Working Paper No. **HDH-07-05rev**
(7th HDH meeting, 12 to 14 October 2011)

Developing a Methodology for Certifying Heavy Duty Hybrids based on HILS

Work allocated to TUG

Description of possible approaches

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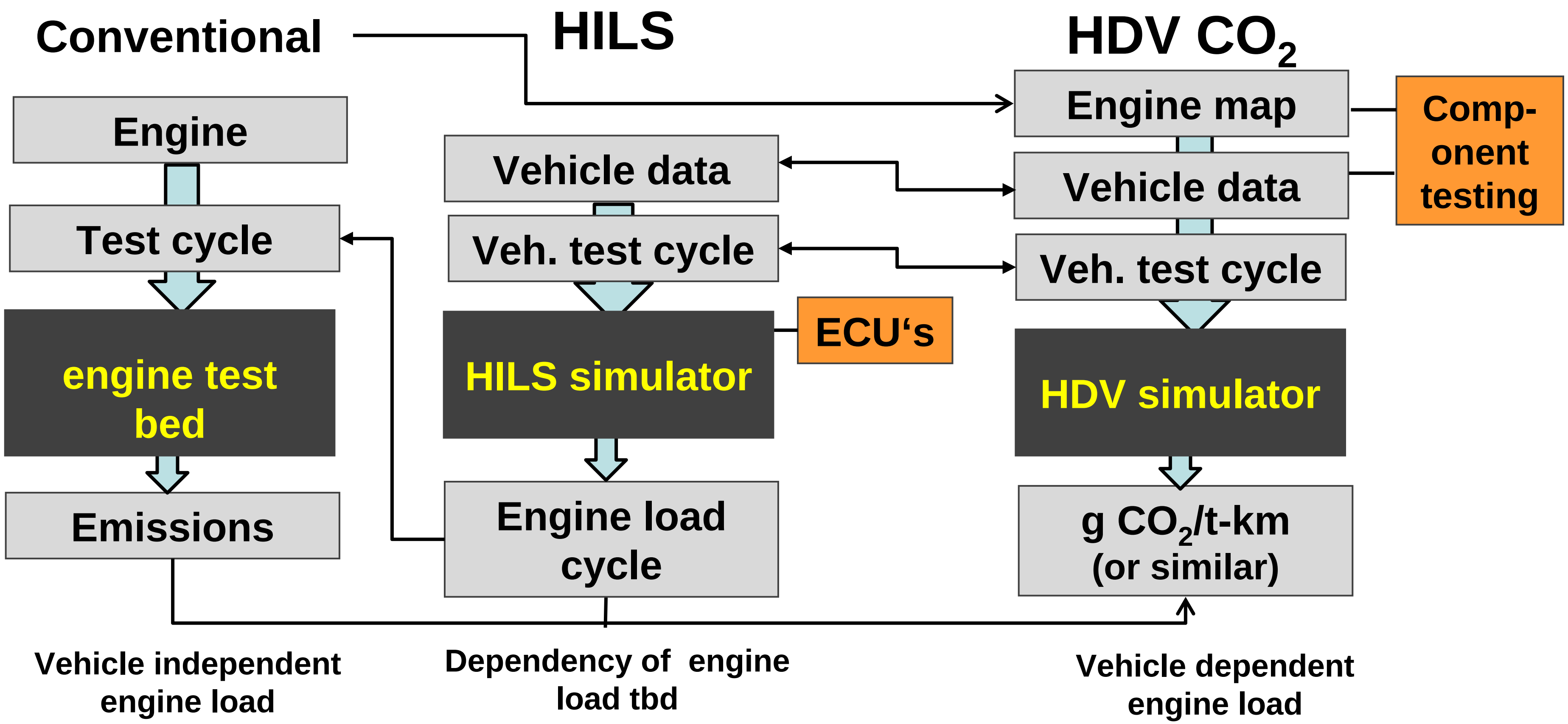
Content

1. Overlapping between conventional engine testing, HDV CO_2 test procedures and HILS
2. Vehicle related data
3. Inclusion of PTO operation
4. WHVC weighting factors
5. Consolidation of HILS and HDV-CO_2-method

Review of vehicle related data

Tasks:

Look for options to design compatible testing systems



Test cycles, vehicle data +methods for component testing shall be harmonized

Review of vehicle related data

Difficulties to be solved:

Conventional engines are tested in the WHTC

➢A comparable test cycle for HDH should result in ~WHTC engine load if applied with HILS for a very mild HDH. This requires ~WHVC as test cycle.

HDV CO_2 test procedures foresee different vehicle speed cycles than WHVC, to consider different mission profiles and variable road gradients.

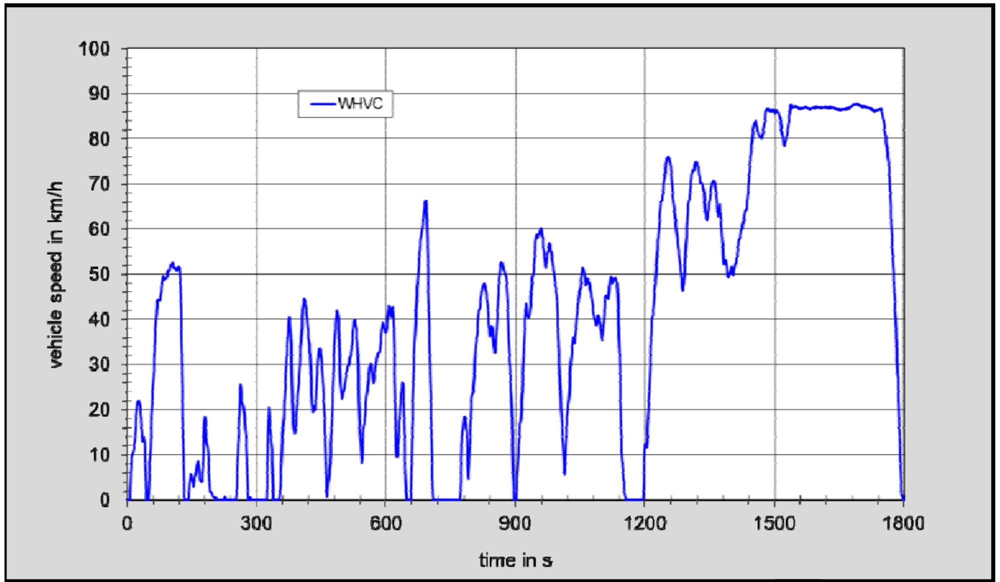
➢Different test cycles (vehicle speed cycles) may be advantageous for regulated pollutants and for $CO_{2.}$

Vehicle data (rolling resistance, aerodynamic drag, mass, etc.) are necessary for HILS and for HDV CO2 testing.

Simulation of auxiliaries and PTO is considered for HILS and for HDV CO_2 testing

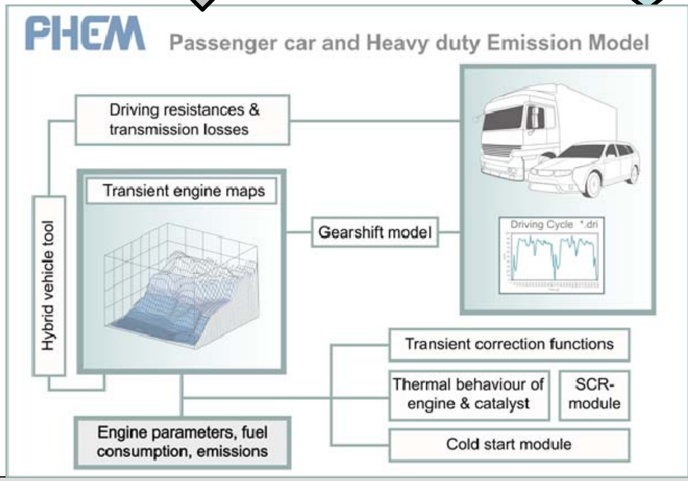
➢Common test procedures for components and vehicles and comparable simulation methods would be advantageous.

Simulation of WHVC for different vehicle categories



„Average vehicles“ data from HBEFA V3.1 simulation

Solo trucks	<7.5t GVW
	7.5-12t
	12-14t
	14-20t
	20-26t
	28-32t
Semitrailer	40t
	60t
Coach	16-18t
	>18t
Bus	Midi
	Standard 2 axis
	articulated

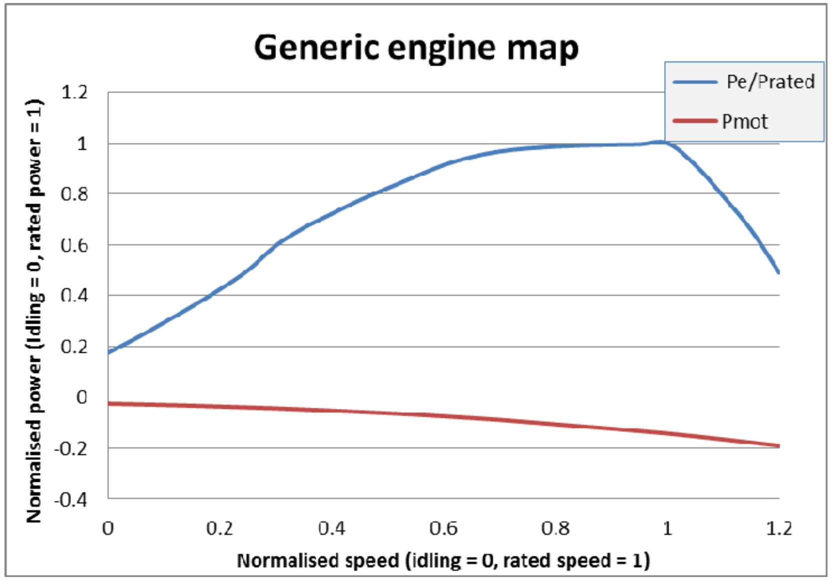


power demand from the power pack

Model PHEM used instead of HILS since many vahicle data sets already available at TUG

Generic engines used

Definition of normalised engine to standardise analysis, similar auxiliary power demand and losses in gear box (defined as % from engine rated power)



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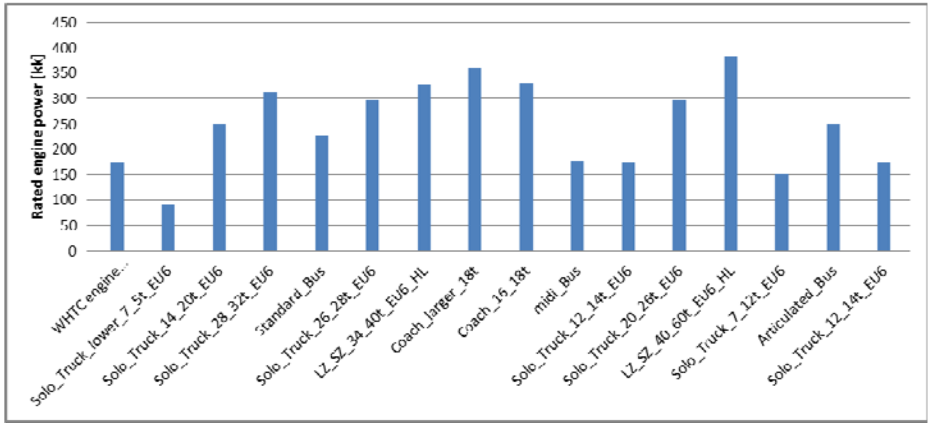
Emissions and fuel consumption normalised as [g/h] / kW-rated power

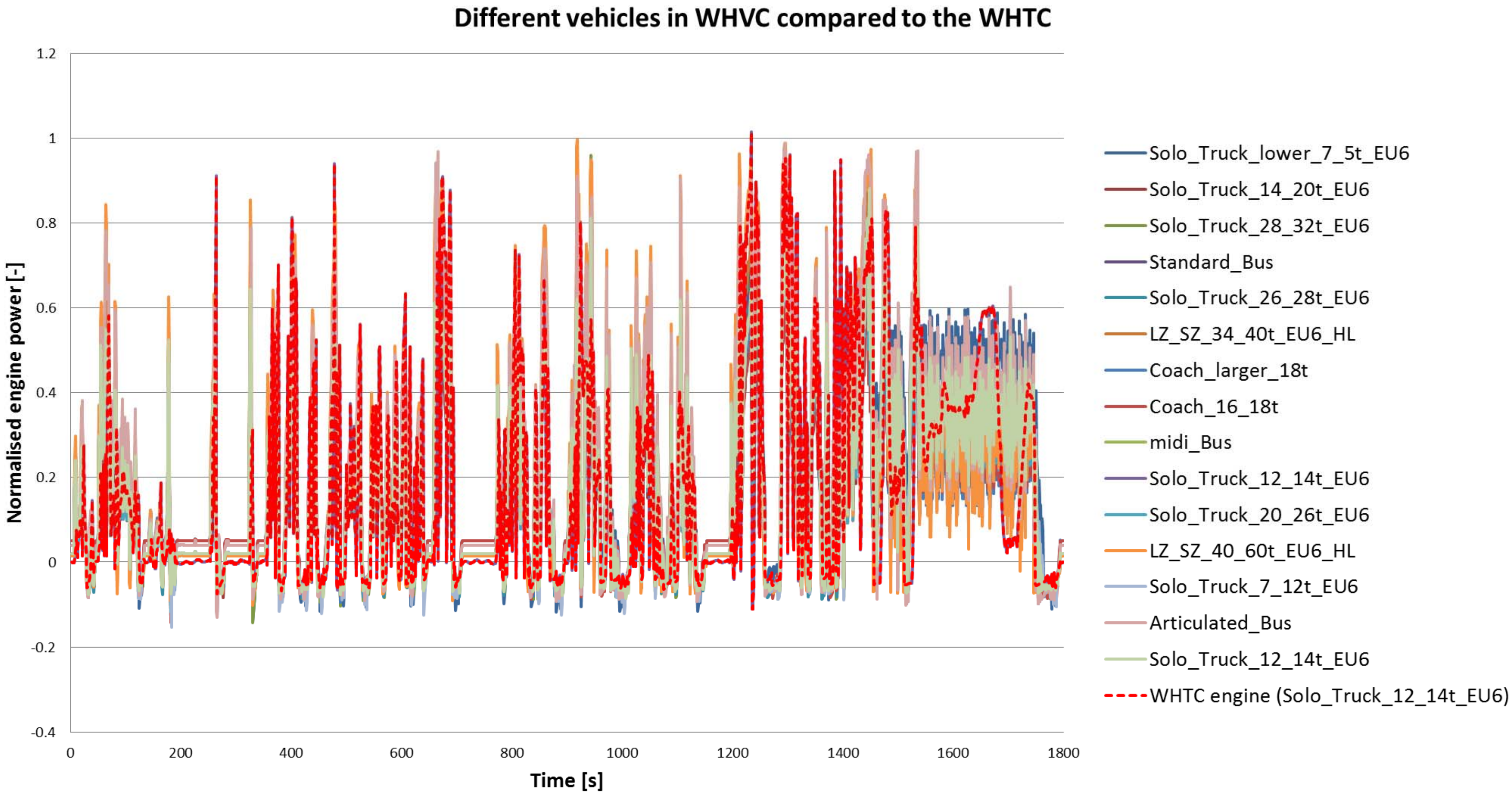
Denormalisation with vehicle specific engine rated power data



„Comparable engines“ in all simulated HDV categories

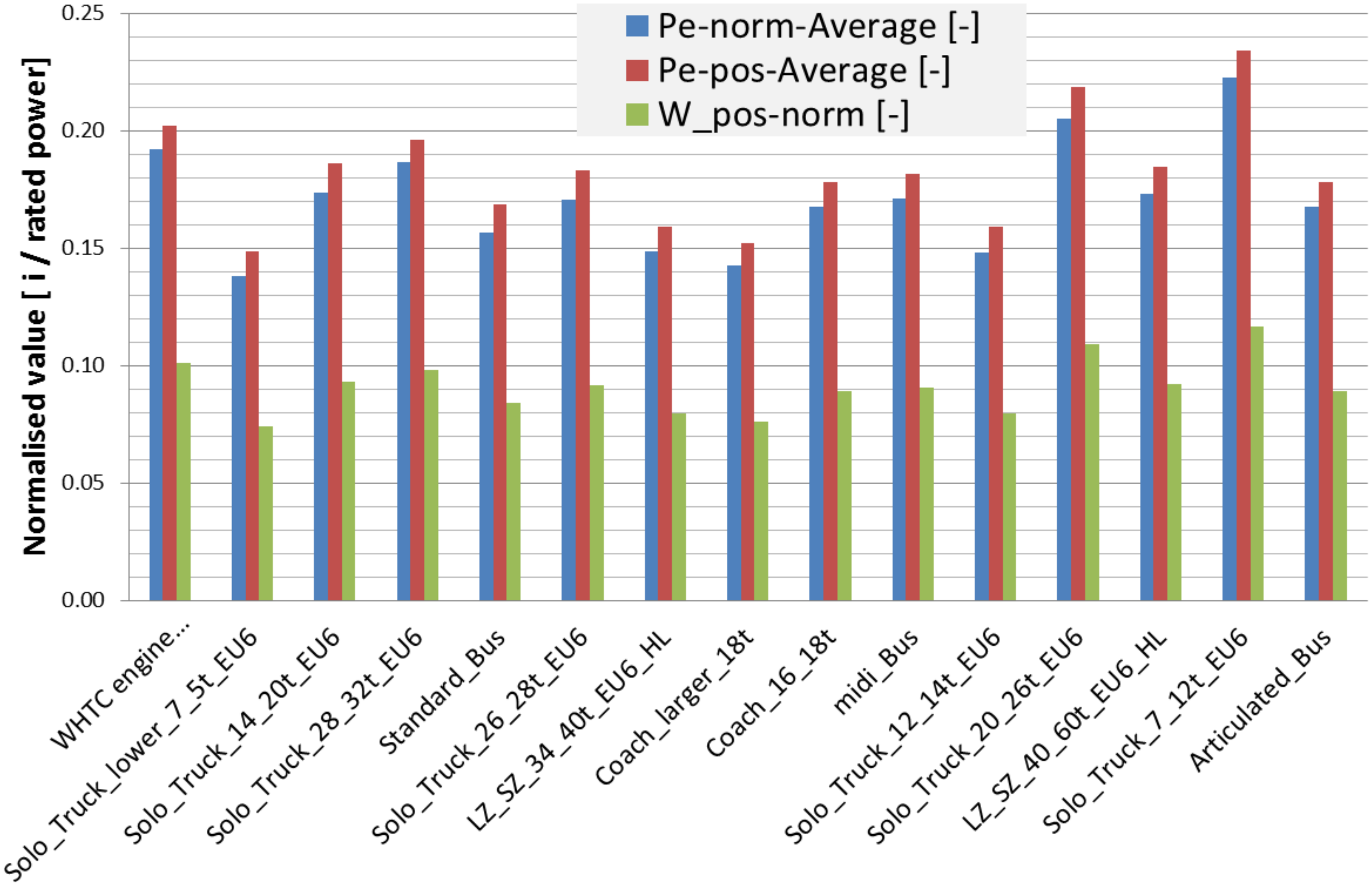
Results from vehicle simulation in WHVC

Result: Propulsion power demand is different for each vehicle category



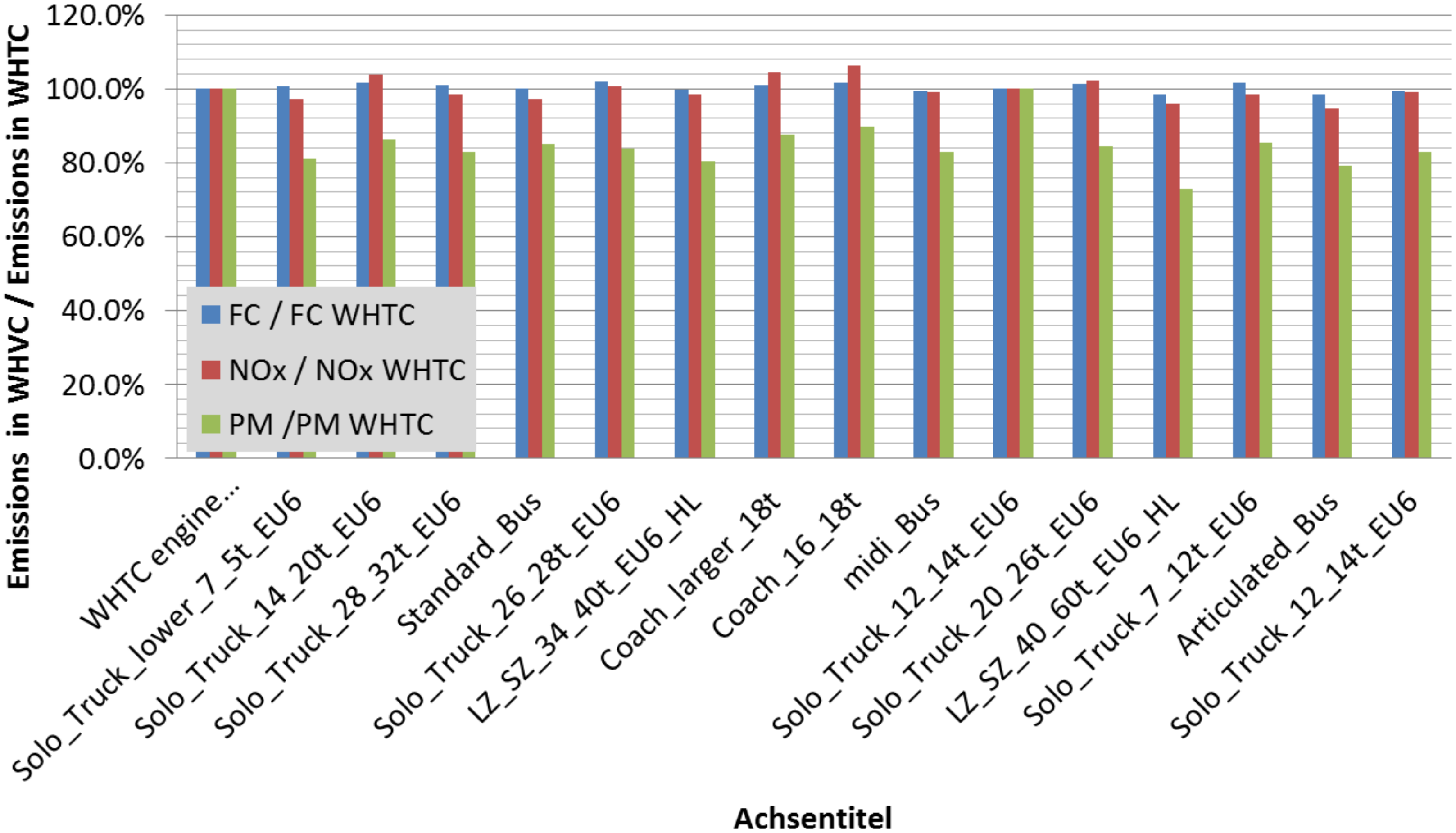
WHVC versus WHTC: total cycle results

Integral values for WHVC engine load also differ

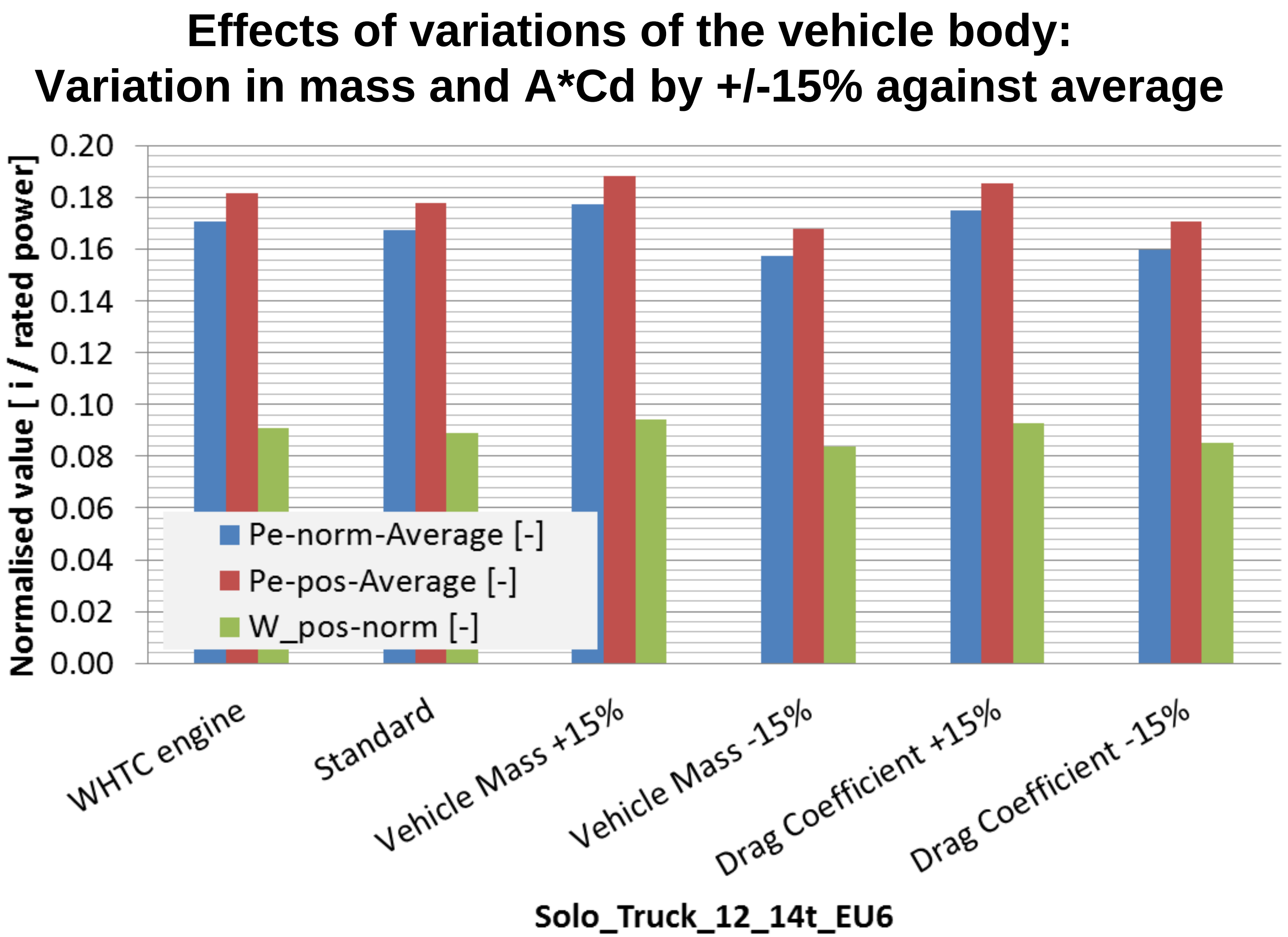


WHVC versus WHTC: total cycle results

Fuel consumption and engine out emissions in [g/kWh]:
Influence on FC: ~+/-2%, NOx: +/-6%, PM: +/-25%



WHVC versus WHTC: total cycle results



Simulated effects on FC and NOx < 2.5%

Analysis vehicle related data

If specific vehicle data is used for HILS simulation, industry may be faced with high test burden in future if HDH become more popular (e.g. a HD power pack in a truck which is sold with different bodies)

For validation of HILS model however, the vehicle data from the tested vehicle has to be used in HILS.

Options:

a)elaborate regulation to define which vehicle version has to be used for HILS procedure to be simulated with WHVC, if different combinations of bodies, gear boxes, tires etc. are used with same power pack and chassis.

b)Use original vehicle data for HILS model validation but apply less variable input when the engine test cycle is computed

Options to handle vehicle specific differences in HILS

Options to reach "fair" P_{engine} (or P_{drive} respectively) compared to WHTC without taking variations of vehicle into consideration:

A) Elaborate generic vehicle data to fit the WHTC exactly (vehicle data would depend on full loach curve of power pack!)
complicated

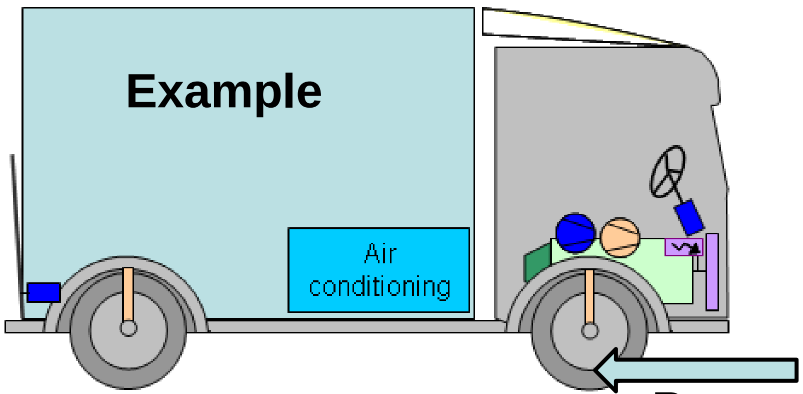
C) Use real vehicles and calculate „vehicle specific road gradient course" which adapts propulsion power demand exactly to WHTC
(gradients could be defined to also let some power left for auxiliaries and PTO)
too difficult calculation scheme and eventually very bumpy virtual road?

D) Replace power demand simulated in the HILS simulator by WHTC power demand (either P_{engine} or P_{drive}). Best interface for this replacement seems to be the driver model via relation gas pedal position and desired power.
<u>= Suggested approach</u> (or are there any difficulties in HILS?)

Options to handle vehicle specific differences in HILS

Analysis of compatibility of generic vehicle data with WHTC

Simulation of power demand:



$P_{engine} = P_{drive} + P_{transm} + P_{aux} + P_{PTO}$

$P_{drive} = P_{roll} + P_{air} + P_{gradient} + P_{acc.}$

$P_{transm} = P_{loss\ gear\ boxes} + P_{loss\ axis}$

$P_{aux} = P_{cooling\ fan} + P_{compressor} + P_{alternator} + \ldots$ (all auxiliaries not engaged in engine test)

P_{PTO} = Power take off (e.g. compressor for cooling system)

Engine load from HILS test shall be fair compared to engine load in WHTC.
2 options to solve this demand:

a) HILS simulator + WHVC shall give P_{drive} comparable to WHTC (=suggested)
P_{transm} P_{PTO} and P_{aux} can be different for HDH compared to conventional HDV.
Disadvantage: difficult to include vehicle specific auxiliary and PTO data in simulator (main open topic in the actual European HDV-CO_2 test procedure study)

b) HILS simulator + WHVC shall give P_{engine} comparable to WHTC.
Disadvantage: intelligent transmission and auxiliary designs at HDH will not be awarded. Maybe OK for pollutant tests, not ok for CO2?

How to gain the P_{drive} cycle compatible to WHTC?

1. De normalise WHTC → engine power course
2. Subtract losses in gear boxes and transmission (generic functions)
3. Subtract power demand from auxiliaries and PTO
4. Add power lost in mechanical vehicle braking in WHVC

WHTC has negative engine power down to motoring curve

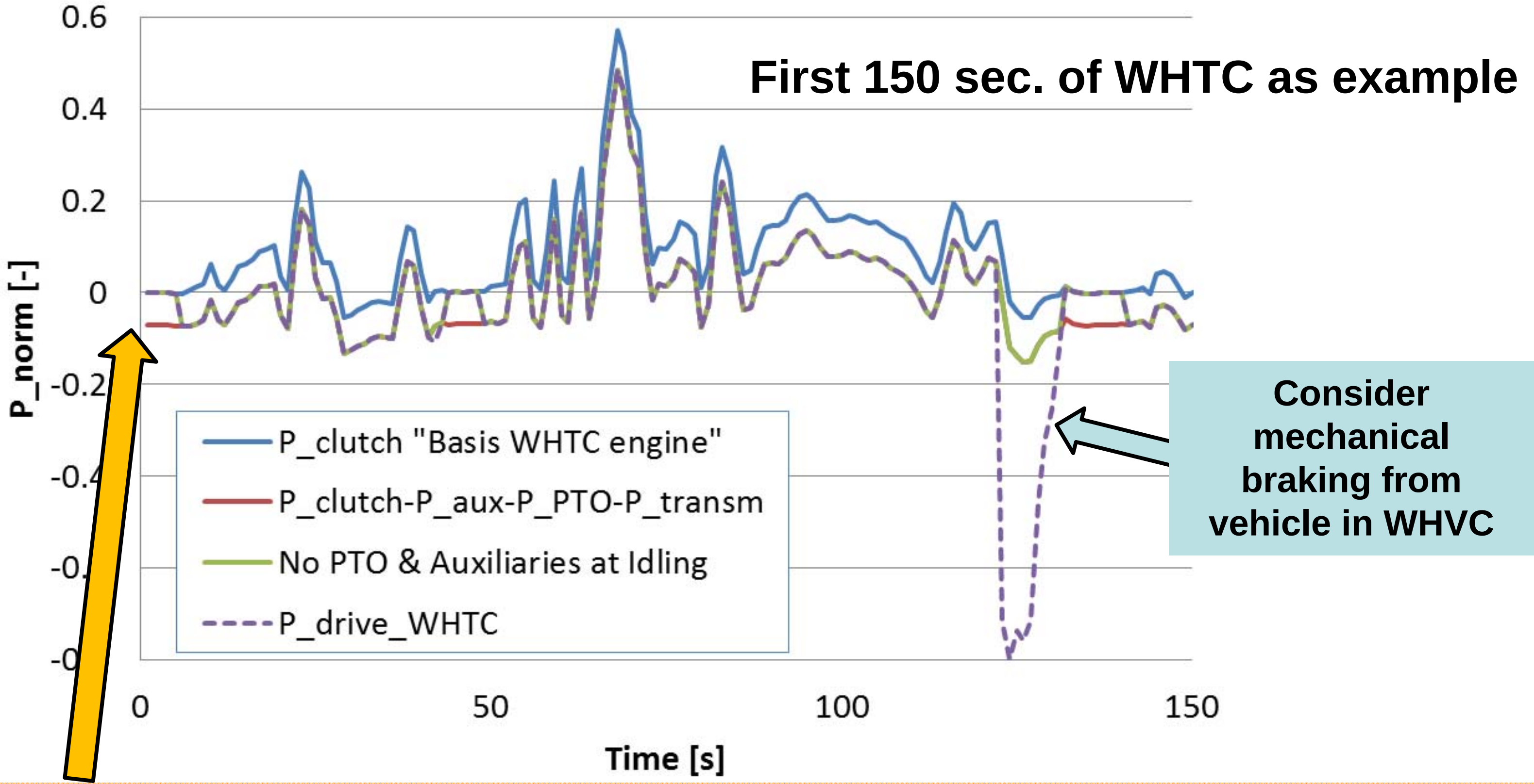
WHVC leads also to mechanical braking

→Negative Work in WHVC approximately 4 times higher than in WHTC

→For HILS the negative driving power from WHVC shall be applied

How to gain the P_{drive} cycle compatible to WHTC?

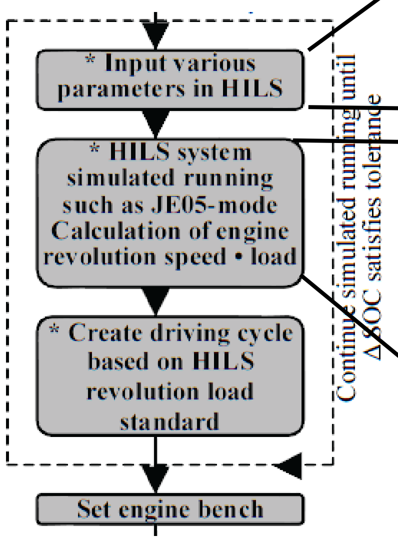
Example for result for a given full load curve
results normalised by division with rated engine power
Auxiliaries set here to constant 2% of rated power, PTO to 5%



Idling in WHVC result in negative P_drive to allow Auxiliaries and PTO running
→ virtually switched off at 0 km/h (= totally untypical usage of PTO!, better solution?)

Adaptations in HILS method for suggested approach:

HILS test according to Kokujikan No. 281 of March 16, 2007



Start as original

Input vehicle data according to CO_2 test procedure (e.g. US EPA, EC LOT 2 project) (air resistance, rolling resistance, transmission, auxiliaries, optional also PTO)

→establish Global Technical Regulation?

<u>Step 1 in HILS Simulation</u>: WHVC + original vehicle data for model validation.
<u>Step 2 in HILS Simulation</u>: Run WHVC and replace „Pdrive-sim„ by „Pdrive-WHTC“ in driver/engine torque model to calculate rpm and torque at ICE.

Go ahead as original

Open issues:

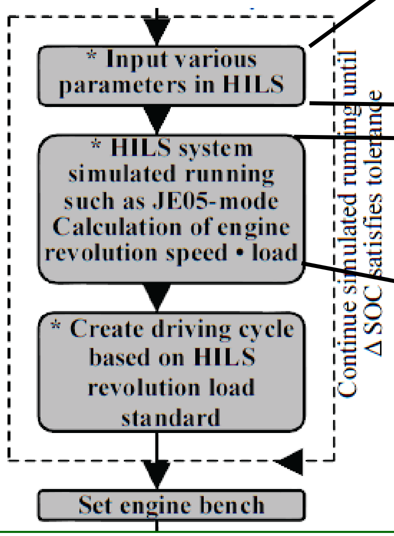
- **reasonable simulation of auxiliaries not defined yet (neither in HDV-CO_2 procedure nor in HILS)**
- **Details of definition of “Pdrive-WHTC”**
- **Programming and test of alternative “driver/engine torque model”**

Suggested approach may also be used for HDV CO2 values

With small changes in work flow, marked in red

Start as original

HILS test according to Kokujikan No. 281 of March 16, 2007



Input vehicle data according to CO2 test procedure (e.g. US EPA, EC LOT 2 project)
(air resistance, rolling resistance, transmission, auxiliaries)

Step 3 in HILS Simulation: CO2-Test cycle + OEM vehicle data. Use „Pdrive-sim„ in driver/engine torque model.
Calculation of rpm and torque at ICE. Interpolation of fuel consumption from engine map as defined in HDV-CO2 test procedure.

Validation: options discussed in HDV-CO2 group:

- **a) „SORT-like“ cycle driven during driving resistance tests, measure fuel consumption and for HDH also Ampere at battery)**
- **b) chassis dyno (not suitable for all HDV)**
- **c) PEMS (restricted accuracy in actual definition, for CO2 only small uncertainties allowed → road gradients and wind conditions need to be measured exactly)**

Open tasks for inclusion of PTO operation (1)

Approach from Task 1-2 to be followed?:

$$P_{engine} = P_{drive} + P_{transmission} + P_{auxiliaries} + P_{PTO}$$

Tasks to be solved:

Are there (global) sources on PTO power demand?
We are aware of single data sources only (e.g. US EPA)

Do methods for standardized simulation of PTO exist to be included in HILS?

If not, is a constant PTO power demand over cycle sufficient and for which applications is zero PTO power demand in vehicle idling reasonable?

Can PTO power demand be defined as % of power pack rated power?

Next steps: expert consultations planned.

WP 5: WHVC weighting factors

5.1 Analysis of typical profiles for vehicle speed and propulsion power

Planned to adapt existing method based on model PHEM (vehicle longitudinal dynamic and emission model from IVT)

1) Simulate representative real world cycles and the WHVC for different vehicle categories (categories according to CO2 and PEMS test procedure)
→ PHEM gives kinematic cycle parameters, driving power, engine power, engine speed, fuel consumption, emissions, exhaust gas temperatures, etc.

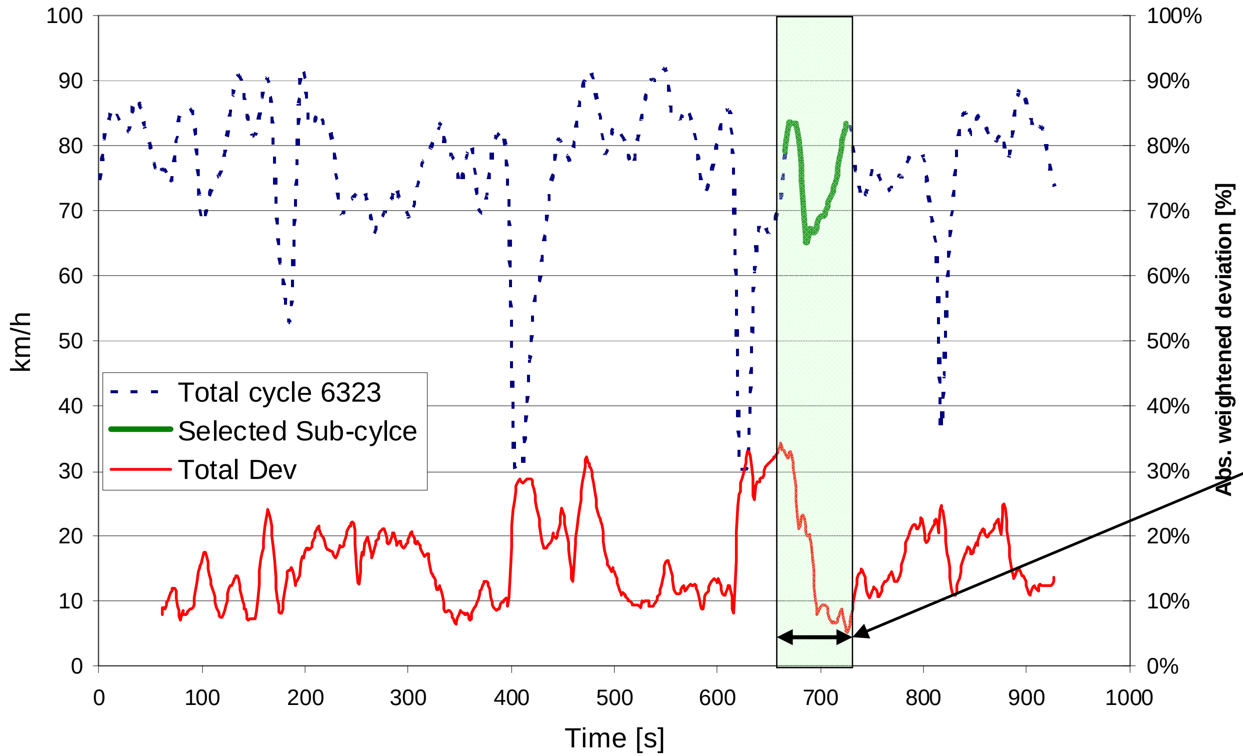
2) Elaborate weighting factors for WHVC sub-cylces, which give similar cycle parameters in weighted WHVC as the representative cycles per HDV category.

WP 5: WHVC weighting factors (2)

Weighting factors (example)

km/h	P_{norm}	n_{norm}	FC	NOx	CO	HC	PM	PN	dP_2s	dyn_Ppos3s	Ampl3s	LW3p3s	P_brake
0.115	0.115	0.103	0.115	0.115	0.023	0.023	0.080	0.057	0.057	0.057	0.057	0.057	0.023

Example from analysis of a real world cycle:



Criterias e.g.:

Total deviation in 60 sec. gliding average is minimum
Single factors deviation <15%
V, Pe, fc <5%

WP 5.1: WHVC weighting factors (3)

Adaptation of software to extract weighting factors instead of single sub-cycles shall be possible.

Agree to basic method → programming
(software necessary, since input of “representative cycles may change frequently during HILS project)

Not agree → discuss alternatives

3) Measurement of a HDH city bus (Volvo) in WHVC on chassis dyno at TUG

apply weighting factors and compare with real world fuel consumption and emissions
(in service PEMS tests in Graz and analysis of refuelling data over 1 year)

Consolidation of HILS and HDV-CO2-method

Work planned:

Option a) already sketched before (use HILS with HDV-CO_2 test data)

Option b): apply WHVC + HILS simulator for conventional vehicle and for HDH version of the vehicle. Use resulting ratio in fuel efficiency to correct HDV to HDH in the CO_2 test procedure.

Next steps:

Analyse advantages and disadvantages.

First simulation will be done with "SILS" since no HILS model is available yet.

SILS simulation shall cover a parallel and a serial power pack integrated in a city bus and in a municipal truck.

Summary to work performed

- WHVC leads to similar engine loads as WHTC for all tested vehicles. Effect of deviations against WHTC is expected to be rather low for regulated pollutants for conventional engines
- But HDH with different options for body, tires etc. would result in manifold engine test cycles.
- “WHTC-corresponding” power cycle at the wheel hub would allow an vehicle independent approach and an agreement of power pack load for HILS and for conventional engine tests. Negative driving power has to be adapted against WHTC to account for mechanical braking.
- This approach also allows to consider PTO and these auxiliaries, which are not engaged in engine tests. But for this option PTO and Auxiliaries would have to be simulated in HILS.
- This approach could follow the basic idea of model validation from the Japanese HILS method
- This approach could be extended to be applied for HDV CO2 test procedures if component testing is harmonized.
- Methodforeseen to elaborate WHVC weighting factors seems to be suitable, data sources still to be defined. If weighting shall be applied has to be discussed when results are available.

Thank you for your attention!