Challenge to Front-Loading of the Vehicle Development Using Virtual Prototyping and Reformation of the Process

Honda R&D Co., Ltd. Automobile R&D Center
Advanced Engineering Process Division
Shun Kawabe
Honda Motor Co., Ltd.

- **Established**: September 24, 1948
- **Capital**: ¥86,067,000,000
- **Employees**
  - Consolidated: 225,638 (As of Mar. 31, 2018)
  - Non-consolidated: 21,543 (As of Mar. 31, 2018)
- **Main product**: Automobile, Motorcycle, Power Product
  (agricultural products, generator, general-purpose engines, outboard engines)
- **Consolidated subsidiaries**: 440 companies
  including Honda R&D Co., Ltd.
  and Honda Engineering Co., Ltd.
  (As of Mar. 31, 2018)

Takahiro Hachigo
President, CEO & Representative Director

Head office: 2-1-1, Minami Aoyama, Minato-ku, Tokyo
Motor Sports

Formula One

Moto GP

INDY

WTCR

WCT

WMX
Overview of Honda Business

- **Unit sales by business category**
  - 20 million customers in the world annually
  - **Automobile business as Honda’s core business / The world’s No. 1 motorcycle business / Power product business with wide range of needs**

- **Proportion of sales by business category**
  - **Automobiles 72.0 %**
  - **Motorcycles 12.3 %**
  - **Power products 2.3 %**
  - **Financial services 13.4 %**
Automobile R&Ds Worldwide Operation

26 global sites

Honda R&D Europe
- U.K.
- Germany

Honda R&D China
- Guangzhou

Honda R&D India

Honda R&D Asia Pacific

Honda R&D Japan
- Global Headquarters
- Tochigi
- Proving Ground
- Sakura
- Wako

Honda R&D Americas
- Los Angeles
- Ohio Center

Honda R&D Brazil

Automobile R&D center
Automobile R&D site (Local market research, development support for local companies, etc.)
Automobile R&D Center and Proving Ground

Tochigi Proving Ground: Approx. 1,450 km²

Automobile R&D Center (Tochigi): Approx. 680 km²

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Big Business Change

Connectivity
- Honda is targeting 2025 for the introduction of vehicles with "Level 4" highly-automated driving systems installed.

Autonomous

Sharing

Electrification
- Honda is going to “Electrify” 2/3 of models by 2030.
2020 Honda AD Car Configuration (Level 3 / Highway)

**Localization**
- Backend server
- Multi-GNSS ANT
- TCU (Telecommunications Unit)
- Map ECU + High-Definition map

**Driver state monitoring**
- Driver Monitor Camera
- Grip sensor
- Steering torque detection
- Monitoring of driver’s face direction

**External sensing**
- Camera
- Radar
- LiDAR
- Sub-ECU
- Surrounding vehicles

**HMI**
- Center display (NAVI)
- Head-up display
- Full-LCD meter
- Steering wheel Indicators

**Vehicle control**
- Function redundancy
- <Stop> Redundancy of braking
- <Turn> Redundancy of EPS
- <Power supply> Addition of DC/DC power source + 2nd battery

**Action plan**
- Coordinate matching
- Lane marking correction
- Distance and velocity of obstacles
- Selection of optimum target trajectory

**Vehicle control**
- Main-ECU
- Local map processing
- Map integration

**Vehicle control**
- TCU (Telecommunications Unit)
- Backend server
- Driver Monitor Camera
- Grip sensor
- Steering torque detection
- Monitoring of driver’s face direction

**External sensing**
- Camera
- Radar
- LiDAR
- Sub-ECU
- Surrounding vehicles
Honda’s Vision of the Next-generation Clean Car

- **CO2 (g/km)**
  - **ICE**
  - **CVT**
  - **Series**

- **Advanced thermal efficiency technology**
- **Advanced electrification technology**
- **Zero Emission technology**

- **Global warming**
  - Melted glaciers
  - Rising sea levels
  - Enlargement of deserts
  - Melting glaciers

- **Present (2018)**
  - URBAN EV CONCEPT
  - FCX CLARITY
  - FIT EV
  - CLARITY FCV
  - CLARITY EV

- **2010**
  - ACCORD PHEV
  - CLARITY PHEV
  - ACCORD HEV

- **2020**
  - INSIGHT HEV

- **2030**

- **ZEV**
- **PHEV**
- **HYBRID**
- **ICE**

- **core vehicles**
  - ACCORD
  - INSIGHT
  - FCX CLARITY
  - FIT EV
  - CLARITY FCV
  - CLARITY EV
  - URBAN EV CONCEPT
  - ACCORD PHEV
  - CLARITY PHEV
  - ACCORD HEV
  - INSIGHT HEV
E-CVT (electric coupled CVT) including 2 motors

For driving

For power generation

Enables the system to change 3 operation modes

E-CVT
Driving Modes

Intelligently transition between 3 modes to achieve high efficiency

<table>
<thead>
<tr>
<th>Start/acceleration</th>
<th>Low-speed cruising</th>
<th>Powerful acceleration</th>
<th>High-speed cruising</th>
<th>Deceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>62mph</td>
<td>50mph</td>
<td>37mph</td>
<td>24mph</td>
<td>12mph</td>
</tr>
<tr>
<td>Idling stop</td>
<td>Low-speed cruise</td>
<td>Powerful acceleration</td>
<td>High-speed cruise</td>
<td>Deceleration</td>
</tr>
<tr>
<td>EV Drive mode</td>
<td>Hybrid drive mode</td>
<td>Engine drive mode</td>
<td>EV drive mode</td>
<td>Regeneration</td>
</tr>
</tbody>
</table>

Engine stops while vehicle is stopped
*Air conditioning and other equipment remains on
Challenges for Increasing Complexity of Automobile

**Increase of development scale**
- Expected workload for software development (internal assessment)

![Graph showing increase in workload from 2017 to 2023 to 2025 with factors x2, x4]

- Cooperation with external development partner
  - Standardization of
    - Requirement Description
    - Development Process
    - Data Format
  - etc...
  - How to Assure the product quality??

**Functional safety**
- Limitation of traditional safety approach
- Response to future legal systems and certification criteria

![Swiss Cheese Model diagram]

- STAMP/STPA

Reformation of the current development process is essential

ISO 26262 STAMP/STPA
Front Loading Development

Example AD/ADAS Control System Development

As Is

- Concept
- Design
- Verification
- S/W Coding
- HILS
- Prototype
- Big Rework

- Hardware based V&V
- BIG Loop
- BIG Rework

To Be

- Concept
- Design
- Verification
- CBU Validation
- V&V Plan
- S/W
- MILS
- SILS
- Prototype

- Utilize Virtual Prototype

GO
Application of Systems Engineering

As Is process (H/W based)

Component・parts design

Integration / Validation

Power Train
- Hardware development
- Verification

Platform
- Hardware development
- Verification

Control
- Control sys. development
- Verification

Actual Vehicle Tests
Large rework
Application of Systems Engineering

**To Be** process

**Concept Phase**

- Define “Lifecycle” Requirement
- Analyze Requirement
- Allocate Requirements To Functions
- Virtual Verification

**Requirements**

- Function A
- Function B
- Function Z

**Virtual Validation**

**Traceability**

**Change Management**

**Verification & Validation Plan**

**MBSE (Model Based Systems Engineering)**

**Mechanical development**

**Verification**

**H/W development**

**Verification**

**S/W development**

**Verification**

**Actual vehicle Test**

**Small rework**
Simulation for Development Phases

Concept Phase

- Logic Base
- 1D (+MBS/FEM)
- Validation of the conceptual design
- Multi Domain (Mech./Hard/Soft)
- Simple (Fast = Many Iterations)

Start

Virtual Prototype

Design / Validation Phase

- Crash
- Aerodynamics
- NVH
- Strength & Durability
- Detailed Shape
- 1D/MBS/FEM/CFD
- Replacement of the physical test
- Single Domain
- Complicated (Nonlinear = much CPU time)

GO

Crash

Aerodynamics

NVH

Strength & Durability

.......

Virtual Prototype

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CM Model Preparation Procedure

Virtual Validation Plan

Model Requirements

- Chassis / Device Model
- Powertrain Model
- Sensor / Controller Model

Model Check

Merge

Common Data Base (PLM/ALM)
- Model of Previous YM
- Specification
- Measured Data
- Scene Model
- Road Model
- Common Model = Virtual Prototype

Publish

NG OK

*Cross divisional organization Needed
Introduction of specific examples

**Power train**
- Real driving emission

**Challenges**
- Road accuracy
- Dynamic Engine torque
- Dynamic Engine out emission
- Catalyst and Filter modeling

**Autonomous driving**
- Controller development

**Challenges**
- Huge Validation scenario
- Vehicle dynamics accuracy
- Supplier model integration
Common Model structure

Model Platform (CarMaker)

Road  Traffic  Environment

Driver

Vehicle behavior control

ECU  xCU

Engine  Catalyst  Motor Battery  Driveline  Vehicle

Scenario

Control

Hardware
Vehicle model fidelity

Model Platform (CarMaker)

- Road
- Traffic
- Environment
- Driver

Vehicle behavior control

- ECU
- xCU

Modeling

- Engine
- Catalyst
- Motor
- Battery
- Driveline
- Vehicle

Control

Scenario

Hardware
Model Correlation

Application of important characteristics on actual vehicle

- **Steady state**: Tire $\mu$ on actual road

  - Cornering test
    - Lateral acceleration vs. steering wheel angle
    - Lateral acceleration vs. slip angle

- **Transient state**: Tire dynamics (Delay)

  - J-Turn
    - Lateral acceleration vs. time
    - Phase vs. frequency

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**Tire Actual $\mu$ model**

- Measurement
- Base model
- Actual $\mu$ model

**Tire dynamics model**

- Measurement
- Base model
- Actual $\mu$ model + Dynamics model

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**Measurement**

- Lateral acceleration
- Wheel angle
- Slip angle
- Frequency

**Base model**

- Lateral acceleration
- Wheel angle
- Slip angle
- Frequency

**Actual $\mu$ model**

- Lateral acceleration
- Wheel angle
- Slip angle
- Frequency
Model Correlation

Double lane change: Lateral acceleration

Honda Extended Tyre Model

CM Vehicle model can realize enough accuracy in wide region including DLC
Road and Traffic Modeling

Model Platform (CarMaker)

Modeling
- Road
- Traffic
- Environment
- Driver

Control
- Vehicle behavior control
- ECU
- xCU

Hardware
- Engine
- Catalyst
- Motor
- Battery
- Driveline
- Vehicle

Scenario
## Scenario Field

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment and Driver →Common(CM Default)</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>+Speed Limit</td>
</tr>
<tr>
<td></td>
<td>+Signal</td>
</tr>
<tr>
<td></td>
<td>+Traffic Flow</td>
</tr>
<tr>
<td>Road</td>
<td>Google KML Format</td>
</tr>
<tr>
<td></td>
<td>Simple PT Use</td>
</tr>
<tr>
<td></td>
<td>Here ADAS RP DIG Format</td>
</tr>
<tr>
<td></td>
<td>High Accuracy PT (RDE)</td>
</tr>
<tr>
<td></td>
<td>Off-Road Capability</td>
</tr>
<tr>
<td></td>
<td>HD MAP</td>
</tr>
<tr>
<td></td>
<td>AD/ADAS</td>
</tr>
</tbody>
</table>

- **Coordinate [x,y,z]**
- **+Road Surface Shape**
- **+Road Width**
- **+Lane**
- **+Intersection**
- **+Obstacle**
- **+Building**
Utilizing Map Data (ADASRP)

Test Course

Comparison of z coordinates

On the elevated highway, the roads were almost overlapped because the height difference was not accurate.

HERE ADAS RP allows to create highly accurate course models in a short time.

Field photos
Off Road Surface Measurement

Measuring Vehicle

Measuring Scene (Outside)

Measuring Scene (Onboard)

Simulation (using measuring data)
Power Train Real Driving Emission (RDE)

Model Platform (CarMaker)

- Road
- Traffic
- Environment
- Driver

Vehicle behavior control

- ECU
- xCU

Application

- Engine
- Catalyst
- Motor
- Battery
- Driveline
- Vehicle

Scenario

Control

Hardware
RDE compliant virtual engine calibration

**Requirement**
- Regulation Change
  - WLTC RDE ...

**Requirement Analysis**
- Vehicle simulation

**Allocate Req. To Function**
- ECU modeling

**Engine Emission Simulation**

**Virtual Engine Calibration**

**Virtual Prototype Validation**

**Verification**
- Power train Dynamic Test bed

**Validation**
- Vehicle

**H/W**
- Measuring
- H/W Modeling
Example: Emission Simulation Results of Diesel Engine

Achieve the quantitative prediction of EM/FE at RDE with CM Simulation
Optimal Control of Combustion Engines

Model Platform (CarMaker)

- Scenario
  - Road
  - Traffic
  - Environment
  - Driver

- Control
  - Vehicle behavior control
  - ECU
  - xCU

- Hardware
  - Engine
  - Catalyst
  - Motor
  - Battery
  - Driveline
  - Vehicle
Future powertrain control concept

Data storage

Machine learning

Analysis

- Route information (slope, curvature)
- Driver state
- Distance
- Relative speed
- Traffic information
- Camera
- LIDAR

Sensor signals

Recognition

Judgement

Action

Driver action

- Pedal
- Brake
- Stealing etc

Actuators demand

- Injection quantity
- VGT
- EGR valve etc

Torque

Power train

Optimal power train control using predicted future driver demand

Stochastic driver pedal prediction

\[ f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right) \]

ECU

Route information (slope, curvature)

Distance

Relative speed

Traffic information

Vehicle (engine) behavior

Optimal power train control using predicted future driver demand

Vehicle (engine) behavior

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Autonomous Driving Car Controller Development

Model Platform (CarMaker)

- Road
- Traffic
- Environment

Scenario

- Driver

Control

- Vehicle behavior control: ADU
- ECU
- xCU

Hardware

- Engine
- Catalyst
- Motor
- Battery
- Driveline
- Vehicle
SIP-adus Workshop

Cross-ministerial Strategic Innovation Promotion Program

1. Main Theme
2. Summary
3. Program
4. Plenary Session and Breakout Workshop
5. Breakout Workshop
6. SIP-adus Display
7. Automated Vehicle Test Ride
8. SIP-adus Workshop 2017 website
9. SIP-adus Workshop 2018

- International AV test rides were held with SIP-adus FOT OEM cooperation
  - Speakers and Japanese government officials experienced latest AV technologies
Virtual Validation of AD Performance

- Lane Keep (Multi Lvl Crossing)
- Branch
- Lane Change
- Merge
- Lane change
- Shiodome IC
- Daiba IC
- 4.6km
Autonomous Driving Car Development

- Concept
- Test Spec.
- MILS (SW)
- Validation (SW/HW)

- Huge Validation Scenario (Road x Traffic)
- Virtual Validation (High Speed Simulation By HPC Parallel Computation)
- Validation of Dangerous Scenario (Real Time Simulation)

Realize the front loading of the S/W verification and debugging
Summary

• Complexity of the Automobile is drastically increasing especially in S/W region caused by the big business changes in the automobile industry.

• To overcome these challenges, the transformation of the development process is essential and urgent.

• The keys are “the Front-Loading of the Vehicle Development Using Virtual Prototyping and Reformation of the Process” toward systems engineering.

• IPG CarMaker’s virtual prototyping is becoming very important to realize these objectives at Honda R&D and the usage is increasing.

• Next challenge will be the supplier involvement into the model chain.
Thank you very much
For your attention