Evaluation of Hybrid System and Plug-in Hybrid System In Japanese Fuel Efficiency Regulation

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1. Top Runner Approach for FE regulation
2. Fuel Efficiency regulation for HDVs
   - Simulation Test Method
   - for HD HEV Test
3. Fuel Efficiency Regulation for LDVs
   - Conventional Test Method
   - for LD HEV Test
   - Challenge for PHEV Evaluation
4. IPT Bus : PHEV for HDVs
By target year, average fuel consumption must be higher than the best fuel efficiency in the base year.

- Standard should be high but reachable because target values are already achieved by actual vehicles in the base year.
- Particular types of cars such as HEVs and MT mounted cars are excluded from top runner.

Positive Factors: Technological Improvement
Negative Factors: Exhaust Emission Regulations, etc. (trade-off relation with fuel economy)
“Top runner approach”: Positive factor (+α)

- **Conventional fuel efficiency improvement technologies (2 – 4 % in total)**
  - Engine compression ratio increase, Friction reduction, Weight reduction,
  - Reduction of vehicle travel resistance, Low rolling resistance tires
  - Optimizing overall control of engine

- **Engine improvement [Gasoline engine]**
  - 4 valves (1%), 2 valves and 2 ignitions (2%), Variable valve system (1 – 7 %)
  - Direct-injection stoichiometric engine (2%), Direct-injection lean-burn engine (10%)
  - Variable cylinder (7%), Miller cycle (10%) 
  - High volume EGR (2%), Roller cam follower (1%), Offset crank (2%), Variable compression ratio (10%)

- **Engine improvement [Diesel engine]**
  - 4 valves (1%), Electronically controlled fuel injection device (1.5%), Common rail (2.5%), Direct-injection diesel engine (8%), High pressure injection (1%), Supercharger and supercharger efficiency improvement (2 – 2.5%), Intercooler (1%), EGR (0.5 – 1%), Roller cam follower (1.5%), Offset crank (2%)

- **Auxiliary equipment**
  - Electric power steering (2%), Charge control (0.5%)

- **Driving system improvement**
  - Idle-neutral control (1%), AT with more gears (1 – 4%), Switch to CVT (7%), Switch to automated MT (AMT/DCT) (9%), Switch to MT (9%)

- **Introduction of fuel-efficient vehicles**
  - Hybrid vehicles (15 – 70%), Diesel vehicles (20%), Idling stop vehicles (4 – 7%)
• **Exhaust emission regulations (▲3 to ▲7.5% in total)**
  – Caused by technologies used on diesel vehicles and direct-injection lean-burn vehicles in response to the 2009 exhaust emission regulations.
  – Technologies considered were engine body improvement (NOx reduction by improving EGR, PM reduction by high pressure injection, etc.) and aftertreatment devices such as NOx occlusion reduction catalyst and continuous regeneration type DPF, etc.

• **Safety regulations (▲0.1 to ▲1.4% in total)**
  – Caused by increased weight and travel resistance as a result of measures against/for offset crash, pedestrian protection, ISO-FIX, etc.

• **Noise regulations(▲0.1% in total)**
Maximum improvement: “Top runner approach”

Current Fuel Economy Performance and Level of 2015 Target Standard Values
* Example (passenger vehicle: 4 weight categories between 971kg and 1420kg)

* Fuel economy values on this table are measured by JC08 mode.
Fair Competition: Segmentation by vehicle weight

- Segmentation by weight so that competition will become fair in each category
  - Promoting introduction of advanced power-train and vehicles technologies by classifying vehicles into different categories by weight, transmission, fuel, and vehicle type.

In the case of a single standard value

- Company A sells mostly compact cars that are above the standard value, so no improvement is necessary.
- Company B sells mostly larger vehicles that are below the standard value, so most cars need improvement.
- Meeting the standard is possible just by increasing the sales of compact cars.

In the case of a standard value for each category

- Both Company A and B must improve the fuel efficiency of cars that are below the standard.
- Both companies cannot meet the standard by change of model mix and therefore, introduction of advanced technologies is necessary for all the weight class.
• For N1 vehicles, segments are defined by “several other features” in addition to “vehicles weight”, taking into consideration:
  – Market of each vehicle type
  – Applied technology for each vehicle type
  – Specification/Vehicle structure of each vehicle type

<table>
<thead>
<tr>
<th>Type</th>
<th>Fuel</th>
<th>Vehicle structure</th>
<th>Transmission</th>
<th>Weight category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Passenger car</td>
<td>Gasoline or diesel oil</td>
<td></td>
<td>MT</td>
<td>AT</td>
</tr>
<tr>
<td>2. Small bus</td>
<td>Gasoline, Diesel oil</td>
<td></td>
<td>MT</td>
<td>AT</td>
</tr>
<tr>
<td>3. Mini freight vehicle</td>
<td>Gasoline or diesel oil</td>
<td>A, B</td>
<td>MT</td>
<td>AT</td>
</tr>
<tr>
<td>4. Light-weight freight vehicle</td>
<td>Gasoline or diesel oil</td>
<td>A, B1, B2</td>
<td>MT</td>
<td>AT</td>
</tr>
<tr>
<td>5. Med-weight freight vehicle</td>
<td>Gasoline, Diesel oil</td>
<td>A, B1, B2</td>
<td>MT</td>
<td>AT</td>
</tr>
</tbody>
</table>
1. Top Runner Approach
2. Fuel Efficiency regulation for HDVs
   • Simulation Test under JE05
   • HD HEV Test
3. Fuel Efficiency Regulation for LDVs
   • Conventional Test Method
   • for LD HEV Test
   • Challenge for PHEV Evaluation
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Japanese test mode for HDVs (JE05)

Combination of Urban Driving Mode (JE05) and Inter-urban Driving Mode

Urban Driving Mode = JE05 Mode (Emission Test Mode)

• Stand-alone Engine Measurement Method
• Including Transient Operating Points

Interurban Driving Mode: 80km/h Constant Speed Mode with Road Gradient

Conversion to Histories of Engine Speed and Engine Torque
Actual Engine Test of Fuel Efficiency by JE05 Mode is NOT feasible and effective.

Stand-alone engine test of fuel efficiency by JE05 mode may require a large number of different engine types.

The manufacturers spend large resources (time, labor and money) for constructing the testing facility and performing measurements.

Evaluation of Fuel Efficiency by *Simulation Method*
Characteristics of Simulation Method

- Using real vehicle and engine specifications
  
- The method is an extension way of the emission test.
  
  → Low cost and Hi test efficiency
  
  → Problems of reproducibility of driving resistance
Simulation Method

Driving mode = \{Urban driving mode, Interurban driving mode\}

Conversion program
- Determine gear-shift positions.
- Calculate engine speed and torque.

Vehicle specifications

Fuel efficiency map

Engine Operating Mode

Fuel consumption

\[
\text{Fuel consumption} = \sum_{i=\text{start}}^{\text{end}} F.C.(i)
\]

Fuel efficiency

Phase of conversion
- Speed vs. time
- Engine speed / torque vs. time

Phase of calculation of fuel efficiency

*Before simulation, perform operation tests to create a fuel efficiency map

Simulation Method Flowchart and Equation

**Urban Driving Mode**
JE05 mode

**Engine Operating Mode**

$E_u$: Fuel Efficiency

**Interurban Driving Mode**
80km/h constant speed mode with gradient

**Engine Operating Mode**

$E_h$: Fuel Efficiency

**Combined**

$E$: Fuel Efficiency

$$E = \frac{1}{\alpha_u / E_u + \alpha_h / E_h}$$

- $E$: Heavy vehicle mode fuel efficiency (km/L)
- $E_u$: Urban driving mode fuel efficiency (km/L)
- $E_h$: Interurban driving mode fuel efficiency (km/L)
- $\alpha_u$: Proportion of urban driving mode
- $\alpha_h$: Proportion of interurban driving mode
• Fuel Efficiency Test
  ⇒ desired simple method: Simulation Method

• Emission Test
  ⇒ desired dynamo test with only engine: without electric system

• System Bench Method for HEV
  - Structurally-complex system
  - Need multiple E/D for 4-wheel drive vehicles

Hardware-In-the-Loop Simulator (HILS) Test Method was developed
HILS Test Method

Chassis Base

HEV (Hybrid Electric Vehicle)

RESS

Run JE05

Fuel Consumption Ratio

Speed (km/h)

Time (sec)

HILS (Hardware In the Loop Simulator)

Vehicle Model

Battery model

Inverter

Motor model

Engine model

Driver model

Hybrid ECU

Input Vehicle Parameters
- Gear Ratio, eff.
- Eng. spec
- Vehicle spec etc.

Virtual JE05 Running on CPU

Get E/G rpm, E/G Torque

Fuel Consumption

Exhaust Emission

Torque

Engine speed

E/D

Measurement of Exhaust Emission
**1st Step**

**HILS**

**Urban Driving Mode**

**Interurban Driving Mode**

Simulated driving by HILS Program to determine Engine Torque & Engine Speed

Input

Vehicle Specification

- Vehicle weight, Driving Resistance
- Full load engine torque, Motor characteristics
- Battery characteristics, etc.

Connect

Hybrid ECU (Real)

**2nd Step**

**Engine Operating Mode**

Fuel consumption

\[ \text{Fuel consumption} = \sum_{i=\text{start}}^{\text{end}} F.C.(i) \]

Fuel efficiency

Engine torque

Engine speed

Time (s)

*Before simulation, perform operation tests to create a fuel efficiency map*

2nd step is same as Simulation Method
HILS System

Main parameters
- Engine (Torque map)
- MG (Torque map, Electric-power consumption map)
- RESS (Internal resistance, Open-circuit voltage)
- Vehicle mass
- Inertia
- Transmission efficiency
- Gear ratio

Driver model
- Acceleration & Braking

Simulation results
- Calculated fuel economy with F.C. map or Measure exhaust emissions with an engine unit

Reference vehicle speed
(JE05 driving cycle)
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- Vehicle’s driving wheels placed on virtual road surface (rollers). Exhaust emission and fuel economy measured when operating vehicle in fixed pattern.
Tests corresponding to traffic conditions of the respective areas and operation modes are conducted.
Correction of current balance

The **current balance is corrected to zero** based on relational expression with $\Delta$ SOC, considering effects by battery’s state of charge (SOC).

1. **Exhaust emission measurement**  
   [Technical Standard (Attachment 42)]
   ① Mode test is conducted several times. Relation between current balance ($\Delta$ SOC) and exhaust emission weight are obtained.
   ② When statistical significance can be recognized for each exhaust emission component, exhaust emission weight of the prescribed tests shall be corrected to an exhaust emission weight corresponding to a current balance of zero, based on the inclination of the linear regression formula (correction factor).
   ③ When there is no statistical significance, corrections do not need to be made.

2. **Fuel consumption measurement** [TRIAS (5-9-2007)]
   ① Fuel consumption shall be calculated by carbon balance method using exhaust emission value corrected to a current balance of zero, similar to exhaust emission.
From vehicle with internal combustion engine to HEV, Plug-in HEV

Vehicle with internal combustion engine

- Reduces of petroleum energy consumption

HEV

Plug-in HEV

- Replaces petroleum energy with electricity
Characteristics of Plug-in Vehicles

Charge Depleting (CD) mode: Vehicle is operated by consuming electric energy supplied from external source (while reducing battery’s state of charge (SOC)).

Charge Sustaining (CS) mode: By fossil combustion power (Engine + regenerated electric energy), operation of the vehicle is controlled so the SOC value remains constant.
Challenges in evaluation of Plug-in HVs

1. Definition of Plug-in range (CD range)

- Plug-in range (CD range) does not always show the total work of charged electric power. How can we define capacity of electricity?

- How can we estimate the changing point (A or A') from test result?

2. Combination of two different performances of CD mode/CS mode

- How can we incorporate utility factor in the process of combination of two different performance of?

- How can we accommodate further and rapid improvement of Plug-in performance in the near future (mainly achieved by new technology on battery power intensity or cost down)?

3. Consumer Information

- How can we inform consumers of the multi-layered performance of Plug-in HV without confusion?

- The actual performance differs depending on ways of use.
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iPT Hybrid Bus: “Plug-less” Plug-in for HD Vehicle

Lithium Ion Battery Unit

Power Unit
IPT Hybrid Bus

- Battery
- Air Conditioner
- Inverter
- Diesel Engine
- Motor
- Power Supply
- IPT Unit
- IPT Primary Coil
- IPT Secondary Coil
- On Board Secondary Coil
- Big Power Quick Charge
- Concrete-covered Primary Coil
Driving Demonstration Test

Haneda Airport Shuttle Bus

- Depot
- Charge Station
- 8.8km / RT by HV drive
- 3.1km / lap by EV drive
Vehicle Energy Source Shift

Now

Internal Combustion Engine Vehicle
- Gasoline
- Diesel
- Etc.

Near Future

PHEV
PHEV is EV with On-board Re-charger

IPT

Need more Power Density Energy Density for Battery.

Far Future

Full Electric Vehicle
Right Vehicle to Right Place

Driving Mode

Distance

- Diesel
- Intercity
- Suburbs
- Urban area
- Delivery
- PHEV
- HEV

Right Vehicle to Right Place
Thank you all for listening so attentively

For further questions:

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