# Minutes

IFA visit to Japan within the framework of the GRPE-HDH-Project (Worldwide harmonization of Heavy-Duty-Hybrid-Vehicles' Certification)

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This document also contains the questions from the previously sent „Question list for the study on the Japanese HILS Commercial Hybrid vehicle regulation“ and the corresponding answers from the Japanese experts, which are partly supplemented by notes from the authors of this document.

## 1. Day one

Monday, .July, 25th 2011

Location: Tokyo, JASIC (Japanese Automobile Standards Internationalization Center), 3F SHOEI Building, 6 Rokubancho, Chiyoda-ku Tokyo 102-0085

Participants:

- Mr. K. Narusawa, Director International Harmonisation Office
- Mr. N. Osaki (Mitsubishi Fuso + JASIC)
- Mr. S. Yamaguchi (Hino Motors)
- Mr. Keiichi Buma (Denso Corp.)
- Ms. Y. Toba (JASIC)
- Mr. K. Morita (JARI)
- Mr. T. Kakihara (Isuzu Motors)
- Mr. N. Suzuki (Ministry of Land, Infrastructure, Transport and Tourism)
- Mr. A. Kajiwara (Ministry of Land, Infrastructure, Transport and Tourism)
- Mr. B. Schneeweiss (IFA)
- Mr. M. Planer (IFA)

Topics:

### *1.1. Greeting, Introduction of experts.*

### *1.2. Presentation on the Project tasks and the IFA/TU Vienna research institute (Mr. Schneeweiss).*

### *1.3. Presentation on the Japanese Fuel Efficiency Regulation For Heavy Duty Vehicles and the test methods used (Mr. Narusawa):*

- Document is available in printed version as well as in .pdf format.
- Mr. Narusawa comments on figures on Greenhouse Gas Emissions by Heavy Duty Vehicles in Japan.
- Presentation of the „Top Runner Approach“, which is the method to define future fuel efficiency standards considering today’s vehicles and positive (+α) as well as negative (-β) factors.
- Vehicles are divided into several weight classes; each weight class has its own fuel efficiency standard value.
- For each weight class, a target standard value for FY2015 is defined
- Presentation of the method to obtain a conventional vehicle’s fuel efficiency value:
  - It is determined by using two different driving cycles (JE05 and Interurban Driving Mode (constant velocity of 80km/h with road gradient))
  - An engine speed pattern and engine torque pattern is created using a simulation algorithm (referred to as „conversion program“). The conversion program uses vehicle-specific data such as full load engine torque, number of gears, gear ratios, Rolling resistance and air drag, vehicle mass etc. to calculate combustion engine speed and combustion engine torque from the two driving cycles.
  - Fuel Efficiency for both driving cycles is then calculated using a fuel consumption map of the engine.
  - Both Fuel Efficiencies are combined to one single value using weighting factors. Weighting factors are fixed for each vehicle category and each vehicle weight class.
- Presentation of the HILS-Method to obtain a Heavy-Duty-HYBRID-vehicle’s fuel efficiency value:

- Determination of Combustion engine’s speed and torque pattern is done by using a Simulation method, in which the hybrid vehicles engine control unit (hybrid ECU) is included as a hardware component (Hardware-in-the-Loop). The Hybrid-ECU contains the vehicle’s Hybrid-control strategy, which has an essential influence on the combustion engine’s speed and torque.
- After determining speed and torque for the hybrid vehicle, Fuel Efficiency is obtained according to the method for conventional vehicles (using a fuel consumption map and weighting factors – see above).
- A detailed discussion on the HILS method is scheduled for the following two days.

### *1.4. Questions and Answers:*

1.4.1. Q: How are the emissions of pollutants determined? A: They are determined using an engine test bed with open-loop control of the engine using the Speed and Torque profile. Fewer tests than for fuel efficiency are necessary. One family of 14 engines has to be tested only once. The results are representative for a variety of vehicles.

1.4.2. Q: How can you guarantee that the “conversion algorithm” is correct for a broad variety of vehicles? A: The Algorithm was tested by comparing the algorithm’s results to actual measured data of two different vehicles. It proved to be accurate while using several kinds of speed profiles and varying payload conditions. Portability to other vehicles is proven by that.

1.4.3. Q: How are pollutants referred to? A: Pollutants are given in g/kWh, measurement of the pollutants results in a measured mass, which is given in grams.

1.4.4. Q: What is the basis work for the specific pollutants emissions (the kWh) for a hybrid vehicle? A: The reference work is the overall powertrain work (energy), which is the summation of the propulsion work of combustion engine and Motor/Generator. This is to ensure that the advantage of a hybrid powertrain can be exploited (mainly regenerative braking).

1.4.5. Q: Did you consider Engine-in-the-loop rather than Hybrid-ECU-in-the-Loop? A: Engine-in-the-Loop has never been considered.

1.4.6. Q: How do you handle non-charge sustaining energy management strategies (Plug-In-Hybrids)? A: There is no regulation for Plug-In-Hybrids so far, but HILS is able to deal with Plug-Ins. The electric energy consumption is declared separate from the value for fuel efficiency. In the case of “Plug-in hybrid vehicles” the regulation for passenger cars is already established but not for heavy duty HEV.

1.4.7. Q: Did you have any cases of "misuse" of the system, or misinterpretation of the regulation, which lead to unrealistically positive test results (emissions and fuel consumption)? A: In general, Japanese manufacturers are trusted to bring the original ECU and perform the certification process as intended by the authorities.

### *1.5. End of first meeting*

## 2. Day two

Tuesday, July, 26th 2011

Location: Tsukuba, JARI (Japanese Automobile Research Institute), 2530 Karima, Tsukuba, Ibaraki 305-0822

Participants:

- Mr. K. Narusawa, Director International Harmonisation Office
- Mr. T. Kawai, Ph.D. (NTSEL)
- Mr. N. Osaki (Mitsubishi Fuso + JASIC)
- Mr. S. Yamaguchi (Hino Motors)
- Mr. Keiichi Buma (Denso Corp.)
- Mr. K. Morita (JARI)
- Mr. T. Kakihara (Isuzu Motors)
- Mr. Keiji Furumachi (Isuzu Motors)
- Mr. Kunihiko Hikiri (Volvo + UD Trucks)
- Mr. Akihiro Kurokawa (JARI)
- Ms. Michiko Yoshihara (JARI)
- Mr. B. Schneeweiss (IFA)
- Mr. M. Planer (IFA)

Topics:

### *2.1. Greeting, Introduction of experts.*

### *2.2. Presentation by Mr. Morita: Overview of the Fuel Economy and Exhaust Emissions Test Method with HILS for Heavy-Duty HEVs.*

- General overview of test system setup and utilization of ECUs to obtain engine Speed and Engine Torque within a driving cycle.
- System bench method is a second method for HDH certification, which is allowed by Japanese authorities, but issues occur with the reproduction of negative torque on the test bench.
- For HILS certification, five types of hybrid electric vehicles are considered (four parallel, one serial hybrid). Powertrain models for these five types have been developed.

- The five topologies and parameters (including battery type) are inspired by actual vehicles on the Japanese Market. Production for one of the vehicles has already ended.
- New powertrain topologies can be implemented, but it takes some time to build up the model + verification.
- The Control Units which are used for the HILS System are Hybrid Control Unit and Gearbox Control Unit. Engine Control Unit is not used.
    - All five hybrid vehicles existing on Japanese market have the hybrid control unit separated from the engine control unit.
    - With the gearbox control unit, this is the same
    - It was decided NOT to use the engine control unit in the HILS system, because in this case it would be impossible to standardize the engine model.
    - In the HILS system, Hybrid control Unit and Gearbox Control Unit shall be used.
- So, a multi-Control Unit configuration is necessary: A separate Presentation “Study of multi ECU” has been shown.
    - In modern vehicles, a network of many different control units exists (e.g. Engine CU, Hybrid CU, AMT CU, IdleStopStart CU, DC/DC CU, etc.). An increase in the number of Control units is expected.
    - The HILS System will become huge, if all of these Control Units are considered.
    - A solution could be, to implement the most important functions of minor important Control units into the Interface Model of the HILS system (kind of simplified software-in-the-Loop).
    - Thus, verification process (comparing model output to actual measured data) is important to get correct results.
    - The interface model is developed by the individual vehicle manufacturer; it is confidential and not open-source.
- The powertrain Model is discussed in detail:
    - Driving resistances, engine model, Motor/generator model, battery model, rigid body drivetrain model (details see presentation charts)

- HILS Verification process:
  - To verify the reproducibility for the behavior of the actual vehicle (or system).
  - The Verification process is divided into two sub-verifications: Short-Period Vehicle Operation and Correlation of Load and fuel efficiency within the whole test cycle.
  - Short-Period Vehicle Operation: A small trip during urban driving part of JE05 test cycle. Verification means comparison of actual measured data and model result data of:
    - vehicle speed or engine rpm
    - torque and power of the electric motor
    - torque and power of the engine
    - power of RESS
  - Correlation of Load and fuel efficiency within the whole test cycle: Comparison of actual measured data and model result data of:
    - Total engine work
    - fuel consumption
- Prior to the HILS test, a SILS system verification is done. This is mainly to test the DSP (Digital Signal Processor) for sufficient calculation performance.
- An overview of the Simulink model of the powertrain is given.
- The Interface model is described in more detail: Each manufacturer is allowed to create his own interface model to connect his Control Units.
- The purpose of the interface model is
  - To convert physical quantities of ECU electric signals to fit on the open source model calculations.
  - To generate dummy signals if necessary to prevent vehicle fail.
  - to convert some ECU signals necessary for calculations if needed
- It is mandatory to verify the accuracy of HILS result by comparing with actual HEV test result for verifying the interface model. Thus, it is impossible to create an illegal interface model.

## *2.3. Questions and answers:*

2.3.1. Q: How often does the manufacturer have to do a verification test? A: A separate presentation describes the cases, in which a verification is necessary (‘verification test’ – ‘overview of hybrid system test flow for the verification of HILS - “Kokujikan No.281):

- First case to use HILS system
- Cases to change hybrid system layout consists of engine, electric motor, transmission (TM) and clutch (CL),
- Cases to change the structure of components or constant
- Cases to change sort of components
- Cases to change delay time of engine model, time constant of engine/electric motor models
- Cases of other reasons

If a HILS system is already verified, the following changes do NOT require a new certification: Changes in:

- Engine torque characteristics
- Electric motor torque, electricity characteristic
- Battery internal resistance, voltage characteristic
- Vehicle specification except changing GVW cross over 12tons

2.3.2. Q: Where is the driver model? A: It is located in the Interface model. The Structure of the driver model can be chosen freely (e.g. PID-control or Time-series-data). The resulting vehicle speed has to stay within the given borders.

2.3.3. Q: How do you manage to have a balanced State of Charge at the end of the driving cycle? A: This is mostly done by doing a variation of the initial SoC-Value until End-SoC is correct. This is easily done by the manufacturers.

2.3.4. Q: How is the intermittent start/stop engine operation of a Heavy Duty Hybrid Vehicle handled on the test bed? A: Serial Hybrid Powertrain: Like in the vehicle, the engine is dragged by the dynamometer. A starter motor is not needed.

2.3.5. Q: Is there a continuous improvement process to adapt the procedure or the models according to the experience gained while working with the method? A: The vehicle manufactures improve the vehicle model if necessary to get the certification. Japanese vehicle model for the certification will be replaced by the ”Open Source Model”, which is fully open to everyone. User i.e. vehicle manufactures can use the “Open source model” without any change or it is possible to modify it to fit their HEV system. In any case the vehicle model must prove its accuracy in comparison to actual vehicle/system data and pass the criteria. It is possible to keep a newly developed simulation model confidential, in order to protect intellectual property until the actual vehicle is available on the market.

2.3.6. Q: Is there a possibility to do the verification procedure with random driving cycles? A: This is not considered, it is always JE05 mode

### *2.4. Demonstration of HILS on the test bench: Hardware setup, DSP and control system is presented at JARI facilities. A HILS System run with an actual ECU is performed. Results are displayed on the monitor.*

### *2.5. Technical round/tour through the JARI facilities.*

### *2.6. Questions and Answers:*

2.6.1. Q: Fuel consumption: Do you calculate overall fuel consumption by using the engine map or is it (maybe in addition to that) measured on the test bench (e.g. by measuring CO2 emissions)? A: We use engine fuel consumption map which is measured on steady state hot condition not only for HEV but also for the conventional vehicle. The test to measure fuel consumption on the engine test bed is a process of the certification. The engine torque/speed historical data is provided by HILS and calculate the sum of the fuel consumption on the map. However in the case of chassisdyno or power pack test bed to measure fuel flow rate or measure $CO_2$ emissions in the driving cycle.

2.6.2. Q: Is the cycle work (kWh positive work of the power pack) from HILS comparable to the cycle work in the test cycles for standard Heavy Duty Engines (13-mode and/or JE05, other relevant cycles?) A: We use JE05 driving cycle to compare the HILS work with actual work to prove the accuracy of HILS.

2.6.3. Q: Is there a sensitivity analysis available, which looked at the influence of the generic data on the resulting test cycle? As example a variation of vehicle mass, aerodynamic drag, rolling resistance coefficients, moments of inertia etc. with the same ECU connected to the HILS simulator? A: In the case of Japanese certification, the fixed value for “rolling resistance coefficient”, “air resistance coefficient ”, “ transmitting efficiency of Transmission and final Diff” and “inertia of the driven parts of the vehicle” is used. In the case of “inertia of driving parts i.e. engine and input part of the transmission” fixed value is used for conventional but actual/designated value for HEV because of adding electric motor. In the case of vehicle specification i.e. tested weight, whole width, whole height etc. actual data or standard data by MLIT is used for the exhaust emission test and only standard data by MLIT is used for fuel efficiency. The parameter study of coefficients etc was done by NTSEL.

2.6.4. Q: Is it necessary to run the system in real time? A: Yes we think so because the use of the actual ECU and real time simulation is needed for HILS certification.

2.6.5. Q: Have you considered using Software-in-the-Loop instead of HIL for the certification process? A: We are sorry we have never experience to study software- in – the –loop for the certification. All software certification cannot be accepted for the certification because the actual part is needed for the certification.

2.6.6. Q: Have you considered using the method for all type of vehicles, hybrids - non-hybrids, passenger cars - heavy duty trucks? A: The scope of HILS certification is only for the heavy duty vehicles. Middle and light duty vehicles, mainly GVW<3.5ton, is tested on chassisdyno. The exhaust gas of the conventional heavy duty is tested on engine test bed by using torque/speed calculated by conversion program of MLIT. Using HILS for all vehicles has not been considered.

2.6.7. Q: SOC is not a measurable quantity, how do you handle this problem? A: During the driving cycle, the battery current is being measured and the total sum of current, charging and discharging, is evaluated within the criteria of the energy balance. Experience shows that the correlation of the SoC is good. The actual SoC values are not so important. The Energy balance is important.

## *2.7. End of second meeting*

# 3. Day three

Wednesday, July, 27th 2011

Location: Tsukuba, JARI (Japanese Automobile Research Institute), 2530 Karima, Tsukuba, Ibaraki 305-0822

Participants:

- Mr. K. Narusawa, Director International Harmonisation Office
- Mr. T. Kawai, Ph.D. (NTSEL)
- Mr. N. Osaki (Mitsubishi Fuso + JASIC)
- Mr. S. Yamaguchi (Hino Motors)
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- Mr. Akihiro Kurokawa (JARI)
- Mr. B. Schneeweiss (IFA)
- Mr. M. Planer (IFA)

Topics:

### *3.1. Explanation on the test procedures for Components:*

- Engine: Test condition is steady-state and hot, there must be 80 measuring points or more (for the engine torque map) or 30 or more (fuel economy map). Friction torque must be measured under at least 6 conditions (different revolution speeds). Results are interpolated and put into the simulation model.
- Electric motor: wiring should be similar to the configuration used in the actual vehicle. Electric motor performance certification is done by measuring 72 Points within the whole motor/generator map. Interpolation between the points is done to put the map into the simulation model. Temperature is also measured. DC power source can be chosen by the manufacturer. It is not necessary to achieve steady-state condition for a longer period of time.
- Battery: The internal resistance and the open circuit voltage are determined on a battery test bench. The battery shall be in in-vehicle

condition. Either Battery Packs or Modules can be used. A single Cell is not allowed for testing. These tests are executed by the battery manufacturers in Japan.

### *3.2. Actual Vehicle test for the HILS verification process: Necessary data is gained by reading CAN Bus messages as well as using different sensors on the vehicle.*

### *3.3. Questions and Answers:*

3.3.1. Q: Which Hybrid topologies can be covered by the simulation models / which of them do you expect will occur in the future (e.g. powersplit/parallel/serial)? A: At this time there are 2 types of vehicle models: parallel hybrid with single e-motor and serial hybrid. At the moment, automatic transmission model with torque converter and Dual clutch type automated manual transmission are under the development.

3.3.2. Q: Battery Size - Are Plug-In Hybrids considered in the model (e.g. by adapting battery parameters)? A: HILS has a possibility for the application for Plug-in hybrid. It seems possible to input the appropriate battery capacity and the initial SOC for plug-in use.

3.3.3. Q: Component's thermal behavior has an influence on fuel consumption and pollutants of the powertrain. A hybrid vehicle control strategy may focus on optimizing also the cold start behavior of the engine: Have you considered integrating the thermal behavior into the models and the component testing? A: If basic control map (in the ECU) of the engine was changed when cold starting, HILS is not available, however if the same map is used for both cold and hot condition, HILS seems available. Cold start is not considered in the HILS system.

3.3.4. Q: Engine Model - Dynamic Torque Buildup: Why was the kind of modeling chosen? A: engine torque characteristic is provided only from the steady state torque map test. Transient characteristic is provided by time-delay constant but the accuracy of engine torque behavior shall be verified by comparing with the actual data. If the verification is okay, this kind of modeling is sufficient. The manufacturer is allowed to change the value.

3.3.5. Q: How does the Clutch/Torque Converter model work? A: Torque-converter model is under development. Clutch model simulates the operation of clutch behavior between the transmission and engine. Input speed to transmission (with e-motor) and loading torque to the engine model are calculated by the clutch model.

3.3.6. Q: Starting System: There are several possibilities to start the internal combustion engine in hybrid vehicles (e.g. by means of a starter motor or by the Motor-Generator): Is the model able to deal with this variety? A: Both cases to use high voltage electric motor and to use low voltage starter are available.

3.3.7. Q: Engine/Motor/Generator ASR Control: Is it necessary to simulate it as there is no slip/friction model for the tires or lateral dynamics? Is there a slip/friction model? In your opinion, what would be the advantage of a slip/friction model for the tires? A: We use the fixed rolling resistance coefficient, air resistance coefficient so we do not use the complicated tire model. We do not consider the slip event of the tire but the accuracy of HILS is proven and in addition in the case of the conventional vehicles we do not consider it. ASR control is used to control the slip within the clutch model.

3.3.8. Q: Accessories Model: Which of the accessories are considered in the Driving cycle to be activated and how do you deal with them (constant power demand, intermittent power demand, …)? A: the map of accessory driven torque is prepared in the vehicle model for the verification of HILS accuracy to fit the condition of the actual vehicle. However it is not used for the exhaust gas/fuel efficiency certification same to the conventional vehicle certifications.

3.3.9. Q: Accessories Model: How are "non-usual" accessories like electrically actuated water pumps etc. represented in the model? A: it is not used for the certification same to the conventional vehicles. A map for the DC/DC-converter is used in the model, electrical accessories have an influence on the SoC → Actual vehicle measurements must fit the model results (verification process).

3.3.10. Q: Regenerative Braking Model: Brake Force Splitting between Motor/Generator and mechanical friction brakes is done in the HCU/ECU? A: We use the minimizing algorithm of the electronic braking system in the interface model to use first priority of the recuperating braking before using mechanical braking.

3.3.11. Q: Battery long-time degradation: How do you deal with lifetime influencing parameters, e.g. SoC-Range, maximum Battery Current, etc? A: We don’t use SOH (State of Health) because it is not still clarified in definition etc. and it is not so important for the HEV. Swing width of SOC is due to the actual ECU for the normal use.

3.3.12. Q: Could you please clarify how your model verification is done? A: The verification process is described in the presentation (Two stage verification (short-term and long-term)).

3.3.13. Q: You have very tough limits on your model verifications, why? A: it is needed to evaluate precise exhaust emission/fuel efficiency.

3.3.14. Q: Model errors or inaccuracy can make huge influence on the end result, due to control. What considerations have you considered for this fact? A: We use the verification process in the certification to prove the HILS accuracy.

3.3.15. Q: How difficult is it to include a new type of hybrid powertrain in the HILS method? A: Any manufacturer may create a new vehicle model and is allowed to use it for the certification, if the verification result to prove HILS accuracy is approved by NTSEL.

3.3.16. Q: No temperature models are included, how do you ensure not to overuse the electric machine or the battery pack? A: In the verification process, actual vehicle/system test for JE05 driving cycle is evaluated so if over heat or other problems would occur; it is clarified in the certification process.

3.3.17. Q: What happens, if a temperature signal from the powertrain is needed as an input value for the HCU? A: The signal has to be created in the simulation model → new models would be necessary

3.3.18. Q: Which models are the most critical to model accurately? A: All of the models are important, we think.

3.3.19. Q: Is the Driver Model part of the hardware interface model? A: Driver model exists in the interface model and is created by manufactures.

3.3.20. Q: Who is in charge of developing the driver model? OEMs or the authorities? A: OEMs develop the driver model in their interface model. 2 types of driver model are considered, one is PID control model and another is time history table of accelerator pedal/braking pedal signals during the driving cycle.

3.3.21. Q: Can you simulate a forward-looking driver behavior? A: It is allowed to use a forward-looking driver model and there is no limitation for the driver model only needed to keep the vehicle speed within the tolerance of the target speed.

3.3.22. Q: What type of functions can you include in the interface blocks? A: Fail mask and translation in unit are basic function of interface model but please see the material of “study of multi ECU” regarding other functions.

3.3.23. Q: Do you have any ideas on how to handle a distributed control system? A: please see the material of “study of multi ECU” regarding distributed control systems.

3.3.24. Q: If a Distributed Control System is used: Who is responsible for correctly connecting all Control units? OEM or authorities? A: OEM is responsible for the structure of their HILS system. The most important process is to prove the accuracy of the HILS system.

3.3.25. Q: Do the driving cycles incorporate roads with ascending/downward slope? A: JE05 driving cycle on the flat road condition and the inter-city high-way driving cycle with gradients on constant 80km/h speed. Please see the material presented by Narusawa-san on day 1.

3.3.26. Q: Future Energy Management strategies may incorporate forward-Looking energy management (e.g. using GPS signals) to improve fuel economy or emission of pollutants (e.g. in urban areas). Is there any idea how to handle this in the HILS certification procedure? A: HILS has a technically possibility to include the GPS signal of road condition or special control for the reduction of pollutant emission in the city by using Car-navigation information but it is needed to study the driving cycle for the certification to consider the GPS/Car-navigation information for not only HEV but also conventional vehicles.

3.3.27. Q: A second energy management strategy could be recording of frequently driven journeys and optimizing energy management based on this data, so that it is optimal for this single journey. How can that be dealt with in the certification procedure? A: Similar to the above answer, it shall be clarified for the driving cycle for the certification to deal with the optimizing the control of hybrid system according to the learn of driven journeys.

3.3.28. Q: Do you think it could be advantageous to do measurements for the engine dynamic torque buildup instead of using fixed values (delay-Time = 0.01s and time constant = 0.01s)? A: We need the verification process to prove HILS accuracy so it seems convenient to use the delay time for the model if verification is achieved.

### *3.4. End of meeting*