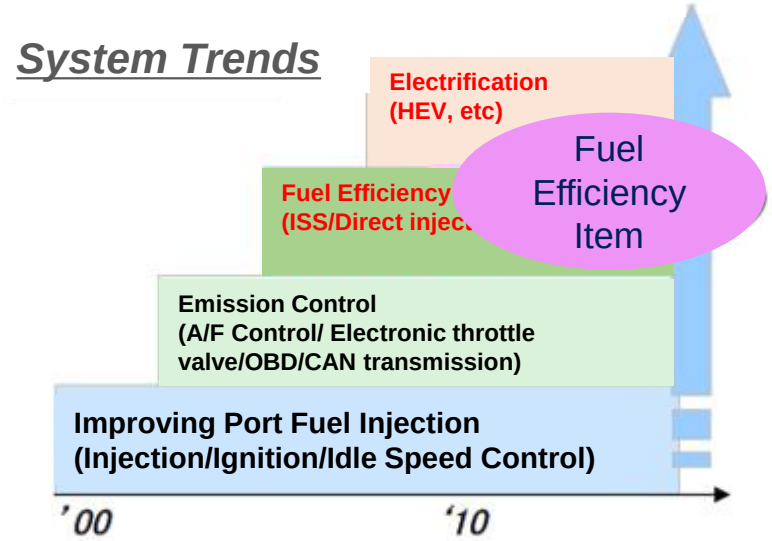
ODCM to Improve the Efficiency of Model-Based Calibration

SUBARU Corporation
Vehicle Environment Development Dept. Engineering Division
Taiki Takahashi, Hirohki Usijima and Issei Matsushita

Current Issues in ICE Development

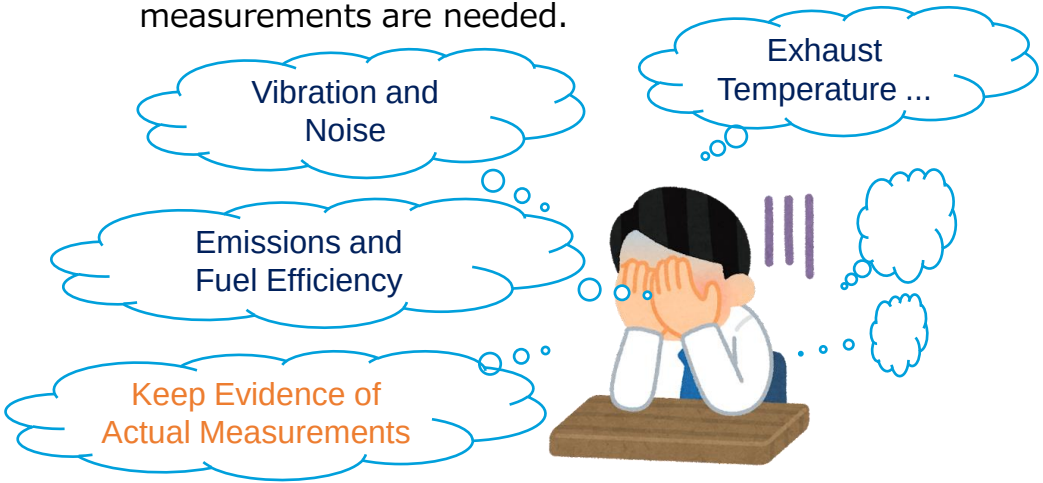
Limitation of Manual ICE Calibration

- Increased system complexity due to regulation and electrification



- Specific requirements for calibration and transparency obligation

Extremely fine calibration values and numerous measurements are needed.

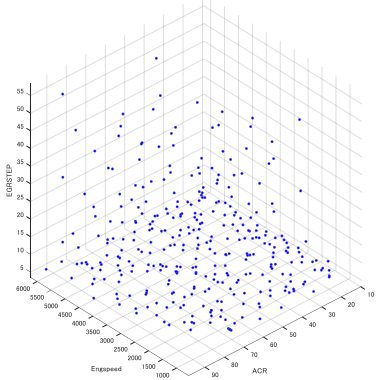


▶To optimize ICE calibration,
Automated measurement + **MBC (Model Based Calibration)**
should be promoted.

Using MBC for ICE Calibration

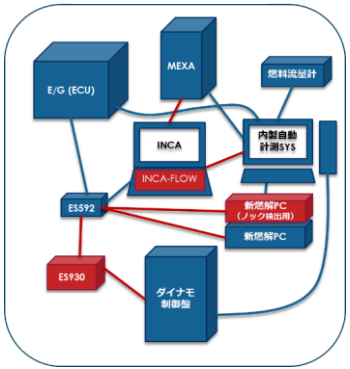
MBC (Model-Based Calibration) -- Generate models and optimize parameters based on the measurement points obtained through Design of Experiments (DoE)

4 Steps of MBC

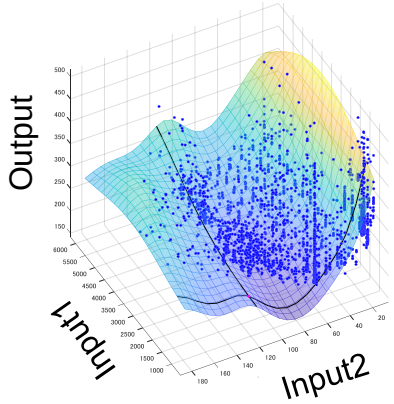


Create DoE Points

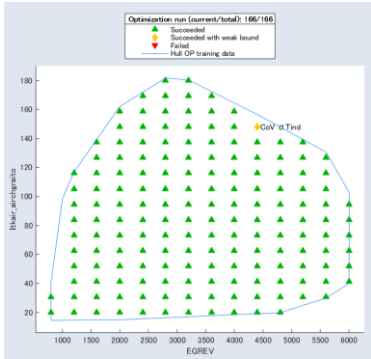
The Structure of EDM



Measuring



Modeling



Optimizing

Create Design points (measurement points) using the DoE methodology

Measure the DoE points

Generate statistical models out of the experiment data

Optimize performances and device values

Ideal Model Creation Process for MBC

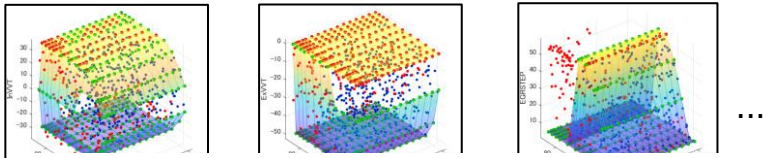
Two things need to be improved
"To enable anyone to safely create highly accurate models in a short time" :

Complexity of creating DoE points

DoE points creation process

Define control parameters
Define calibration requirements and hardware constraints

DoE



...

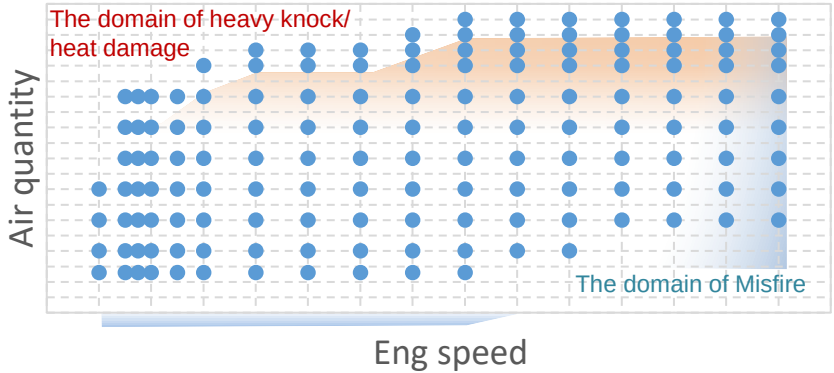
Determine the scope of the DoE based on the requirements and constraints
A boundary search may be required in the advanced test.

- Expertise required to create DoE points and time required for review
- Lack of information on requirements and constraints for new engines

▶Simplify the process of DoE point creation

Safety of automatied measurement

Measure the corners of DoE points to improve model accuracy, although the corners can be risky as they can usually be the combustion/ hardware boundary limit.



The automated driving sequence takes evasive action. However, it is not effective in all cases.

- Engine damage due to interlock activated in the dangerous area
- Inefficiency due to re-inspections required each time an interlock occurs

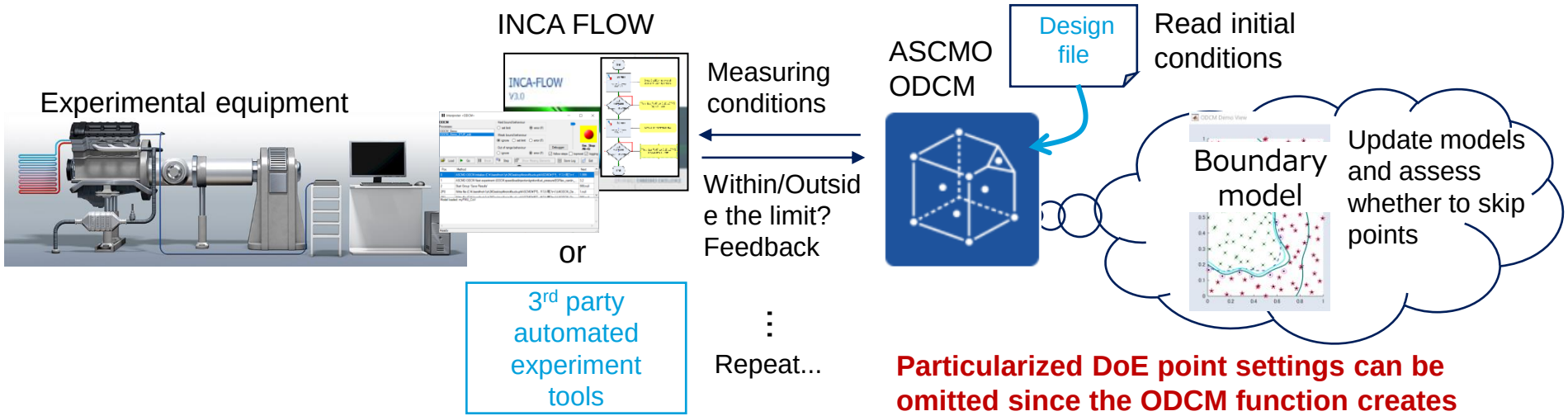
▶Reduce the frequency of entering dangerous domain

ODCM (Online DoE with Constraint Modeling)

*Excerpts from the Product Material Provided by ETAS K.K.

ODCM defines engine performance limits (model boundaries) and updates them during the DoE measurements. **The tool reduces the risk of damage to the target system and shortens the measurement time**, while eliminating the risky measurement conditions.

(The tool is an option SW of ETAS ASCMO. The automated experiment tool issues a command via API to use the functions.)

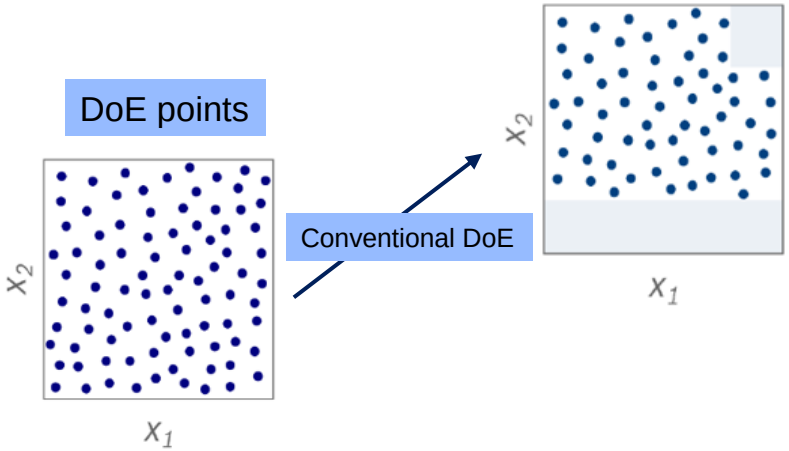


Particularized DoE point settings can be omitted since the ODCM function creates the boundary models.

*This model shows a combination of INCA FLOW and our existing engine dynamometer system.

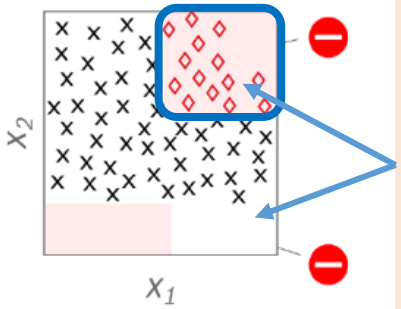
Solution by ODCM – Key Points

Rely on experience and wild guess to mask measuring points



◇: Unmeasurable design points

X : Measurable design points



The method tries to measure the unmeasurable points

⇒Setting the measurement condition wastes time

⇒Too much intrusion into the boundary resulting in the interlock stop

Source: Robert Bosch GmbH

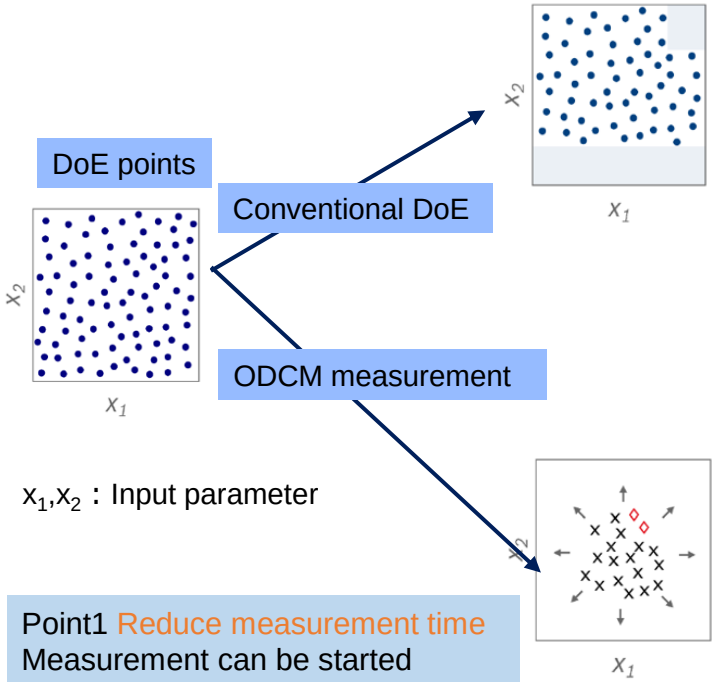
Solution by ODCM – Key Points

Rely on experience and wild guess to mask measuring points

DoE points

Conventional DoE

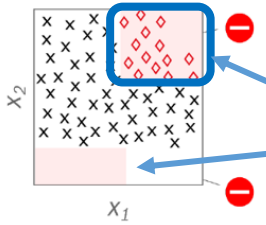
ODCM measurement



x_1,x_2 : Input parameter

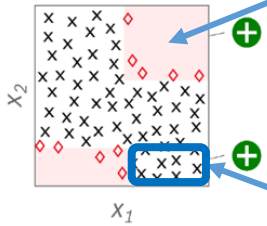
Point1 Reduce measurement time
Measurement can be started without setting the DoE Points
⇒Reduction of DoE creation time

◇: Unmeasurable design points
X : Measurable design points



The method tries to measure the unmeasurable points
⇒Setting the measurement condition wastes time
⇒Too much intrusion into the boundary resulting in the interlock stop

Point2 Avoid dangerous domain
Find and confirm boundary during measurement⇒Avoid DoE points that do not meet any criteria



Find and confirm boundary during measurement ⇒Improve model accuracy by increasing the interpolated range

Source: Robert Bosch GmbH

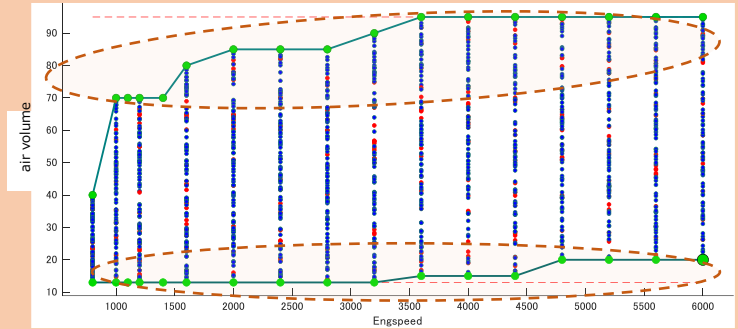
Effect Verification: Shorten the DoE process

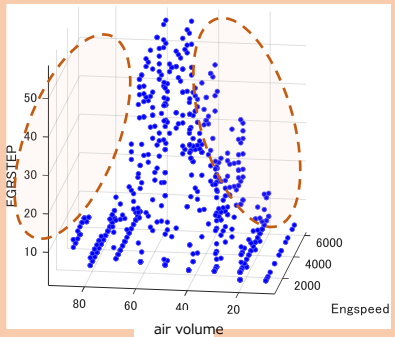
No expertise is required to review the experimental design, since a measurement area is learned by ODCM.

Upper/ Lower airflow limit setting

Upper EGR limit setting

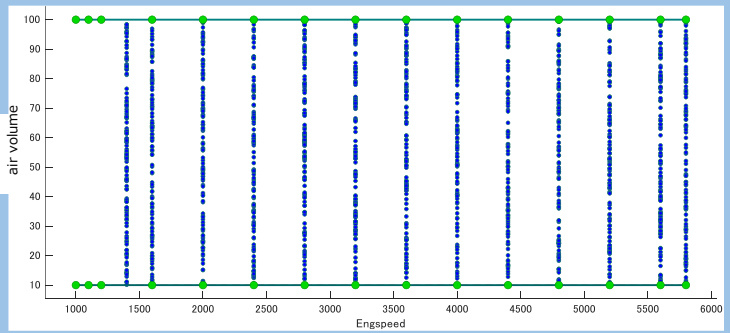
Conventional DoE

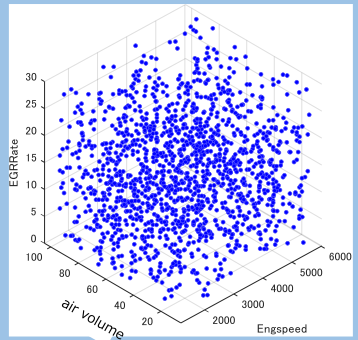




Pre-setting is required to avoid measuring unmeasurable area.

ODCM





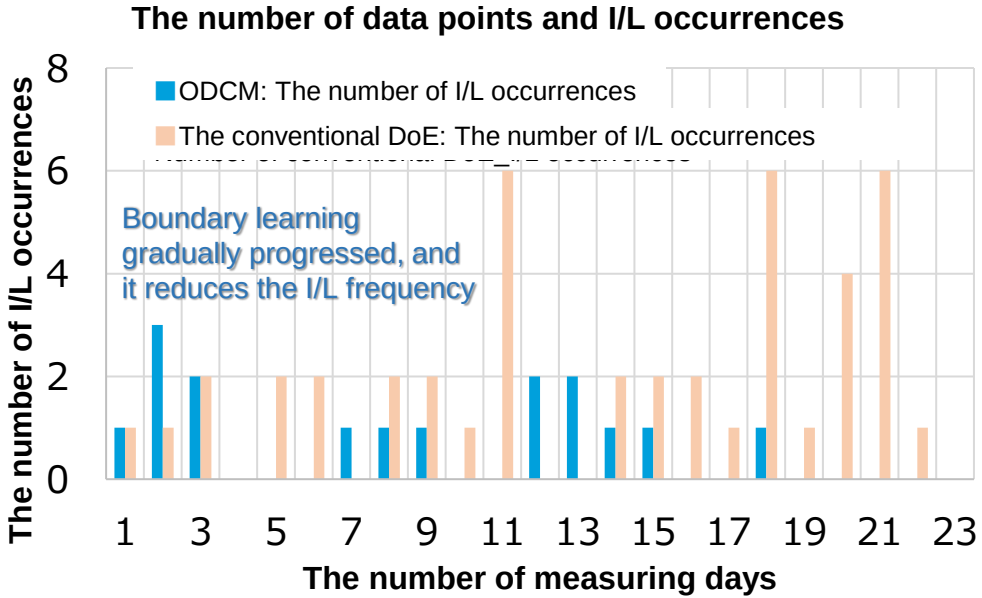
No need to strictly consider HW and SW constraints.

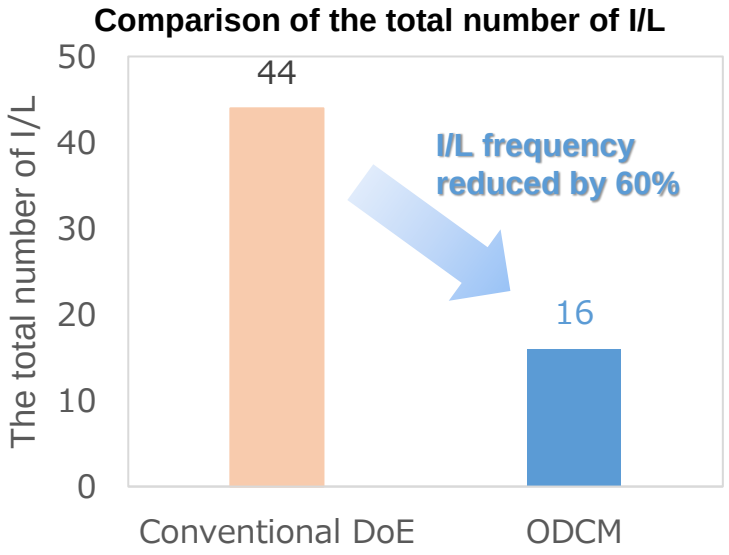
Comparison of range settings between ODCM and conventional DoE

Effect Verification: The Efficiency of Measurement

The effects of ODCM boundary learning

- Positively skips unmeasurable conditions as the measuring progresses
  ⇒Reduces wasted time and improves measurement efficiency
- Approximately 60% reduction in interlock (I/L) frequency (The number of interlock occurrences: 44 to16)
- Model accuracy is equivalent to conventional DoE (approx. 2,000 measurement points)



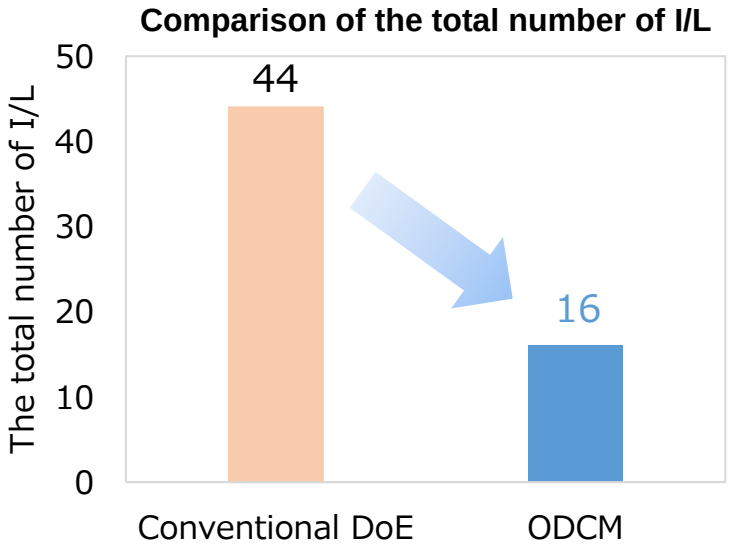


Summary

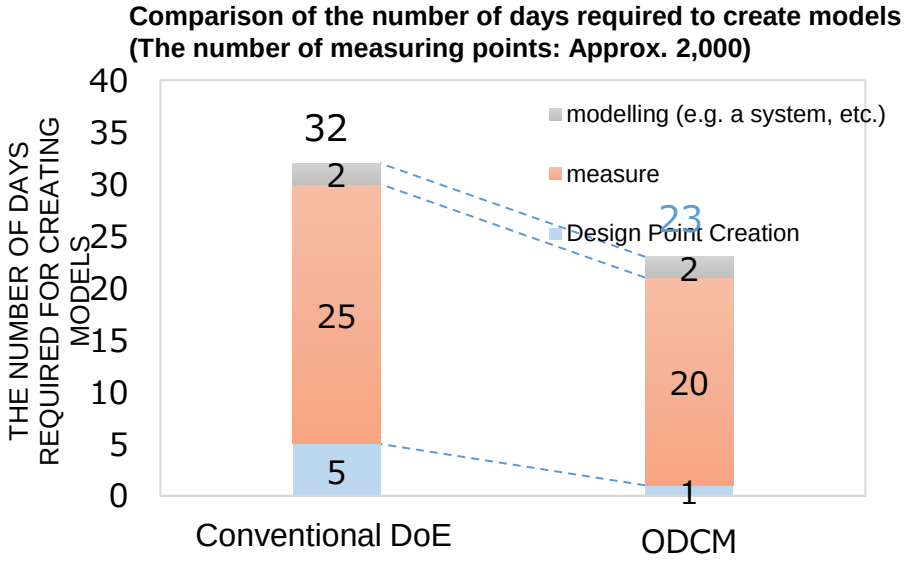
Through effect verification, the following advantages of ODCM over conventional DoE were identified.

- Reduce the risk of engine damage by minimizing the frequency of I/Ls through the creation of boundary models.
- Reduce the number of days required to create models by simplifying the creation of DoE points and reducing the number of measurement stops.

By using ODCM, **"anyone can safely create highly accurate models in a short time"**



Decreasing the frequency of I/L => Reducing the risk of engine damage



Achieved an efficiency of approx.30% in the whole test process.

Thank You!