Recent Clean Diesel Engine Projects

Jin KUSAKA, Professor, Ph.D

WASEDA UNIVERSITY

+ Research Organization for Next generation Vehicles

http://www.waseda.jp/nextgv/top/

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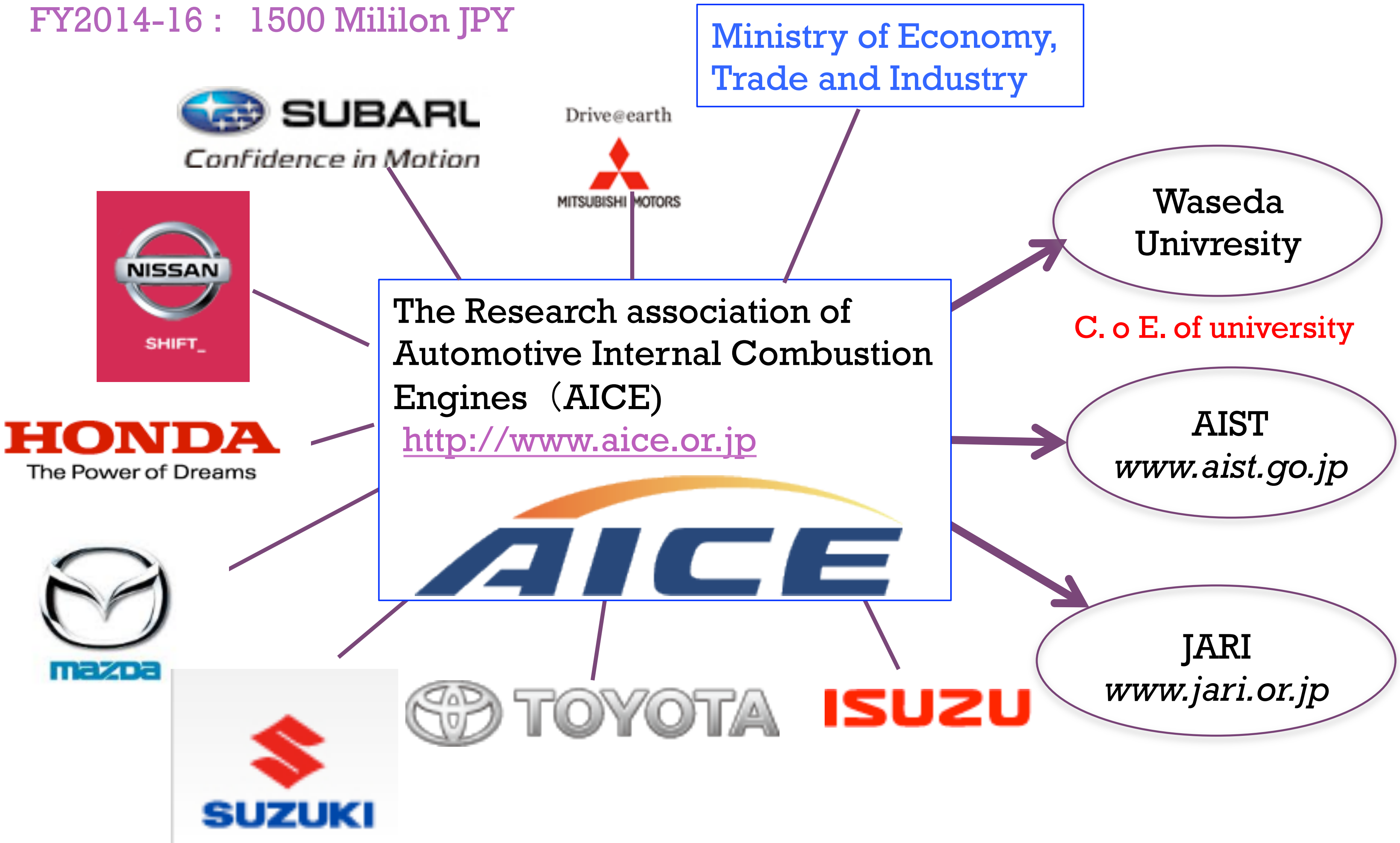
+ Joint research(1)

FY2014-16 :　1500 million JPY
（1/3 financial support by METI）

Passenger car OEM : 9
FY2014-16 :　1500 Mililon JPY



+ Overviews METI+AICE clean Diesel research

Basic Research on EGR Deposit Inhibition Technology

Research performed by:
National Institute of Advanced Industrial Science and Technology,
Ibaraki University

Basic Research to Enhance DPF Functions

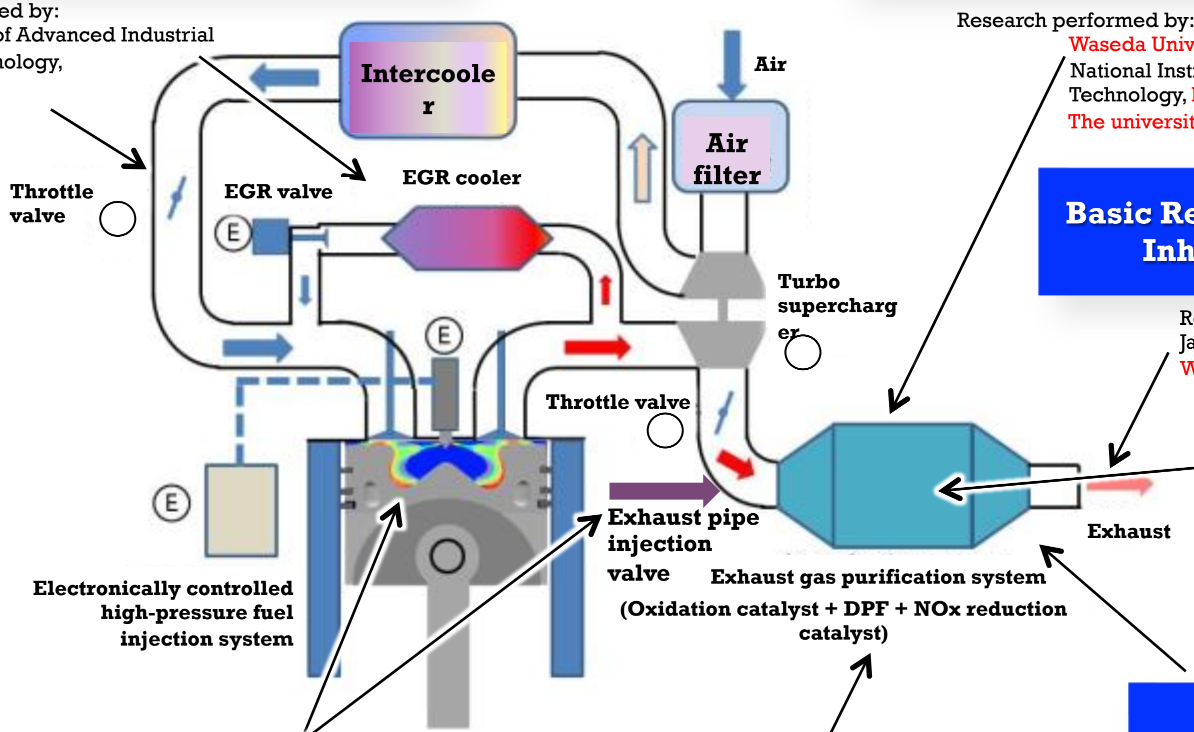
Research performed by:
Waseda University, Japan Automobile Research Institute, National Institute of Advanced Industrial Science and Technology, Ibaraki University, Doshisya University
The university of Tokyo

Basic Research on White Smoke Inhibition Technology

Research performed by:
Japan Automobile Research Institute,
Waseda University

Studies for OBD of DPF

Research performed by:
Ibaragi University
Hokkaido University



DPF Simulation Applied Research

Research performed by: Waseda University, Japan Automobile Research Institute
,
Nagoya University
Tohoku University,
Tokyo Institute of Technology

Basic Research to Enhance DPF Regeneration Functions

Research performed by: Japan Automobile Research Institute,
Hokkaido University, Kyoto University,
Doshisha University, Waseda University,
National Institute of Advanced Industrial Science and Technology

Basic Research on Innovative NOx Reduction Catalyst

Research performed by: The University of Tokyo, Waseda University,
Yokohama National University,
Hiroshima University, Tokyo Institute of Technology
Hokkaido University,
National Institute of Advanced Industrial Science and Technology

+ Joint research(2)

Sub leader
Jin Kusaka

Control Technology Team

University of Tokyo — **Honda Toyota**

- Control Gr.
- CFD Gr.
- PM Gr.

21 Cluster Universities

Diesel Combustion Team

Kyoto University — **Mazda Nissan**

- Fuel Injection Gr.
- Afterburning Gr.
- Combustion Noise Gr.

18 Cluster Universities

Gasoline Combustion Team

Keio University — **Toyota Subaru**

- Knocking Control Gr.
- Flame Propagation Gr.
- Ignition Gr.

23 Cluster Universities

Loss Reduction Team

Waseda University — **Suzuki Daihatsu Honda**

- Mechanical loss Gr.
- Turbocharging Gr.
- Fuel reforming Gr.

16 Cluster Universities

Cabinet Office
（内閣府）
SIP program
「Innovative combustion technology」

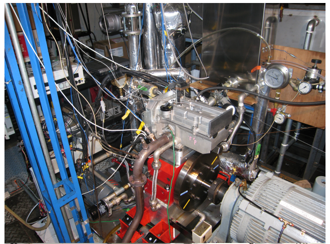
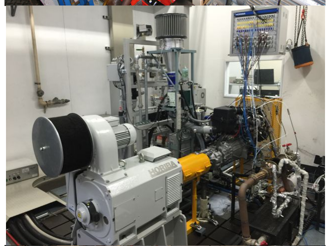
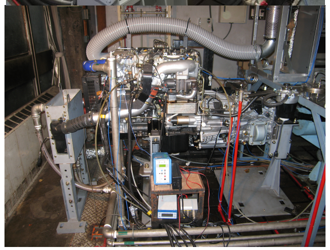
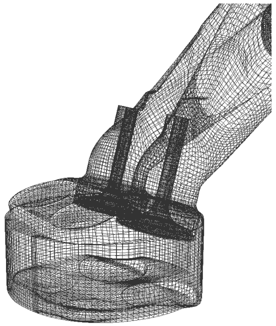
2Billion JPY×5Y

Key Universities

- Waseda
- Keio
- Tokyo
- Kyoto

Waseda CFD code

+ Research (BLG. 58 : room1-6)

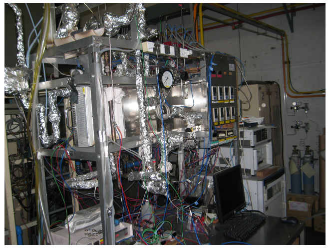
<u>Internal Combustion Engines</u>

1. A single cylinder SI engine for controlling knock occurrence
2. A 2.0 litter, inline-4cylinder, ITC Diesel engine with DOC, DPF, SCR catalysts.
3. A 2.0 litter, inline-4cylinder, ITC Diesel engine for improvements of combustion and emissions
4. A 2.0 litter single cylinder, heavy duty Diesel engine for improvements of combustion and emissions
5. A 2.0 litter ITC Diesel engine for combustion and emissions
6. A Gasoline engine for studying on next generation combustion towards higher efficiency
7. Rapid compression and expansion Machine
8. A 0.5 litter single cylinder passenger car Diesel engine to achieve higher efficiency with VVA

<u>Internal Combustion Engine Numerical Modeling</u>

1. 0-D, 1D thermodynamic modeling with detailed chemistry
2. Multi-dimensional Computer Thermo-Fluid Dynamics modeling with detailed chemistry

+ Research (BLG. 58, 63 : room1-3)




<u>Internal Combustion Engines</u>

1. A Constant Volume chamber for visualizing flame propagation in the various fuels
2. Two Constant volume chambers for visualizing fuel spray in the high pressure and temperature field

<u>Catalysts, Lithium ion batteries</u>

1. Two mini-reactors for studying transport phenomena in catalysts with surface reactions
2. A study on transport phenomena in a lithium ion batteries modeling for automotive applications
3. Hybrid vehicle modeling with an internal combustion engine, a motor, a battery and capacitor

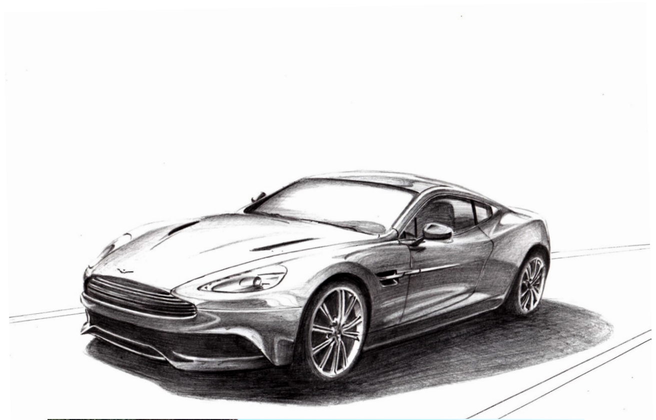
<u>Numerical Modeling on Transport phenomena</u>

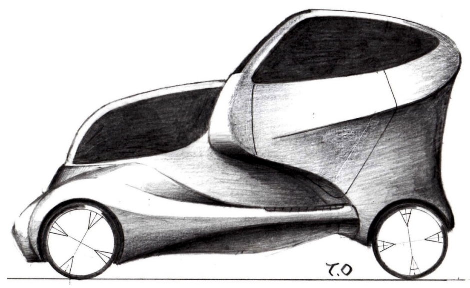
1. Multi-dimensional Computer Thermo-Fluid Dynamics modeling with surface chemistry

+ Research (BLG. 58, 63)

<u>Making a concept & Designe for future Vehicle</u>

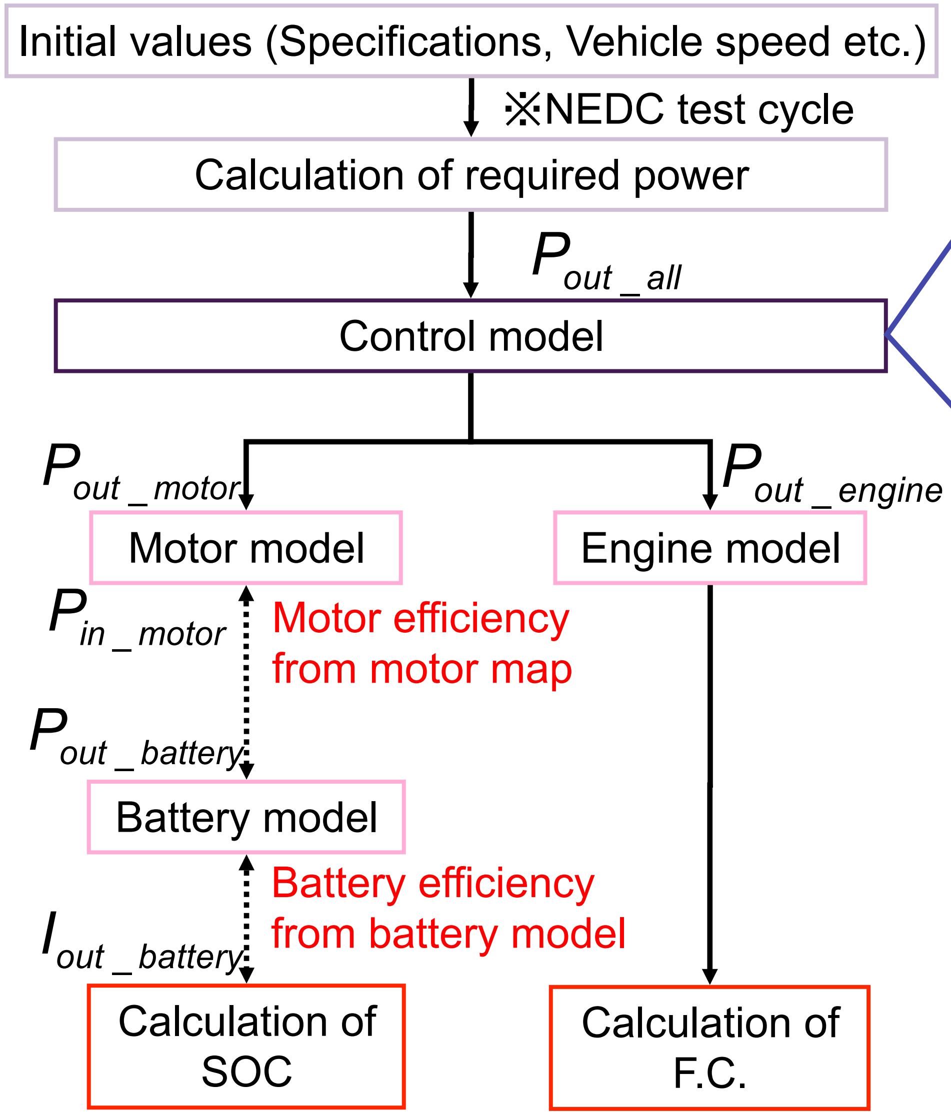
A quite new concept making, exterior design and its modeling





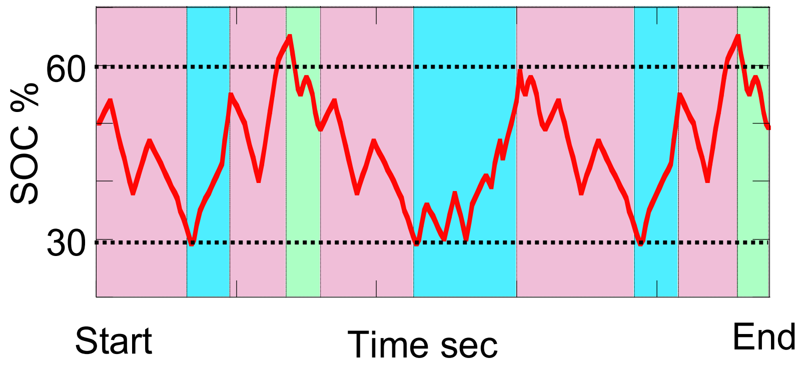
HEVモデル概要

車速から消費エネルギを逆算するBackward Facing Approachを採用



SOCの状態に応じて3つの制御方法を導入

- Optimized control
- Strong discharge control
- Strong charge control



Optimized control
エンジンの最適動作点で運転を行う.

Strong discharge control
モータによる走行を行う.

Strong charge control
エンジン単体走行を行う.

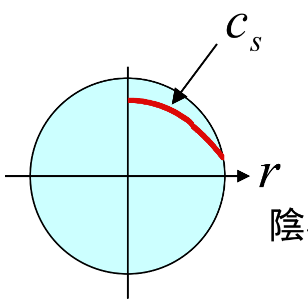
バッテリモデルの概要

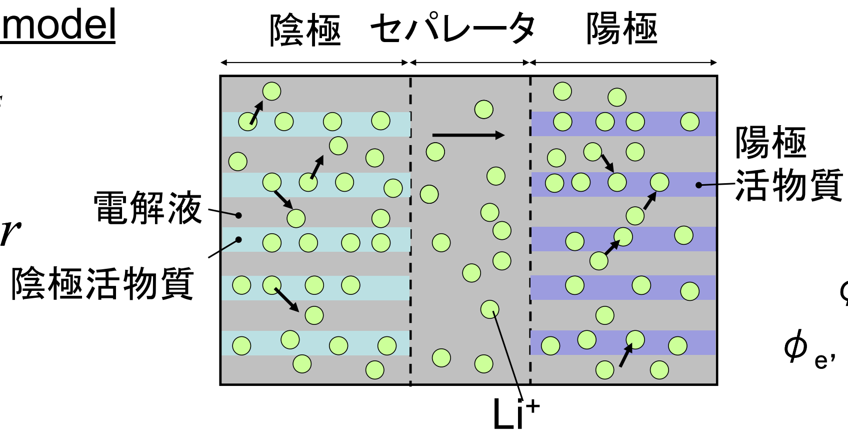
➤ モデル概要

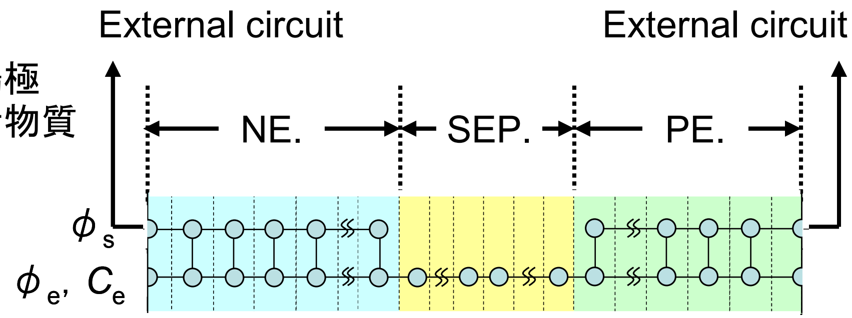
CD-adapco社製の数値計算ソフトBDS (Battery Design Studio)を導入し，リチウムイオンバッテリのエネルギ効率及び最大充放電率を算出

phase		Conservaton equations	Boundary conditons
Solid phase	Charge	$\frac{\partial}{\partial x}\left(\sigma^{eff}\frac{\partial}{\partial x}\phi_s\right)=j^{Li}$	$-\sigma_-^{eff}\frac{\partial\phi_s}{\partial x}\Big\|_{x=0}=\sigma_+^{eff}\frac{\partial\phi_s}{\partial x}\Big\|_{x=L}=\frac{I}{A},\frac{\partial\phi_s}{\partial x}\Big\|_{x=\delta_-}=\frac{\partial\phi_s}{\partial x}\Big\|_{x=L-\delta+}=0$
	Species	$\frac{\partial c_s}{\partial t}=\frac{D_s}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial c_s}{\partial r}\right)$	$\frac{\partial c_s}{\partial r}\Big\|_{r=0}=0,-D_s\frac{\partial c_s}{\partial r}\Big\|_{r=R_s}=\frac{j^{Li}}{a_sF}$
Electrolyte phase	Charge	$\frac{\partial}{\partial x}\left(\kappa^{eff}\frac{\partial}{\partial x}\phi_c\right)+\frac{\partial}{\partial x}\left(\kappa_D^{eff}\frac{\partial}{\partial x}\ln c_e\right)=-j^{Li}$	$\frac{\partial\phi_e}{\partial x}\Big\|_{x=0}=\frac{\partial\phi_e}{\partial x}\Big\|_{x=L}=0$
	Species	$\frac{\partial(\varepsilon_e c_e)}{\partial t}=\frac{\partial}{\partial x}\left(D_e^{eff}\frac{\partial}{\partial x}c_e\right)+\frac{1-t_+^0}{F}j^{Li}$	$\frac{\partial c_e}{\partial x}\Big\|_{x=0}=\frac{\partial c_e}{\partial x}\Big\|_{x=L}=0$

Psaeudo2D model







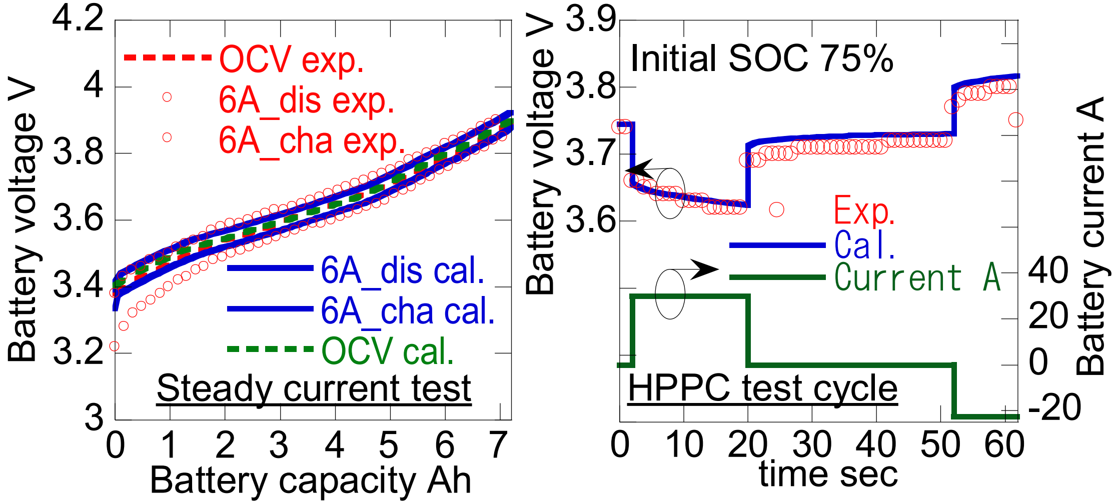
要素モデル(バッテリモデル)

BDSの予測精度検証[1)]

米国のFreedomCAR Programにて開発された
HEV用リチウムイオンバッテリを設計し,
Smithらの論文から得られた実機データと比較

設計バッテリの諸元

Design capacity Ah	7.20
Max voltage V	3.90
Minimum voltage V	3.38
Mean voltage V	3.64



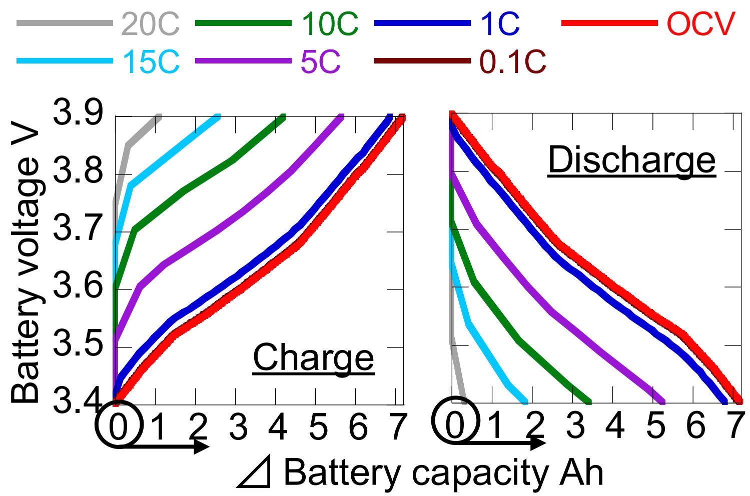
定電流試験及びHPPC試験の双方で
十分な予測精度が得られている.

充放電曲線の取得

BDSを用いて設計したバッテリの定電流試験を
仮定したシミュレーションを実施

定電流充放電試験条件

Charge and discharge rate C	0.1, 1, 5, 10, 15, 20



得られた充放電曲線から,
簡易化した性能をHEVモデルに導入
(エネルギ効率, 最大充放電率)

1)Smith et al, solid-state diffusion limitations on pulse operation of a lithium ion cell for hybrid electric vehicles, Journal of Power Sources 161(2006)628-639.

要素モデル(バッテリモデル)

エネルギ効率の算出

取得した充放電曲線を元にエネルギ効率を算出

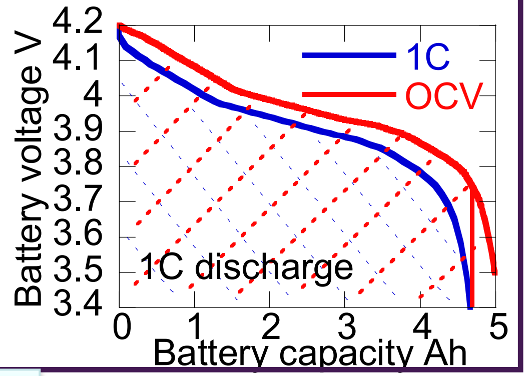
エネルギ効率算出式

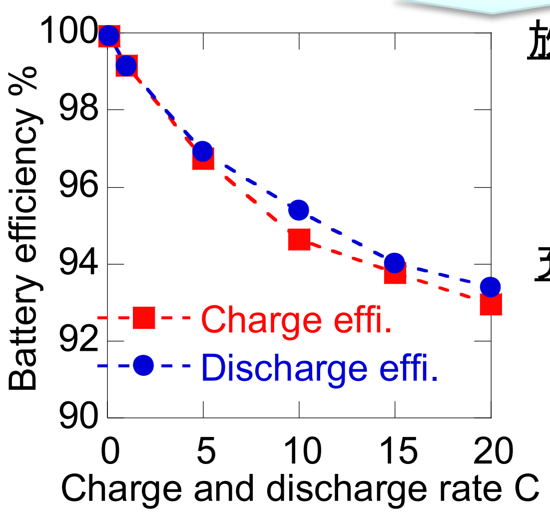
放電時

$$\eta_{dis\_battery} = \frac{\int V_{dis} dQ \text{（図中の青の部分）}}{\int V_{ocv} dQ \text{（図中の赤の部分）}}$$

充電時

$$\eta_{cha\_battery} = \frac{\int V_{ocv} dQ}{\int V_{cha} dQ}$$





放電時

$$\eta_{cha\_battery} = -7.18\times10^{-6}\times Crate_{cha}{}^{3} + 3.65\times10^{-4}\times Crate_{cha}{}^{2} - 0.79\times10^{-2}\times Crate_{cha} + 1.00$$

充電時

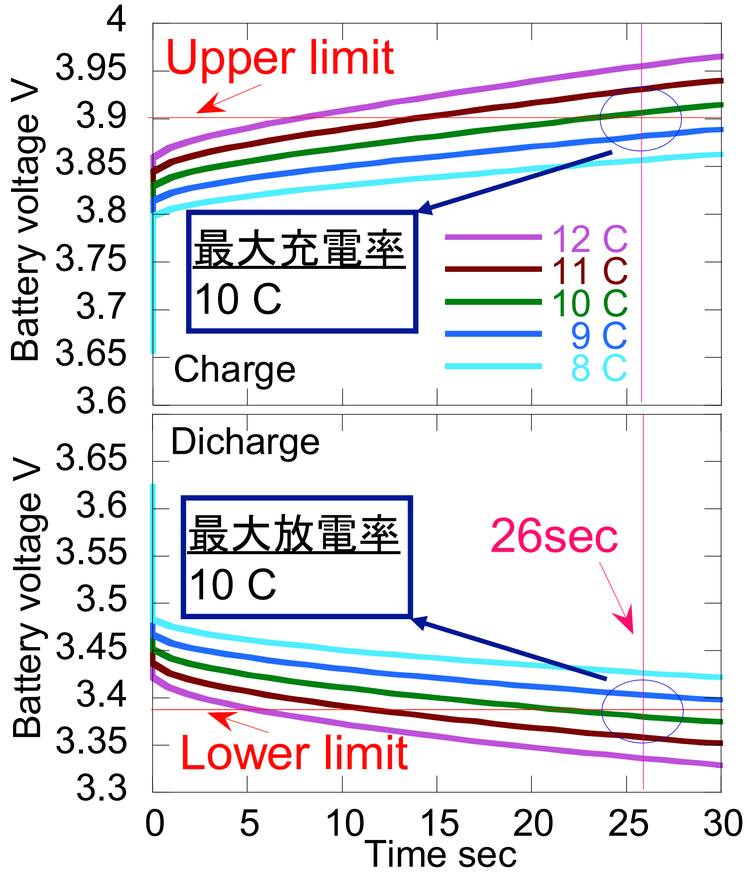
$$\eta_{dis\_battery} = -5.29\times10^{-5}\times Crate_{dis}{}^{3} + 3.01\times10^{-4}\times Crate_{dis}{}^{2} - 7.18\times10^{-3}\times Crate_{dis} + 1.00$$

最大充放電率の算出

「定格電圧から定電流試験を実施し，26 sec後に電圧上限値及び下限値に達しない充放電率の最高値」を最大充放電率と定義

最大充放電率取得のための試験条件

Charge and discharge rate C	8, 9, 10, 11, 12



HEVモデルを用いた検証

- 各構成要素がHEV性能に及ぼす影響調査

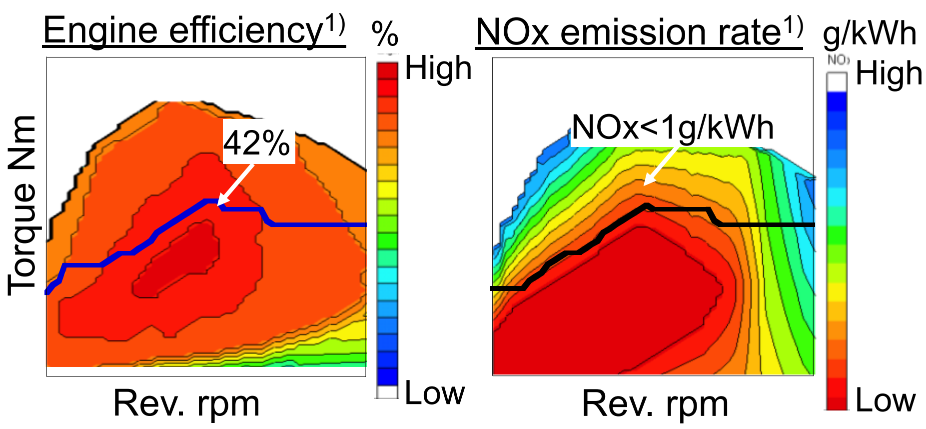
燃費及びNOx排出率の3次元マップを作成

仮定車両条件

Curb weight kg	1655
Vehicle type	1 clutch parallel HEV

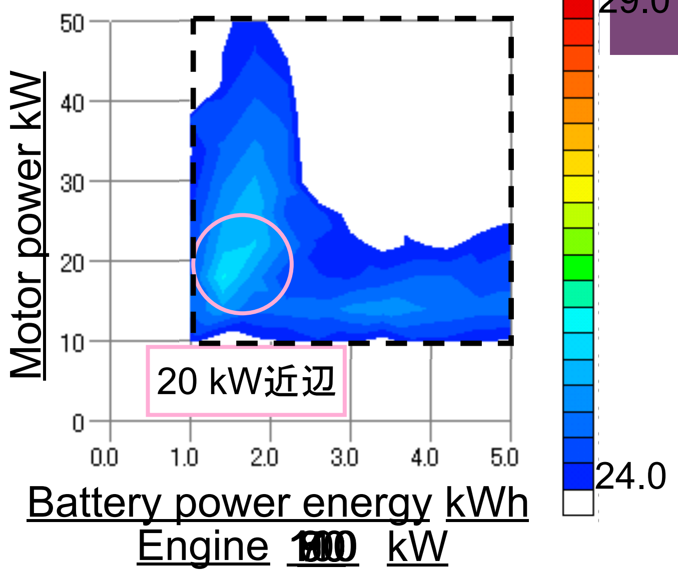
マップ作成の計算条件

Component	Range	Step size
Engine max power kW	60～110	10
Motor max power kW	10～50	4.0
Battery power energy kWh	1.0～5.0	0.4

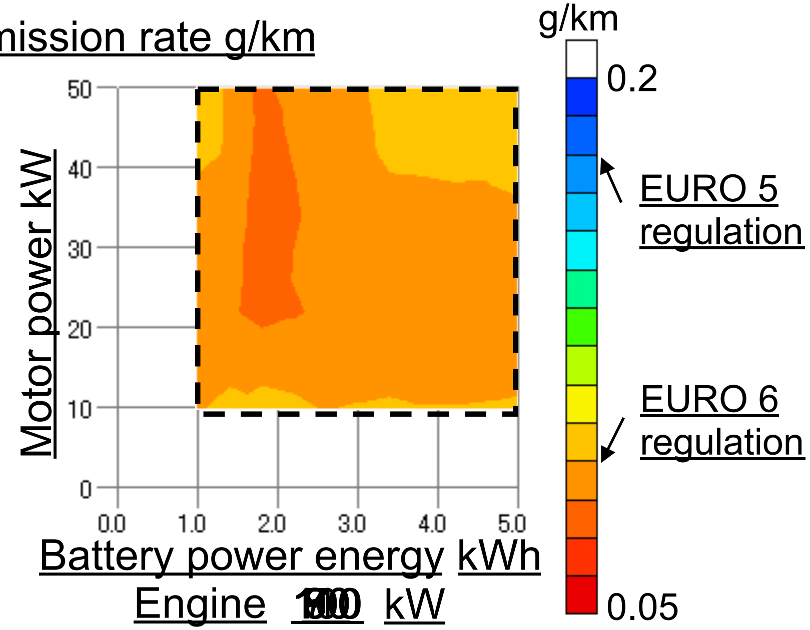


1)山田他，ハイブリッド用ディーゼルエンジンシステムの開発，
自動車技術会2011春季大会前刷集，NO.50-11，7-12(2011).

Fuel consumption km/l

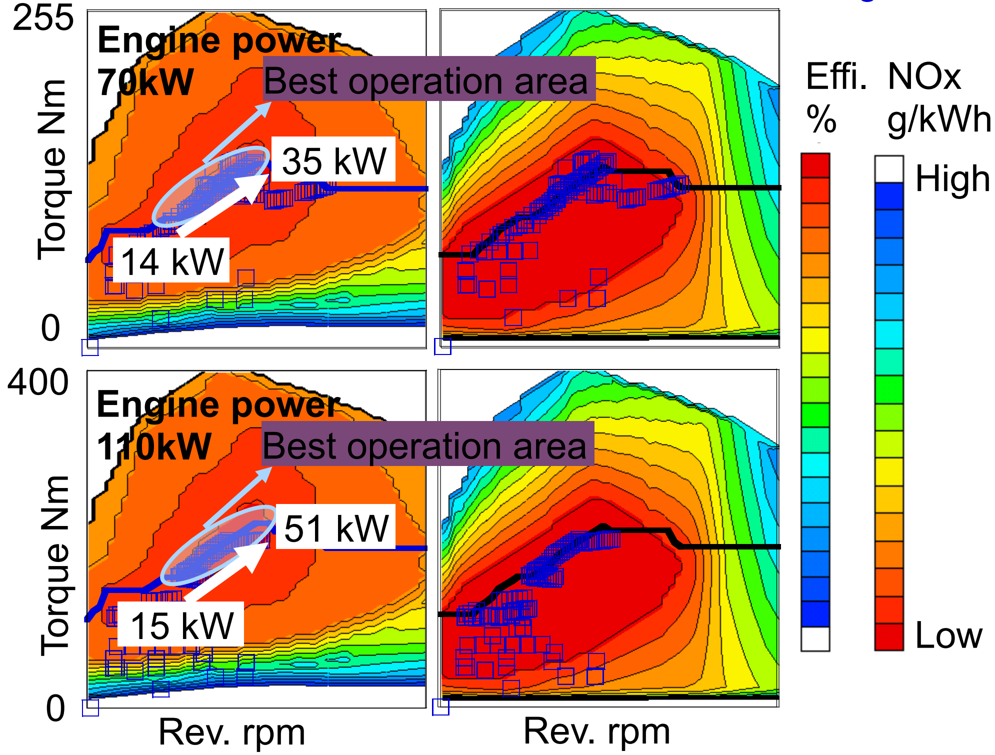


NOx emission rate g/km

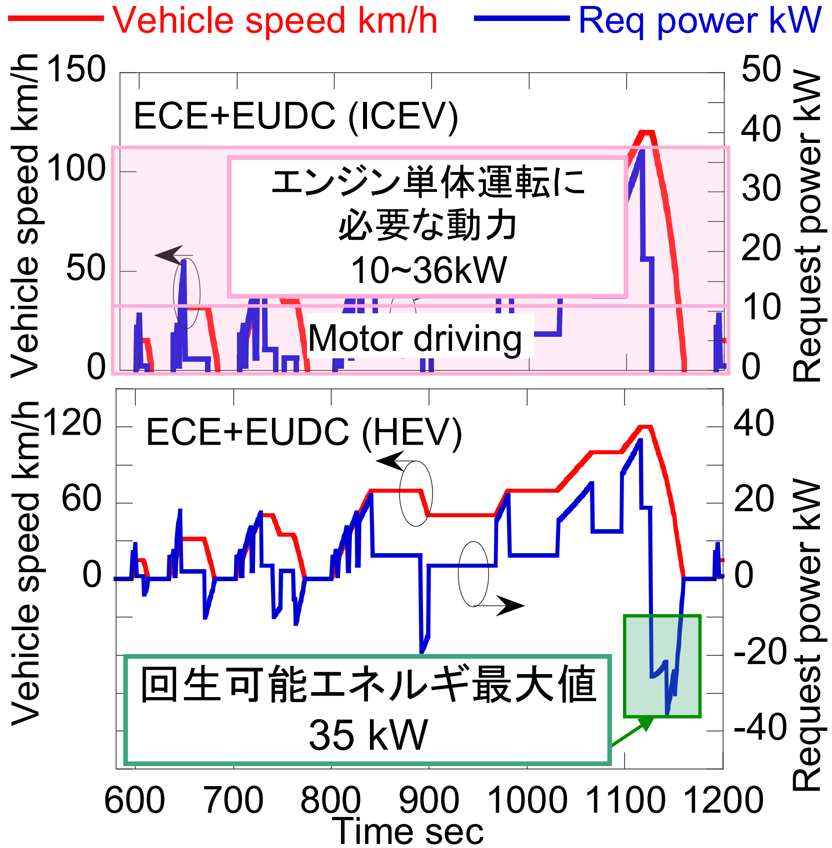


HEVモデルを用いた検証結果

➤エンジン出力変更による動力履歴検証



➤NEDC走行モードの要求動力履歴検証



本シミュレーション条件での検証結果

・最適エンジン出力 70 kW : 最適動作線動力範囲と要求動力範囲がおおよそ一致する出力
(エネルギ変換損失を伴う余剰充電動力等を発生させずに最適動作線上で運転が可能)
・最適モータ出力 14 kW : 回生エネルギ最大値(35 kW)より60 %程度小さい出力
・最適バッテリ出力 1 kWh : モータ出力より多少小さい出力 (モータ-バッテリ間の損失による)

多車種間での構成要素最適化

➤ <u>多車種において部品を共有化させ最適解を導出</u>

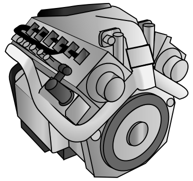
Target

Fuel consumption rate & NOx emission

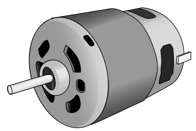
Controlled parameters

Engine & Motor & Battery

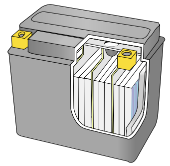
60~130 kW



10~50 kW



1~5 kWh



Optimization model

A車 : 1655 kg

B車 : 1860 kg

C車 : 2080 kg

Optimized combination of the components

多車種のHEV化を想定し，共通の構成要素を用いることで
量産効果によるコスト削減が期待できる．

参考：トヨタ自動車HP
http://lexus.jp/models/index.html

PSOを用いた構成要素最適化

PSO (Particle Swarm Optimization):粒子群最適化

鳥の群は，目標最近辺にいる鳥の情報を共有し周囲が追従する.

群知能を応用した最適化手法

Expression

$$\vec{v} \to \omega \cdot \vec{v} + C_1 \cdot r_1 \left(\vec{x}_{Best} - \vec{x} \right) + C_2 \cdot r_2 \left(\vec{G}_{Best} - \vec{x} \right)$$

$$\vec{x} \to \vec{x} + \vec{v}$$

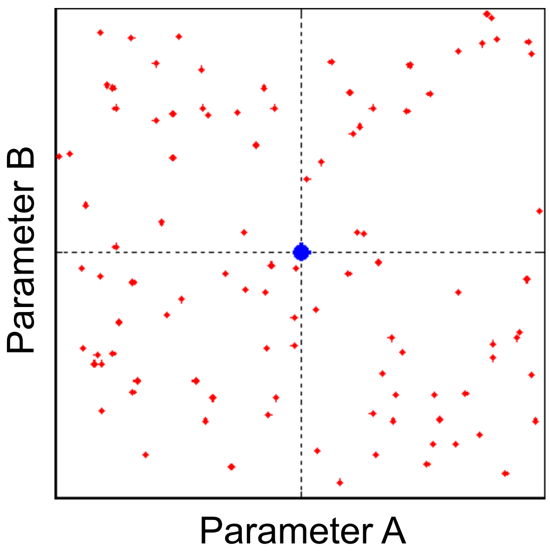
x_{Best} ：粒子が取った値の中で最適値の位置

G_{Best} ：群全体が取った値の中で最適値の位置

C_1 ,C_2 ：係数 (X_{Best} ,G_{Best}からの影響の受けやすさ)

x, v：粒子位置，速度

ω：慣性係数　　r1，r2 ：乱数 (0～1)



● :Particle
● :Goal

Number of Particles
・100

Evaluation Function
・Distance of Goal

Repeat Count
・20

計算フローチャート

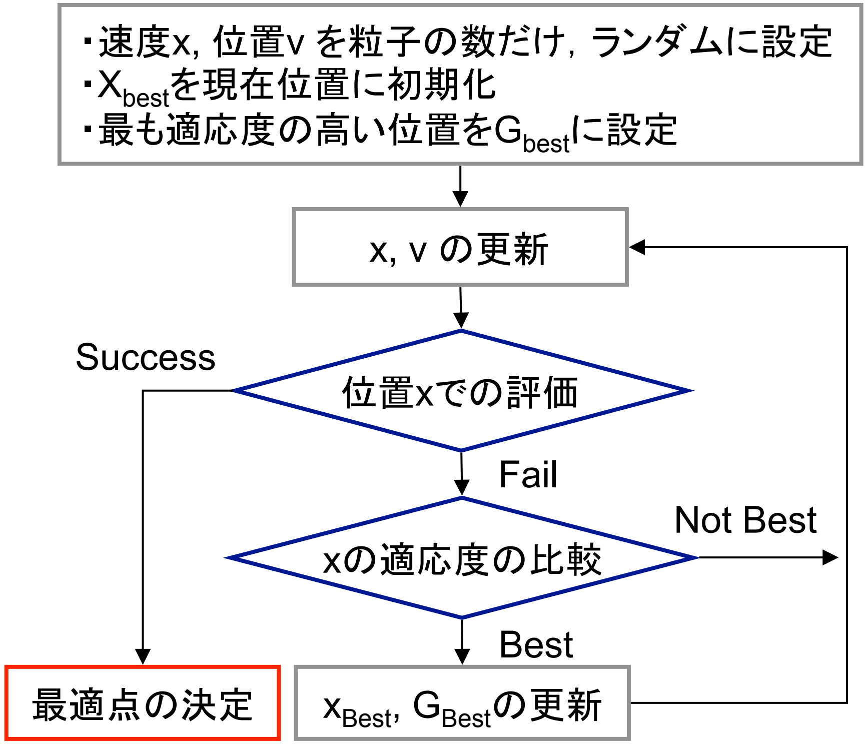
適応度の定義

$$G_{Fit} = C_{FC} \cdot FC_A + C_{FC} \cdot FC_B + C_{FC} \cdot FC_C + C_{NOx} \cdot NOx_A + C_{NOx} \cdot NOx_B + C_{NOx} \cdot NOx_C$$

G_{Fit} ：適応度

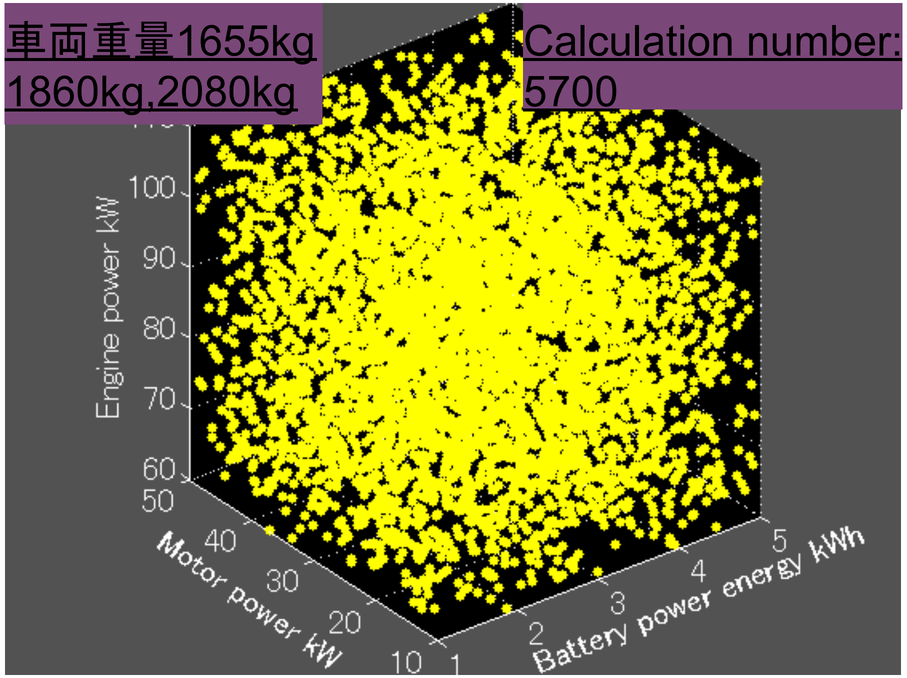
FC_A, FC_B, FC_C ：A車，B車，C車の燃費

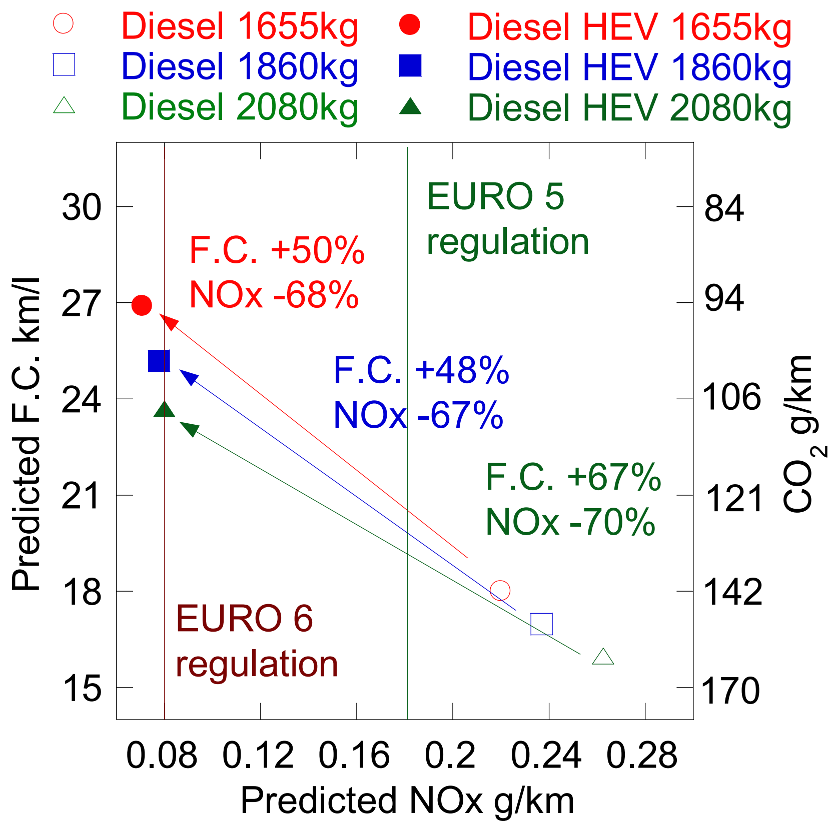
NOx_A, NOx_B, NOx_C ：A車，B車，C車のNOx排出率



多車種間でのPSOによる構成要素最適化結果

➤ 多車種間における最適な車両構成の導出





最適化後の各構成要素諸元

Vehicle type	Engine power kW	Motor power kW	Battery power energy kWh
Diesel	110	-	-
Diesel HEV	87.5	21.8	1.77

PSOを用いた構成要素の最適化により
多車種において共通の構成要素を使用する
最適な車両構成の導出が可能となった.

The total modeling for Diesel vehicle

今後のトータルモデリングについて作成中