Predictive Vehicle Control with Geographic Information

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JAPAN

Contents

1. Introduction

■ Hybrid vehicle development history of Hino Motors

1973
Electric Bus
Field experiment

1976
Series Hybrid
Study

1981
Parallel Hybrid
R&D Started

1989
Exhibit at Tokyo
Motor Show

1st Generation	2nd Generation	3rd Generation	4th Generation	5th Generation	6th Generation
World's first	Ti Engine	Ni-MH battery	Adoption of automobile Parts	New system	Li-ion Battery

1991
Parallel HV
+NA Engine

1993
National Park
Sightseeing Bus
(Nikko)

1993
MD Truck

1995
Parallel HV +TI Engine

1994
(Kami-kochi)

1997
Hi-Power sightseeing Bus
(Tateyama etc)

1995
Broadcasting
Relay Vehicle

2001

2005

2005

2008

2004

2003

2011

2006

2015

2011

2014

Heavy-duty hybrid truck
Release in 2019

1. Introduction

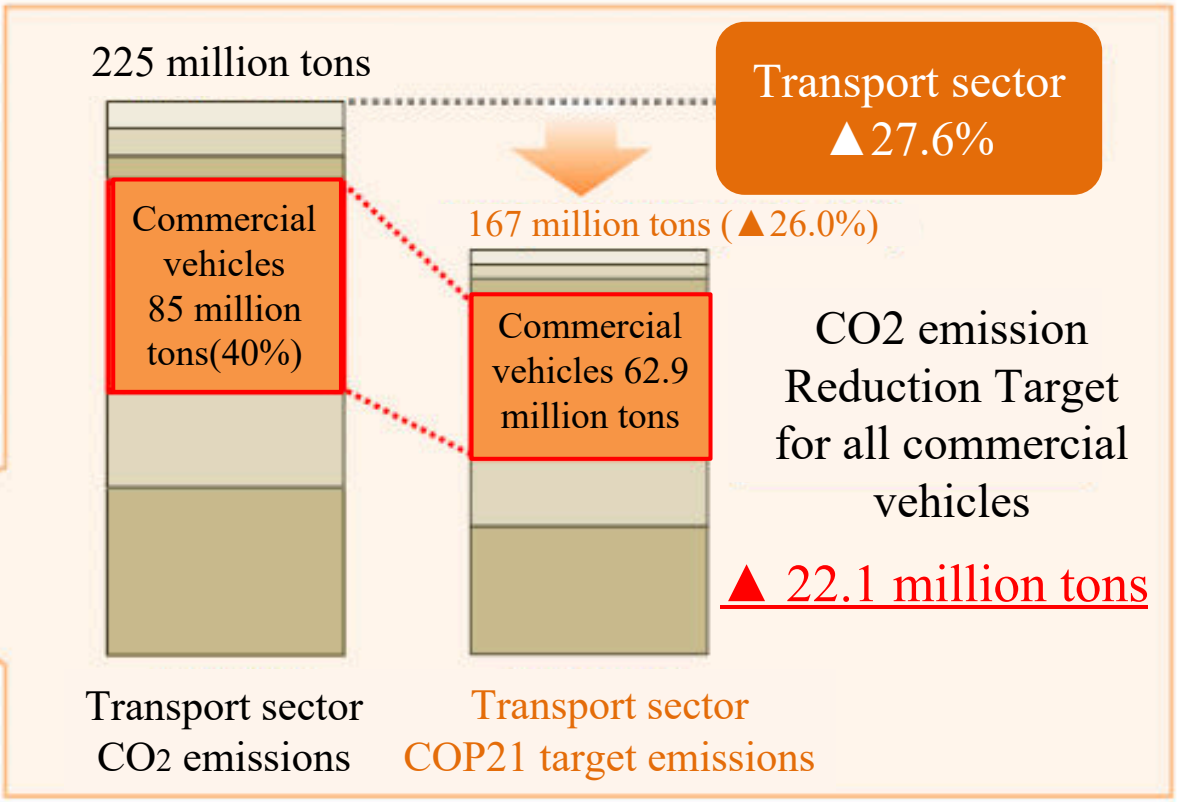
■ Purpose of heavy-duty hybrid truck development

COP21(21st Conference of the Parties)

The Japanese government submitted to the UN a proposal to
reduce annual CO2 emissions by **26%** by 2030 from those of 2013

CO2 total emissions
of Japan(2013)
1,408 million tons

Source: Japanese ministry of the Environment

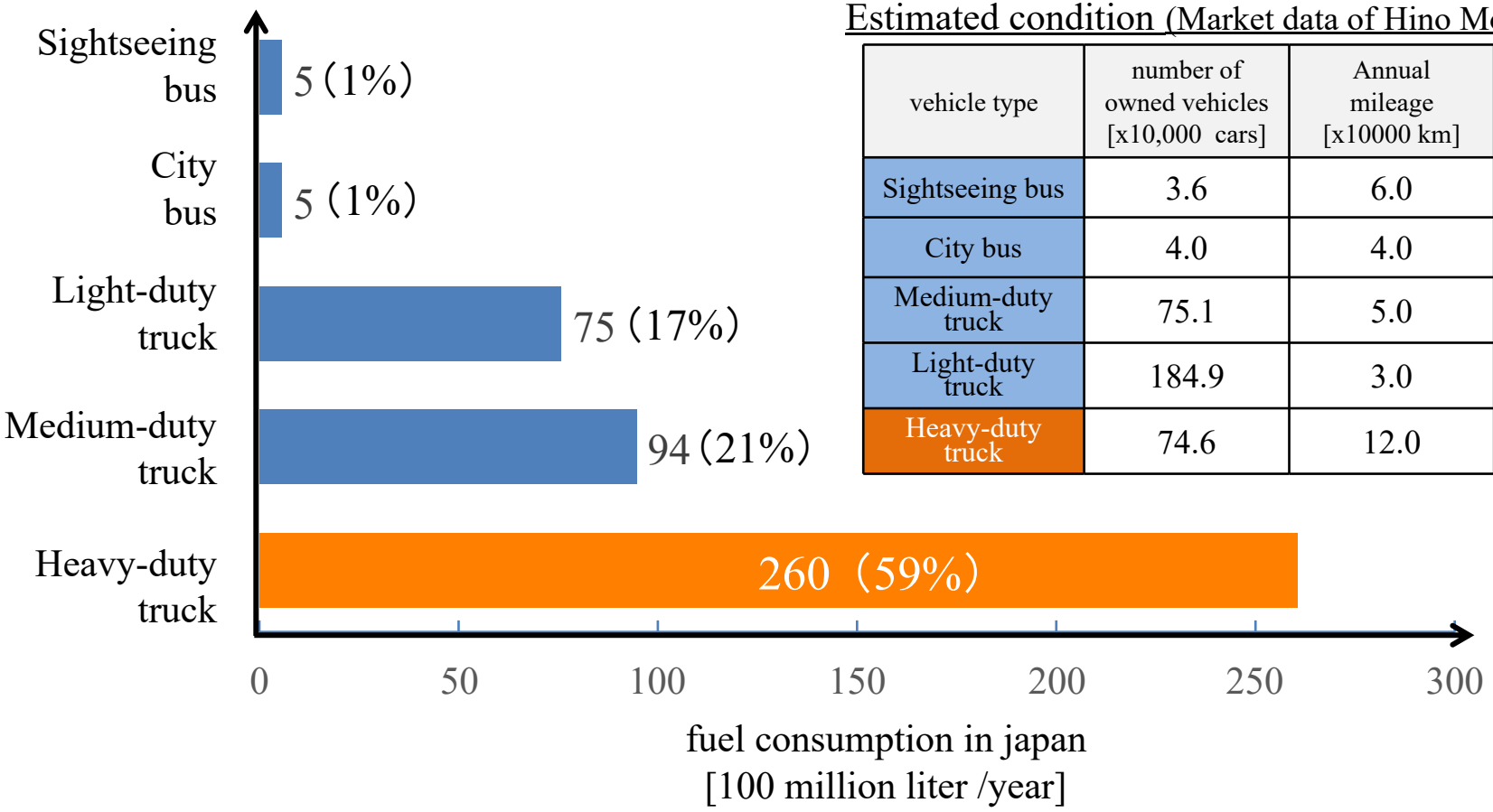


In Japan, it is necessary to reduce 22.1 million tons of CO2 emissions for all commercial vehicles

1. Introduction

■ Purpose of heavy-duty hybrid truck development

Fuel consumption of commercial vehicle in Japan(2013)



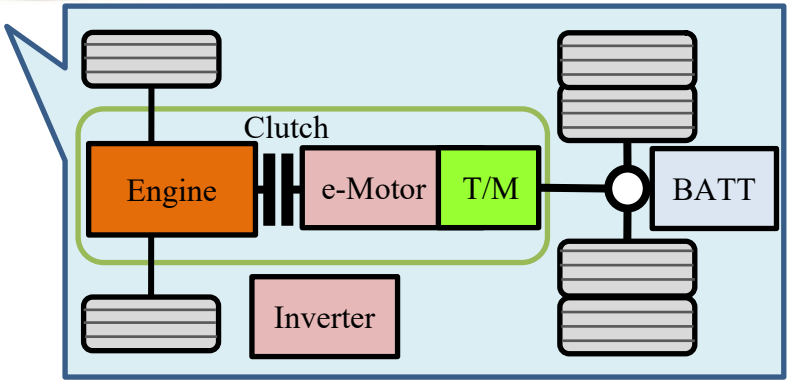
Estimated condition (Market data of Hino Motors collected)

vehicle type	number of owned vehicles [x10,000 cars]	Annual mileage [x10000 km]	Fuel consumption [km/L]
Sightseeing bus	3.6	6.0	4.0
City bus	4.0	4.0	3.0
Medium-duty truck	75.1	5.0	5.0
Light-duty truck	184.9	3.0	6.0
Heavy-duty truck	74.6	12.0	3.5

Measures are required for heavy-duty truck
that account for about 60% of fuel consumption

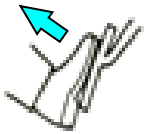
1. Introduction

■ Vehicle Specifications

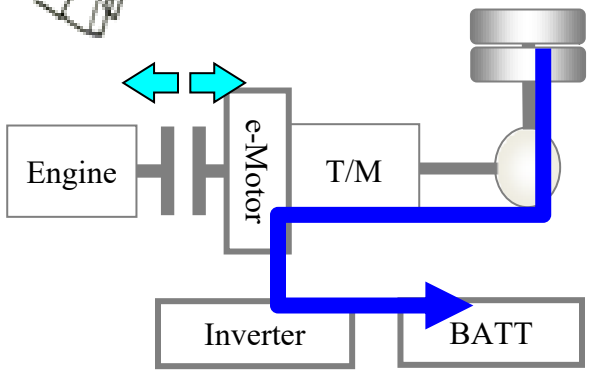


Engine		6-cylinder inline(8.866L)
Transmission		Automated Manual Transmission (12speed)
Vehicle Size (L×W×H mm)		11,540×2,490×3,010
Gross Vehicle Weight		25,000kg
Hybrid System	e-Motor	Synchronous e-Motor (90kW)
	Inverter	Vector control Inverter(180kVA)
	Battery	Li-ion battery (11kWh)

■ Basic function of HEV

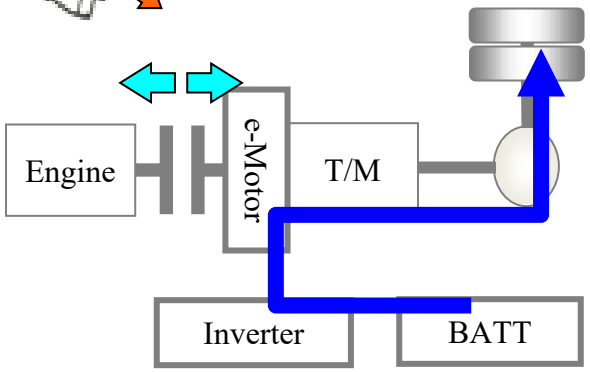


: Accelerator off

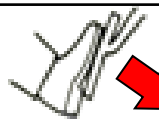


Clutch-off regeneration

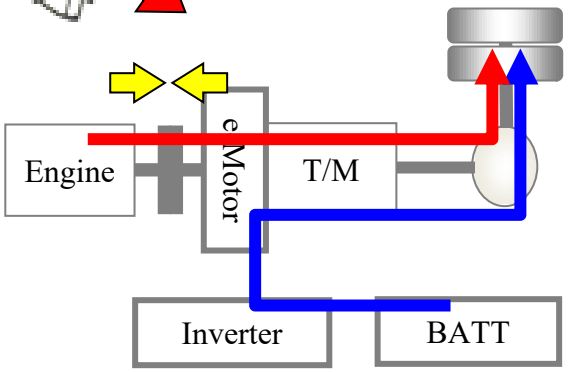
: Accelerator on (Low)



E-Motor running



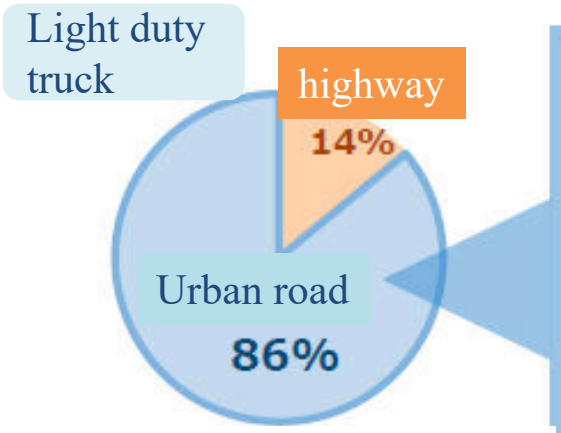
: Accelerator on (High)



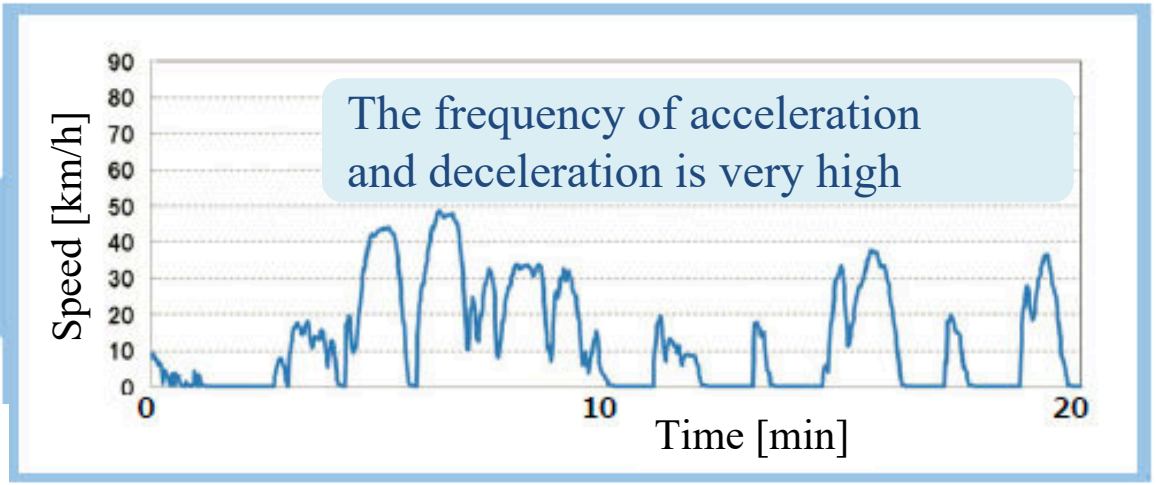
Assist engine power

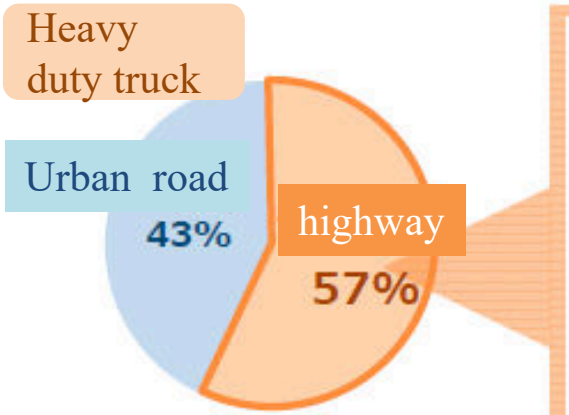
1. Introduction

■ Characteristic of heavy-duty truck



Load percentage (Distance ratio)
Source: Hino Motors, Ltd.





Load percentage (Distance ratio)
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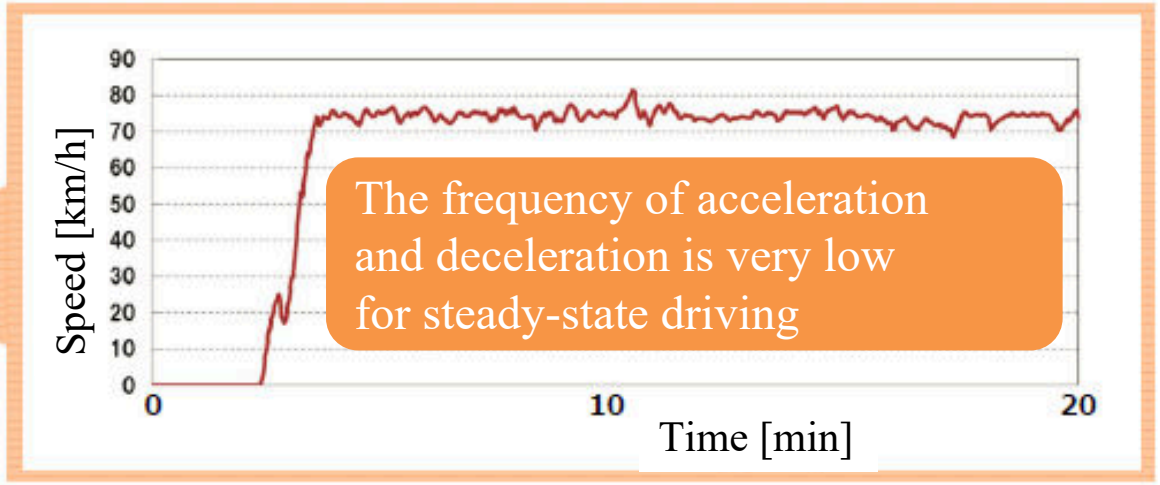
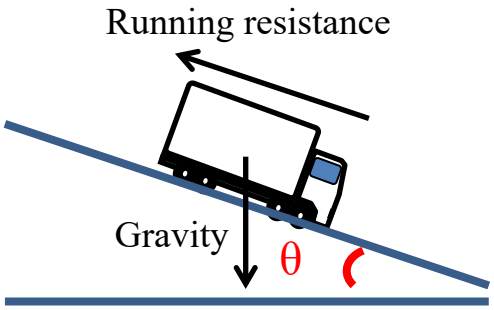


Heavy-duty trucks have a high frequency of steady-state driving on highway

1. Introduction

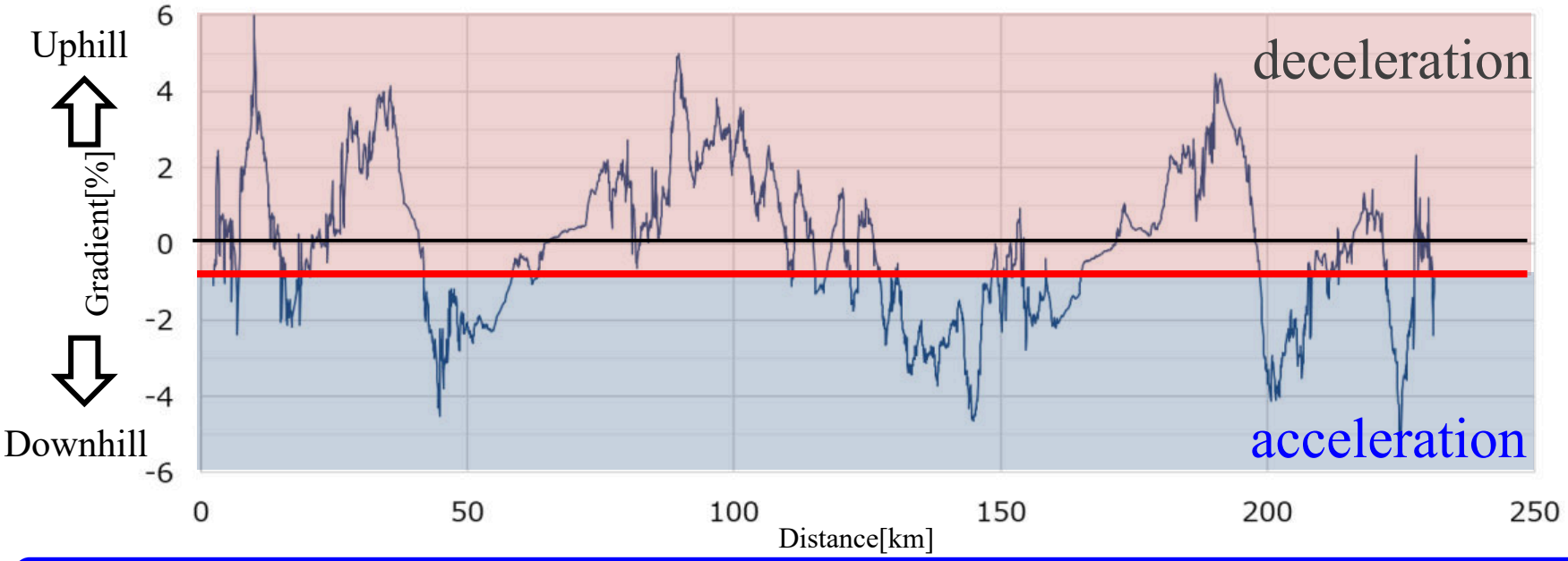
■ Energy regeneration on highway



Vehicle	GVW/Cd/CdA	Balanced gradient @80km/h
Passenger car	1,500kg/0.4/0.83	-3.22%
Light-duty truck	7,000kg/0.57/3.44	-2.38%
Heavy-duty truck	25,000kg/0.75/6.62	-1.18%

Boundary where regeneration from gravitational potential energy is possible

●Highway gradient (Chuo-highway in Japan)

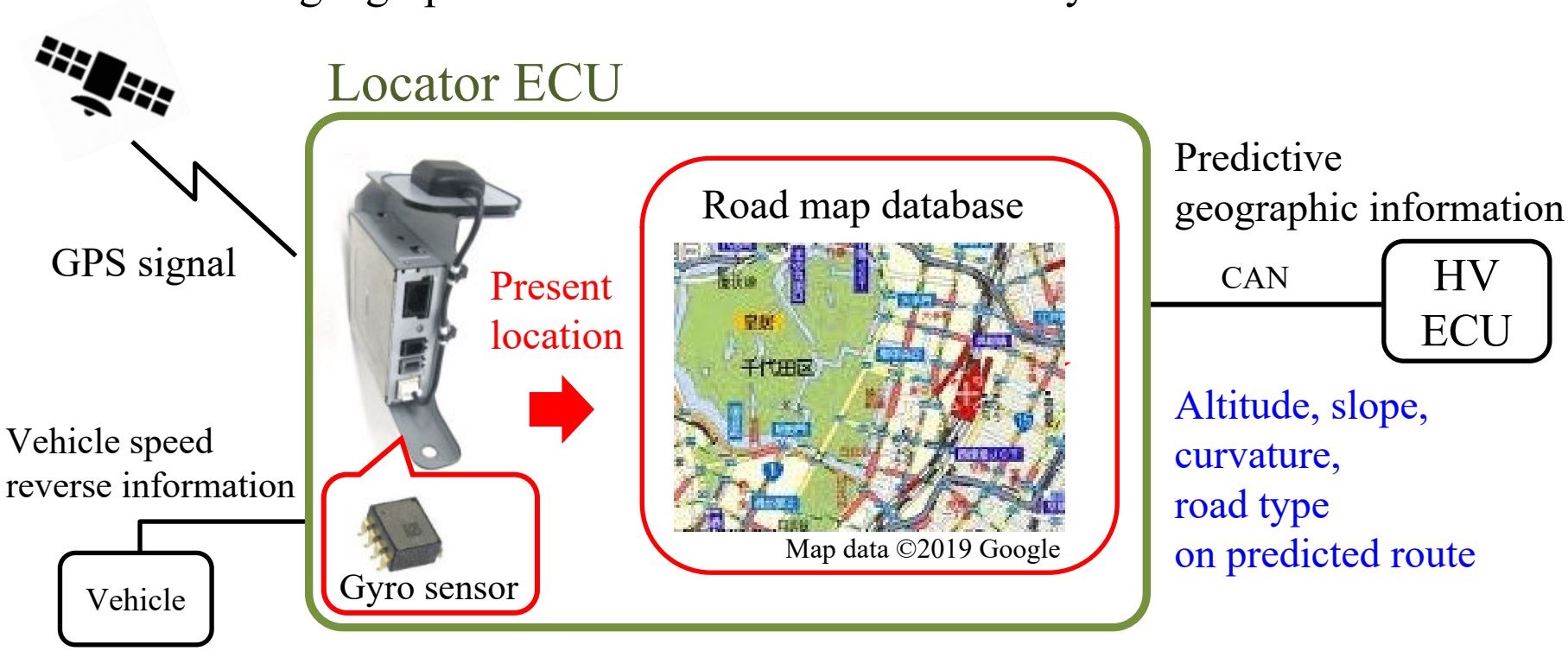


Regeneration is possible using gravitational potential energy at down hill

1. Introduction

■ Locator function

- Identify its present location from the GPS antenna, the gyro sensor, and vehicle speed pulse.
- Generate geographic information contained memory in locator ECU.



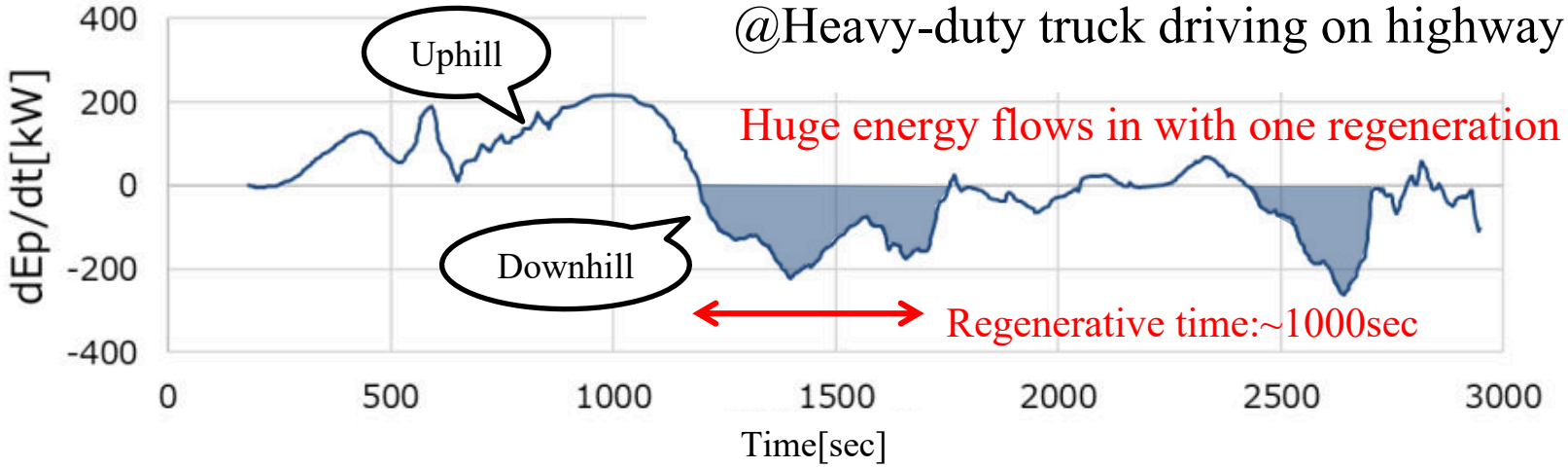
By combining predictive geographic information and vehicle status / specification,
It is possible to predict when and how much change of gravitational potential energy.

2. Development task

■Characteristic of gravitational potential energy regeneration

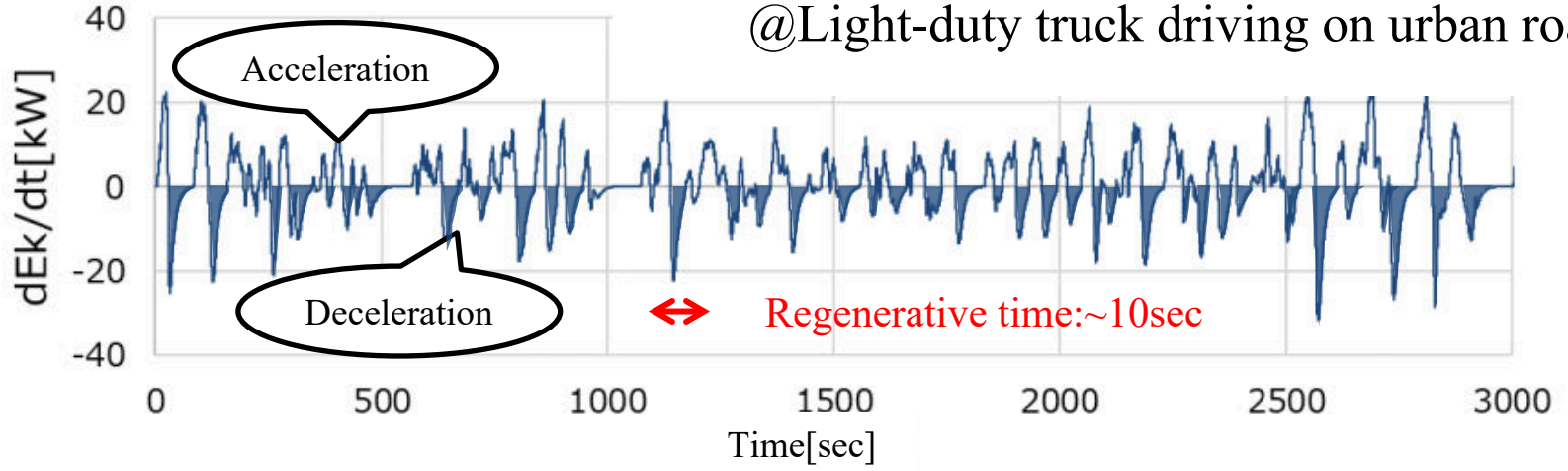
Change of gravitational potential energy(time derivative)

@Heavy-duty truck driving on highway



Cf.）Change of kinetic energy (time derivative)

@Light-duty truck driving on urban road



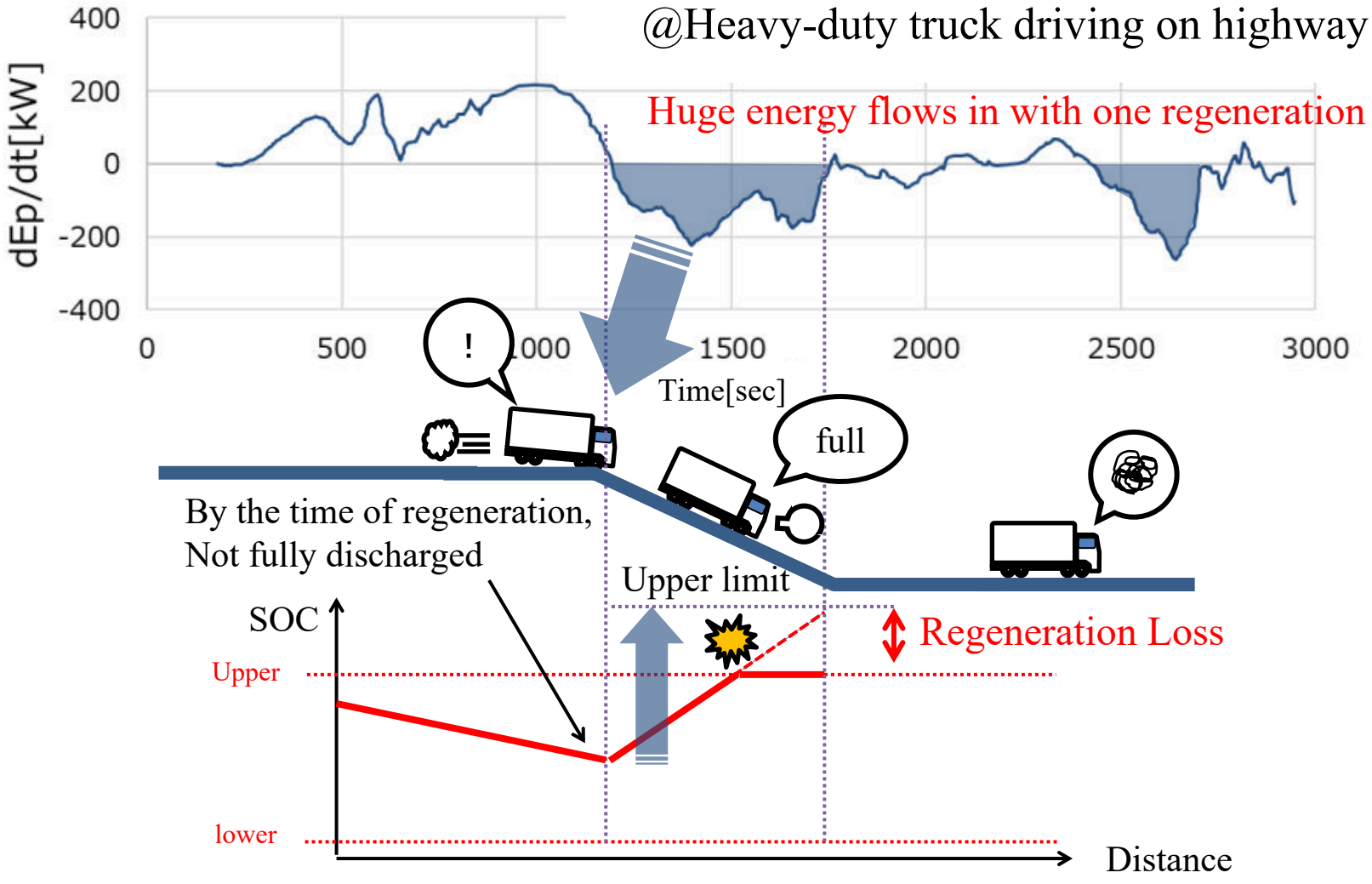
gravitational Potential energy regeneration continues for a long time

2. Development task

■Characteristic of gravitational potential energy regeneration

Change of gravitational potential energy(time derivative)

@Heavy-duty truck driving on highway



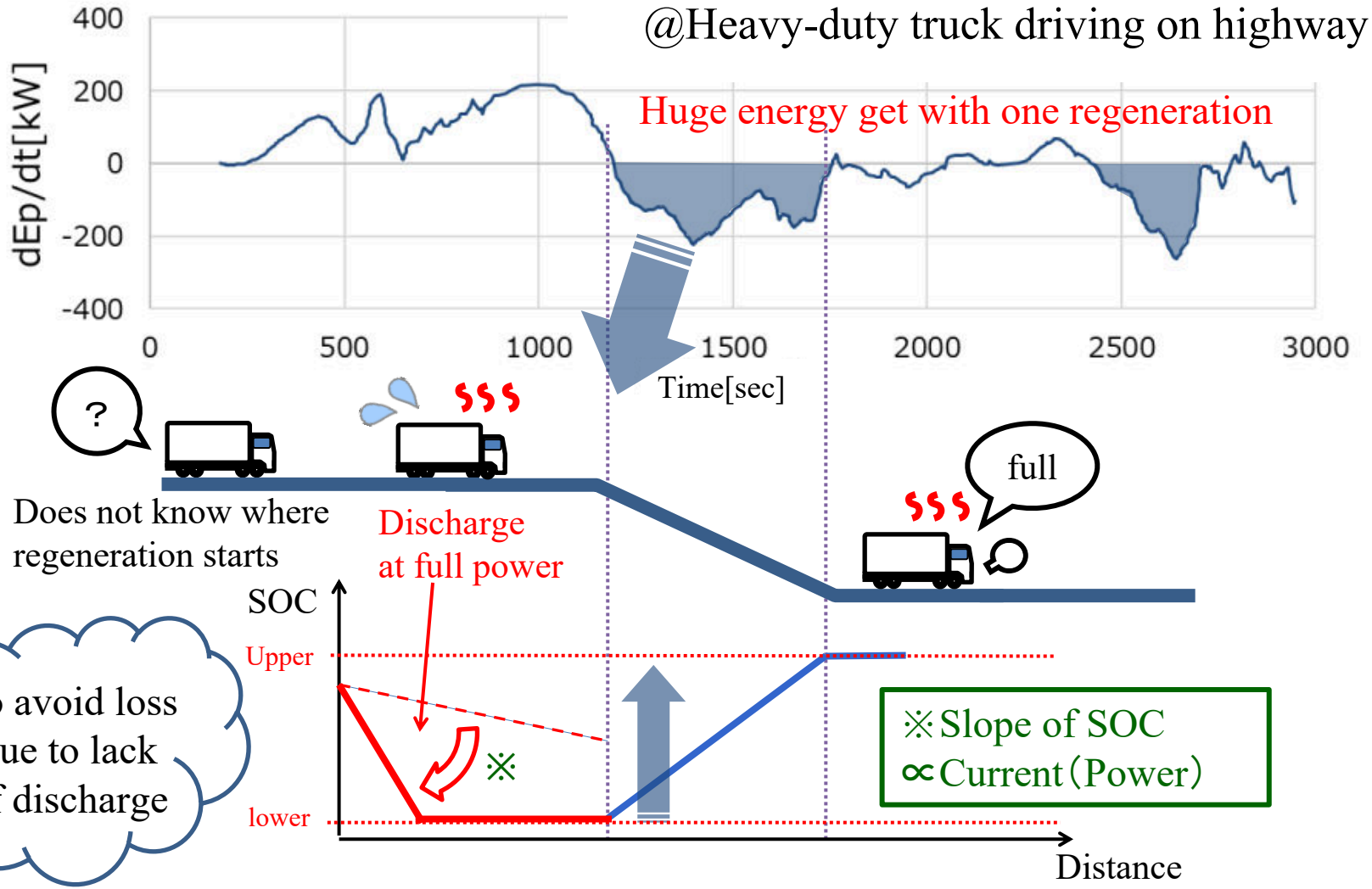
Regeneration lossed due to SOC(state of charge) upper limit

2. Development task

■Characteristic of gravitational potential energy regeneration

Change of gravitational potential energy(time derivative)

@Heavy-duty truck driving on highway



Heat loss increase due to large current discharge

2. Development task

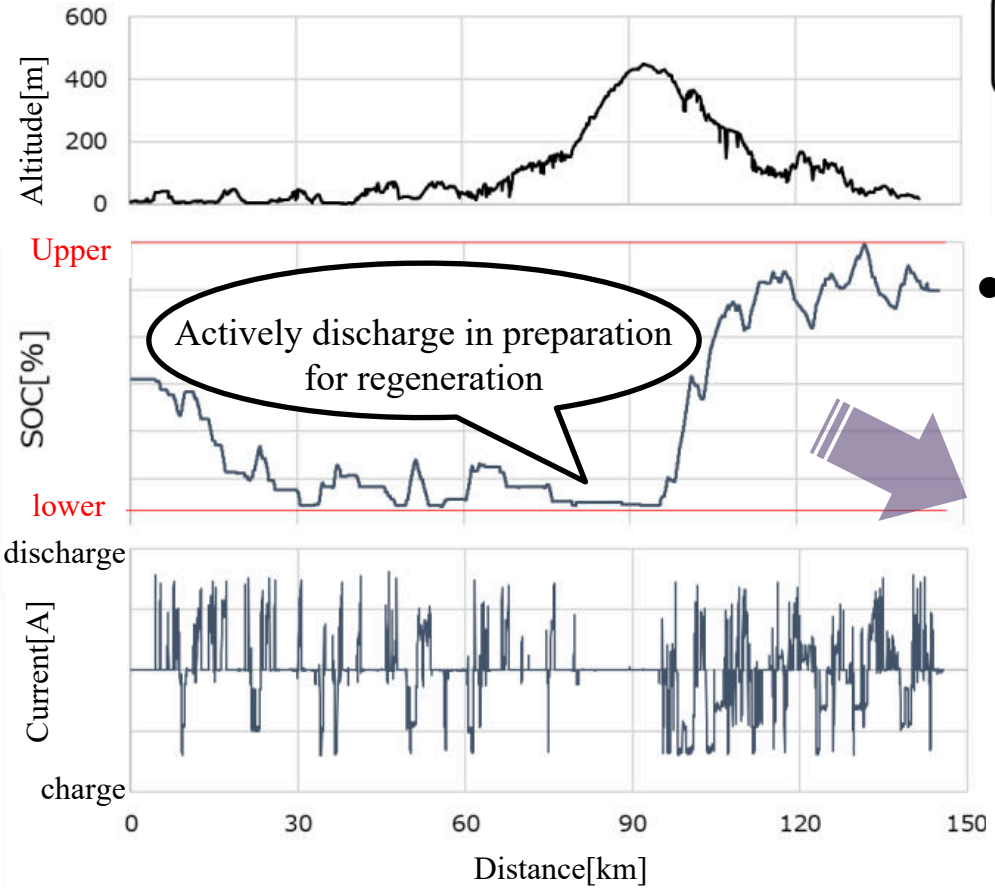
■ Heat loss during actively discharge

Driving conditions

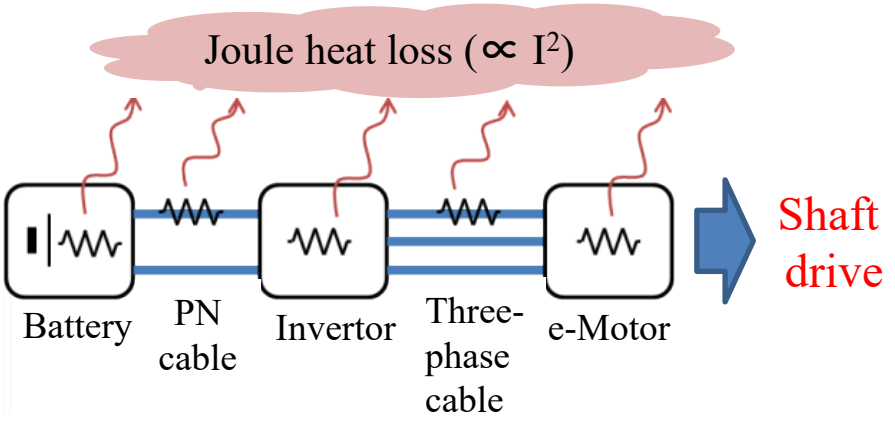
Route : Japanese highway (Tomei highway)

Load : Full load

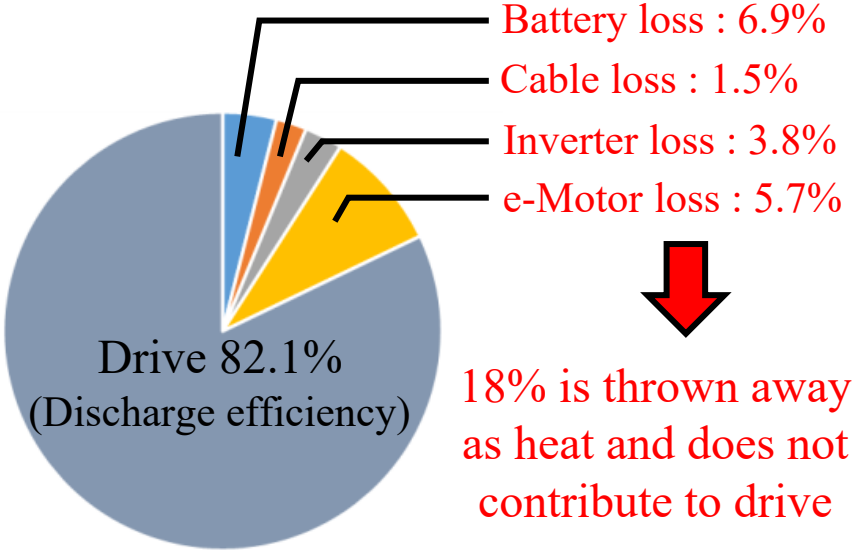
Set Speed : 80 km/h



●Energy flow



●Discharge energy consumption breakdown



18% is thrown away as heat and does not contribute to drive

Trade-off between recovery rate and heat generation

3. Strategy

■ Relationship between current and heat generation

average of squared current ∝ Joule heat	square of average current ∝ Energy supplied to drive	Current standard deviation squared (Current variation)

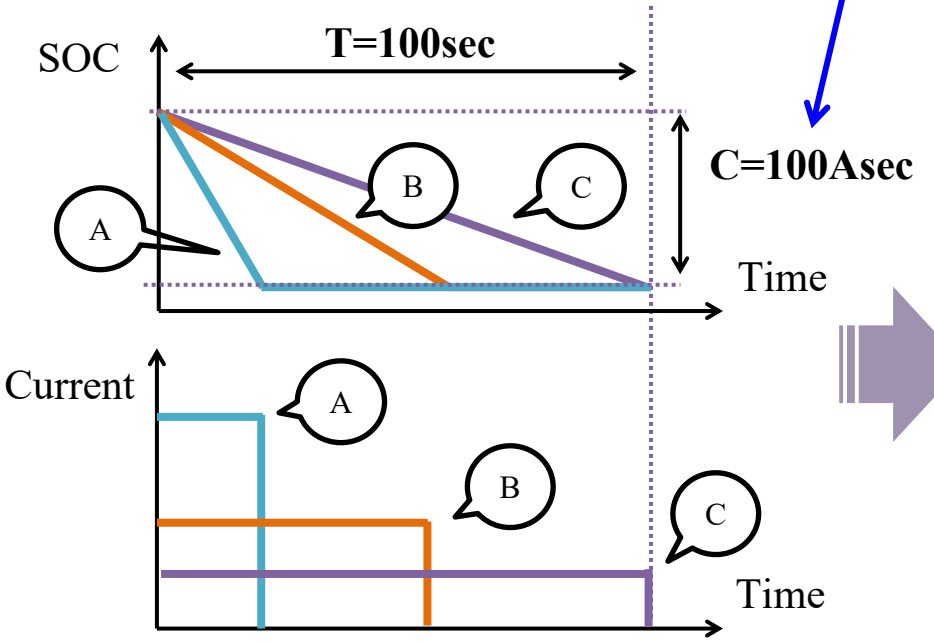
$$(I^2)_{ave} = (I_{ave})^2 + (I_\sigma)^2$$

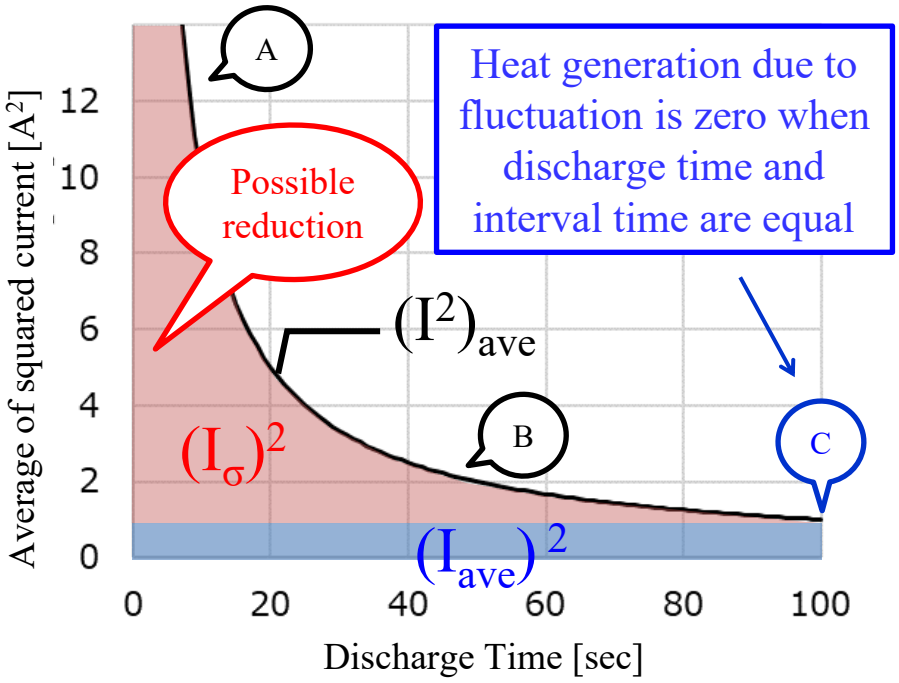
Possible reduction

$(I_{ave})^2$: stationary components

$(I_\sigma)^2$: fluctuation components

When the interval time and the required amount of discharge electricity are known

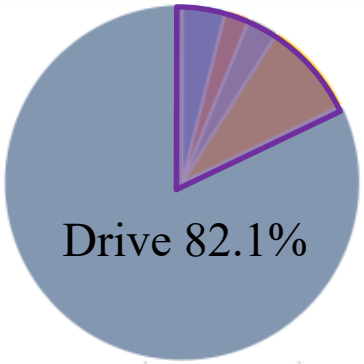




Heat generation can be reduce by current smoothing
(fluctuation component elimination)

4. Effect estimation

Route : Japanese highway (Tomei highway)



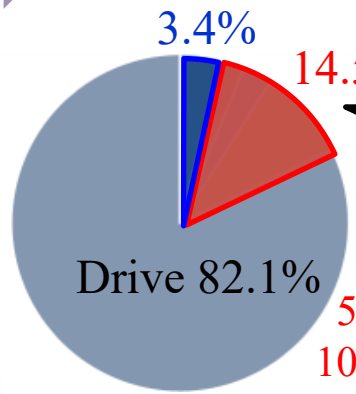
Heat loss
17.9%

$5717A^2$

$1067A^2$ (19%)

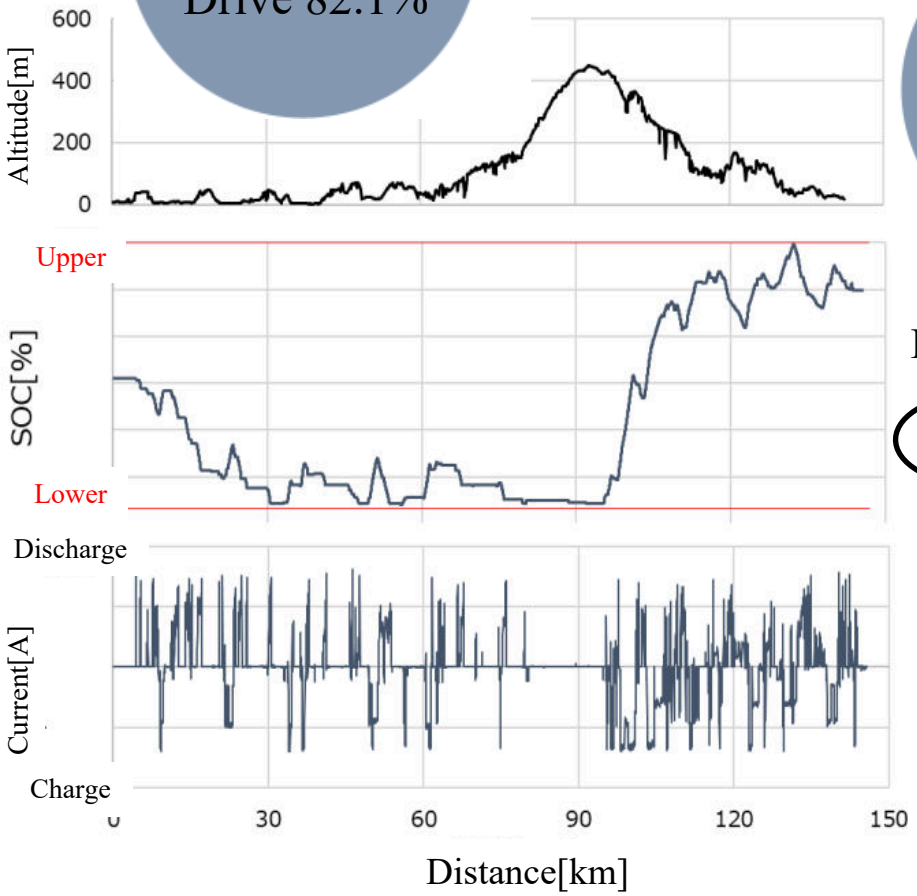
$4650A^2$ (81%)

$(I^2)_{ave} = (I_{ave})^2 + (I_\sigma)^2$

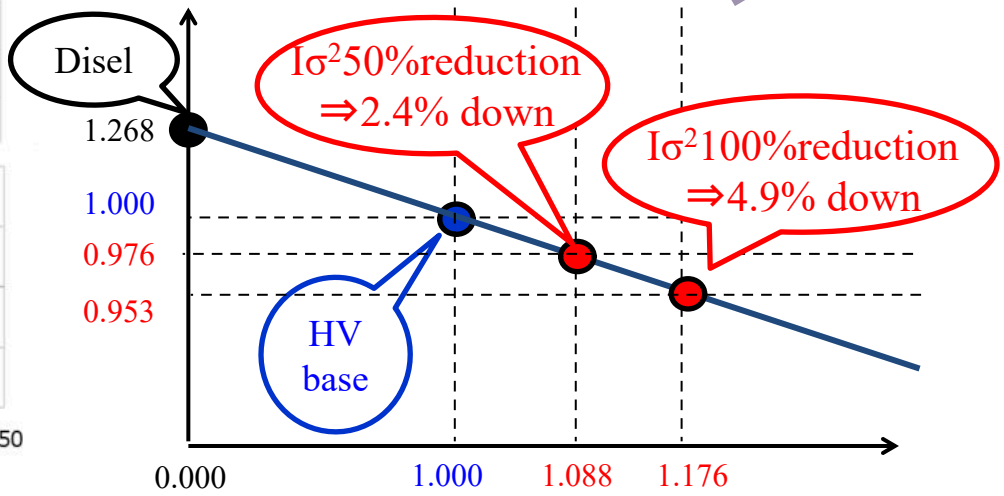


Reduced and replaceable to drive

50%reduction⇒Drive energy8.8%up
100%reduction⇒Drive energy17.6%up

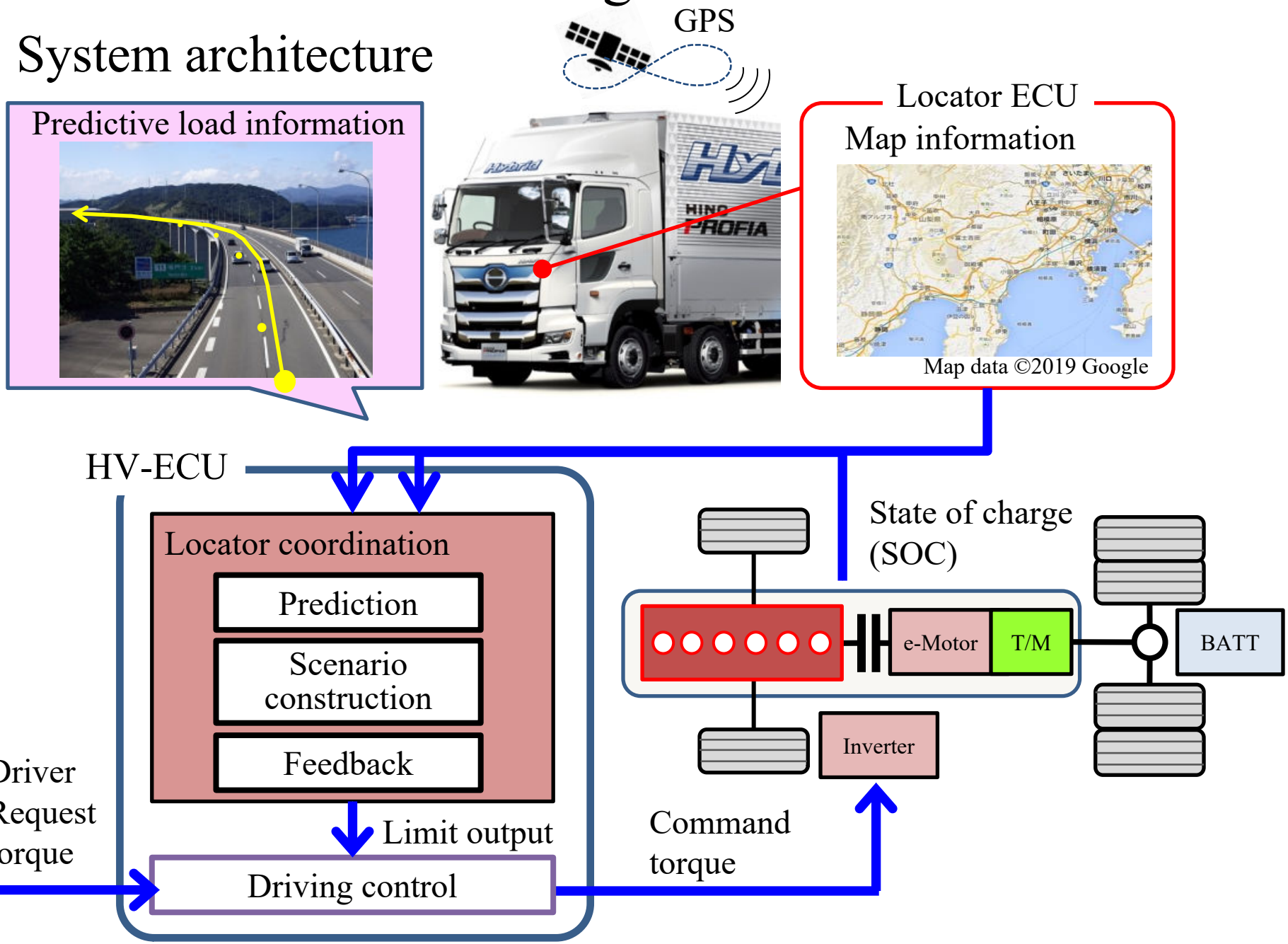


Fuel consumption ratio



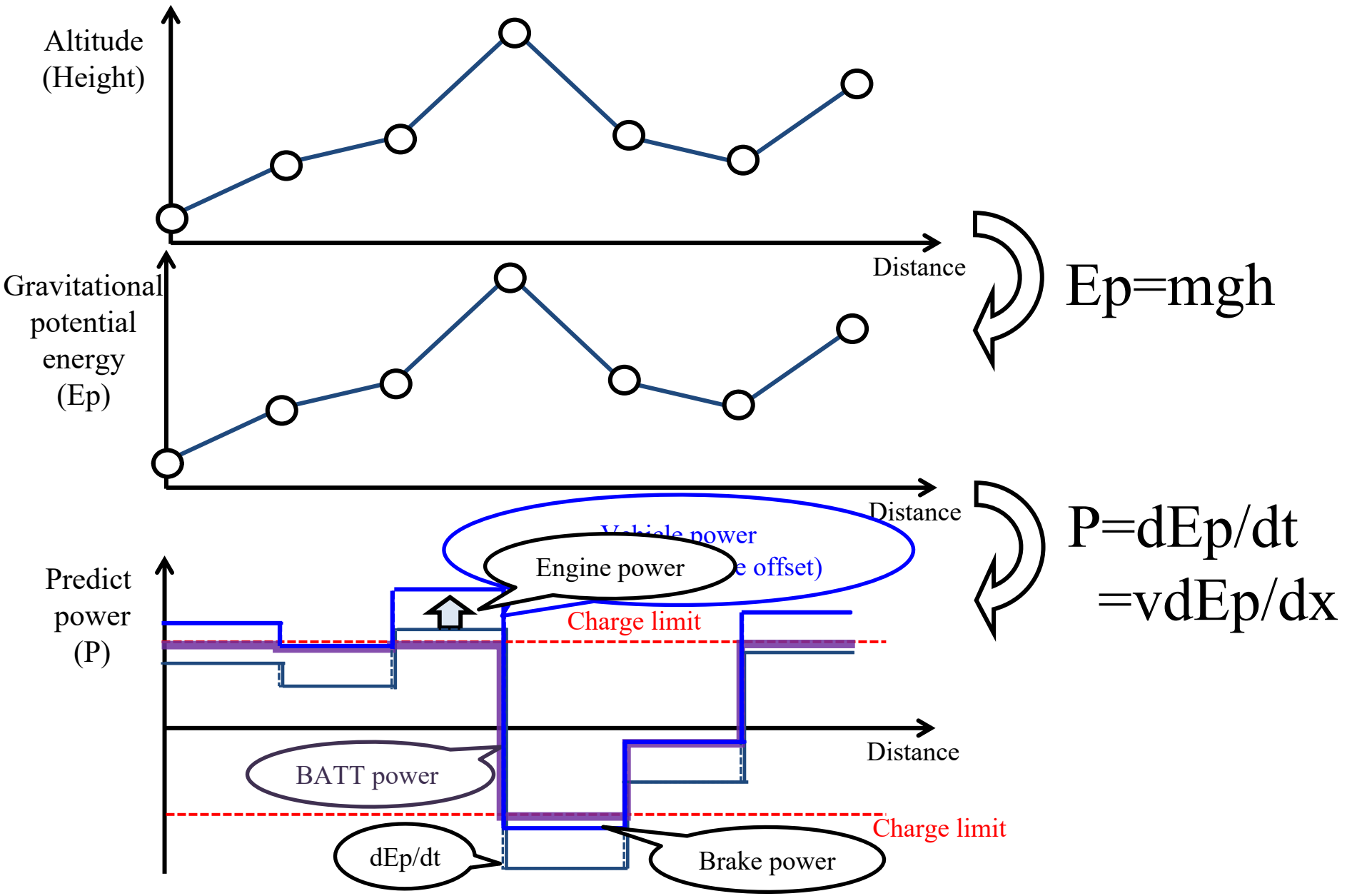
5. Predictive control design

■ System architecture



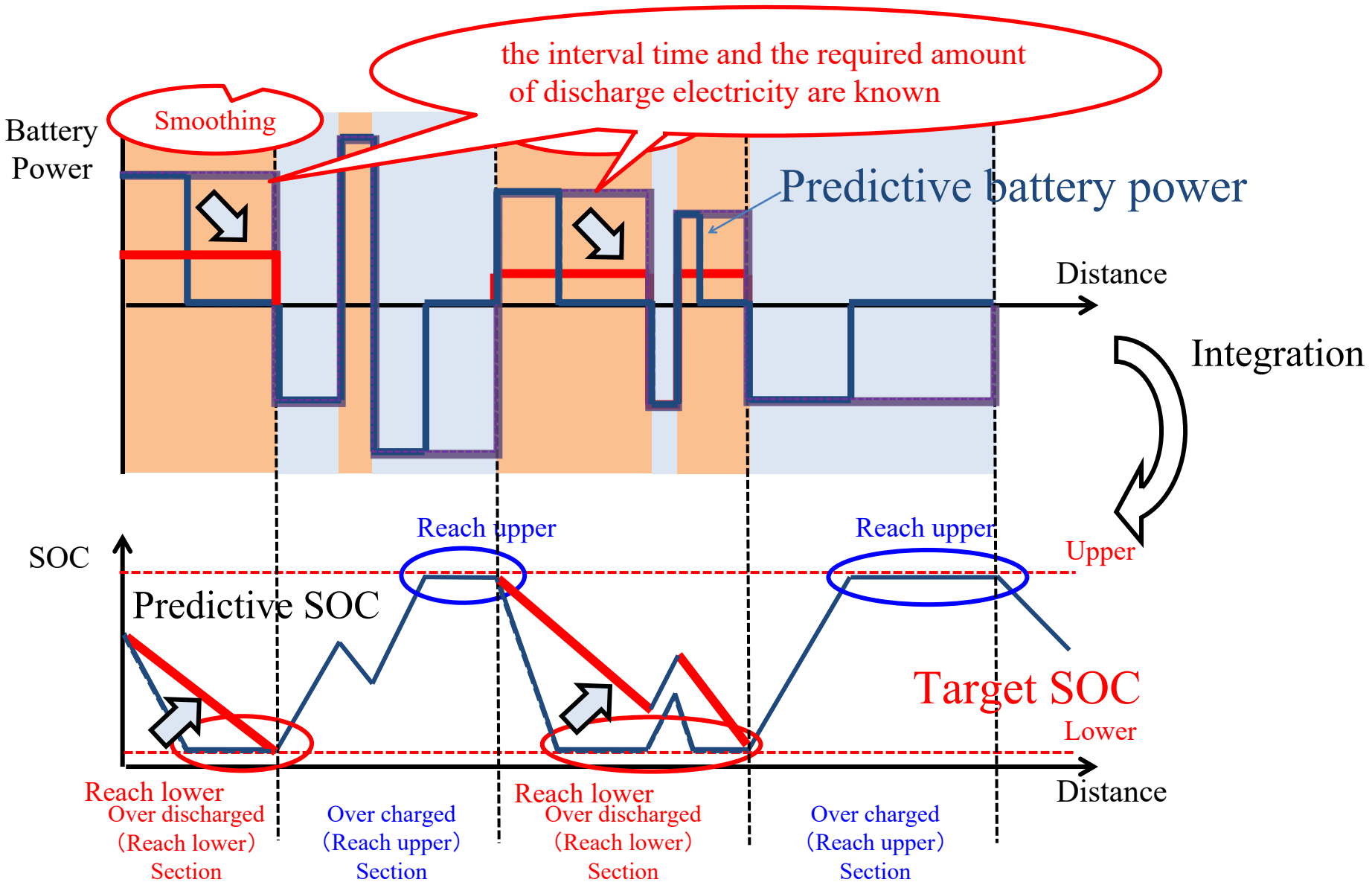
5. Predictive control design

■ Charge and discharge behavior prediction



5. Predictive control design

■SOC prediction construction (Target SOC derivation)

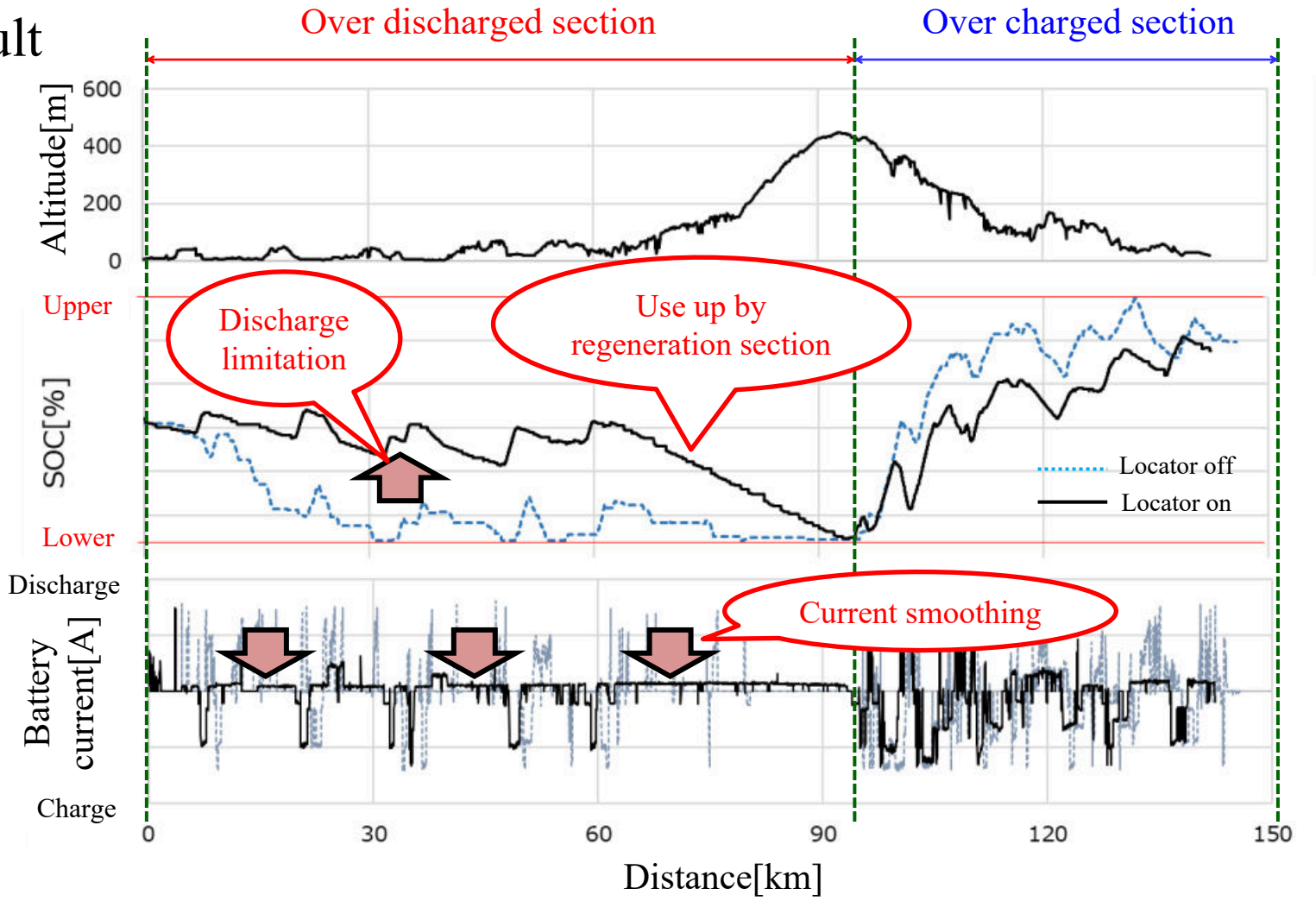


6. Effect confirmation

■ Evaluation condition

- Route : Japanese highway (tomei highway)
- Distance : 140km
- Set speed : 80km/h

■ Result



6. Effect confirmation

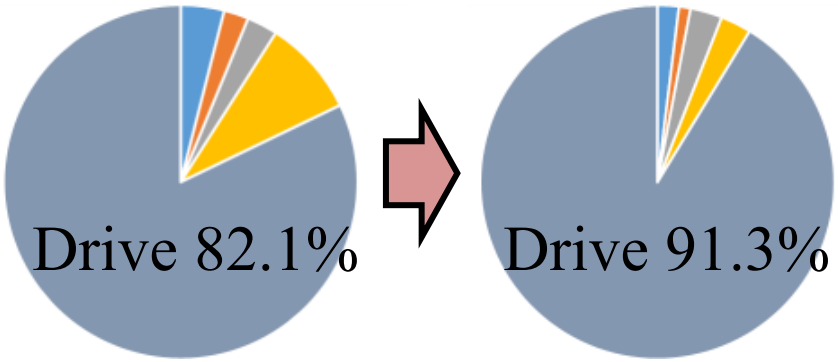
■ Result

- Locator ON/OFF comparison

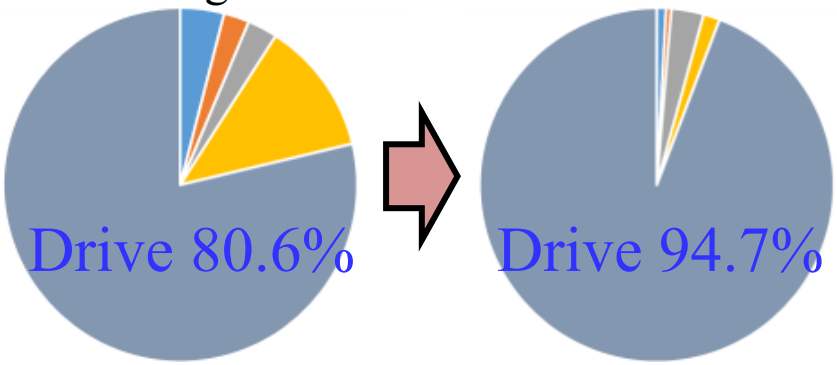
	Total	Discharge section
I^2ave (Total heat)	53% Reduction	82% Reduction
$I\sigma^2$ (fluctuation component)	66% Reduction	92.5% Reduction
Fuel economy	2.7% Up	—
System efficiency	11.1% Up	17.4% Up
Total loss	54% Reduction	75% Reduction

- Discharge section; energy consumption breakdown

【Total】



【Discharge section】



7. Conclusion

・Focus on the trade-off between regenerative recovery rate and heat generation loss in HEV heavy-duty truck potential energy regeneration.

・Development of control logic to reduce unnecessary heat generation by utilizing locator and smoothing discharge current.

・In the vehicle evaluation, the heat loss due to the current fluctuation is reduced by 66%, and the Fuel economy is improved by 2.7%.

Thank you for your attention!