Working Paper No. **HDH-15-04e**
(15th HDH meeting, 24 to 25 October 2013)

GRPE-HDH Research Project

15th meeting of the GRPE informal group on heavy duty hybrids (HDH)

Report of the Institutes

Jonas Fredriksson
Gérard Silberholz
Christoph Six

Content

- Validation test program 1
  - Summary and Conclusion
- Validation test program 2
  - Chassis dyno test program at JRC
  - HDH drive cycle investigation
  - HILS/SILS model verification
- Open issues for a GTR drafting

Validation test program 1

Summary and Conclusion

The main objectives:

- The preparation of a series and a parallel hybrid model using SIL simulation
- Providing additional power pack components/models in order to meet stakeholder demands and ensure the establishment of a comprehensive model library
- Providing different driver models in order to be able to perform model test runs, investigate the model behaviour and the impacts of different test cycles
- OEM & Stakeholders meetings to deliberate on HILS methodology
- HILS model library and more flexible model structure

Validation test program 1

Summary and Conclusion

- Work done…
  - The basic series and parallel hybrid models provided by our Japanese colleagues could be extended and model test runs could successfully be performed with new components, different driver models and different vehicle parameters
  - New power pack components have been developed and already transferred into the later introduced new model structure (except planetary gear set)
  - Development of a model library based on a new model structure, models included in the library are similar to the models given by our Japanese colleagues.
  - Meetings with OEMs and stakeholders

Validation test program 1

Summary and Conclusion

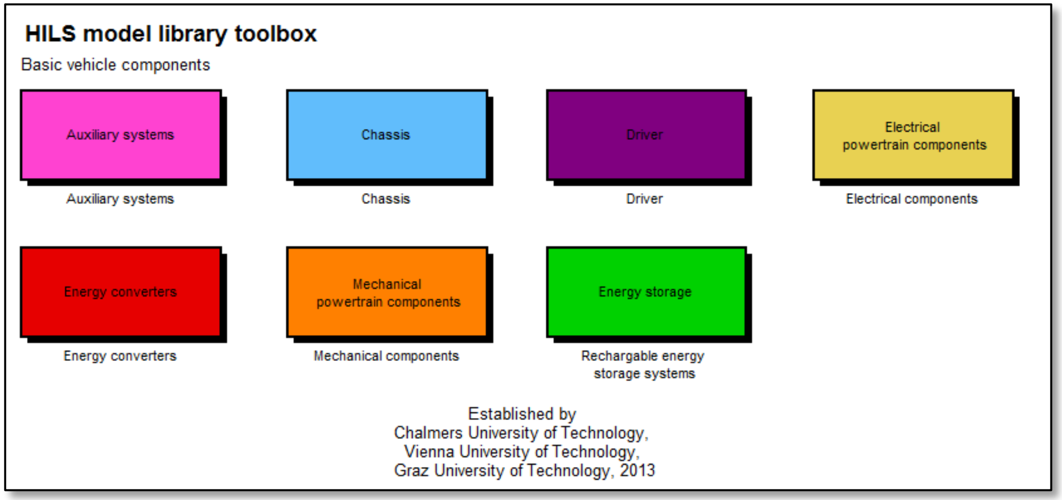
- New AUTOSAR based signal naming convention established
- Inclusion of relevant powerpack components in library toolbox
- Transfer of previously developed models (thermal, non hydraulic, driver model) into model library

```
HILS_GTR............................... The main folder
   |--> Documentation................. Model documentation is located here
   |--> DrivingCycles................. Data of the different driving cycles
   |--> Library....................... The model library is located here
        |--> ParameterFiles........... Template parameter files for all
                                        models (copy if used)
   |--> Misc.......................... All additional files for the
                                        HILS model library are stored here
   |--> Vehicles...................... Vehicle models are stored here
        |--> Parallel................. Models for parallel hybrid vehicles
             |--> PostTransmission..... Post transmission hybrids powertrains
                  |--> ParameterData... Data of the different component models
                  |--> SimResults...... Simulation results
             |--> PreTransmission...... Pre transmission hybrid powertrains
                  |--> ParameterData... Data of the different component models
                  |--> SimResults...... Simulation results
        |--> Series................... Series hybrid powertrains
             |--> ParameterData........ Data of the different component models
                  |--> SimResults...... Simulation results
```

Validation test program 1

Summary and Conclusion

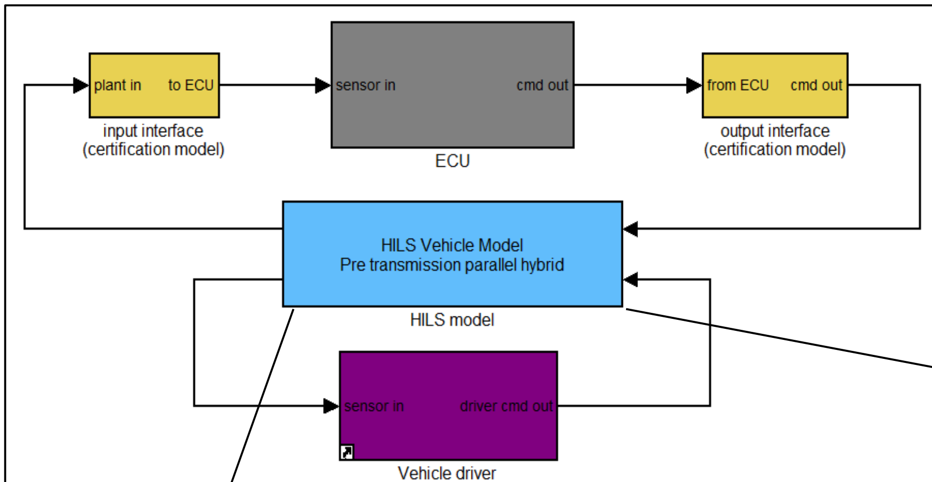
- Drag-and-drop to build new powertrain configurations
- Databus structure for flexibility to add OEM specific control signals
- Same components models can be used in different powertrains configurations
- Models organized into:
  - Auxiliary system
  - Chassis
  - Driver
  - Electrical components
  - Energy converters
  - Mechanical components
  - Rechargeable energy storage systems



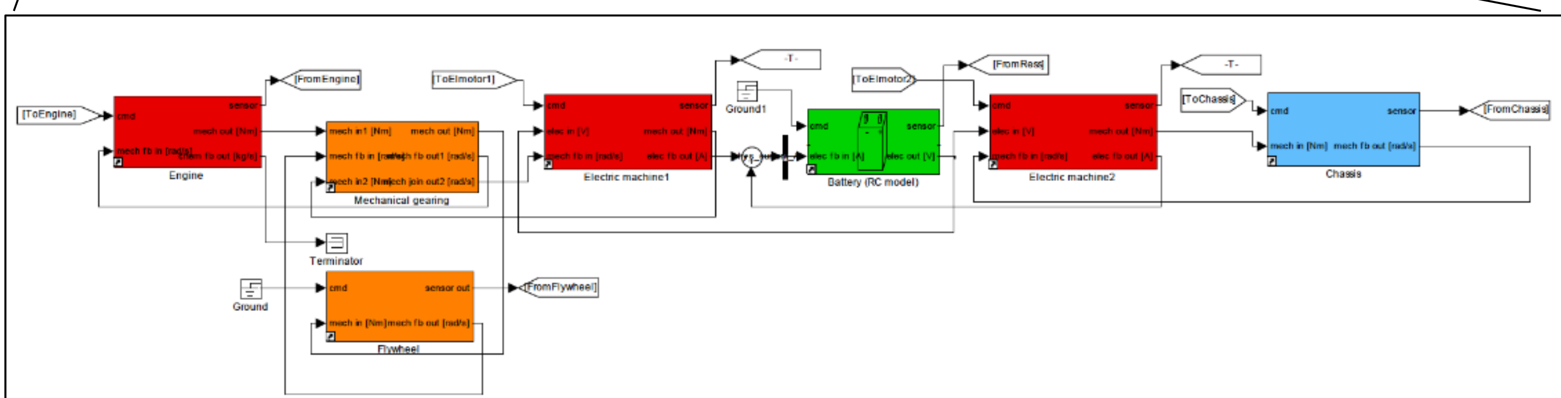
Validation test program 1

Summary and Conclusion

- “New” powertrain models developed based on the new model structure



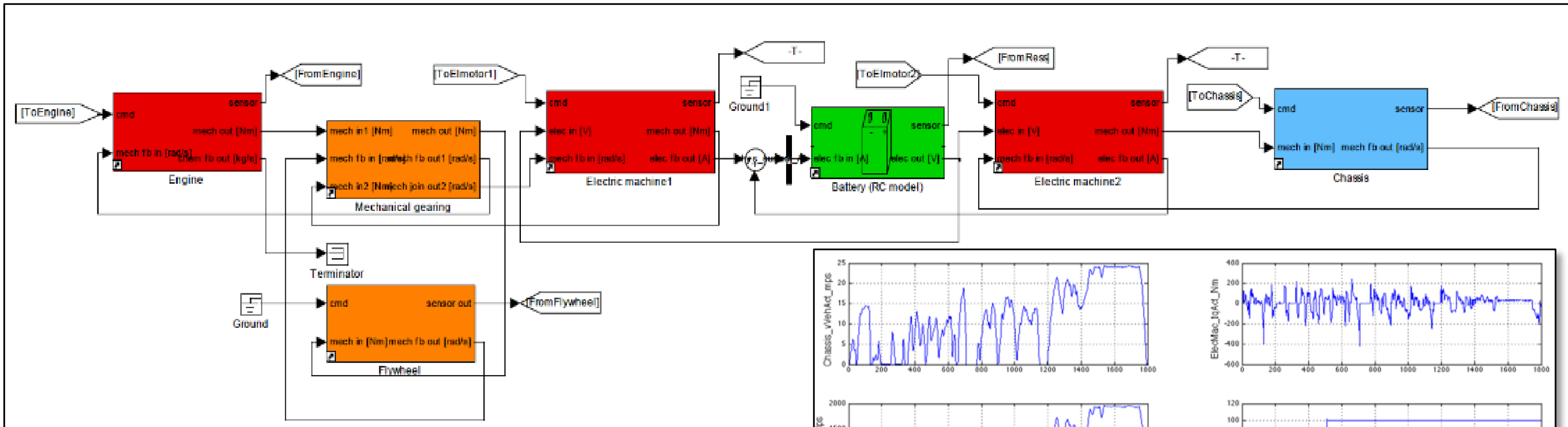
Top level

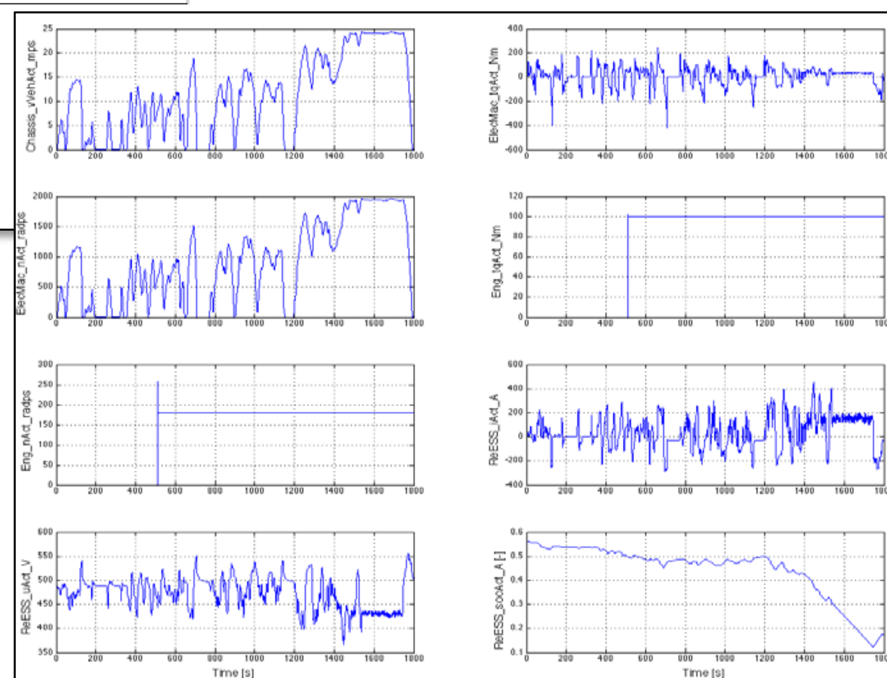


Vehicle level

Validation test program 1

Summary and Conclusion

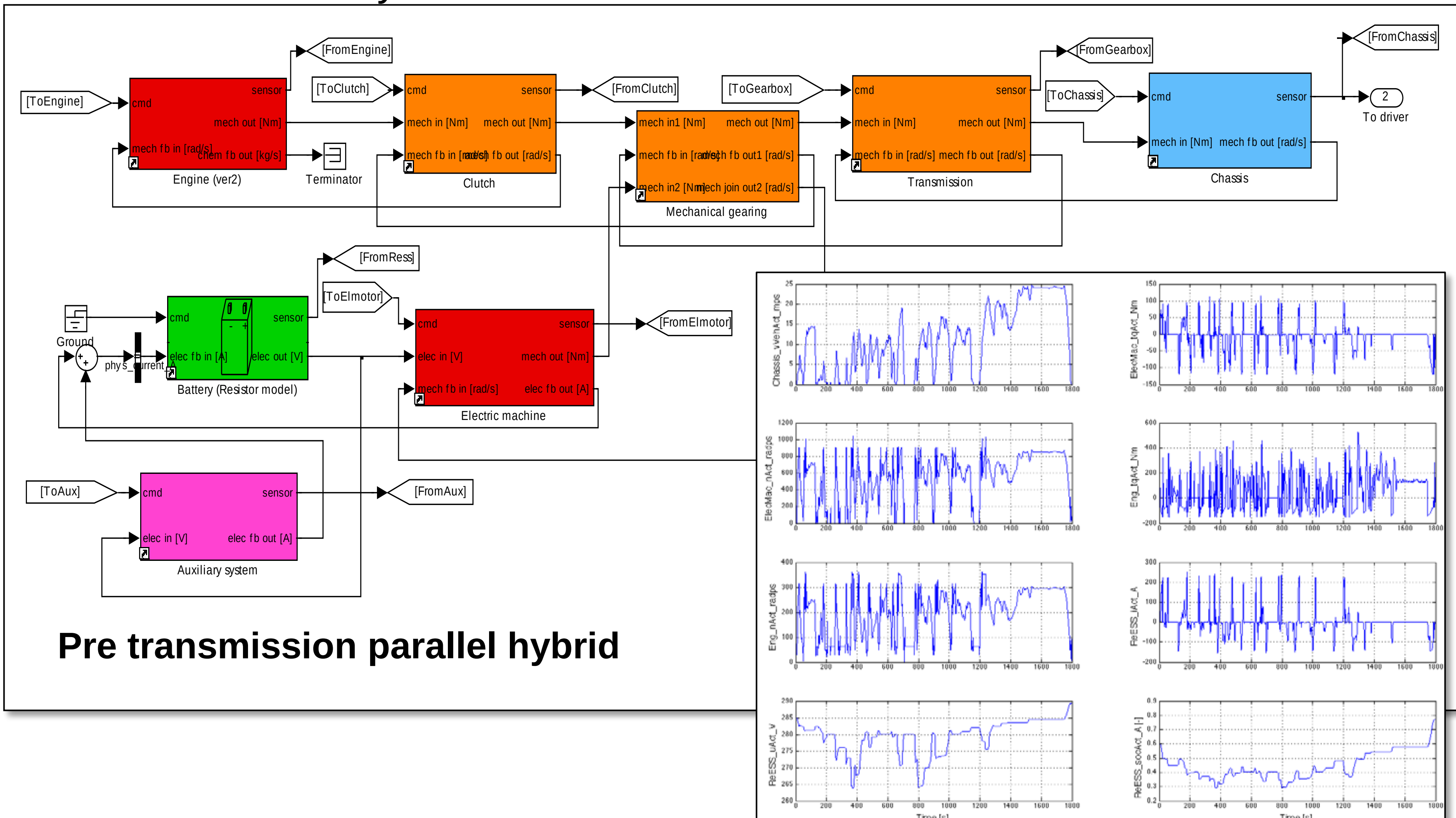




Series hybrid

Validation test program 1

Summary and Conclusion



Pre transmission parallel hybrid

Validation test program 1

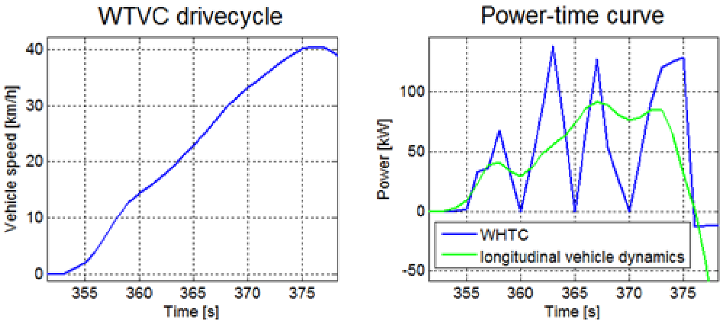
Summary and Conclusion

- New parallel+serial hybrid model circulated (component library based)
- Implementation of simple control strategy „software ECU"
  - Model test runs performed with Kokujikan data.
- New structure enabled implementation of flexible signal data bus
  - Minimum number of signals specified to run models
  - Flexible for adding more signals on data bus
- Extensive changes on models and model structure were made
  - Nevertheless project time schedule was maintained
  - Positive feedback and good cooperation with OEMs
- Next model release (including stakeholder remarks) planned, Oct 2013
- Drive cycle modifications need further investigations

Validation test program 2

HDH drive cycle (WHVC with road gradients)

- Basis: new test cycle should be identical to conv. HDV requirements
- Matching of sec. by sec. power demand of WHTC not feasible nor useful (gear shifts in WHTC not representative for HDHs)



- **Two different approaches for new test cycle**
  - 30 sec. mov. avg. with focus on sec. by sec. matching → high road gradients → smoothing needed → sec. by sec. matching repealed
  - Minicycle with focus on integral matching during cycle sub-sections

Validation test program 2

HDH drive cycle (WHVC with road gradients)

- Main questions:
  - How to achieve positive WHTC cycle work when running a WHVC?
  - What negative cycle work has to be provided by the test cycle?

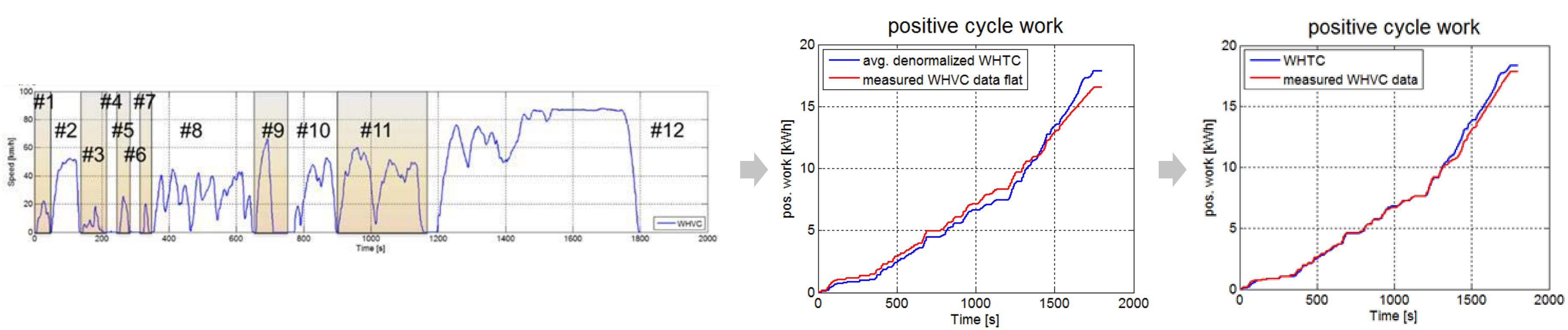
  - Development steps of different approaches
    - Minicycle
    - 30 sec. mov. average
  - Final test cycle proposal

Validation test program 2

HDH drive cycle (WHVC with road gradients)

- Evolution of minicycle test cycle during CD tests (1st approach)

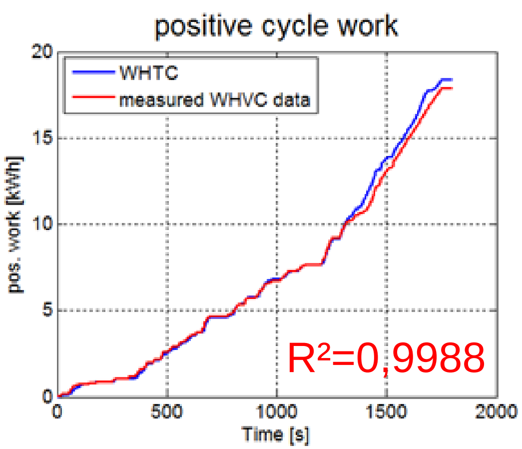
1. Divide WHVC in subsections
2. Run WHVC (flat) on CD
3. Measure vehicle power demand
4. Compare integrated pos. power to reference cycle work (avg. WHTC)
5. Calculate road gradients from difference
6. Re-run WHVC with road gradients on CD

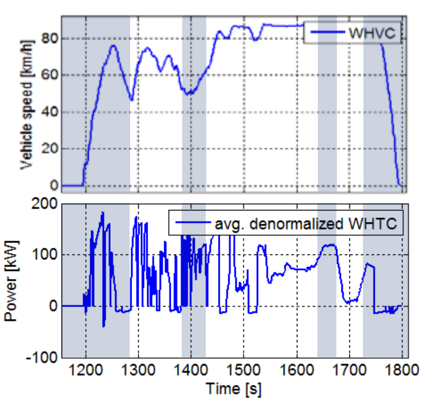


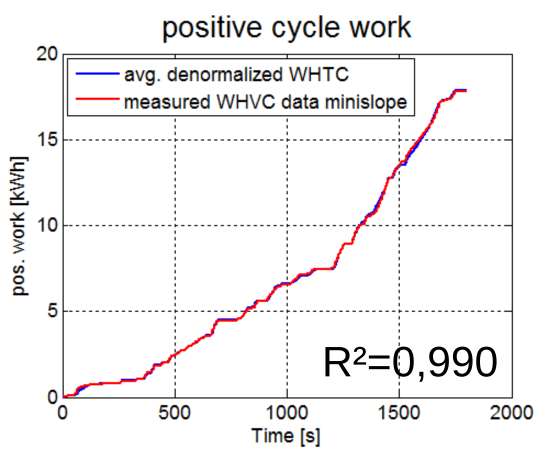
Validation test program 2

HDH drive cycle (WHVC with road gradients)

- Evolution of minicycle test cycle during CD tests (2nd approach)
- Behavior of last minicycle not satisfying (caused by real road gradients during WHTC development)
- Adaptation on last minicycle
- Satisfied tracking of WHTC (proofed by MAN and Volvo CD runs)







Validation test program 2

HDH drive cycle (WHVC with road gradients)

- Evolution of minicycle test cycle during CD tests (3rd approach)
- Road gradients directly influenced by measured CD run
  - tracking of WHVC (high influence even within tolerances)
  - faulty propulsion power measurement problematic? (OBD trustful?, CD not accurate?)
- Test cycle could slightly differ with different test runs - due to inaccurate reference speed tracking or different CDs (reproducibility)
- Using an already verified model would force different cycle generation

1. Divide WHVC in subsections
2. ~~Run WHVC (flat) on CD~~
3. ~~Measure vehicle power demand~~
4. Compare integrated pos. power to reference cycle work (avg. WHTC)
5. Calculate road gradients from difference
6. Re-run WHVC with road gradients on CD

Validation test program 2

HDH drive cycle (WHVC with road gradients)

- Evolution of minicycle test cycle during CD tests (3rd approach)

1. Divide WHVC in subsections
2. ~~Run WHVC (flat) on CD~~
3. ~~Measure vehicle power demand~~
4. Compare integrated pos. power to reference cycle work (avg. WHTC)
5. Calculate road gradients from difference
6. Re-run WHVC with road gradients on CD

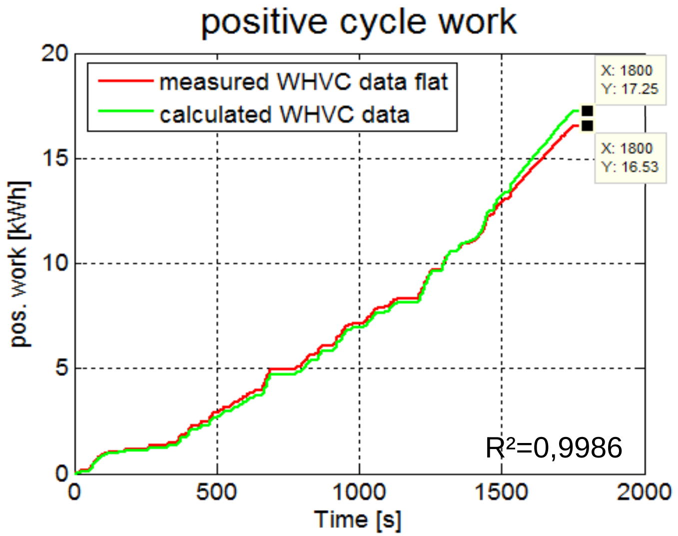
1. Divide WHVC in subsections
2. <u>Calculate WHVC vehicle power demand using vehicle longitudinal dynamics</u>
3. Compare integrated pos. power to reference cycle work (avg. WHTC)
4. Calculate road gradients from difference
5. Run WHVC with road gradients on CD

- No influence of real vehicle behavior on road gradients of test cycle
- Test cycle reproducibility guaranteed
- Premise: Calculated vehicle behavior (longitudinal dynamics) acceptably reflects real behavior during measurement

Validation test program 2

HDH drive cycle (WHVC with road gradients)

- Evolution of minicycle test cycle during CD tests (3rd approach)
  - Analytic vs. measured propulsion power
    - Vehicle data and road load equal to settings on dyno
    - Actual speed profile measured on CD as reference for calculation
    - Average values for rotating inertias, gearbox and final drive efficiencies* (according to Kokujikan No.281)
  - Good correlation (4%) for Volvo parallel hybrid (s-hybrid to be checked)
  - Deviations caused by
    - *Average calc. data
    - Accuracy of CD (load application)



**Measured speed data smoothed for power calculation

R^2 of pos. power time curve = 0,9573

Validation test program 2

HDH drive cycle (WHVC with road gradients)

- Evolution of minicycle test cycle during CD tests (3rd approach)
  - Analytical calculation of actual WHVC propulsion power proposed

    + clear improvement of WHVC

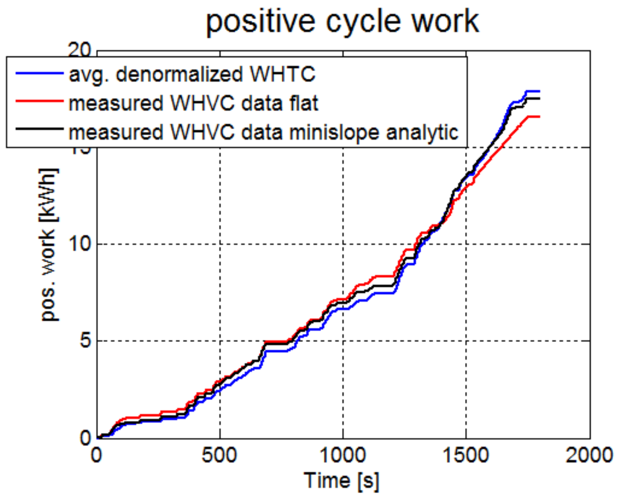
    + pre-definition of test cycle possible without actual measurement data

    + reproducibility of test cycle granted

    + no influence of CD or other measurement systems (CAN data,…)

    - average vehicle data (efficiencies and rot. inertias) are not able to perfectly reflect specific vehicle behaviour

    - Difficult to approve since no dyno run can exactly track WHVC speed profile

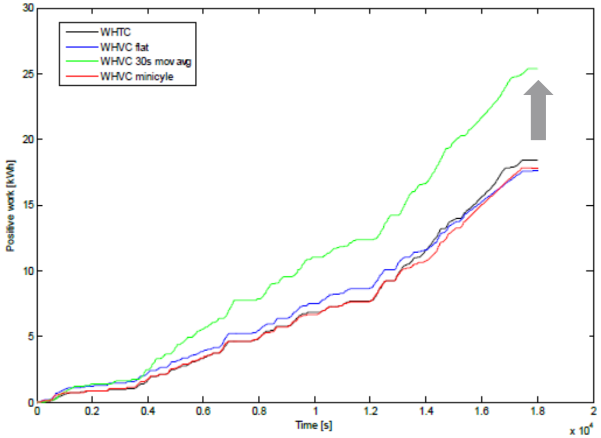


Validation test program 2

HDH drive cycle (WHVC with road gradients)

- Evolution of 30 sec.mov.avg. test cycle during CD tests (1st approach)

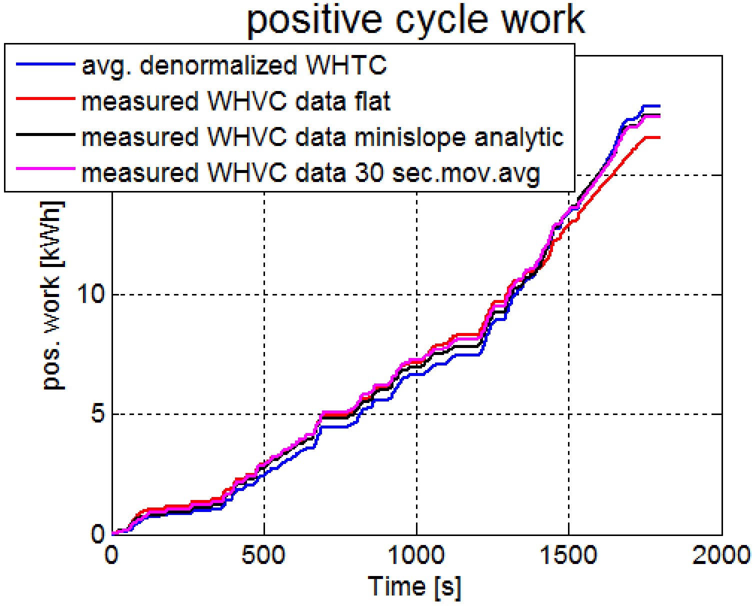
1. Reference cycle determined by WHTC denormalization method + hybrid power pack full load → different to minicycle approach
2. Sections of gear shift at WHTC were filled → increased cycle work
3. Road gradients resulted from work difference reference cycle / WHVC vehicle propulsion work calculated by vehicle longitudinal dynamics
4. Resulting high road gradients smoothed for realistic values
5. Verification run on CD resulted in high cycle work demand



Validation test program 2

HDH drive cycle (WHVC with road gradients)

- Evolution of 30 sec.mov.avg. test cycle during CD tests (2nd approach)
  - Average WHTC used as reference cycle instead of WHTC denormalization
  - Filling of gear shift power gaps at WHTC rejected
  - Agreed on common method for cycle work calculation
  - WHTC matching clearly improved
  - Similar behavior of minicycle and 30 sec.avg.*, both better than WHVC
  - Slightly better performance of mini-cycle in middle section



*for one specific vehicle

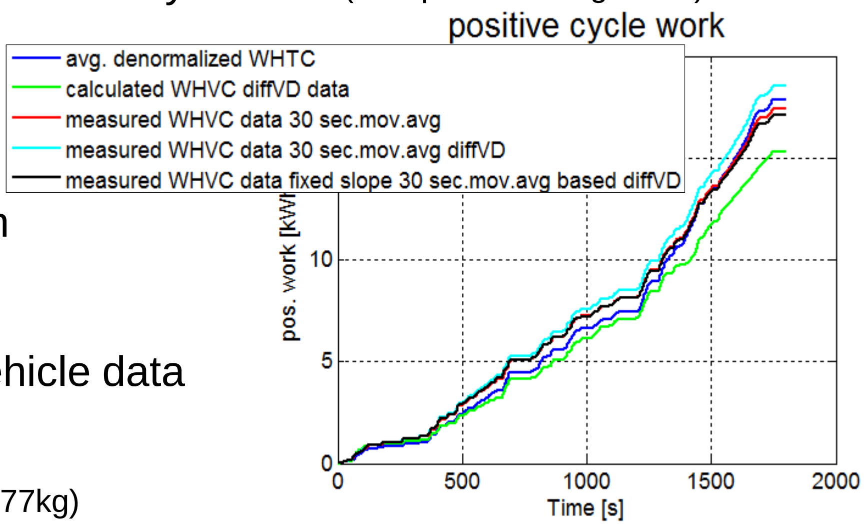
Validation test program 2

HDH drive cycle (WHVC with road gradients)

- Evolution of 30 sec.mov.avg. test cycle during CD tests (3rd approach)
- Fixed slope approach (basically feasible for both methods)
  - Basis for adding road gradients to WHVC:
    - Match WHTC work for each vehicle (calculate each slope profile separately)
    - Introduce a fixed slope which is an average of a sum of vehicles
    - Again deviation from WHTC work for every vehicle (except the average veh.)
  - Transient slope behavior

    forces transient vehicle operation

    → increased work in middle section
  - Deviations in curve and end value
  - Sensitivity of 30sec.mov.avg. on vehicle data



*diffVD = vehicle test mass as function of rated power (15073kg vs. 14277kg)

Validation test program 2

HDH drive cycle (WHVC with road gradients)

- Evolution of 30 sec.mov.avg. test cycle during CD tests (3rd approach)
- Fixed slope approach (basically feasible for both methods)
  - \+ 30sec.mov.avg. method by design not able to exactly meet WHTC work (smoothing) → fixed slope imaginable but not suggested
  - \+ Test cycle and fixed slope profile could be stated in a legislation
  - \- Increased deviations from WHTC for all vehicles (except the average veh.)
  - \- Weak benefit of fixed slope since cycle pre-calc. easily possible
  - \- Not suggested for minicycle approach

Validation test program 2

HDH drive cycle (WHVC with road gradients)

- Summary on tracking positive WHTC work
- Theoretically:
  - Minicycle perfectly meets positive WHTC work
  - 30 sec.mov.avg. not able to exactly meet WHTC work
- Practical experience:
  - Hard to verify because WHVC can not be tracked exactly on CD
  - Strong sensitivity of speed tracking on cycle work (valid for both)
  - Actual measurements not suitable for road gradient determination (rejected 1st minicycle proposal)
  - Good basis correlation between WHVC cycle work calculation and measurement could be shown → basis for gradient calculation
  - Slight preferences for minicycle due to theoretical background

Validation test program 2

HDH drive cycle (WHVC with road gradients)

- What is the correct neg. work to be provided by the test cycle?
  - 30 sec.mov.avg. method
    - Always considered neg. flat WHVC work at actual vehicle data (calculated by vehicle longitudinal dynamics)
  - Minicycle method
    - Balanced altitude approach (rejected)
    - Same as 30 sec.mov.avg. (possible but not proposed)
    - Same pos./neg. power ratio than vehicles used for WHTC generation (proposed)

Validation test program 2

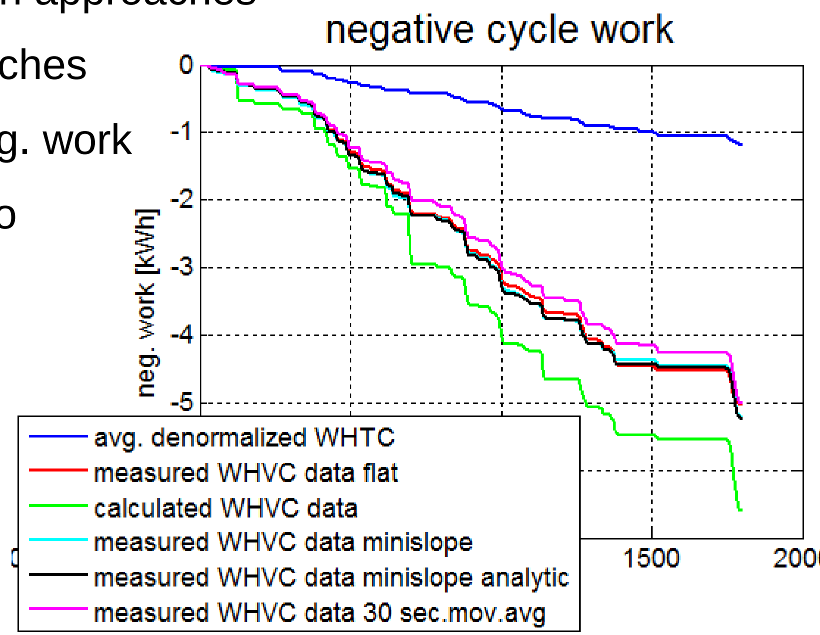
HDH drive cycle (WHVC with road gradients)

- What is the correct neg. work to be provided by the test cycle?
  - Minicycle method
    - Balanced altitude approach (rejected)
      - High powered vehicles:
        - Positive road gradients will demand high propulsion power
        - Altitude will be gained most of the time during test run
        - Balancing has to occur during deceleration – application of neg. road gradient (no effect on pos. cycle work)
        - Short deceleration period with high power availability (unrealistic)
      - Low powered vehicles
        - Negative road gradient will lower propulsion power demand
        - Vehicle steadily driving downhill
        - Positive slopes during deceleration needed to balance altitude
        - Decreased amount of recuperation energy available
      - Since gradients just a tool to manipulate system load, altitude no suitable parameter (see alternative proposal)

Validation test program 2

HDH drive cycle (WHVC with road gradients)

- What is the correct neg. work to be provided by the test cycle?
  - Considering neg. flat WHVC work at actual vehicle data (30 sec.mov.avg. method + possible for minicycle method)
    - Already tested at CD tests for both approaches
    - Basically feasible for both approaches
    - Both minicycle provided same neg. work
    - 30 sec.mov.avg. intended to do so but slight deviation (smoothing)
    - Slight preference for minicycle



Validation test program 2

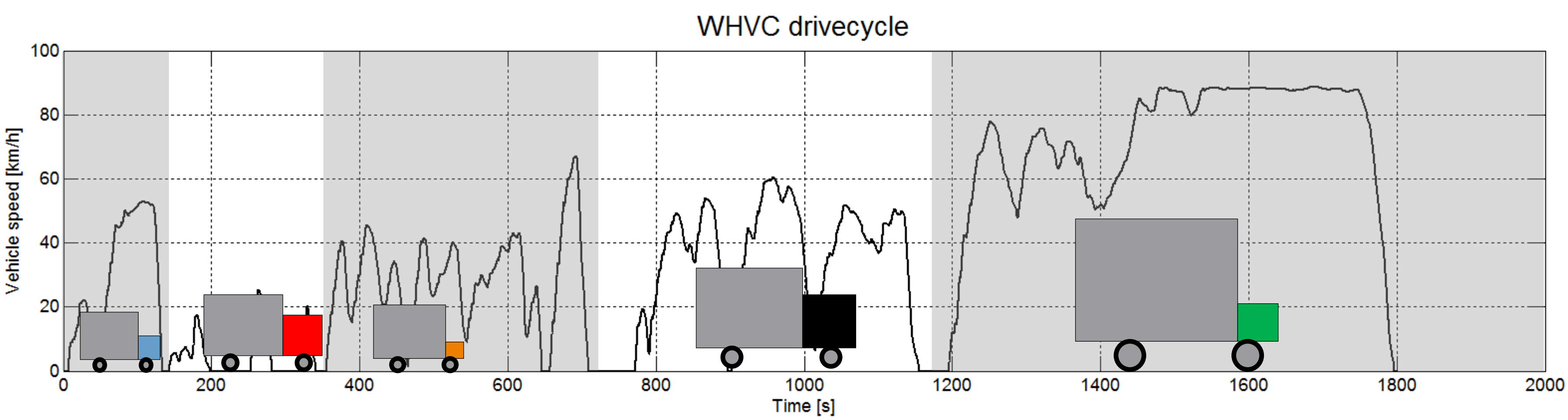
HDH drive cycle (WHVC with road gradients)

- What is the correct neg. work to be provided by the test cycle?
  - Considering neg. flat WHVC work at actual vehicle data (30 sec.mov.avg. method + possible for minicycle method)
    - Unbalanced treatment of pos. and neg. power
      - Vehicle data will **not** affect positive cycle work (road gradients will be adapted to "match" pos. WHTC work)
      - BUT vehicle data will directly affect negative cycle work (energy available for recuperation)
        - m = f(rated_power) → could be lower than vehicle kerb weight (e.g. serial hybrids) → not appropriate for specific vehicle
        - m = kerb weight + half payload → appropriate just for specific vehicle
        - Test weight definition also affects certification procedure

Validation test program 2

HDH drive cycle (WHVC with road gradients)

- What is the correct negative work? – WHTC based approach -
  - Basics: How the WHTC was generated
    - Different data of real vehicles collected and put together

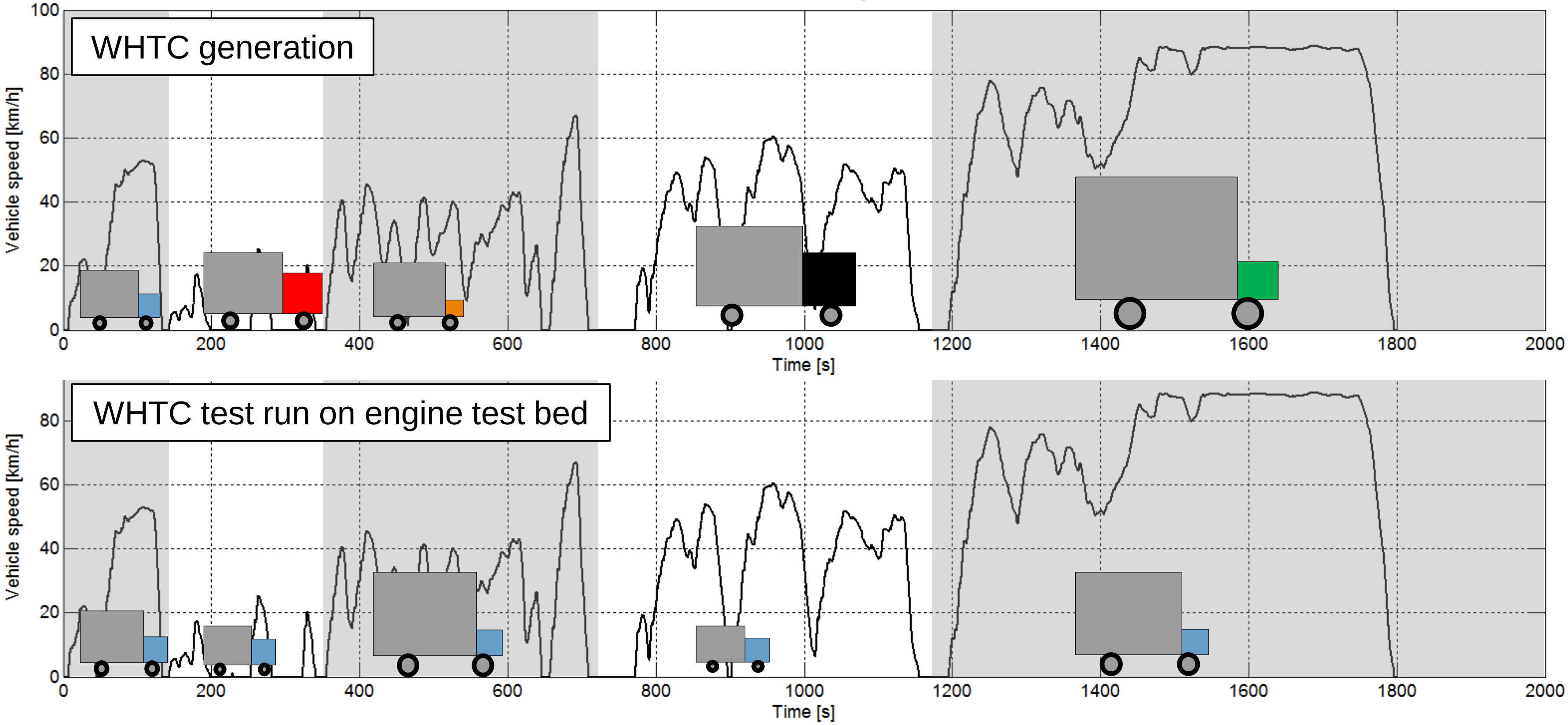


*Size of grey boxes represents vehicle weight
**Size of coloured boxes represents vehicle power

Validation test program 2

HDH drive cycle (WHVC with road gradients)

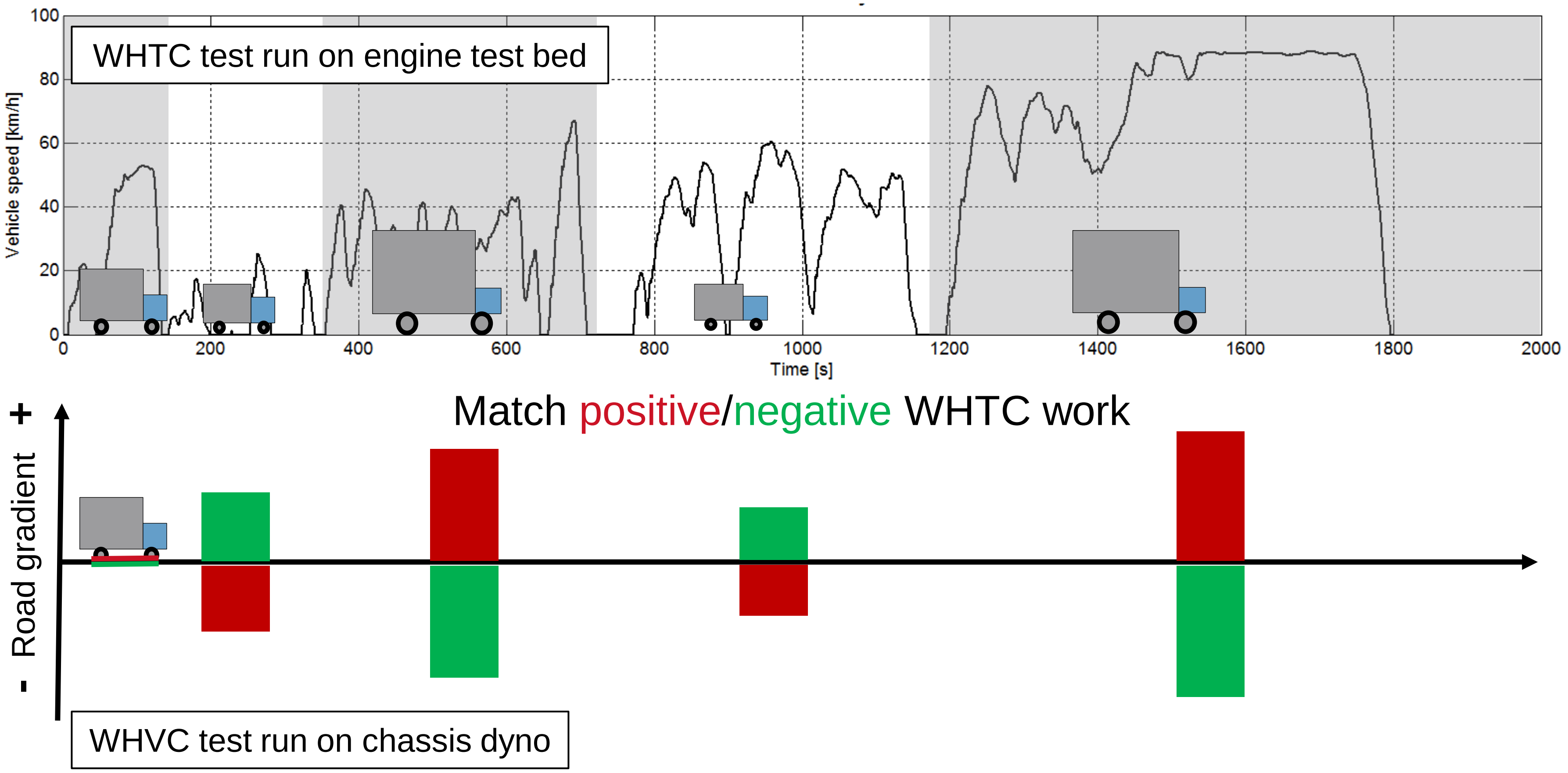
- What is the correct negative work? – WHTC based approach -
  - Scale all vehicles to same power – keep power to mass ratio



Validation test program 2

HDH drive cycle (WHVC with road gradients)

- What is the correct negative work? – WHTC based approach -



Validation test program 2

HDH drive cycle (WHVC with road gradients)

- What is the correct negative work?

  - Summary – WHTC based approach -
    - Minicycle approach comprehensively aligns WHVC and WHTC
      - Solid basis for new test cycle
      - Considers added and removed payloads for pos. and neg. work
      - Matching of pos. WHTC work independent of test weight (slopes adjust work)
      - Great benefit: also negative work independent of test weight, always adequate recuperation energy available, like vehicles at WHTC generation
      - Better reflects real world operation – different payloads

- Test cycle - Summary of investigations		Individual slope					Fixed slope	
	WHVC	30 sec. mov.avg.	Minicycle				30 sec. mov.avg.	Minicycle (var.app)
			ref CD WHVC		ref analytic WHVC			
			neg. WHVC	neg. WHTC	neg. WHVC	neg. WHTC		
match WHTC cycle work (at test end)	X	O	✔	✔	✔*	✔*	X	X
match WHTC cycle work (course)	X	O	✔	✔	✔*	✔*	X	X
match WHTC power (sec. by sec.)	X	X	X	X	X	X	X	X
match negative WHVC work	✔	O	✔	X	✔	X	O	✔/X
Pos.+neg. WHTC work alignment	X	X	X	✔	X	✔	X	✔/X
Negative work not dependent on test weight	X	X	X	✔	X	✔	X	✔/X
Exact reproducibility	✔	✔	X	X	✔	✔	✔	✔/X
Pre-calculation possible	✔	✔	X	X	✔	✔	✔	✔/X

** assumption that vehicle longitudinal dynamics adequately reflect real vehicle behaviour

Validation test program 2

HDH drive cycle (WHVC with road gradients)

- **Minicycle aligned with pos.+neg. WHTC work** (final test cycle proposal)
  - Velocity based, “vehicle independent” test cycle
    - Positive and negative work will - test weight independent - be aligned with WHTC
  - Easy and reproducible cycle pre-calculation possible
  - Clear improvement of flat WHVC
  - Final approval on chassis dyno (pos./neg. work balance) will follow

Validation test program 2

Chassis dyno test program at JRC

- Chassis dyno tests performed with focus on
  - HILS/SILS model verification
  - HDH drive cycle (WHVC with road gradients)

- Three vehicles have been tested (Volvo, MAN, IVECO)

Volvo parallel hybrid bus
Rated power: 193 kW
Test weight: 15.073 kg

MAN serial hybrid bus
Rated power: 150 kW
Test weight: 15.300 kg

Iveco parallel hybrid truck
Rated power: 130 kW
Test weight: 8.675 kg

Validation test program 2

HILS/SILS model verification

- Outlook
  - Verification (R^2 criteria) failed until now (SILS/MILS based)
  - Identification of causes ongoing (related to HILS model, CD measurements / combination of both)
  - CD re-measurements foreseen but not scheduled yet
  - Cold start and on-road measurements not yet considered for model verification

- Status of model verification procedure
  - HILS environment currently under construction at Iveco
  - Verification results available for Volvo bus (SILS)
  - 1st verification work status available for MAN (MILS)

VOLVO

HILS Model Validation

Procedure and results based on second chassis dyno run

Model validation procedure

1. Run WHVC on chassis dyno and log following data

- Engine and electric motor speed
- Engine torque + command values (ex: fuel injection)
- Electric motor torque + command values (ex: torque request)
- Vehicle speed
- SOC level
- Brake and accelerator pedal position
- Current gear
- Battery current
- Battery voltage
- Fuel Injection

NOTE: Even if slopes are used, the ECU should be using a 0% slope reference.

Model validation procedure

2. Configure the SILS model to match chassis dyno

- Set the inertia of rotating sections similar to the inertias on the dyno (e.g. consider that the front axle was not driven)
- Estimates the auxiliary loads. (mechanical, low voltage, high voltage).
- Set the test mass, rolling and drag values equal to the ones used for the dyno test

Model validation procedure

3. Run the SILS model

There are two cases:

- For the 140sec verification (first 2 heaps in WHVC) use **brake and accelerator pedal position** measured on the CD as model input. Open loop, no driver model used.
- For the entire verification test use the driver model and the **speed trace** measured on the chassis dyno (closed loop control) or the brake and accelerator pedal positions (open loop control) or a combination of both.

Model validation procedure

4. Validate the model

- Engine and electric machine torque should not be the measured ones but calculated from a map and the logged command values.
- Optional to ignore validation data one second before/after a gearshift (when calculating the R^2)
- Use formula defined in Kokujikan to calculate the R^2 between model signals and chassis dyno signals.
- Energy balance is calculated and checked using sum of "battery current x time x battery voltage (nominal value)" and the energy derived from the total fuel consumption.

Volvo Validation Results

Euro V parallel-hybrid bus

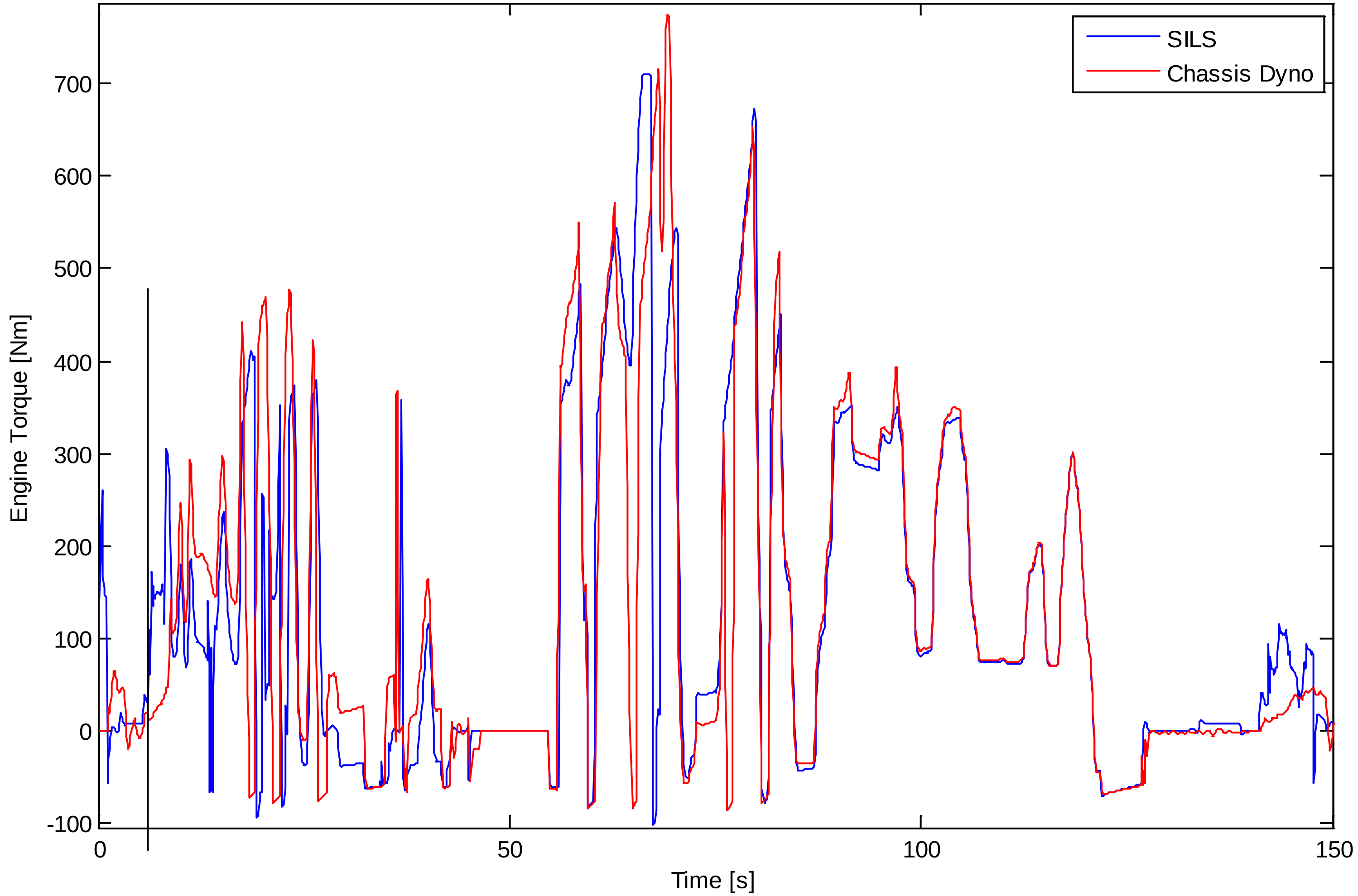
Short cycle in open loop (pedal position used)

WHVC 0s-140s	Vehicle	Electric motor		Engine		Battery
	Speed	Torque	Power	Torque	Power	Power
Kokujikan desired R^2	0.97	0.88	0.88	0.88	0.88	0.88
Volvo TEST 1	1.00	0.88	0.82	0.73	0.67	0.81
Volvo TEST 2	0.99	0.92	0.86	0.80	0.78	0.86

Test 1 corresponds to a flat WHVC
Test 2 corresponds to a WHVC with mini-cycle slopes

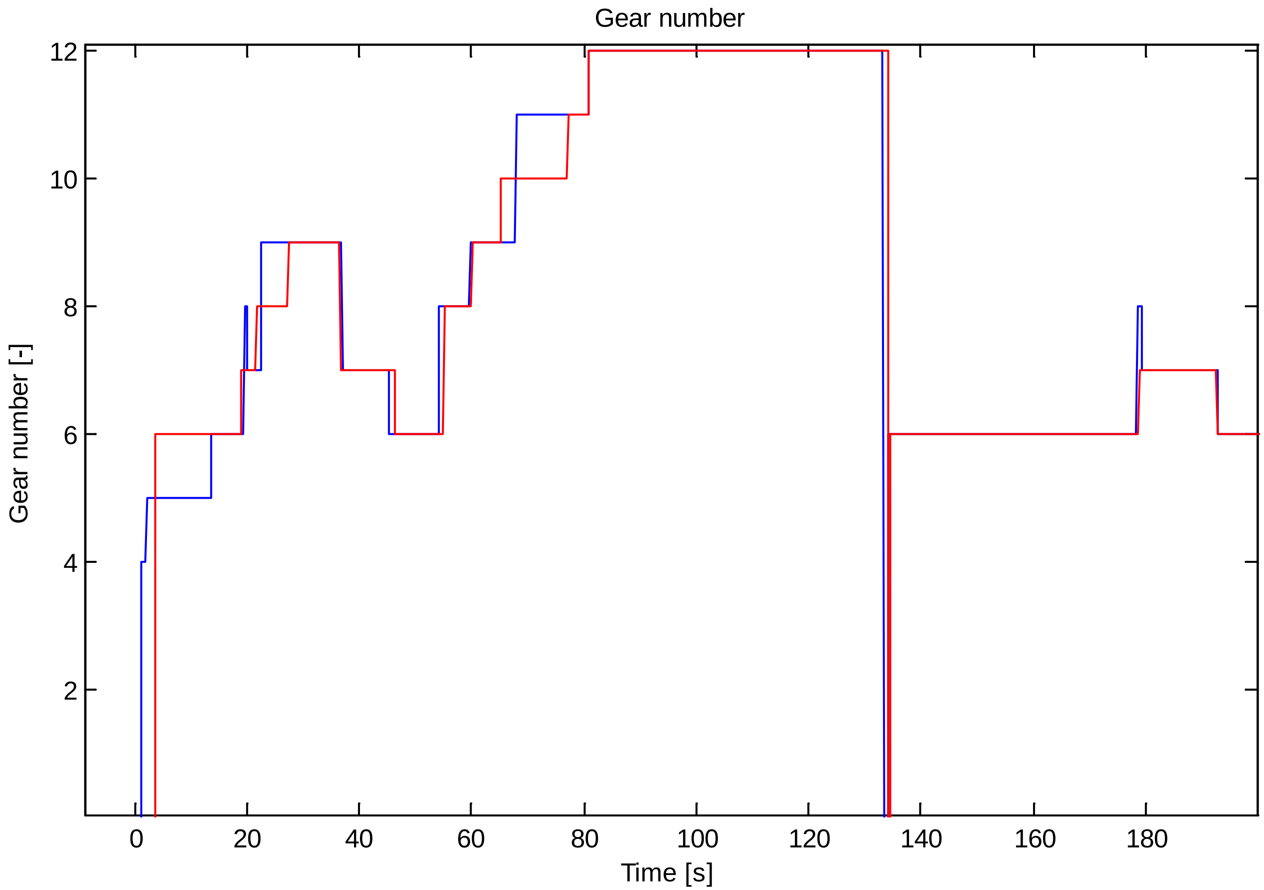
SILS output signals plots

Engine Torque. Open Loop



SILS output signals plots

Gears. Open loop



Volvo Validation Results

Euro V parallel-hybrid bus

Full cycle in open loop (pedal position used)

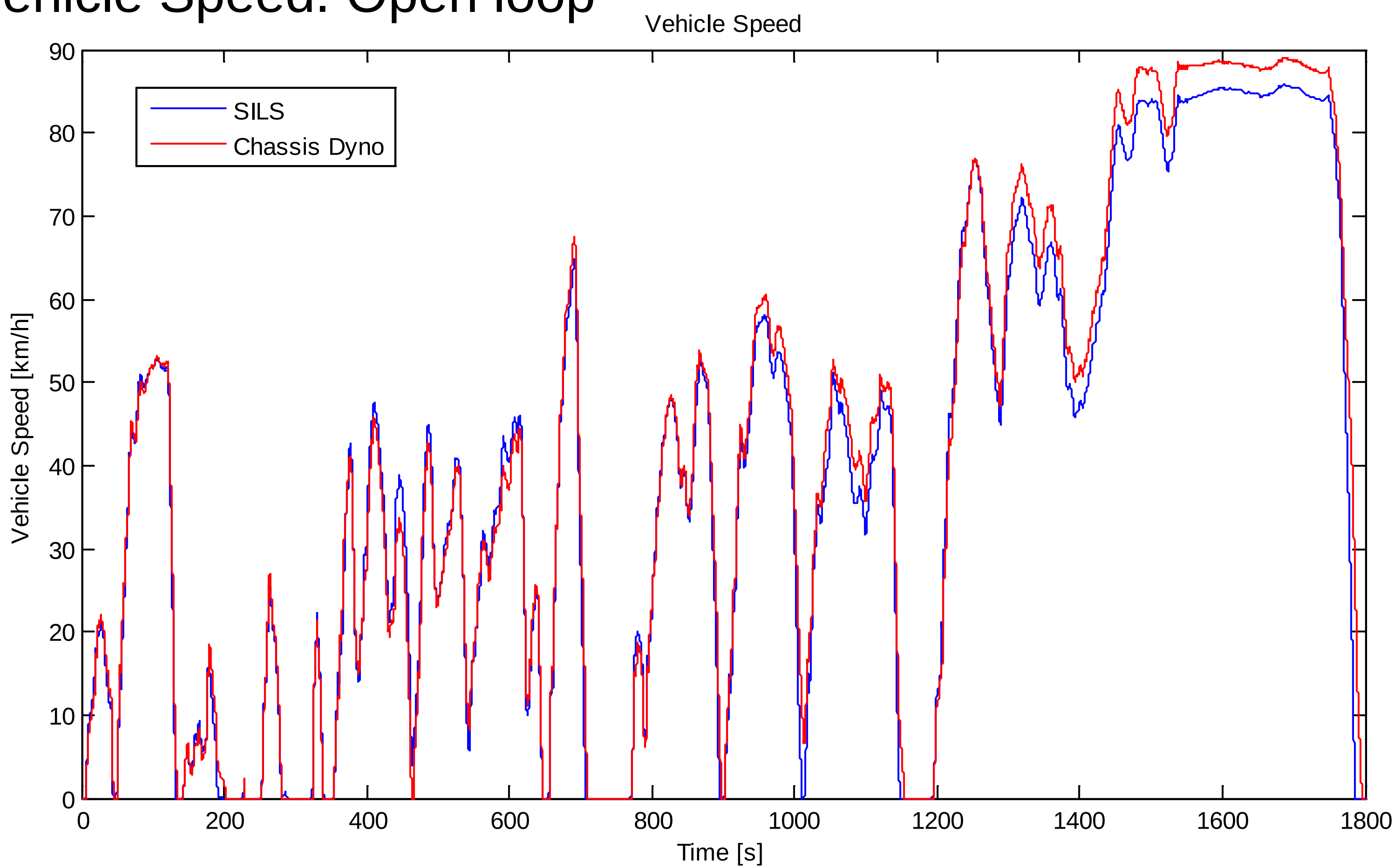
WHVC full	Vehicle speed	Engine Torque	Positive engine work	Fuel economy value
	R^2	R^2	$W_{eng\_HILS}/W_{eng\_vehicle}$	$FE_{SILS}/FE_{vehicle}$
Kokujikan	0.97	0.88	>0.97	<1.03
Volvo TEST 1	0.99	0.87	1.07	N/A
Volvo TEST 2	0.99	0.86	1.06	N/A

Test 1 corresponds to a flat WHVC
Test 2 corresponds to a WHVC with mini-cycle slopes

Note: Using closed loop would lead to an engine torque R^2 of 0.75 and 0.77

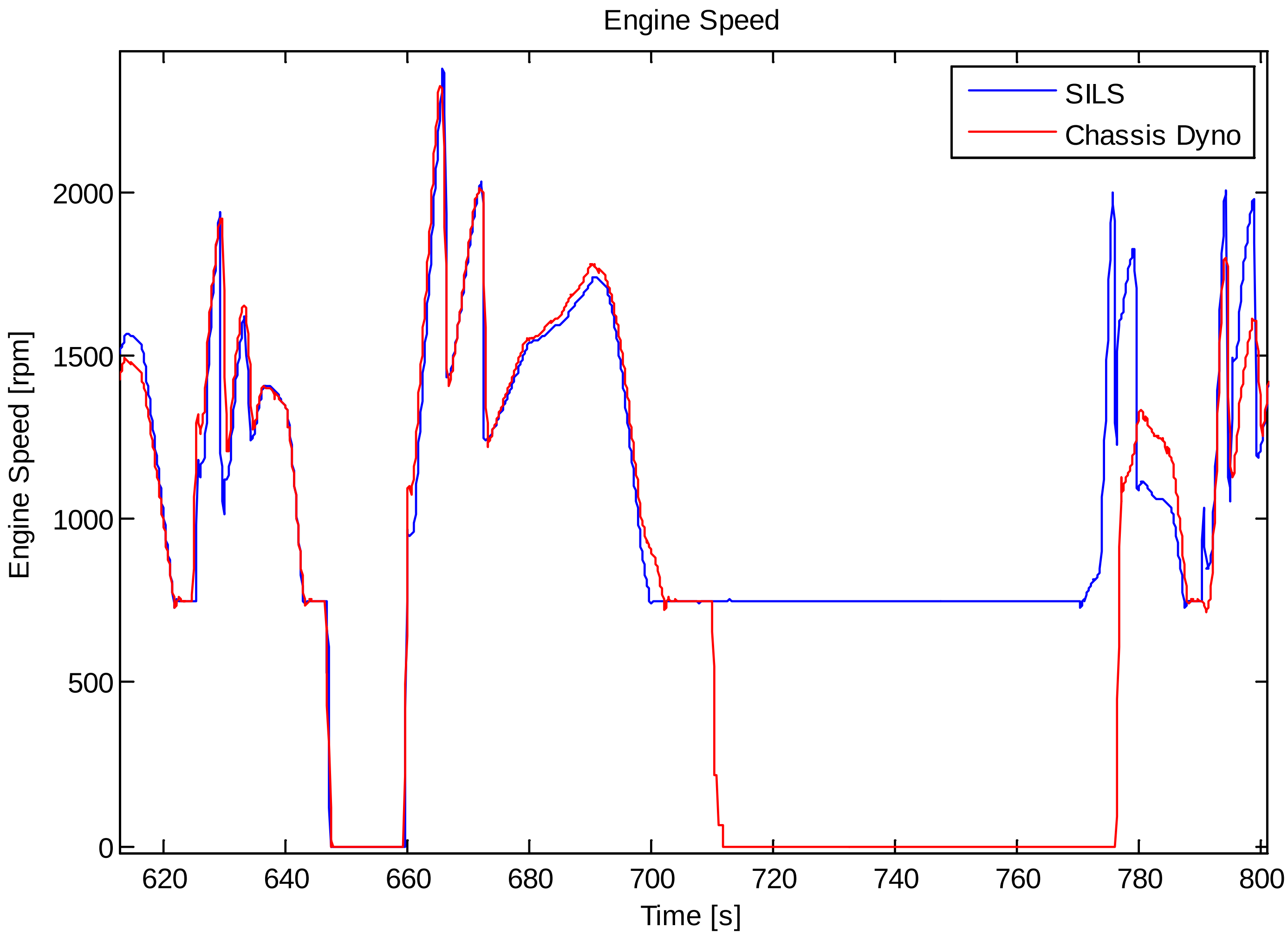
SILS output signals plots

Vehicle Speed. Open loop



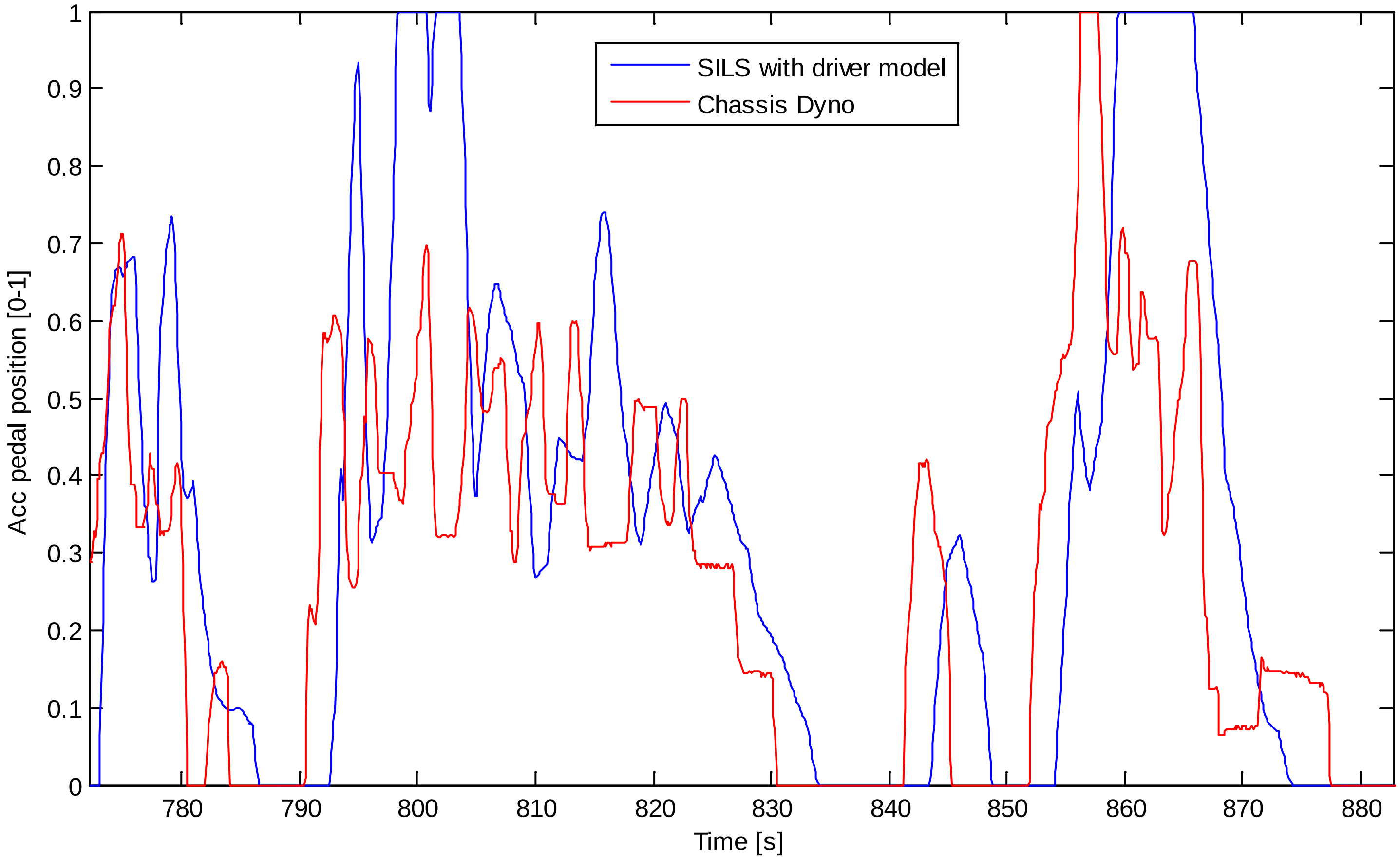
SILS output signals plots

Engine Speed. Open loop



SILS output signals plots

Pedal position. Close loop



Conclusion

Model

- The model is probably alright. Do not need more complexity.
- The interface between model and ECU is alright. The inputs/outputs available are enough to feed the ECUs.
- No thermic model was used. Temperature set to constant values.
  - A warm engine has more or less the same performance (no big diff between 80 or 90°C)
  - Battery temperature already constant on cycle.

Validation

- Very hard to replicate the same behavior. A small deviation in SOC level can lead to a big difference in hybrid strategy.
- Further improvement of verification needed (errors caused by model and/or rollers?)
- Investigate validation criteria that are more robust and less time/event dependent. For example, relax condition on R2 for engine torque and introduce condition on total positive work from engine in relation to total positive propulsion work.

Validation test program 2

HILS/SILS model verification

- Outlook
  - Verification (R^2 criteria) failed until now (SILS/MILS based)
  - Identification of causes ongoing (related to HILS model, CD measurements / combination of both)
  - CD re-measurements most likely not possible before end of year
  - Cold start and on-road measurements not considered yet

- Status of model verification procedure
  - HILS environment currently under construction at Iveco
  - Verification results available for Volvo bus (SILS)
  - **1st verification status available for MAN (MILS)**

HILS Validation

Status MAN Truck & Bus

HILS Validation

Status Model

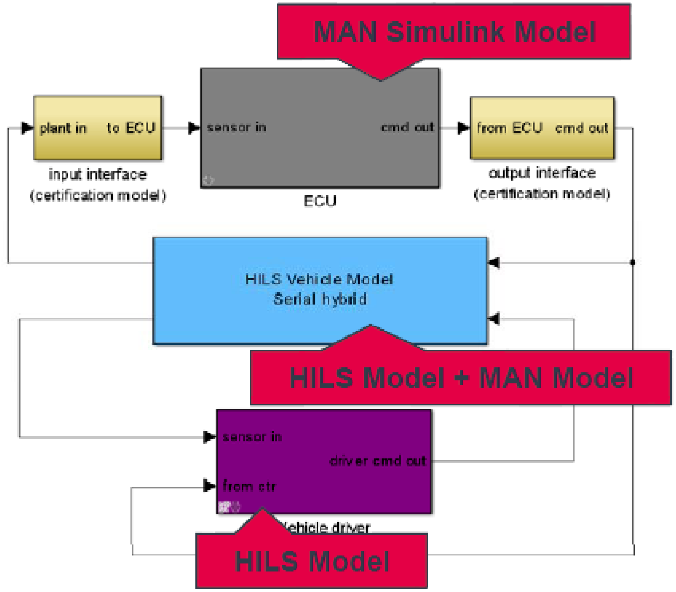
HILS Model - Overview

- Building of a Serial Hybrid Vehicle Model
- Using the HILS model library toolbox version 0.22

- Vehicle Model: see next pages
- ECU: MAN Simulink model with simplified ECU functions
- Driver: HILS Model Driver

- First implementation
- Some improvements/optimizations needed

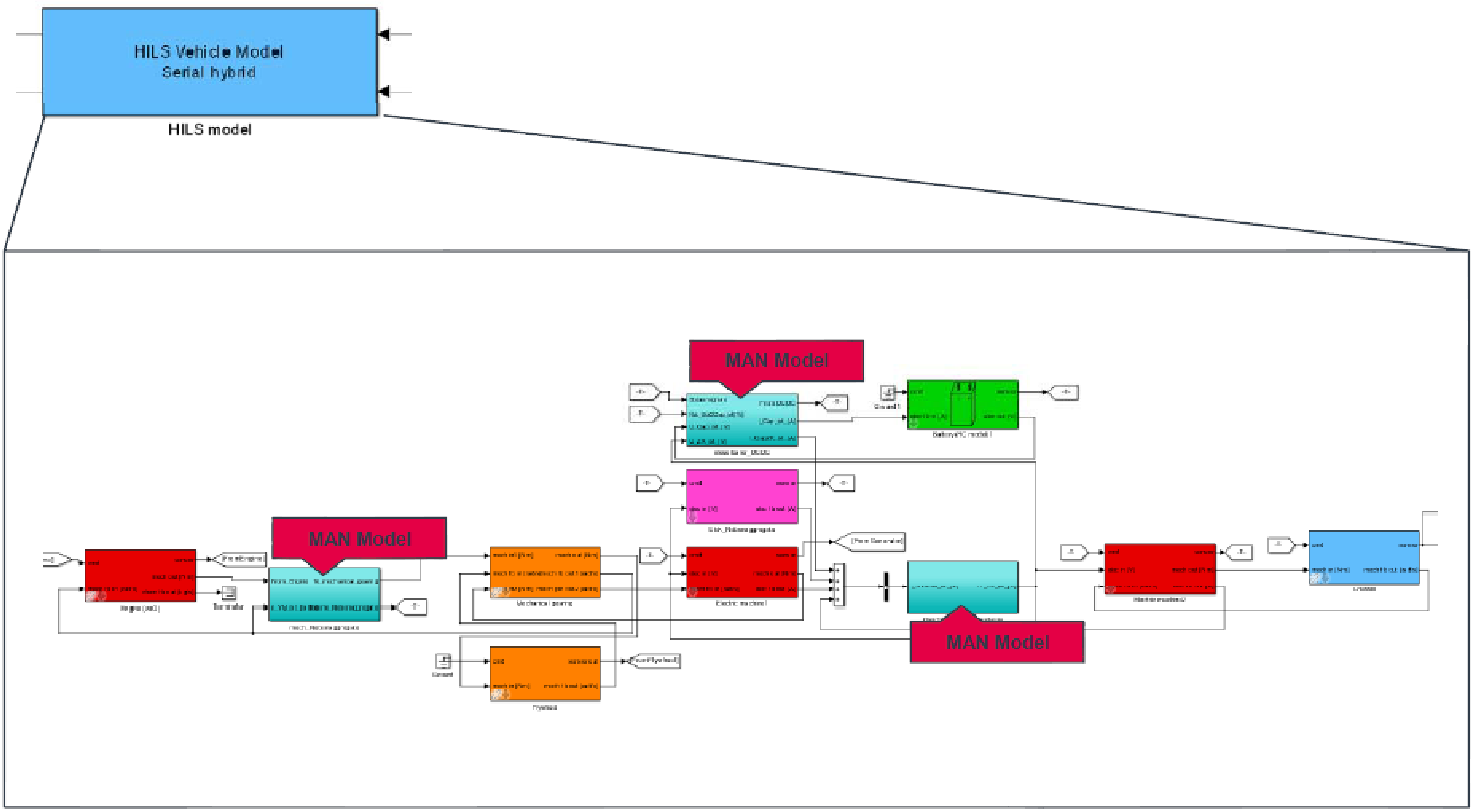
HILS Model



HILS Validation

Status Model

HILS Model – MAN Lion's City Hybrid (Serial Hybrid)



HILS Validation
Status Model

Current Status

- First implementation
- Some HILS components are missing
  -> Using MAN Simulink components
    - e.g. intermediate circuit, mechanical auxiliaries, etc
- Some HILS components need modifications
  -> Using modified HILS components
    - e.g. efficiency maps, etc.
- Parameterisation of the components with MAN values
- First simulation run
- First validation (results on the next pages)
- Needed components/improvements reported to the involved universities

Open Points / Next Steps

- Using a new version of the HILS model library toolbox
- Substitution of the MAN Simulink components with HILS components
- Substitution of the modified HILS components with the original/improved HILS components
- Optimisation of the component parameters
- New simulation and validation

A first implementation and parameterisation of the open source model is made.
For the final model many changes and optimisations are needed.

HILS Validation

Status Validation

Validation - Overview

- Using measured CAN-data from roll bench tests in June 2013 in Ispra
- Using the measured WHVC cycle without slopes from 27.06.13
- Test conditions in separate documentation
- "140sec" Verification
  - Determination Coefficient for: vehicle speed, torque (e-motor, engine), power (e-motor, engine, e-storage)
- "Overall" Verification
  - Determination Coefficient for: vehicle speed, engine torque
  - Positive engine work
  - Fuel economy
- Validation signals and tolerance in tables 1 and 2

HILS Verification

Table 1 Tolerance in Correlation (Determination Coefficient) of Actually-Measured Verification Values and HILS Simulated Running Values

Test condition	Vehicle speed or engine revolution speed	Electric motor		Engine		Electric storage device output
		Torque	Output	Torque	Output	
One heap in JE05-mode	0.97 or more	0.88 or more	0.88 or more	0.88 or more	0.88 or more	0.88 or more

Table 2 Tolerances in Overall Verification

Test condition	Vehicle speed or engine revolution speed	Engine torque	Positive engine work	Fuel economy value
	Determination coefficient	Determination coefficient	$W_{eng\_HILS} / W_{eng\_vehicle}$	$FE_{HILS} / FE_{vehicle}$
Entire JE05-mode	0.97 or more	0.88 or more	0.97 or more	1.03 or less

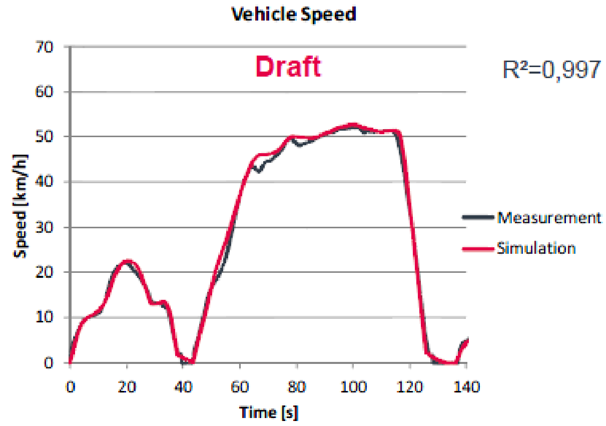
determination coefficient

$$r^2 = \left(\frac{n \times \sum x_i y_i - \sum x_i \times \sum y_i}{\sqrt{\left[n \times \sum x_i^2 - (\sum x_i)^2\right] \times \left[n \times \sum y_i^2 - (\sum y_i)^2\right]}} \right)^2$$

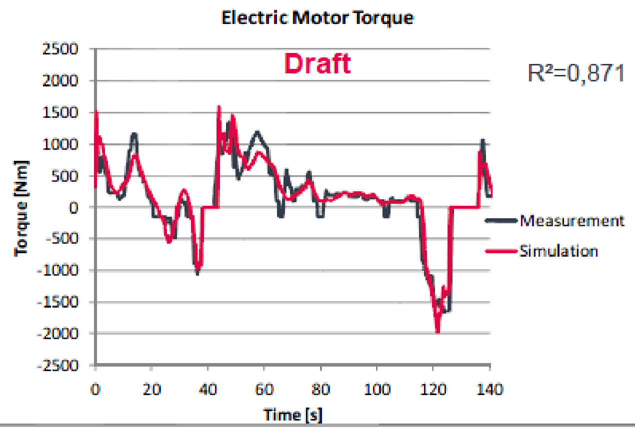
HILS Validation

Status Validation

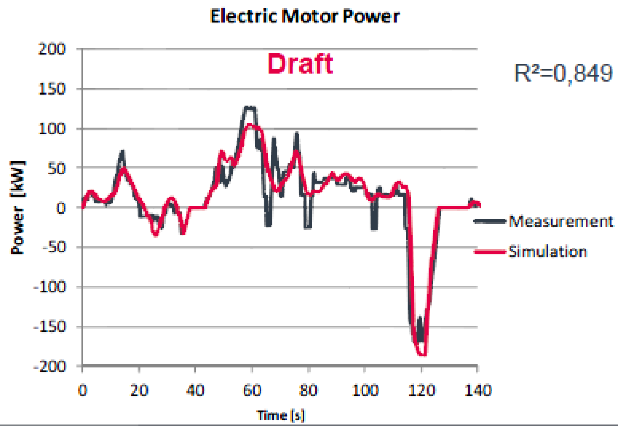
"140 sec" Verification



R²=0,997



R²=0,871

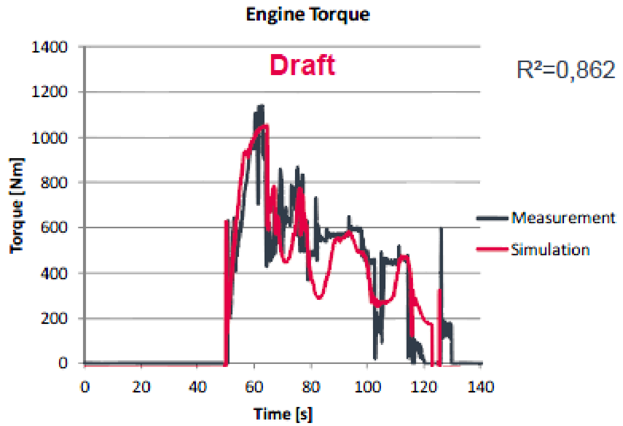


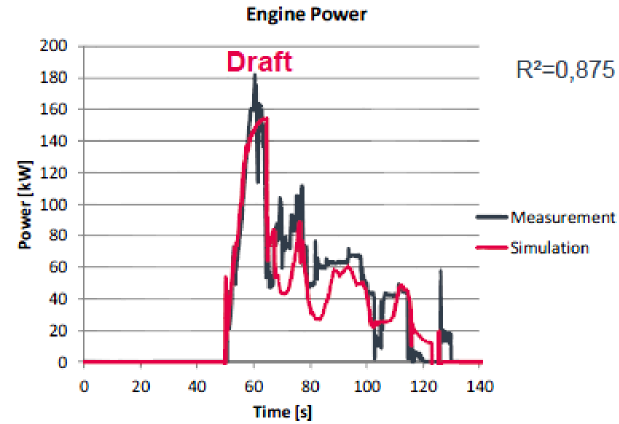
R²=0,849

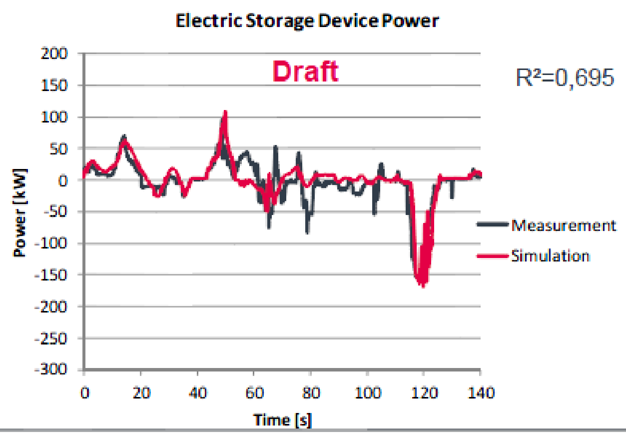
HILS Validation

Status Validation

"140 sec" Verification

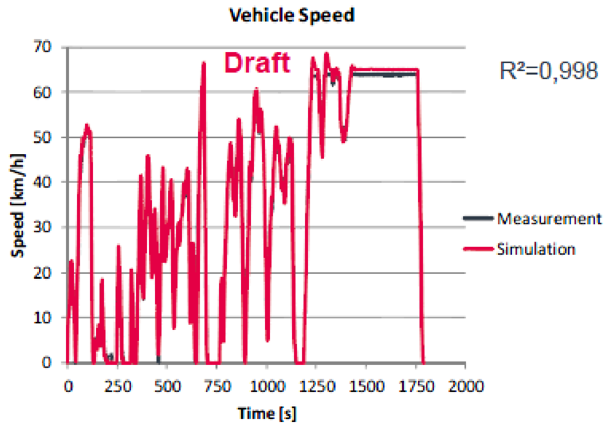


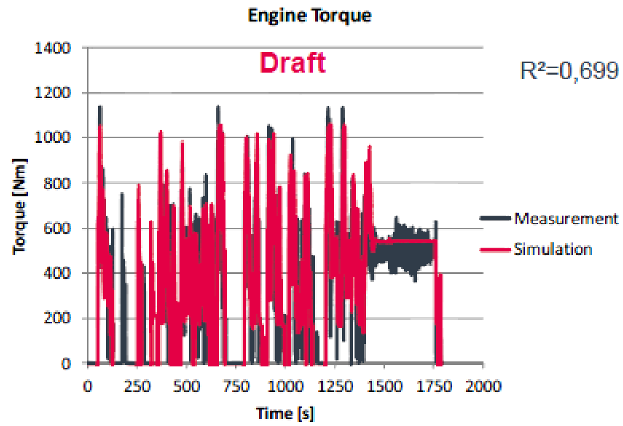


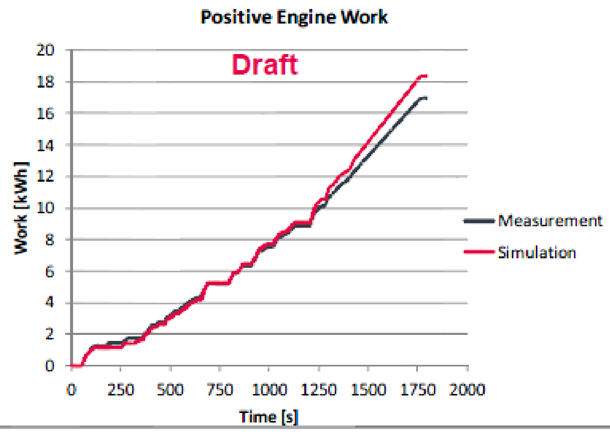


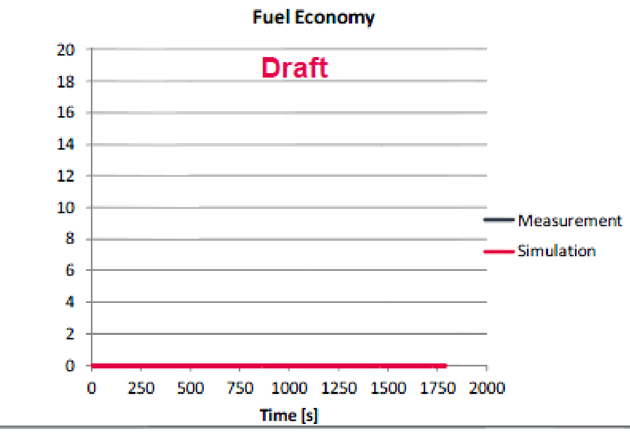
HILS Validation
Status Validation

"Overall" Verification









HILS Validation

Status Validation

Verification

WHVC 0s-140s	Vehicle	Electric motor		Engine		Battery
	Speed	Torque	Power	Torque	Power	Power
Kokujikan	0.97	0.88	0.88	0.88	0.88	0.88
WHVC flat	0.997	0.871	0.849	0.862	0.875	0.695

WHVC full	Vehicle speed	Engine Torque	Positive engine work	Fuel economy value
	R^2	R^2	$W_{eng\_HILS}/W_{eng\_vehicle}$	$FE_{SILS}/FE_{vehicle}$
Kokujikan	0.97	0.88	>0.97	<1.03
WHVC flat	0.998	0.699	1.07	N/A

HILS Validation

Status Validation

Current Status	Open Points / Next Steps

▪ First Validation
▪ Using the driver model with reference speed for the simulation
▪ Using the measured CAN-data from the roll bench
▪ Calculation of the determination coefficients
▪ Calculation of the positive engine work
▪ First results don't match the tolerances
▪ Many Reasons. For example:
  ▪ Quality roll bench measurement
  ▪ Differences between real driver and simulation driver
  ▪ etc.
	▪ Using measured AP/BP values for the simulation for "140 sec" verification
	▪ Using the driver model with measured speed and slope for "Overall" verification
	▪ Using calculated torque values (from map with command values instead measured values
	▪ Verification of the fuel economy
	▪ Verification with new simulation data and recalculated measured data

A first validation of the open source model is made.
For the final validation many changes and optimisations are needed.

Validation test program 2

HILS/SILS model verification

- Summary and conclusions
  - (SIL)model verification could not be achieved until now
  - Causes are investigated (model & measurement related)
    - Accuracy of chassis dyno directly influences validation results
    - Torque measurement system is planned to be applied on vehicle to check chassis dyno accuracy
    - Regression analysis considered as good basis, further investigation regarding time sensitivity and alternatives needed
  - HILS verification (for Volvo & MAN) rather not reasonable before proper SILS verification
  - Too early to agree HILS certification procedure on a solid technical basis

Open issues for a GTR drafting

- Open issues from final report of VTP1
  - Complete list can be found in report document
  - Only priority 1 issues are addressed here
  - Priority 2 and 3 issues depend on decisions for priority 1 issues

Open issues for a GTR drafting
Certification procedure (C1)

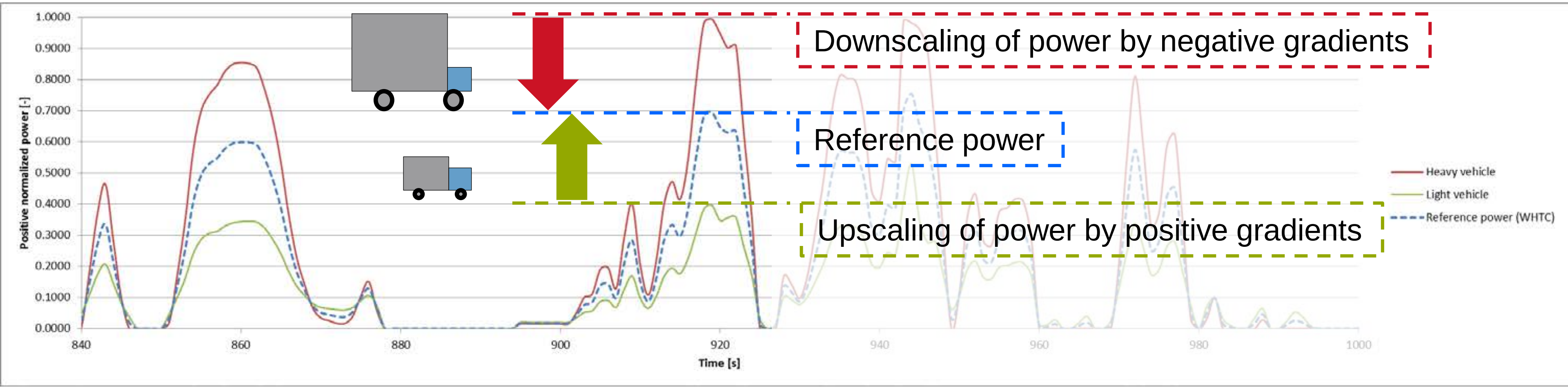
- Define which approach can be used for HDH certification
  - Standardized generic vehicle
  - Worst case vehicle
  - Actual vehicle
  - Approaches as alternative option in parallel

Open issues for a GTR drafting

Certification procedure (C1)

- Define which approach can be used for HDH certification
  - Method for definition of vehicle parameters not really relevant
  - Gap between actual power/work of vehicle on flat WHVC and reference power/work is compensated via gradient calculation for drivecycle

E.g. Two vehicles with the same rated power of powerpack but different mass



Open issues for a GTR drafting
Certification procedure (C1)

- Define which approach can be used for HDH certification
  - proposed test cycle approach by institutes would align positive and negative work to reference values independent of vehicle parameters
  - Proposal: definition of vehicle parameters for certification test (mass and frontal surface) as function of rated power possible
  - Common functions have to be defined representative for global vehicle fleet
    (available data at OEMs as basis for definition?)

Open issues for a GTR drafting

Certification procedure (C3)

- How should gearboxes and shift algorithms be handled? (4.3.2.4)
  - Should a gearbox in general be part of the certification?
  - If yes, should it be a standardized gearbox and shift algorithm or the individual gearbox and shift algorithm?

Open issues for a GTR drafting

Certification procedure (C3)

- How should gearboxes and shift algorithms be handled?
- Proposal: Individual gearbox with individual shift logic should be part of the certification
  - Reference cycle is defined at wheel hub
  - Wide range of different gearboxes for HDH (application specific)
  - Definition of common generic gearbox not so easily possible as for conventional HDV
  - Generic gearbox could lead to engine operation points outside the normal window > could provoke ECU failure, since ECU is most likely vehicle specific
  - Standardized shift logic (VECTO) for manual gearbox

Open issues for a GTR drafting

Certification procedure (C4)

- Should post-transmission powertrain test, HILS with verification on chassis dyno and HILS with verification on system bench (pre-transmission powertrain test) become alternative options for emission certification in the GTR?
  - Inclusion of gearbox in certification process recommended (see previous issue C3)
  - For HILS system test bench (pre-transmission powertrain) an extra offline conversion program from speed cycle to rotational speed and torque pre-transmission powertrain cycle and therefore also generic gearboxes and shift provisions would be needed
  - Generic gearbox, final drive ratio and tyre radius could cause big deviations of engine operation points from real world application

Open issues for a GTR drafting
Certification procedure (C4)

- Should post-transmission powertrain test, HILS with verification on chassis dyno and HILS with verification on system bench (pre-transmission powertrain test) become alternative options for emission certification in the GTR?
  - Pre-transmission option not recommended
    - Connection between hybrid system and vehicle application missing
    - Resulting test cycle not directly comparable to post-transmission approach
    - Post-transmission test is closer to real vehicle operation

Open issues for a GTR drafting

Certification procedure (C4)

- Should post-transmission powertrain test, HILS with verification on chassis dyno and HILS with verification on system bench (pre-transmission powertrain test) become alternative options for emission certification in the GTR?
  - HILS (chassis dyno) and post-transmission powertrain test would be compatible
  - Alignment between post-transmission powertrain testing and HILS (chassis dyno) testing is necessary
  - Same boundary conditions lead to comparable test cycles

Open issues for a GTR drafting

Drive cycle development (D6)

- Definition for the rated power of a hybrid system

  (in order to denormalize the test cycle and/or to calculate vehicle parameters, see 4.3.1.3)
- Directly affects test cycle work demand
  - For a parallel hybrid:
    - Only ICE power or total powerpack power?
      - Dependent of pre-post.transm. topology?
      - Dependent of in-use application?
    - If total power, consider peak of continuous power of el. machine
  - For a serial hybrid:
    - Power of traction machine has to be used – not ICE power
    - Continuous or maximum power?

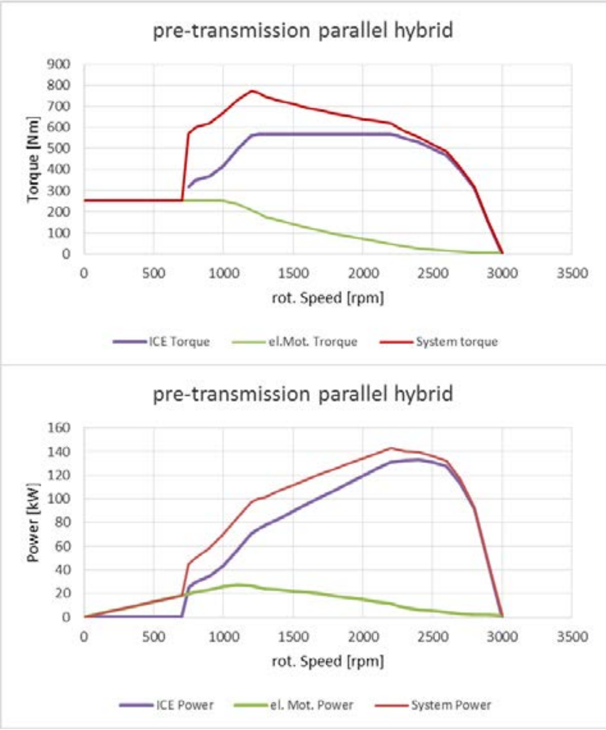
Open issues for a GTR drafting

Drive cycle development (D6)

- Definition for the rated power of a hybrid system

  (in order to denormalize the test cycle and/or to calculate vehicle parameters, see 4.3.1.3)

- For a parallel hybrid:
  - Only ICE power or total powerpack power?
    - Pre-transm. parallel hybrid topology
    - Total power will increase cycle work, (27kW el. Motor + 133kW ICE = 140kW sum) vs. 133kW ICE conv. HDV
    - For pre-transm. parallel hybrid: el. Motor will most likely not affect rated power dramatically



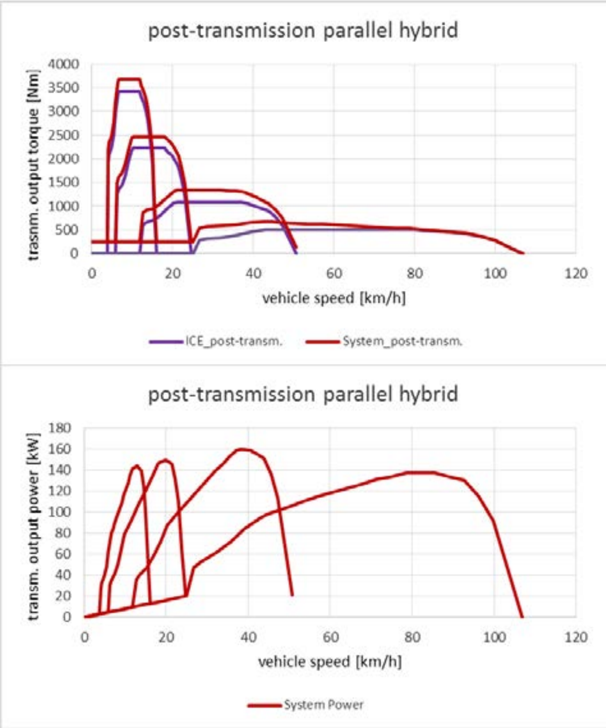
Open issues for a GTR drafting

Drive cycle development (D6)

- Definition for the rated power of a hybrid system

  (in order to denormalize the test cycle and/or to calculate vehicle parameters, see 4.3.1.3)

- For a parallel hybrid:
  - Only ICE power or total powerpack power?
    - Post-transm. parallel hybrid topology
    - Total power will increase cycle work, (27kW el. Motor + 133kW ICE = 160kW sum) vs. 133kW ICE conv. HDV
    - For post-transm. parallel hybrid: el. Motor will more likely affect rated power



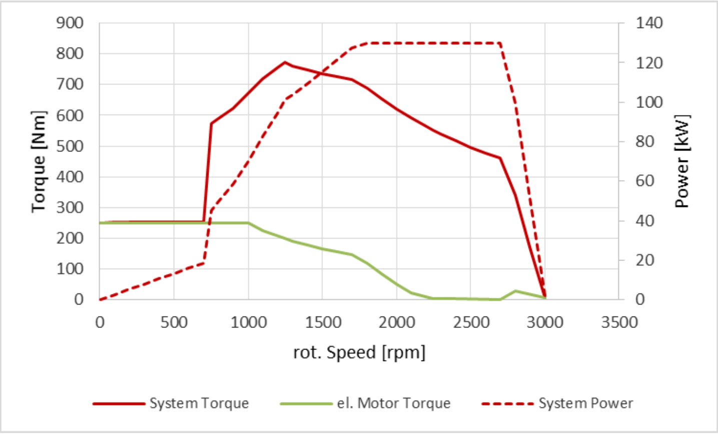
Open issues for a GTR drafting

Drive cycle development (D6)

- Definition for the rated power of a hybrid system

  (in order to denormalize the test cycle and/or to calculate vehicle parameters, see 4.3.1.3)

- For a parallel hybrid:
  - Only ICE power or total powerpack power?
    - Dependent of in-use application?
    - Even though ICE and el. Motor could provide more, only a specific power is applied
    - Compound test needed or OEM statement sufficient?



Open issues for a GTR drafting

Drive cycle development (D6)

- Definition for the rated power of a hybrid system

  (in order to denormalize the test cycle and/or to calculate vehicle parameters, see 4.3.1.3)

  - For serial and parallel (considering el.motor power) hybrids: Consider continuous or peak power of el. machine?
    - El. Machines mostly capable of short term overload
    - Peak power would unrealistically increase cycle work – vehicle would not be able to follow desired speed during the entire test
    - Continuous power could underestimate cycle work – if motor with low continuous power and high overload capacity is used
    - Balance between peak and continuous power may force more complex measurements → suiting measurement procedures already available?

Open issues for a GTR drafting

Drive cycle development (D7)

- How to proceed with vehicles which are by design not able to follow WHVC speed (e.g. city bus max. speed)? → Affect on drive cycle

ignore

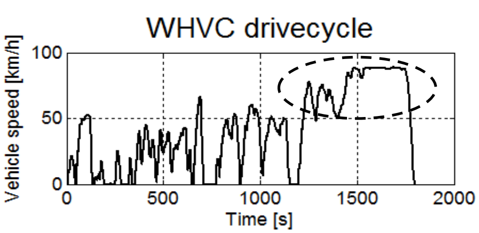
- Calculate gradients like vehicle is able to follow desired speed
- Vehicle will not be able to follow at CD test run
- Vehicle will not match WHTC cycle work at all
- Not possible to compare conv. HDV and HDH

Limit speed to vehicle max. speed (demand WHTC power)

- Consider vehicle max speed (WHVC max speed = vehicle max speed)
- Calculate gradients, anyway demand corresponding WHTC power
- High road gradient results in sections where WHVC speed > veh max speed
- Vehicle may not be able to follow / overheat (~300 sec.)
- General issue of appropriate test cycle

Limit speed to vehicle max. speed (scale down WHTC power)

- Consider vehicle max speed (WHVC max speed = vehicle max speed)
- Calculate WHTC design vehicle power at actual vehicle max speed
- Calculate gradients with scaled down WHTC power
- Actual vehicle will be able to follow and deliver scaled down WHTC work



THANK YOU FOR YOUR ATTENTION!

Jonas Fredriksson
jonas.fredriksson@chalmers.se

Gérard Silberholz
silberholz@ivt.tugraz.at

Christoph Six
christoph.six@tuwien.ac.at