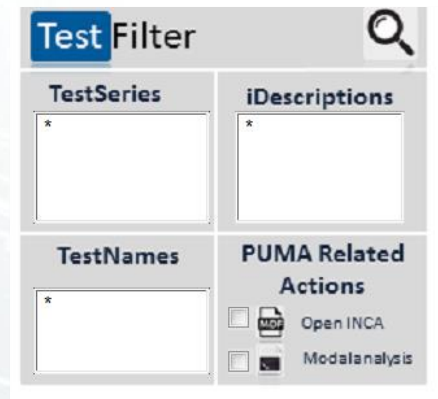
- Choose your current Host (datasource) representing the Testing Environment, like Engine Testbed, PTTB or Chassis dyno, where you want your automated reports.



- Set Filters for the according datasource, like
  - Date and time, from – to (Massive Data Analysis or Continuous Analysis)
  - Project names, Testseries names or even test names (NEDC, FTP75, WLTC, WHTC etc.)



Period of Time	
<b>Begin Date</b> 20.06.2017 dd.mm.yyyy	<b>End Date</b> 20.11.2014 dd.mm.yyyy
<b>Begin Time</b> 00:00 hh:mm	<b>End Time</b> 22:00 hh:mm
<input type="checkbox"/> Start now	<input checked="" type="checkbox"/> End now



Test Filter	
<b>TestSeries</b> *	<b>iDescriptions</b> *
<b>TestNames</b> *	<b>PUMA Related Actions</b> <input type="checkbox"/> Open INCA <input type="checkbox"/> Modalanalysis

# CalRep

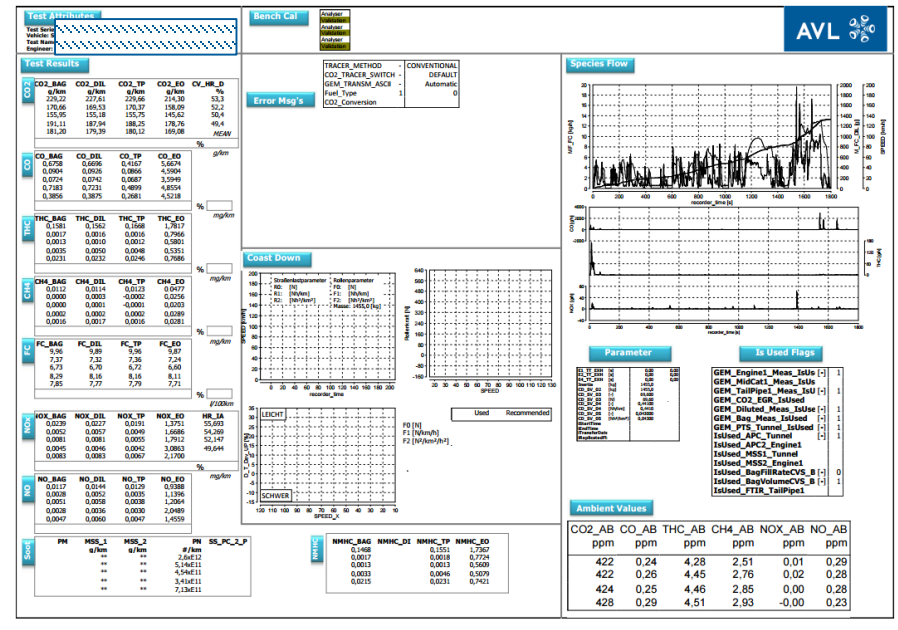
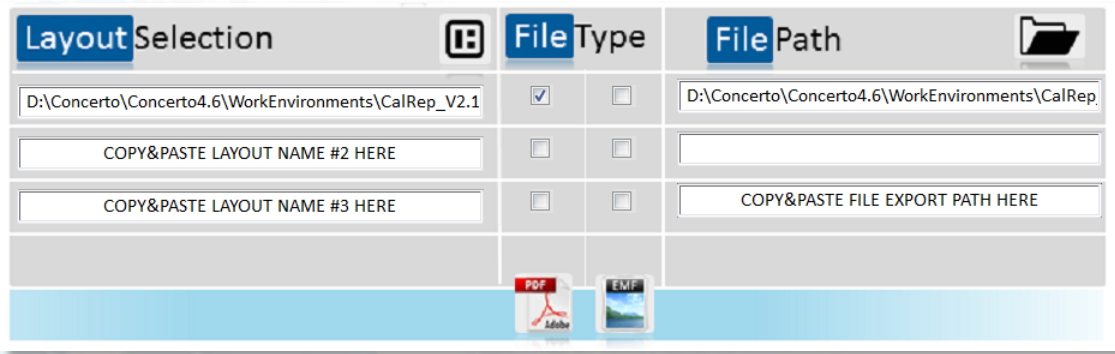
## Looking for the needle in a haystack



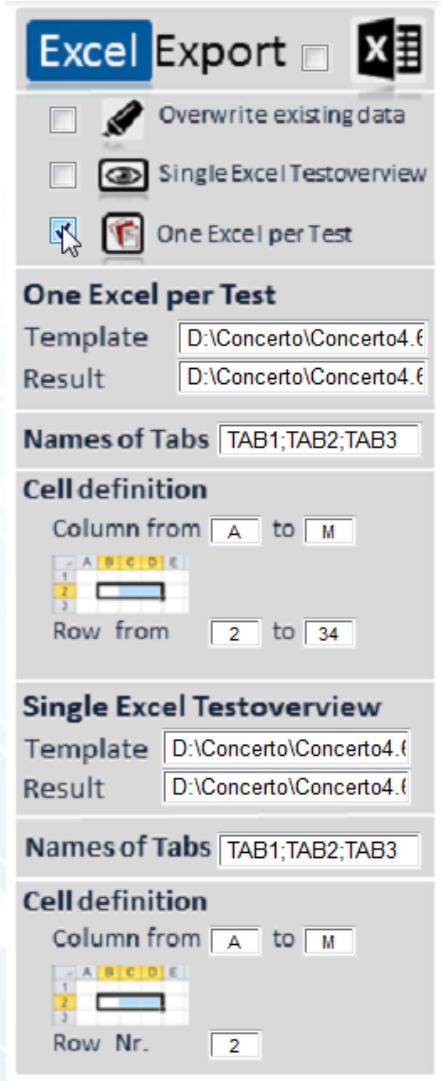
### CalRep V2.0 – with graphical user interface

What can you do with CalRep?

- Choose several customer specific Layout's, that will be applied on each test.
  - Export those Layouts (or its pages seperately) to specific locations in choosable formats like
    - PDF
    - EMF
- could furthermore be used for automated generating of PowerPoint reports!







## CalRep V2.0 – with graphical user interface

What can you do with CalRep?

- Usage of the internal **Excel Report Generator**
  - **Single Test Report**
    - Define an Excel Template. CalRep supports several tabs.
    - Choose as many channels of the test shown concerto as you like. It supports PUMA channels as well as channels from concerto formula
    - Define single results or whole channels to report
    - With additional provided syntax information you can also report average, minimum, maximum or indicated (e.g. use always first, last or n-th entry of the channel) values of the defined channel
    - The Excel Template can also include diagrams to plot the results

# CalRep

Looking for the needle in a haystack



## CalRep V2.0 – with graphical user interface

What can you do with CalRep?

- Usage of the internal **Excel Report Generator**
  - **Overall TestSeries Report** (in addition to the Single Test Report)
    - Define an Excel Template. CalRep supports several tabs.
    - Each test is represented in one row, each column contains a free choosable value of PUMA or Concerto-formula value up to the maximum supported columns of Excel

The screenshot shows the 'Excel Export' dialog box in CalRep V2.0. It features several sections for configuring the report output:

- Excel Export:** Includes a checkbox for 'Overwrite existing data' (unchecked), a checked checkbox for 'Single Excel Testoverview', and an unchecked checkbox for 'One Excel per Test'.
- One Excel per Test:** Contains input fields for 'Template' and 'Result', both set to 'D:\Concerto\Concerto4.6'.
- Names of Tabs:** A text input field containing 'TAB1;TAB2;TAB3'.
- Cell definition:** Includes 'Column from' (A to M) and 'Row from' (2 to 34) fields, along with a small grid icon showing a 3x5 grid with row 2 highlighted.
- Single Excel Testoverview:** Similar to the 'One Excel per Test' section, with 'Template' and 'Result' fields set to 'D:\Concerto\Concerto4.6'.
- Names of Tabs:** A text input field containing 'TAB1;TAB2;TAB3'.
- Cell definition:** Includes 'Column from' (A to M) and 'Row Nr.' (2) fields, along with a small grid icon showing a 3x5 grid with row 2 highlighted.



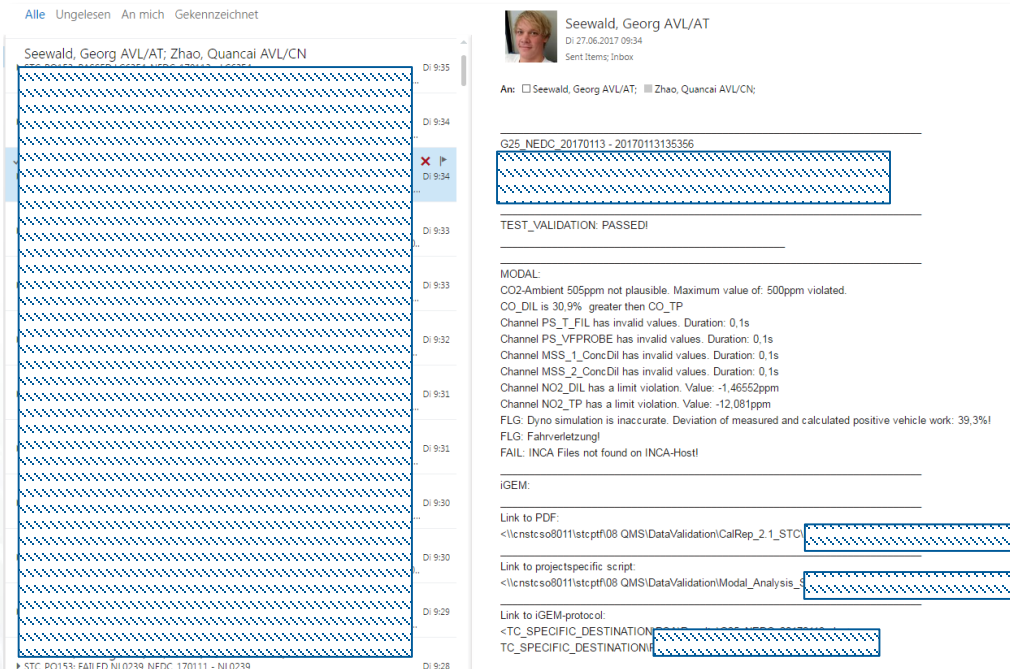
# CalRep

## Looking for the needle in a haystack

## CalRep V2.0 – with graphical user interface

What can you do with CalRep?

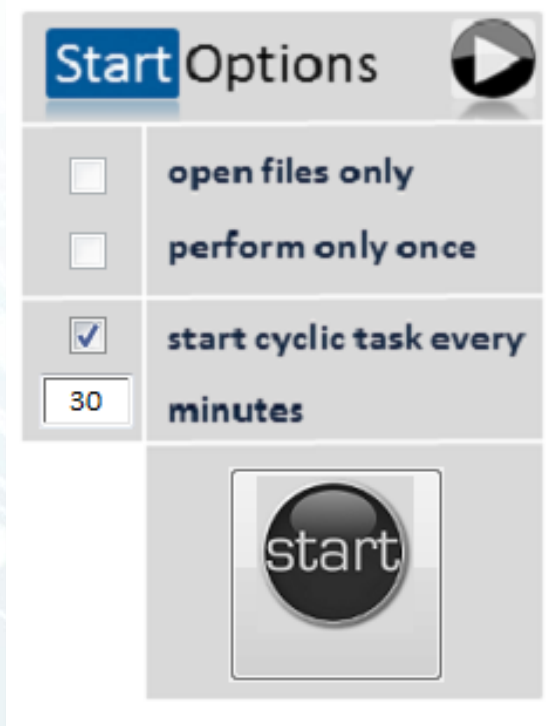
- Choose result for distribution via E-Mail@
  - Choose which results (Layouts, Excel Reports) you want to distribute
  - Define Mail distribution list with the colleagues you want to share the results



### CalRep V2.0 – with graphical user interface

What can you do with CalRep?

- Define Actions that shall be applied on the tests according to your filter setting

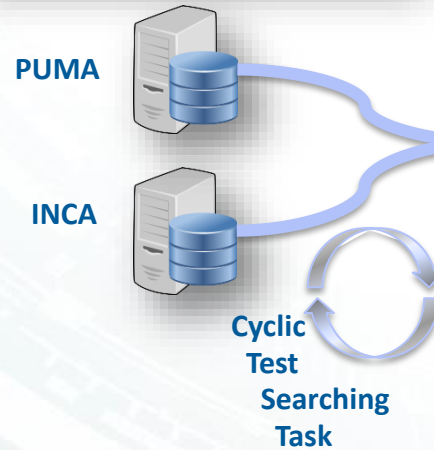
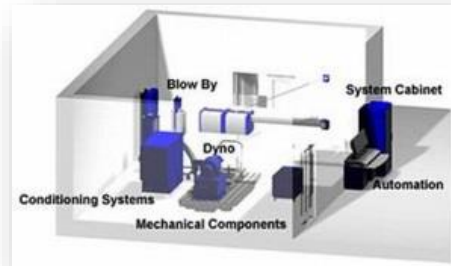


1. Just open the tests meeting the filter settings for other operations than supported by calrep
2. Perform CalRep only once for the selected tests for e.g. massive analysis of the past
3. **Start Cyclic Operation**, where every x minutes new tests on the selected datasource will be searched according the filter settings and the selected layouts and excel reports can be stored on the specified location or sent by mail to the specified mail distribution list.

**Of course, you can use the tool to analyse all historic data (Big Data Analysis)**

# CalRep

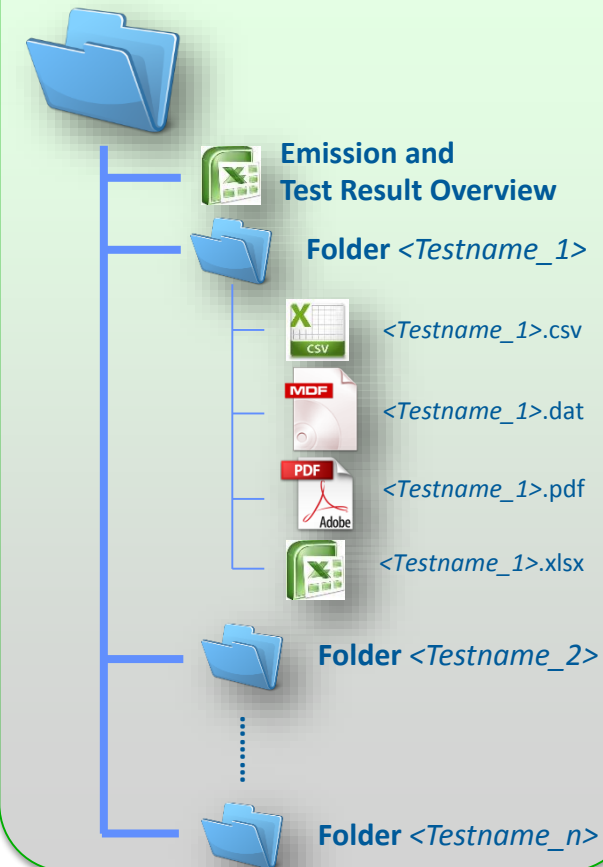
## Looking for the needle in a haystack



### Concerto

- ❖ Emission calculation acc. legislation
- ❖ Automated shifting, cutting and synchronisation PUMA-INCA
- ❖ testspecific time-based PDF export of a defined layout
- ❖ generating a CVS-file including time-based results of emission results and INCA-data
- ❖ automated filling of emission and test results overview

### AVL - Root Destination



## Testfield „OBD“ and massive data analysis



**Nice spin-off  
innovations along  
the road.**

**Artificial Human  
driver algorithm**

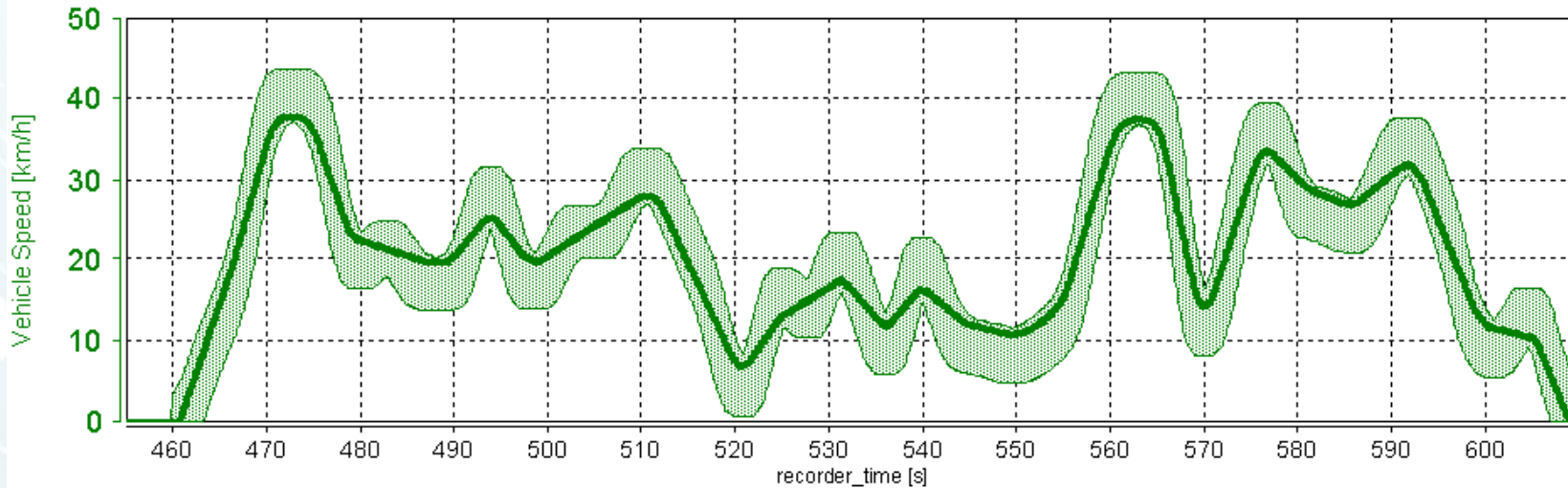
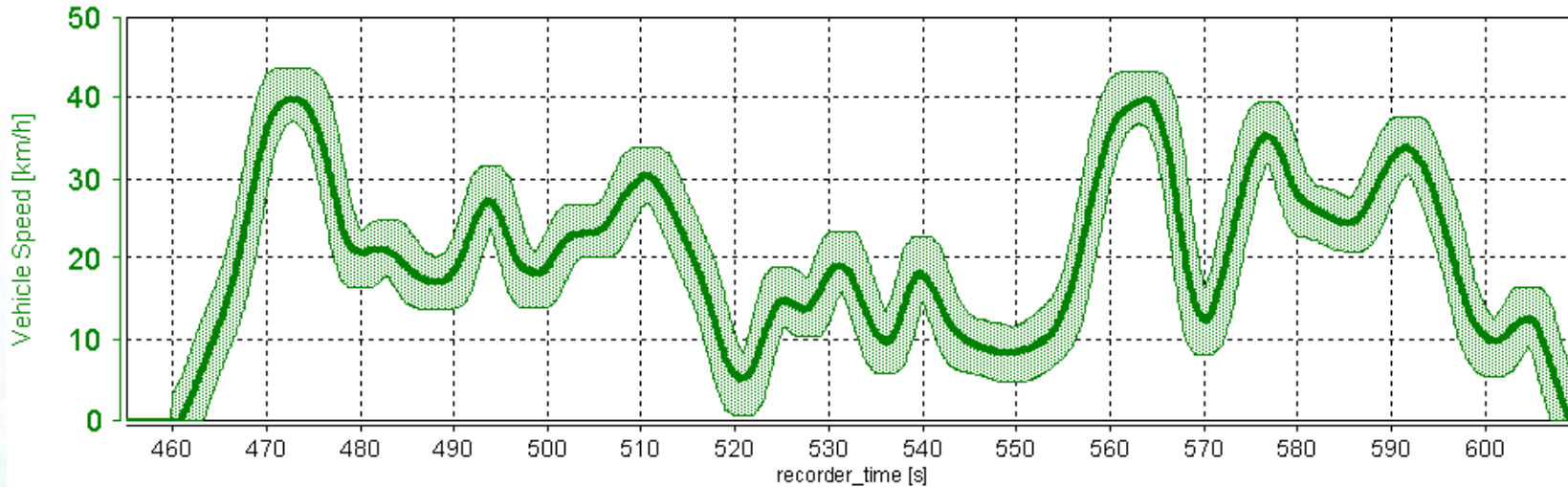
## Human driver algorithm

When complaining about ECU changes were not reflected in the measurement results, or worse: ECU data set has not changed, but results differ significantly in the most cases a different driving style could be identified, but only by means of visual comparison.

An artificial human driver algorithm has been developed to derive an index about the real human drivers performance.



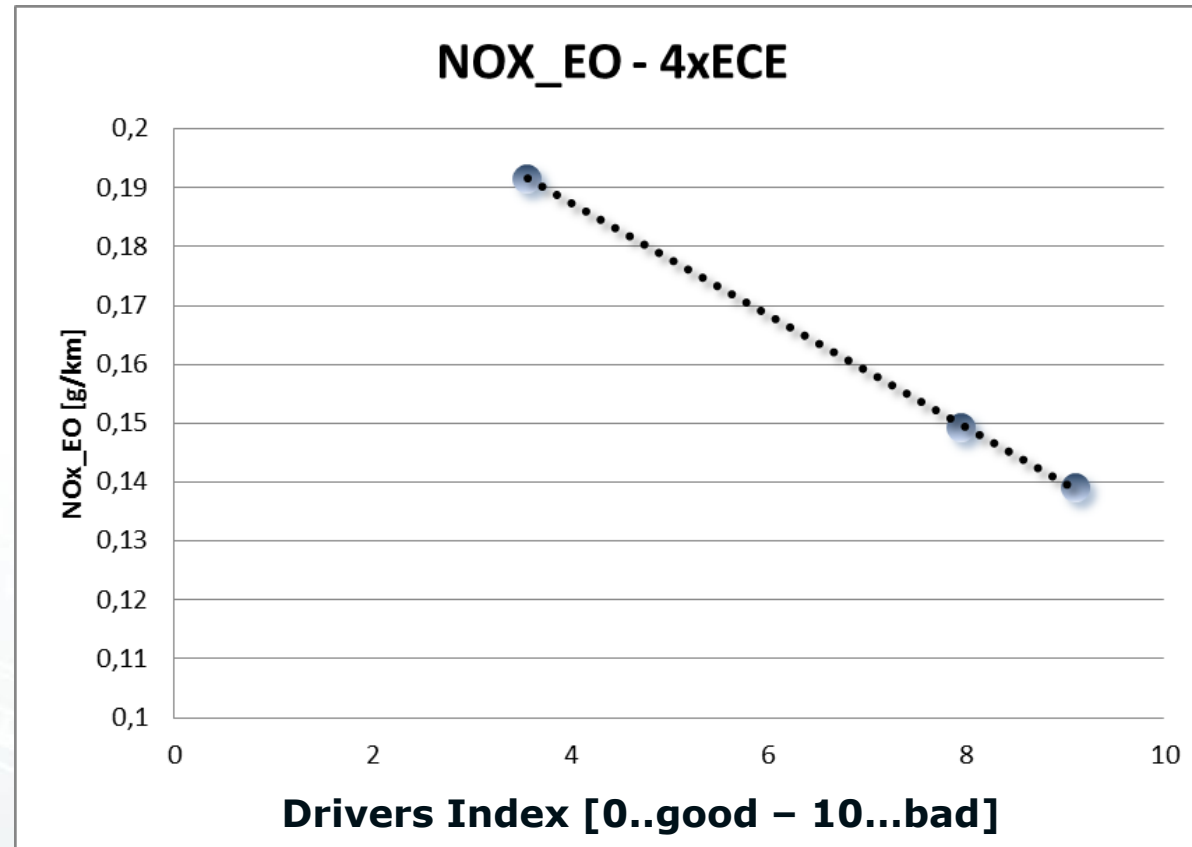
# Human driver algorithm



Self developed „Optimum Path Algorithm“ being quite near to a smooth human driver.

Utilizing curve characteristics for a drivers index.

# Human driver algorithm



Correlation of drivers index with NOX engine out emissions.

## Testfield „OBD“ and massive data analysis



# Massive Data Analysis with CalRep

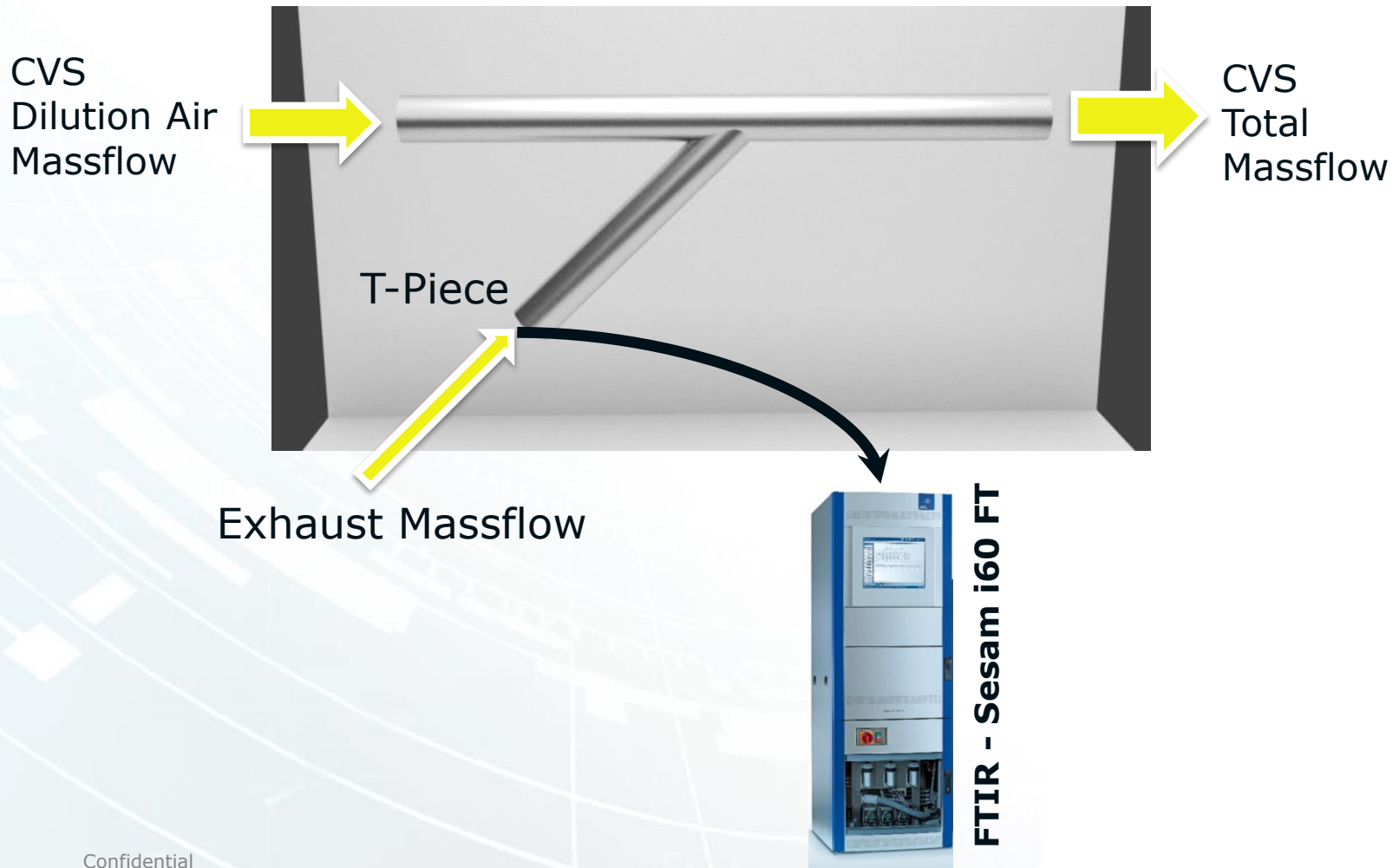
# Bag to Modal with FTIR

# Massive Data Analysis

## Optimization Bag to Raw Modal Correlation

1. BAG AMA i60 vs. FTIR i60 at TailPipe

### Setup



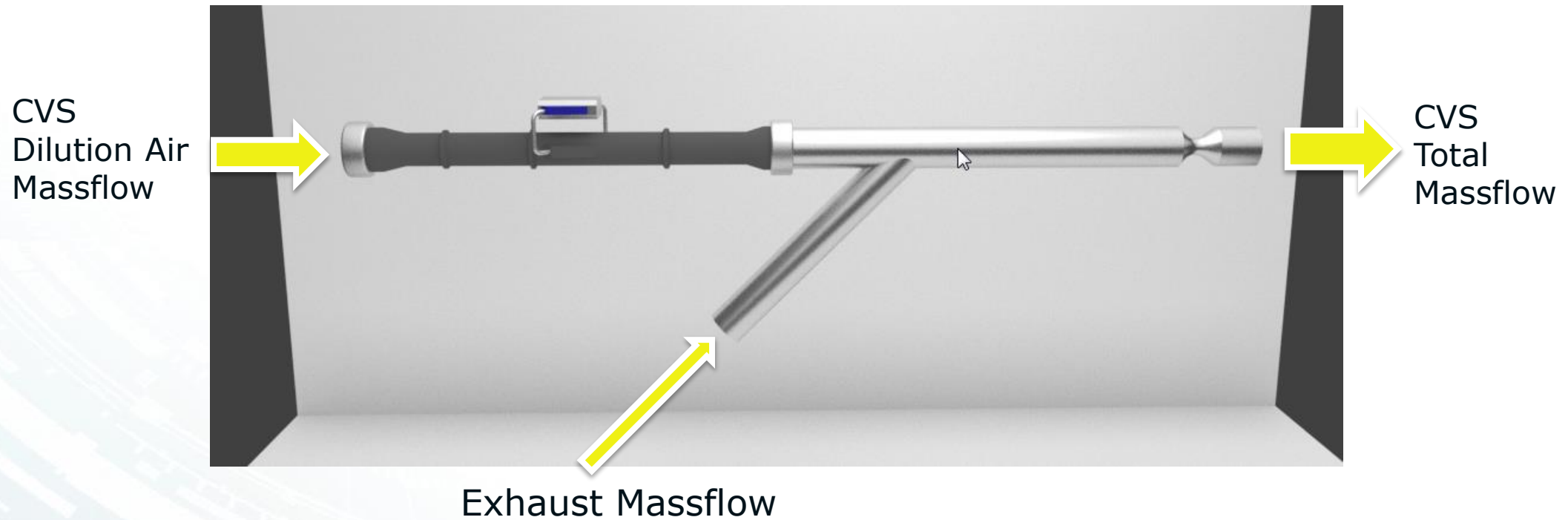
### Testing

Chassis Dynos	3
Total Number of Tests	131
WLTC	77
NEDC	17
JC_08	11
OffCycle	11
FTP75	1
RDE	8
ADACEco	6

# Massive Data Analysis

## Optimization Bag to Raw Modal Correlation

2. Exhaust mass flow determination with CVS total flow and FlowSonix CVS dilution air measurement



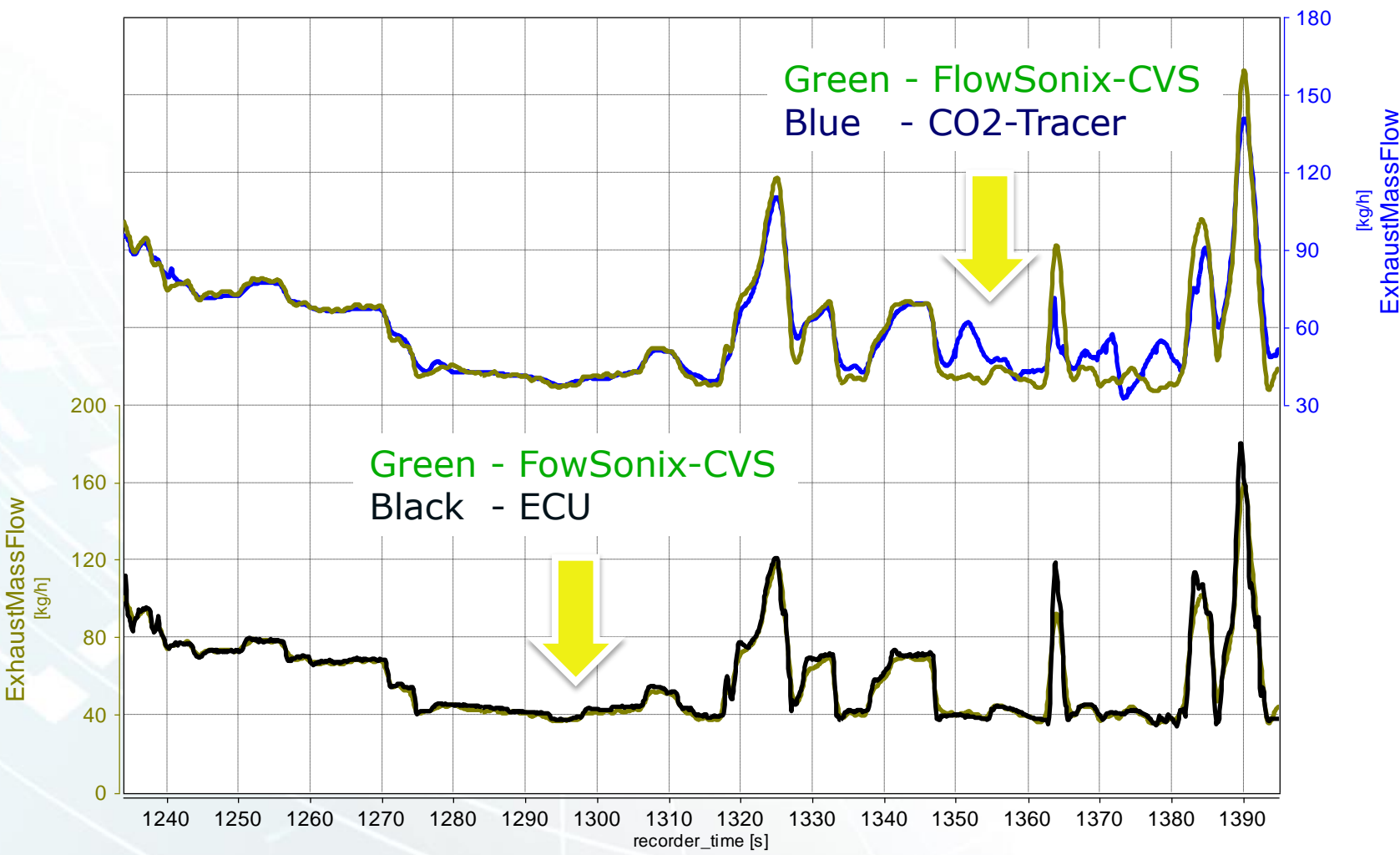
$$\dot{m}_{EXHAUST} = (\dot{m}_{CVS\_TOT} - \dot{m}_{CVS\_DIL}) \dots \text{it is a bit more complex ;)}$$

# Massive Data Analysis

## Optimization Bag to Raw Modal Correlation



### 3. Potential Optimizations to Improve Bag to Raw Modal Correlation



### Exhaust Mass Flow

A further optimization can be achieved to switch from CO2-Tracer to CVS-Dilution Air (FlowSonix) based exhaust mass flow determination.

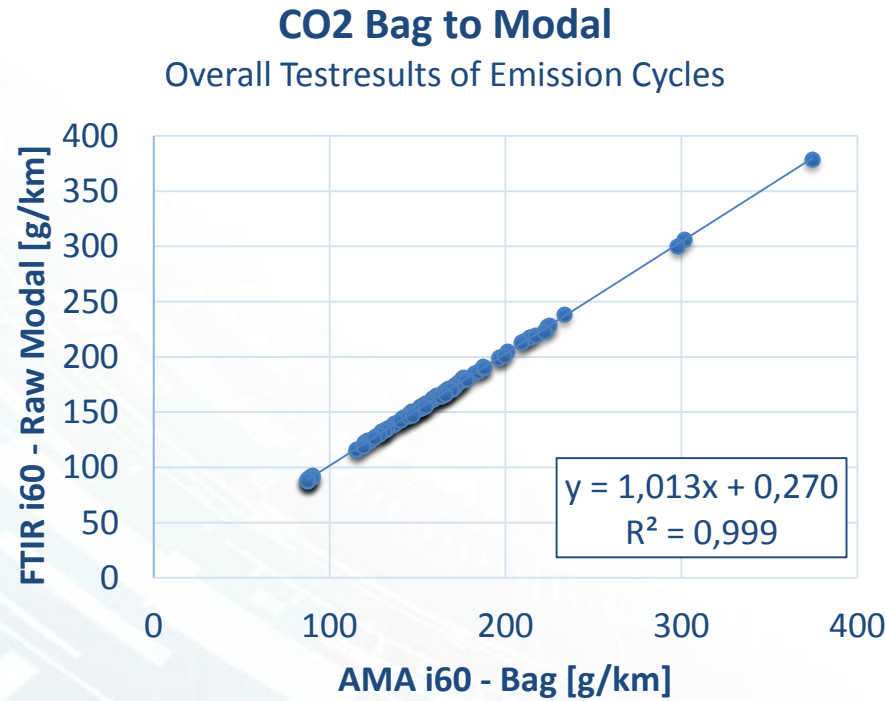
Like shown in the figure, the CO2 Tracer suffers from low analyzer dynamic as well as from motoring phases, where no CO2 is emitted. Furthermore, CO2 Tracer only has no values during engine start.

Despite some signal improvements can be done offline, the direct exhaust mass flow measurement via FlowSonix and CVS achieves much better time based signals.

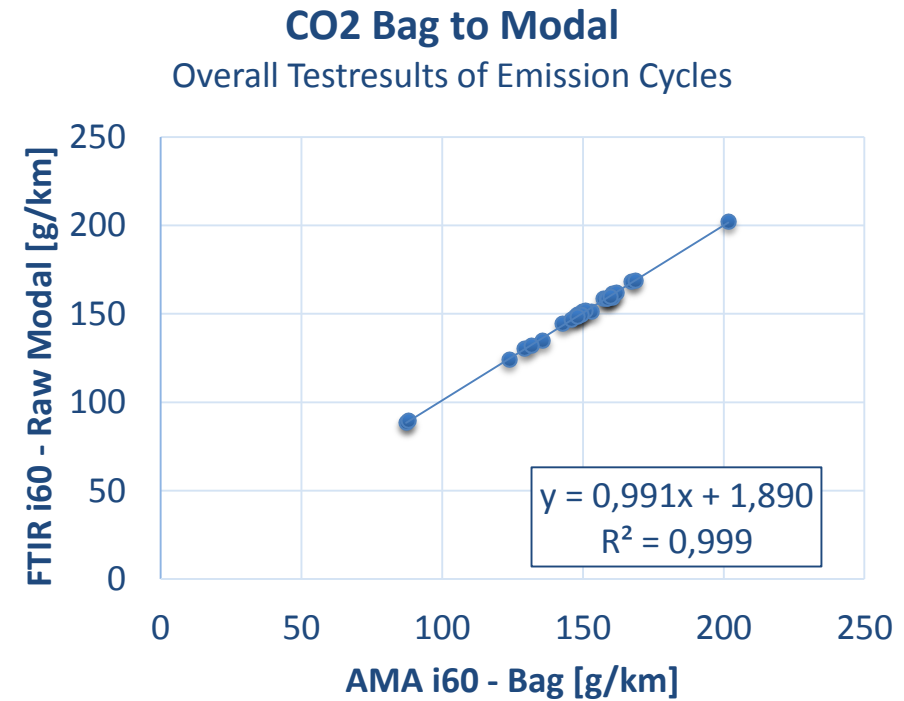
# Massive Data Analysis

## Optimization Bag to Raw Modal Correlation

### 4. Impact of exhaust mass flow method on Bag to Raw Modal Correlation



**CO2 - Tracer**

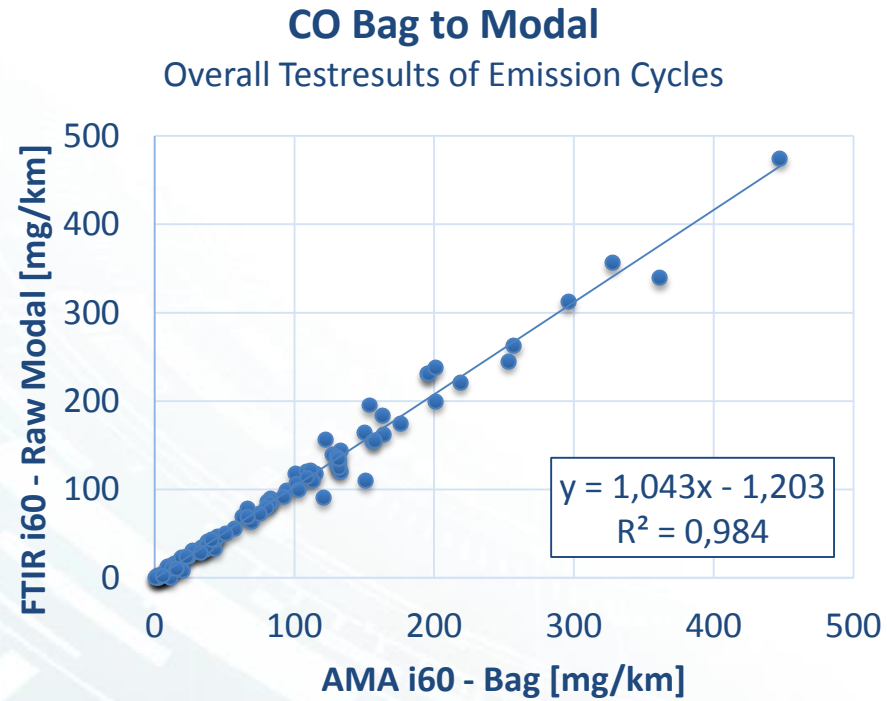


**FlowSonix**

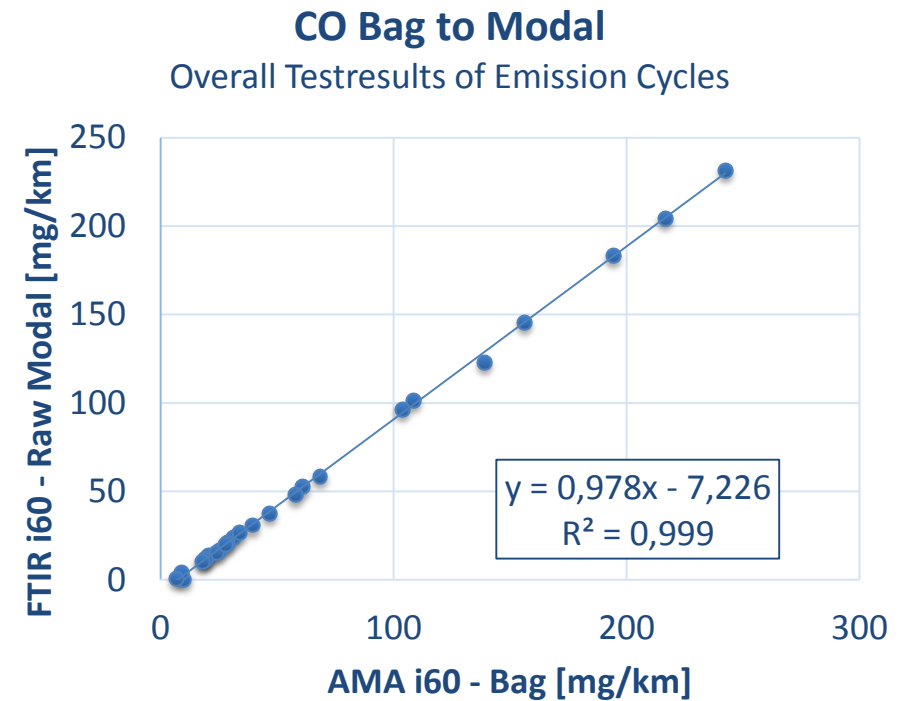
# Massive Data Analysis

## Optimization Bag to Raw Modal Correlation

### 4. Impact of exhaust mass flow method on Bag to Raw Modal Correlation



**CO2 - Tracer**



**FlowSonix**



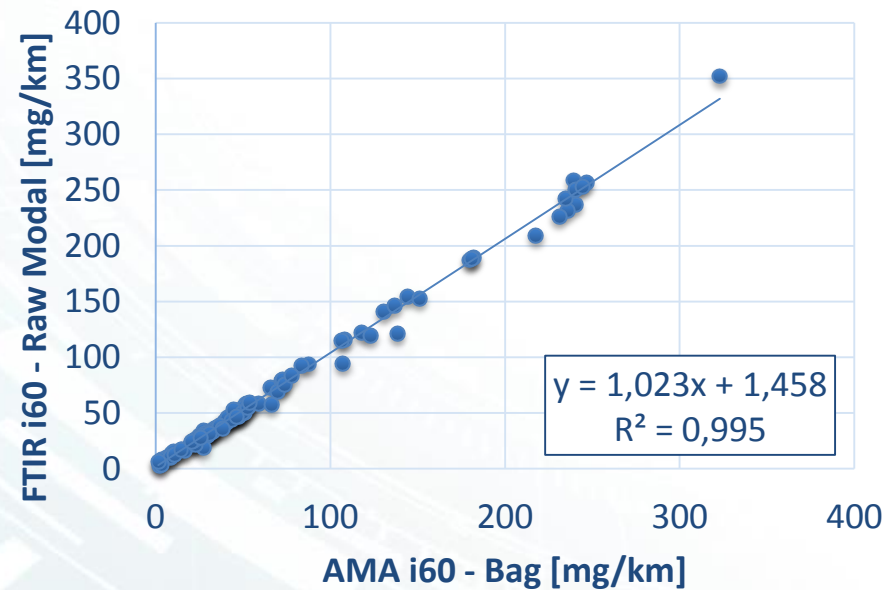
# Massive Data Analysis

## Optimization Bag to Raw Modal Correlation

### 4. Impact of exhaust mass flow method on Bag to Raw Modal Correlation

#### NOx Bag to Modal

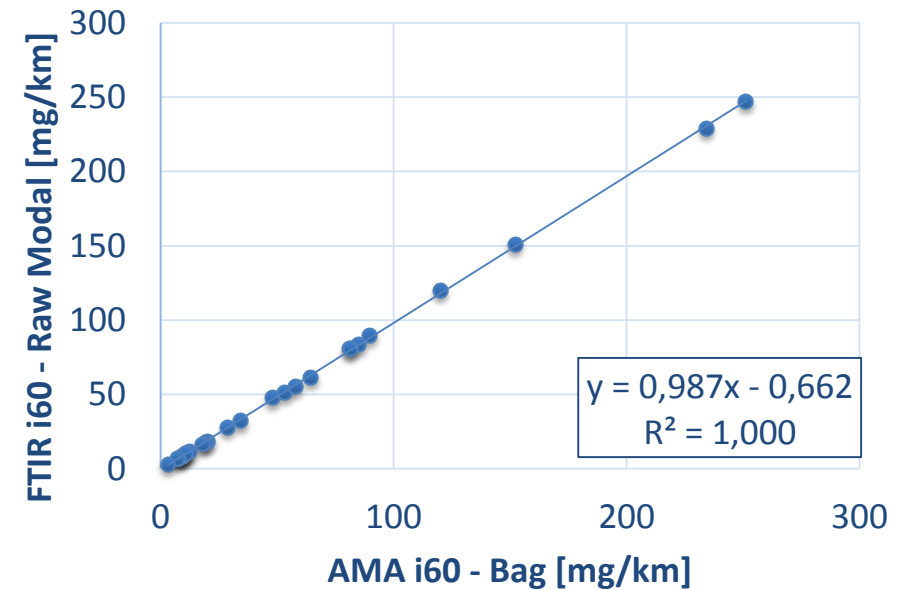
Overall Testresults of Emission Cycles



**CO2 - Tracer**

#### NOx Bag to Modal

Overall Testresults of Emission Cycles



**FlowSonix**

## Testfield „OBD“ and massive data analysis



**How can you benefit from that?**

**Future business models.**

**What about digital services?**