MATLAB EXPO

2024.06.11 | 그랜드 인터컨티넨탈 서울 파르나스

데이터 기반 성능 개발프로세스 구축을 위한 R&H(Ride & Handling) DB 개발

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MathWorks

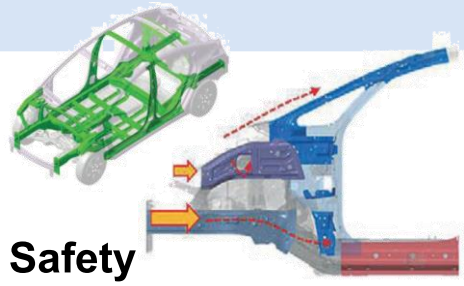
Contents

- Introduction & Purpose of R&H Database
- R&H DB & Analysis Platform
  - ✓ SPMD (Suspension K&C)
  - ✓ Ride
  - ✓ Handling/Steering
  - ✓ Virtual Process (Modeling, Validation, Simulation, Evaluation)
  - ✓ Other Applications - DB Management System, ROM(Reduced Order Model)
- Use Case and Values
- Conclusion

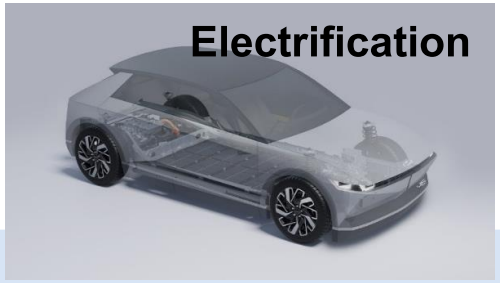
Introduction to Ride & Handling Performance

- **R&H(Ride & Handling) performance**
  - ✓ Vehicle 5 basic performance: R&H, NVH, Durability, Safety, PT/Fuel Efficiency
  - ✓ How a vehicle behaves during driving, how it responds to driver and road input → comfort, confidence
  - ✓ Traditional development method → data-driven, model-based efficient development

Vehicle Basic Performance

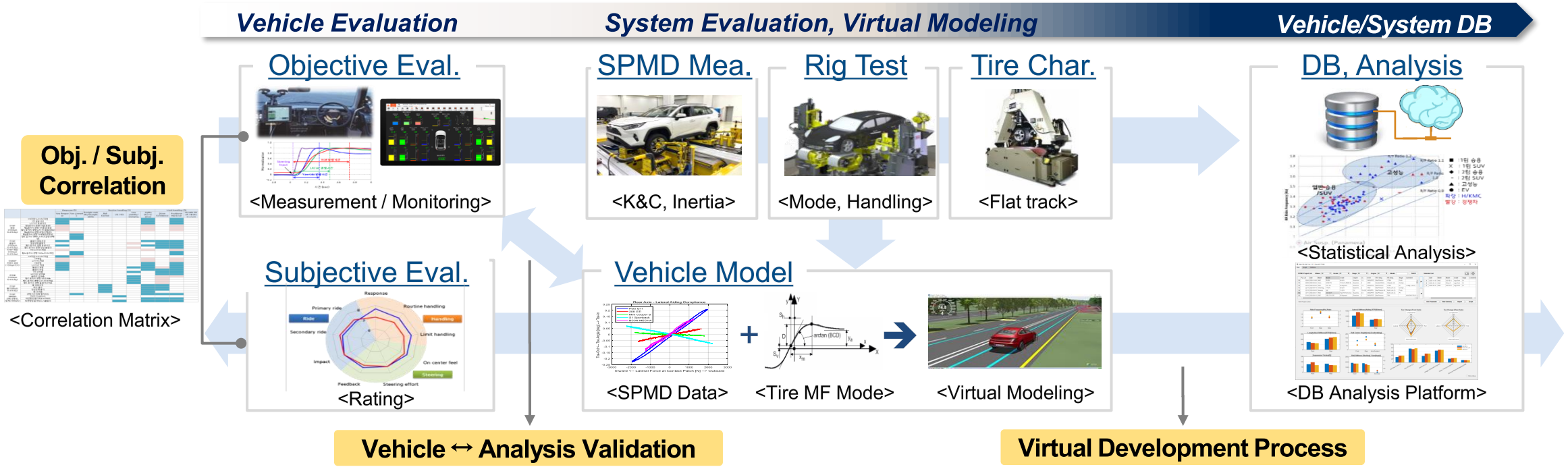


Current & Future Technology Trend



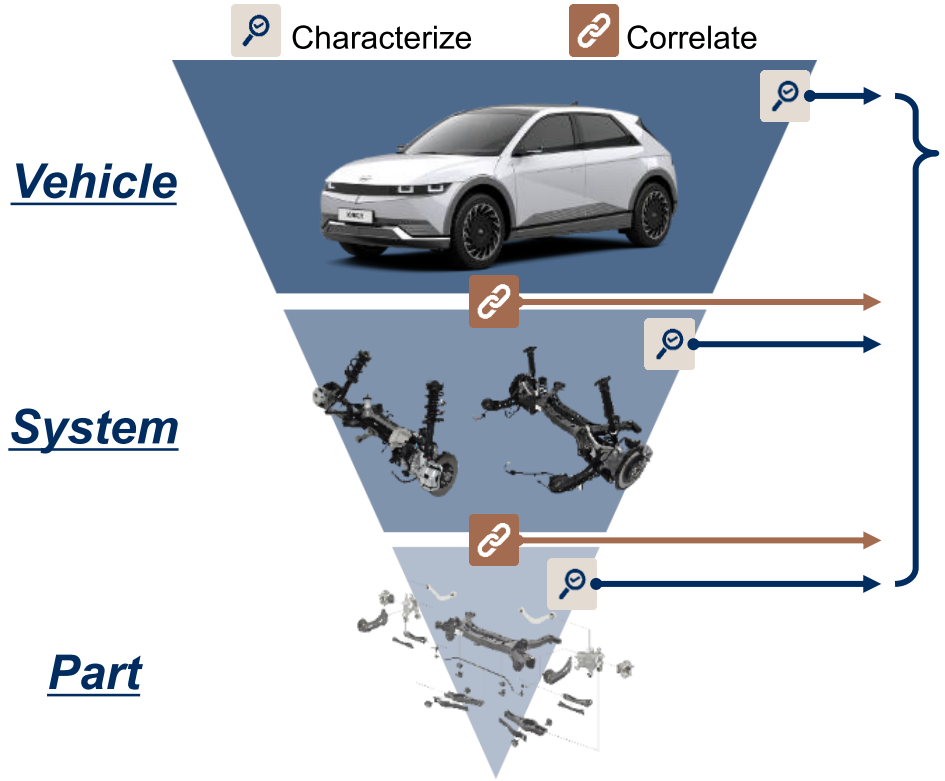
Introduction to Organization and R&R

- Research on **R&H data-driven development** process using various functions & infrastructure
  - ✓ *Vehicle level*: objective/subjective evaluation and discover relationship
  - ✓ *System level*: rig test → suspension K&C(+dynamic K&C), module test, tire, steering, …
  - ✓ *Virtual, database*: DB and analysis platform, virtual modeling / evaluation method



Purpose of R&H DB Development

- Integrated management of scattered data within the DB infrastructure and internalization of data analysis techniques to build a **data-driven engineering ecosystem**
- Efficiency / unification of repetitive and inefficient processes through the establishment of DB-based technology and associated analysis process



- ✓ Providing vehicle performance / system characteristics info.
- ✓ Providing TDP standard development test results

* TDP : Test and Development Procedure

- ✓ Basis for identifying vehicle levels
- ✓ Establishment/verification of system lv. development target (Target cascading)
- ✓ Development / design guide based on database
- ✓ Virtual model development, verification
- ✓ Use for a variety of R&D purposes

R&H DB & Analysis Platform

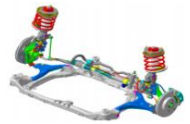
- Platform to connect performance development engineers in each department with vehicle/system test/characteristic data

Test Data (Vehicle / System) → ***DB Analysis Platform*** → ***Engineer in Various R&D Fields***


K&C (SPMD)


Ride


Handling / Steering


Suspension (Component)


Steering


Tire

- ✓ *Share various types of data to performance development engineers with different needs*
- ✓ *Provides 'standardized data' and 'unified analysis process' in the process*
- ✓ *Intermediary between data producers and engineers*

HMC | **HMETC (Europe)** | **HATCI (USA)** | **HMIE (India)**

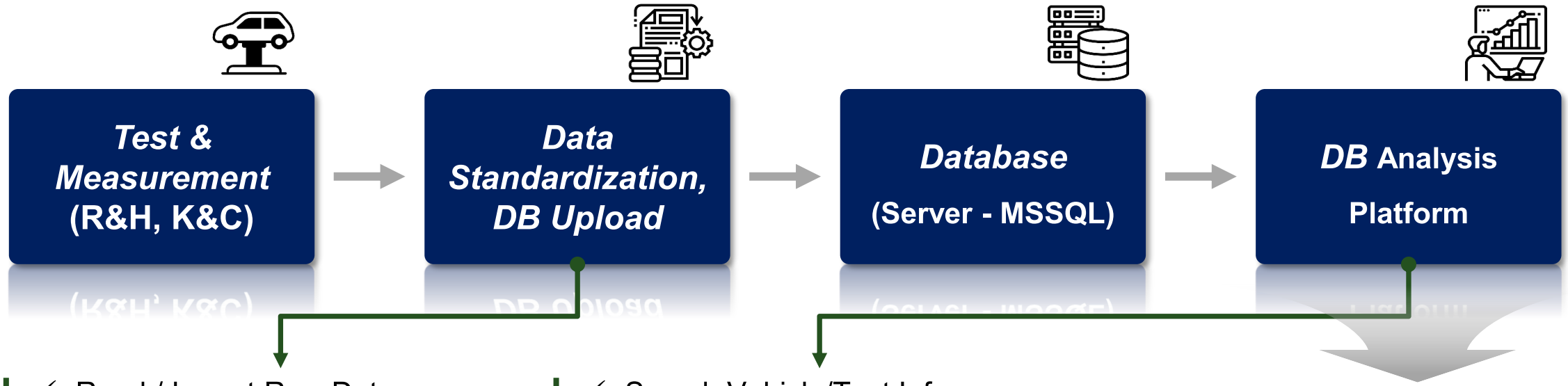
Design (Chassis, Steering, Tire, Brake, etc.)

R&H Test	**Virtual**	**Architecture**
Control	NVH	Safety
Autonomous	Adv. Dev.	Digital Eng.

Utilize data and processes for various performance development / research purposes

Data Storing / Sharing Procedure (Work Scope)

- Custom development based on the needs for entire process from raw data to being provided engineers
- In addition to DB, various data analysis/virtual process used in the development stage included



- ✓ Read / Import Raw Data
- ✓ Classification (Mode, Channel)
- ✓ Data Processing
- ✓ Perf. Index Extraction, Calculation
- ✓ Format Standardization

- ✓ Search Vehicle/Test Info.
- ✓ Performance Analysis
- ✓ DB Statistics
- ✓ Visualization, Report Generation
- ✓ Advanced Functions

Utilize in the vehicle performance development Stage through engineers

(Design, Test, Analysis, Architecture, …)

DB / Process / Application Development in MATLAB

- All procedures are developed and managed in MATLAB environment

  → Data processor, solver, visualization, DB uploader, DB analysis program, DB management program

- ✓ MATLAB
- ✓ Signal Processing Toolbox
- ✓ Curve Fitting Toolbox
- ✓ Optimization Toolbox
- ✓ Statistics and Machine Learning Toolbox
- ✓ Database Toolbox
- ✓ MATLAB Compiler

- ✓ SPMD
- ✓ Ride DB
- ✓ Handling/Steering DB
- ✓ Rig-Test DB (Steering, Tire, …)

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Introduction to R&H Database and Analysis Platform

- Vehicle level database in R&H performance development field
- All DB analysis applications have been developed in MATLAB environment

SPMD (K&C) + Inertia DB

- ✓ Since 2003 (Legacy), Renew 2020
- ✓ More than 1700 measurement project data
- ✓ KPI summary, statistics, link with analysis result, …

Ride Comfort DB

- ✓ Since 2021
- ✓ More than 650 measurement project data
- ✓ Frequency analysis, heat map, transfer Path, …

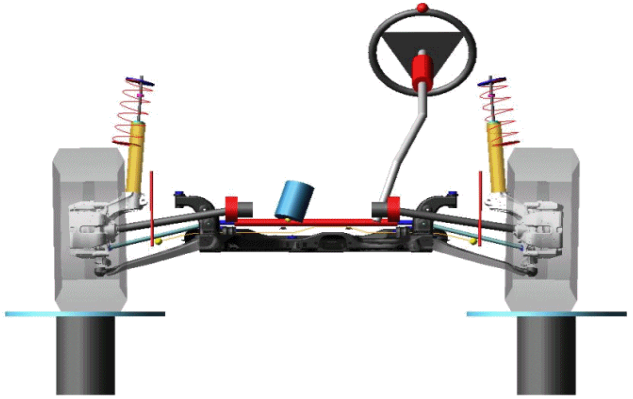
Handling/Steering DB + Virtual Process

- ✓ Since 2021
- ✓ More than 1000 measurement project data
- ✓ Project-based analysis, virtual process, …

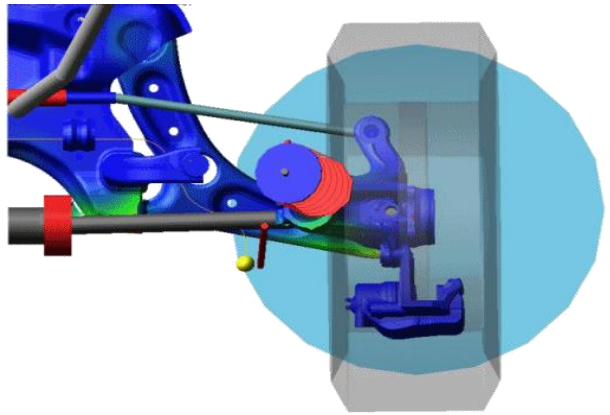
SPMD(K&C) / Vehicle Inertia DB

- **SPMD: *S*uspension *P*arameter *M*easurement *D*evice**
  - ✓ Suspension **K&C** (**K**inematic & **C**ompliance), wheel alignment(toe, camber, …), force characteristics
  - ✓ Vehicle basic specification (weight, cg heigh, w/base, tread, …)
  - ✓ Vehicle CG, moment of inertia(*Ixx, Iyy, Izz*)
- SPMD DB provides basic vehicle & suspension information

Kinematic & Compliance



bump and rebound…
(vertical, roll, …)



under external forces…
(Fx, Fy, Mz, …)

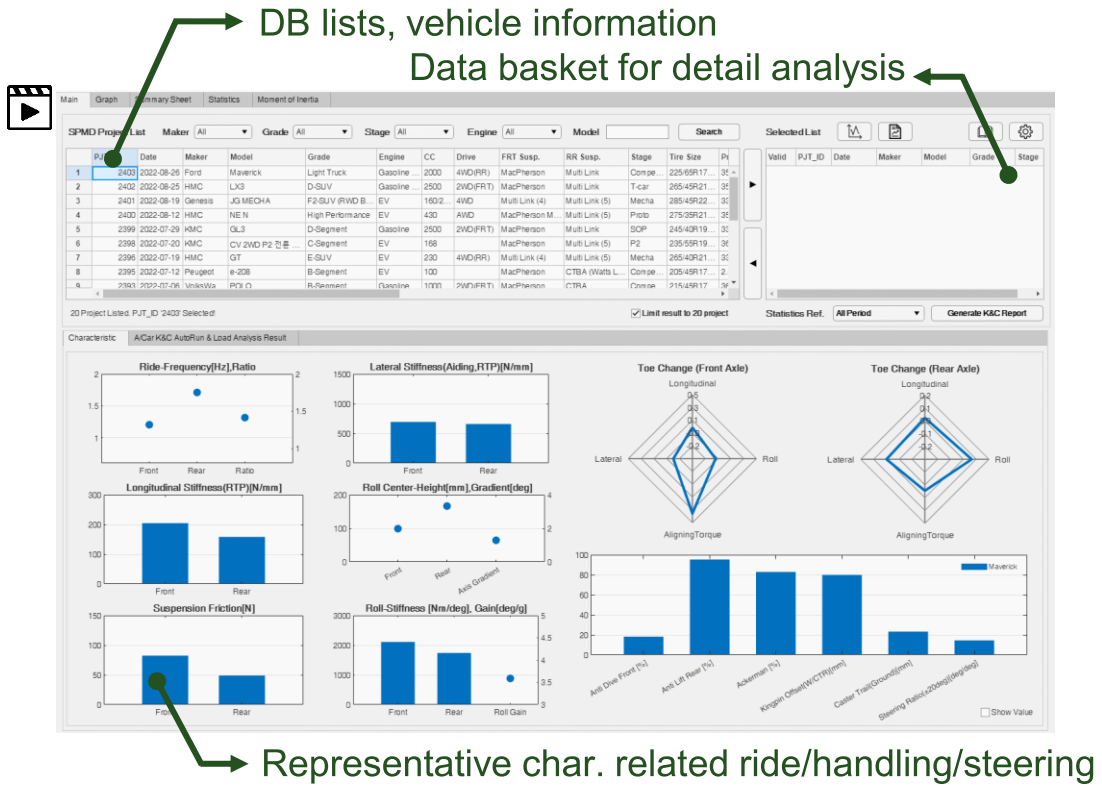
Wheel Motion Sensor
Precise measurement of 6 DOF behavior of suspension and wheel

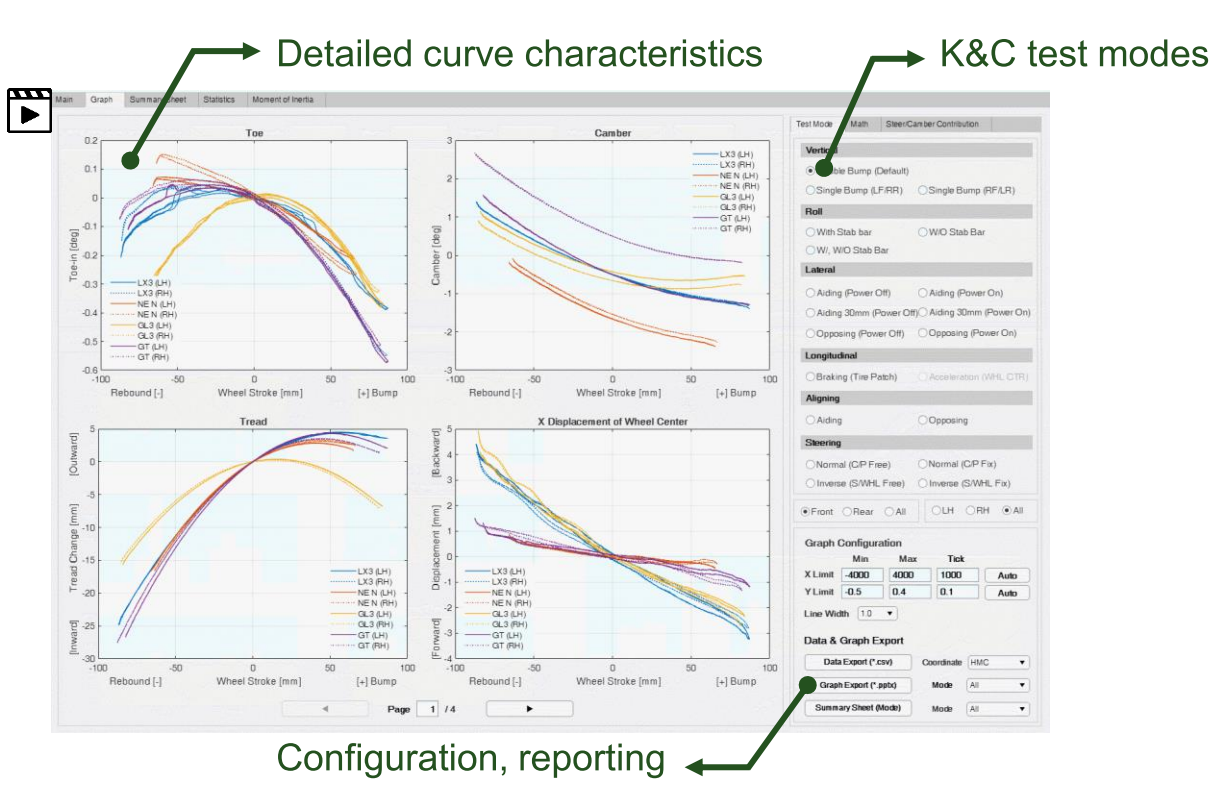
Exciter/Loadcell
Patch/wheel center with 5 DOF and the measurement of the excitation force

Body Fixture
Measure the suspension /steering system characteristics by constraining the movement of the body

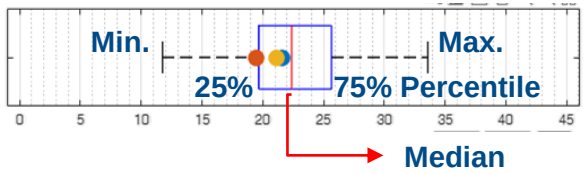
SPMD(K&C) / Vehicle Inertia DB

- **Database main**: search DB list, KPI quick comparison, select project for detail analysis
- **Graph**: K&C characteristic curve by each test mode (vertical, roll, lateral, steering, …), editing graph (math)
- **Additional functions**: generate report, knowledge library (for sharing references, documents)

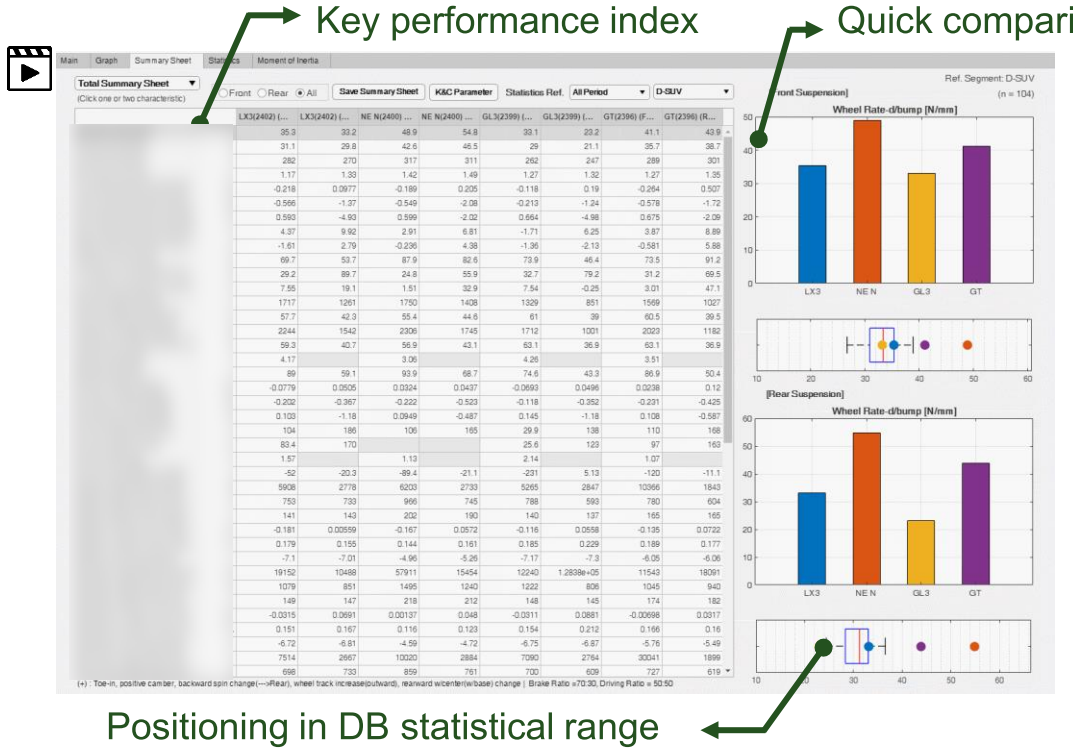


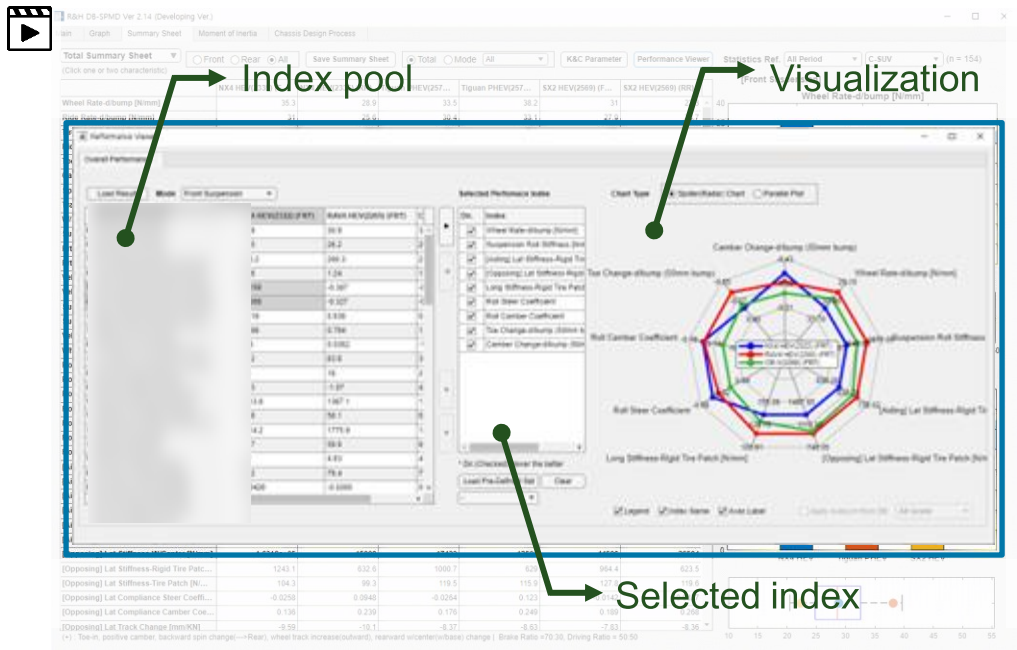


SPMD(K&C) / Vehicle Inertia DB



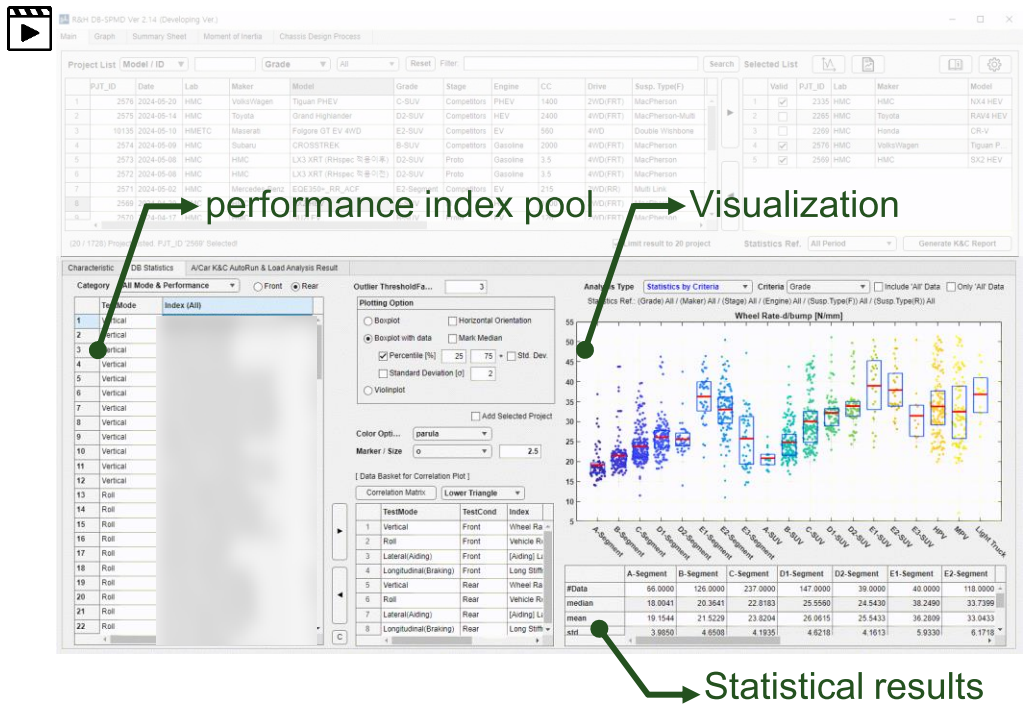
- **Summary sheet**: representative K&C characteristic indices, vehicle information, user-defined additional characteristics, positioning in DB statistical range (with box plot)
- **Performance viewer** : visualization for user-defined multiple char. index (spider chart, parallel plot) (R&H DB shared lib.)

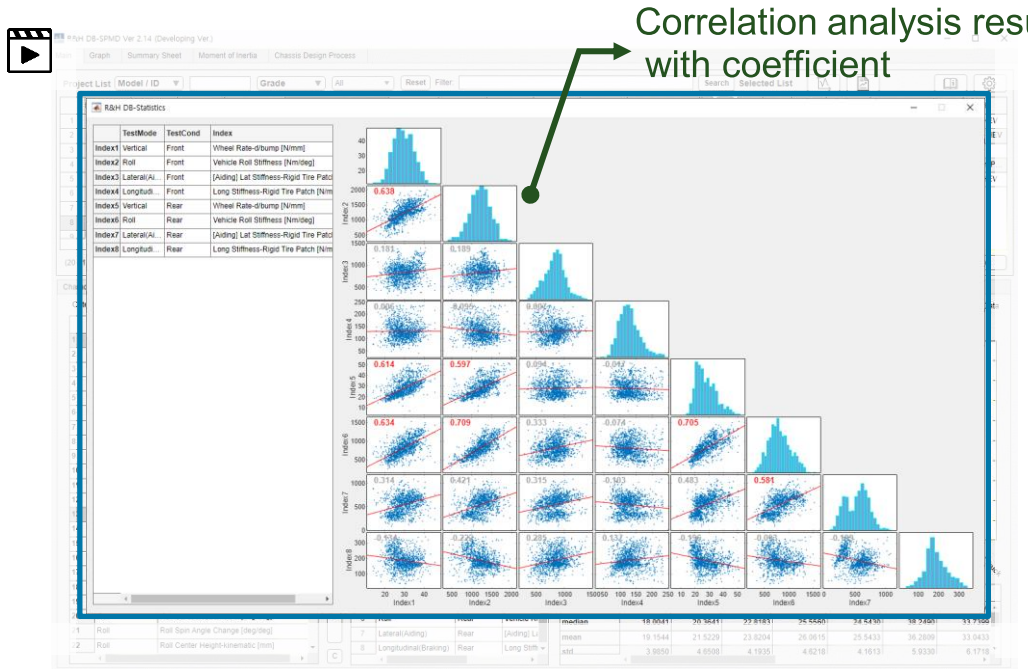




SPMD(K&C) / Vehicle Inertia DB

- **DB Statistics** : specific and customized analysis functions for DB statistics
  - ✓ Statistical analysis for a ‘single’ or ‘coupled’ performance indices (by multi-criteria)
  - ✓ Correlation matrix for discovering relationships of multi-performance indices
  - ✓ Various visualization and processing options(type of plot, information, …)





SPMD(K&C) / Vehicle Inertia DB

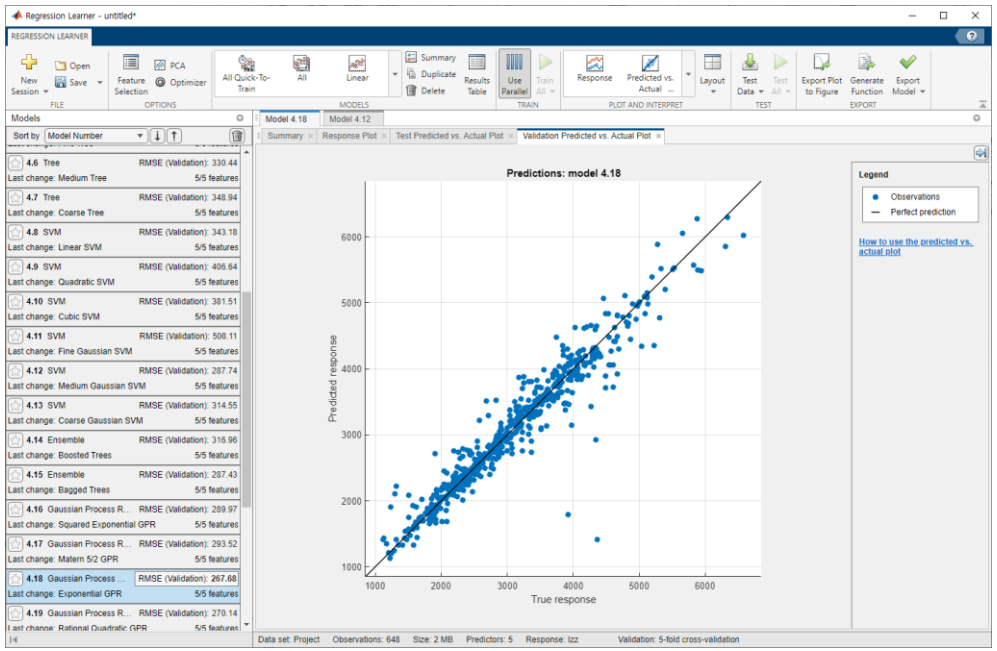
Inertia test

- **Moment of inertia DB**: *Ixx*, *Iyy*, *Izz*, CG height measurement using SPMD
  - ✓ Search/compare test result, ML model for prediction, calculation according to weight condition
  - ✓ ML models are updated periodically by auto-update process (DB → learning → validation → update)

Inertia DB Lists

Inertia comparison for selected vehicle

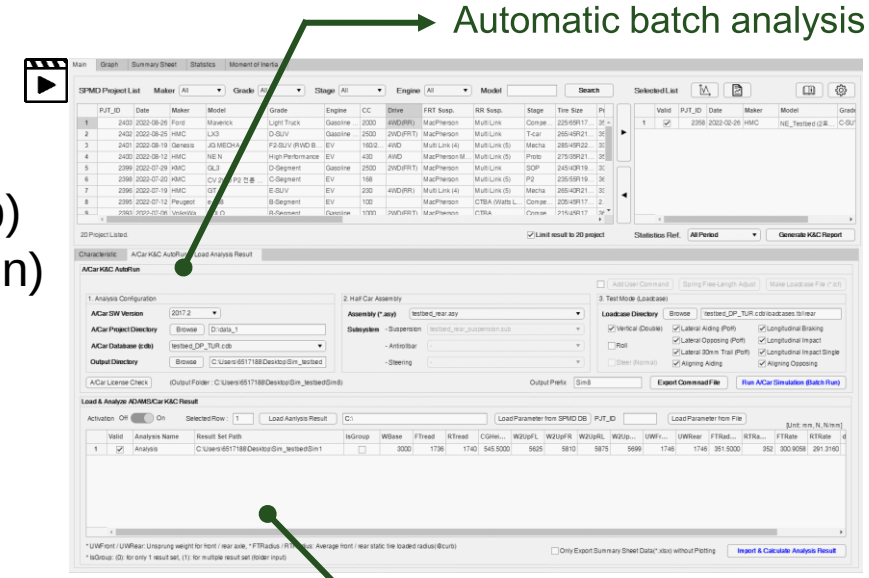
[Inertia prediction using 'Regression Learner']



Inertia prediction using ML model

SPMD(K&C) / Vehicle Inertia DB

- **K&C analysis result processing**: ADAMS/Car auto-run (batch job)
  - Directly compare simulation result with test result (model validation)
- **Steer contribution**: resultant steer considering vehicle spec. and suspension char. in steady-state turning condition (ex. 0.4g)

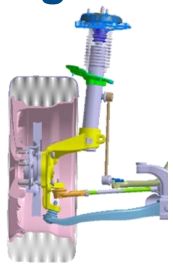


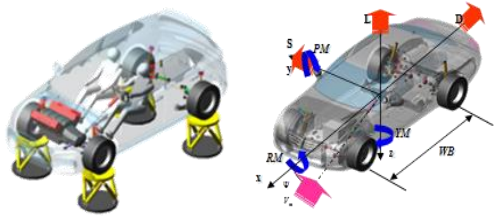
Test

Reflect specialized analysis techniques used in performance development stage

Add new design characteristic index from test data (calculation, estimation)

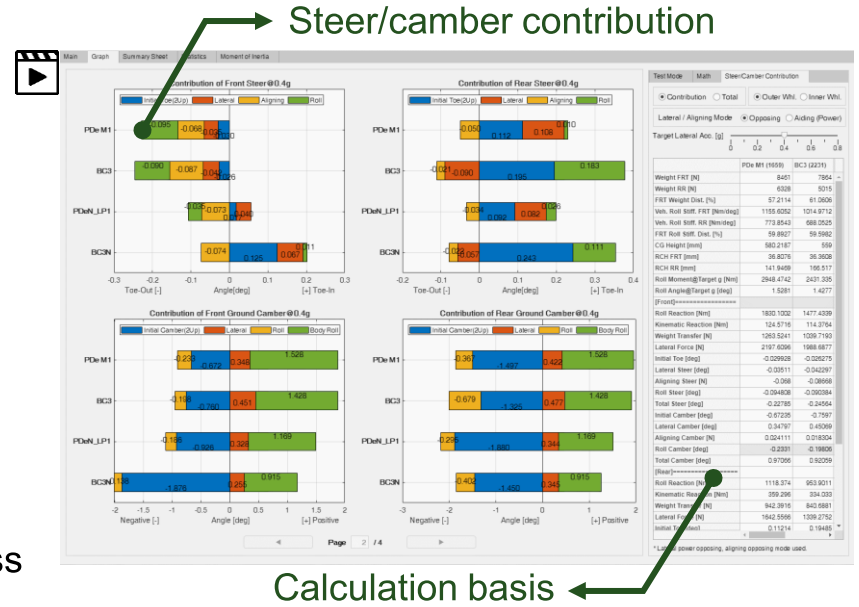
Design





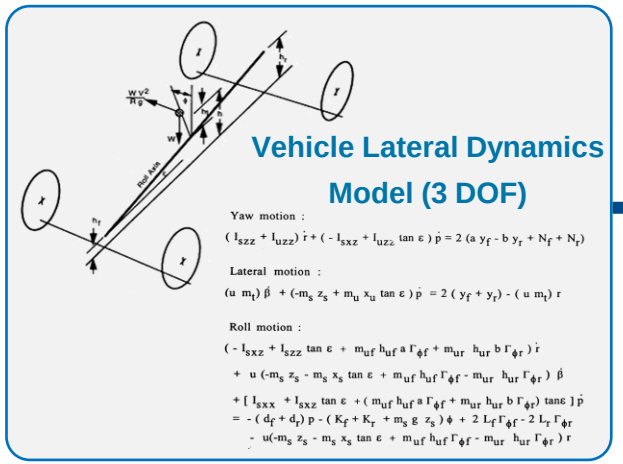
Virtual (Analysis)

Test + virtual model integrated analysis process



SPMD(K&C) / Vehicle Inertia DB

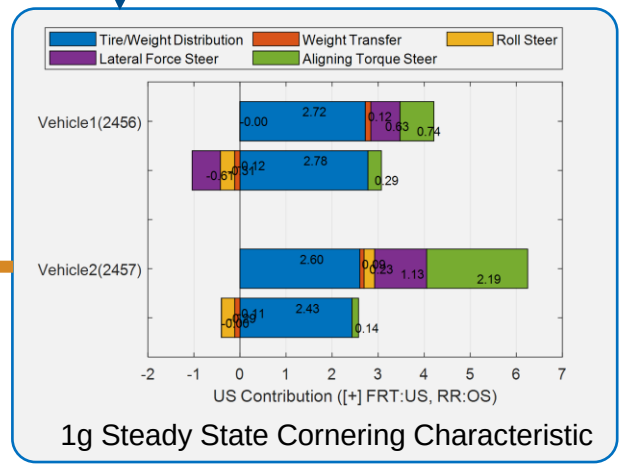
- **Chassis Design Process** (handling char. part): directly connected with DB or 3rd party SW analysis results
  - ✓ **US char. calculation**: vehicle basic char.(US gradient) with given parameter set (vehicle, susp., tire, steering)
  - ✓ **Vehicle target optimization**: find vehicle parameter set to achieve vehicle target performance index



(Forward) Calculation

(Vehicle Parameter → Characteristic)

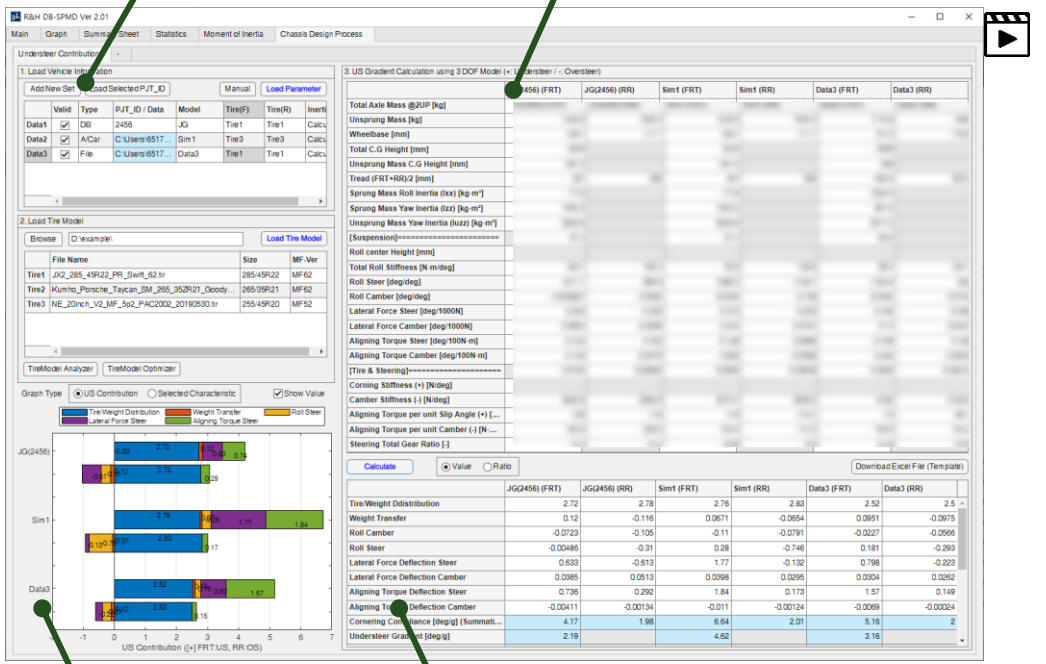
Understeer Gradient and Contribution



1g Steady State Cornering Characteristic

(Backward) Optimization

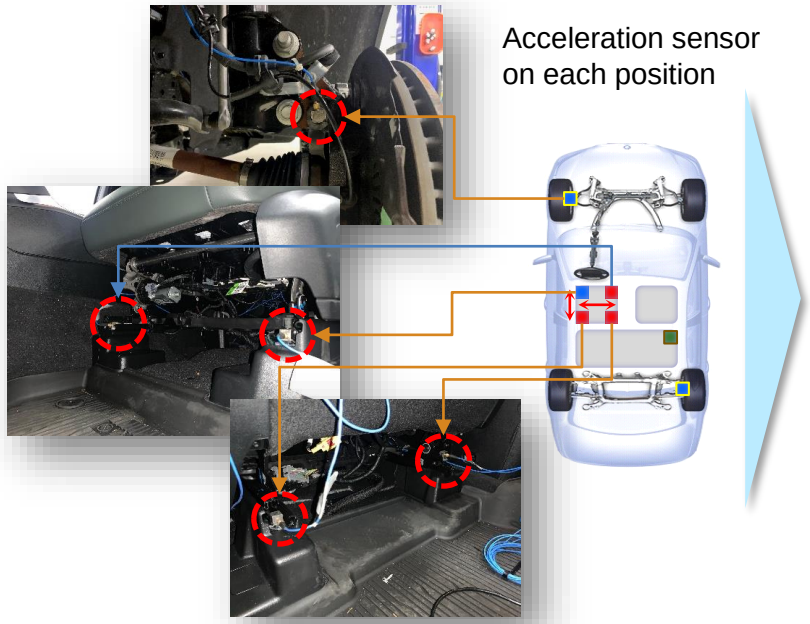
(Vehicle Characteristic → Parameter)

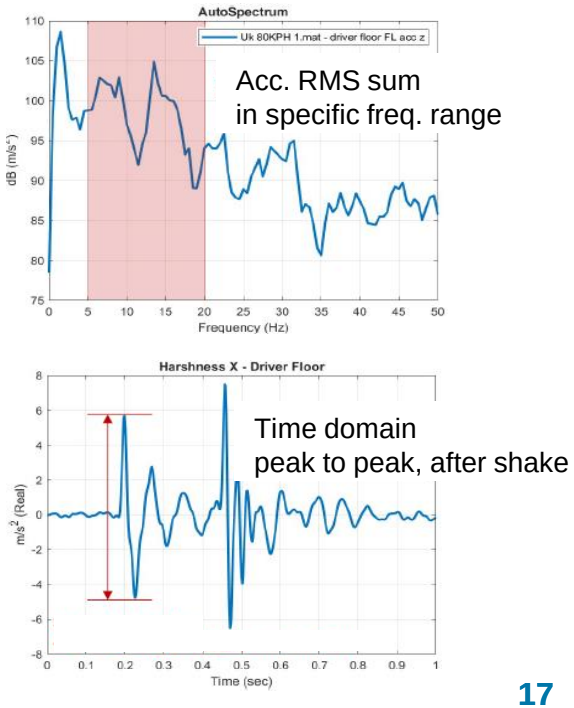


Ride DB

- Evaluation method: acceleration level or driver's feeling on various road condition & speed
- Test condition: road input / profile(smooth, rough, general road, impact bar) with various vehicle speed
- Measurement: acceleration(X/Y/Z) at each position (seat rail, knuckle, top-mount, PT/PE mount, X/MBR, etc.)
- Frequency response analysis, time domain analysis for each measurement data

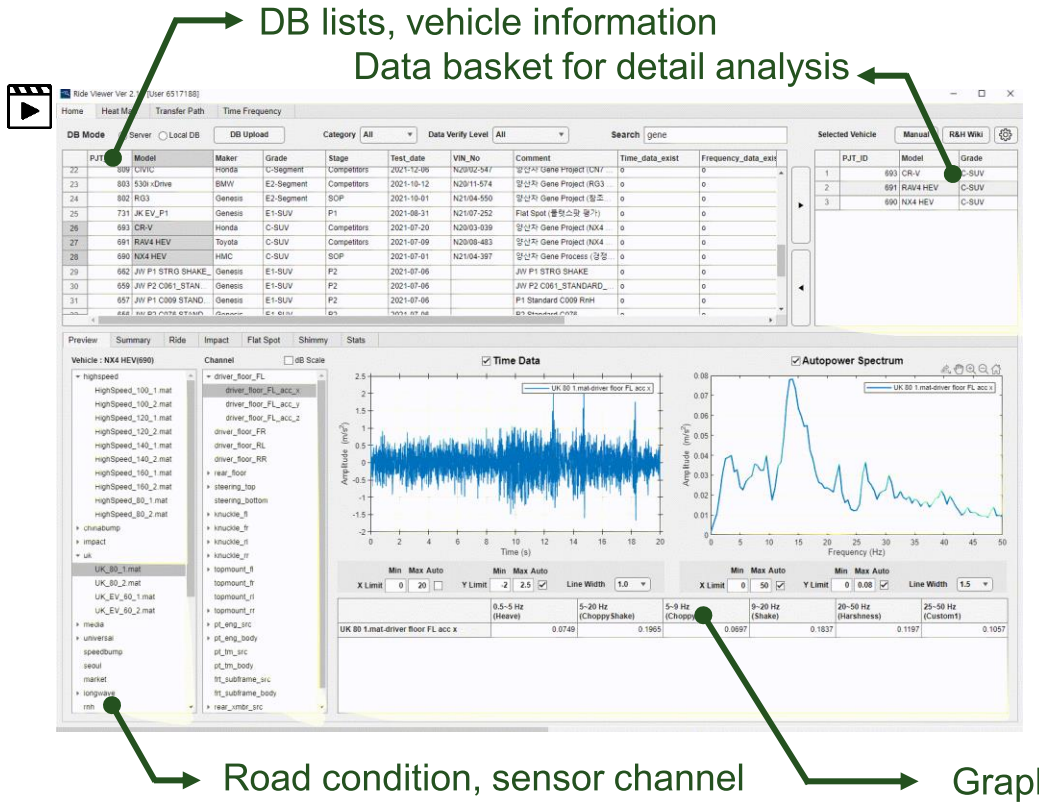
Measurement Set-up ***Test & Measurement*** ***Data Analysis***

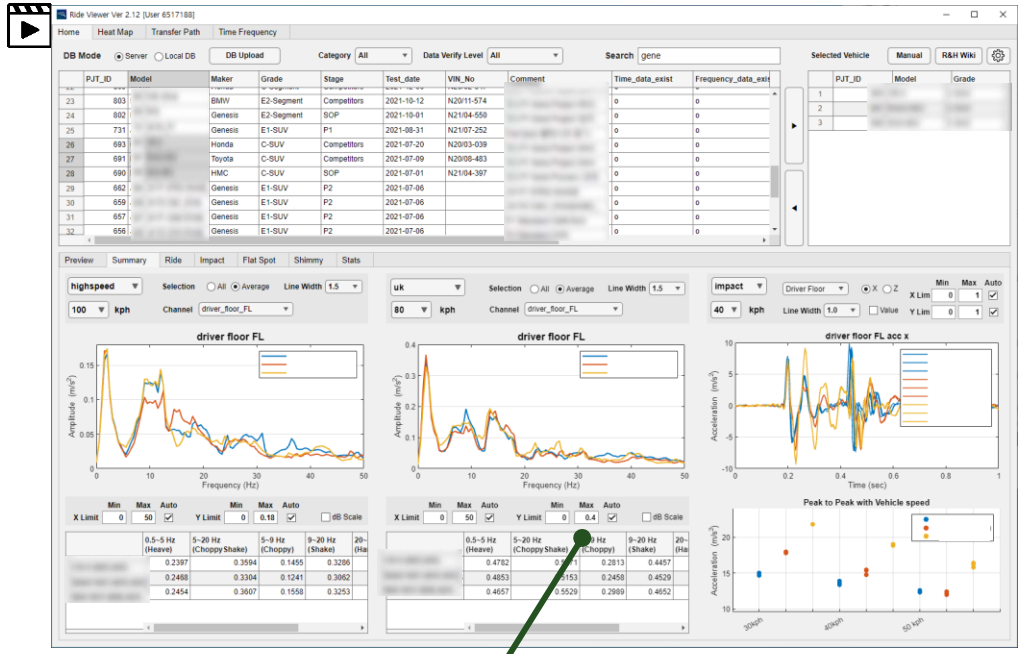




Ride DB

- **Database main**: search DB list, test & vehicle information, select project for detail analysis
- **Preview**: quick search and check data of each road profile and each channel (time / frequency domain)
- **Summary**: summary of representative ride test condition (highway, rough road, impact bar) – graph and KPI

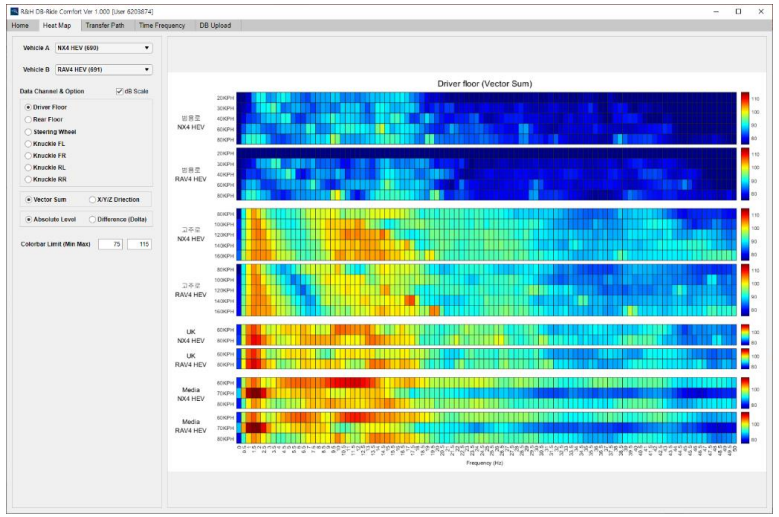




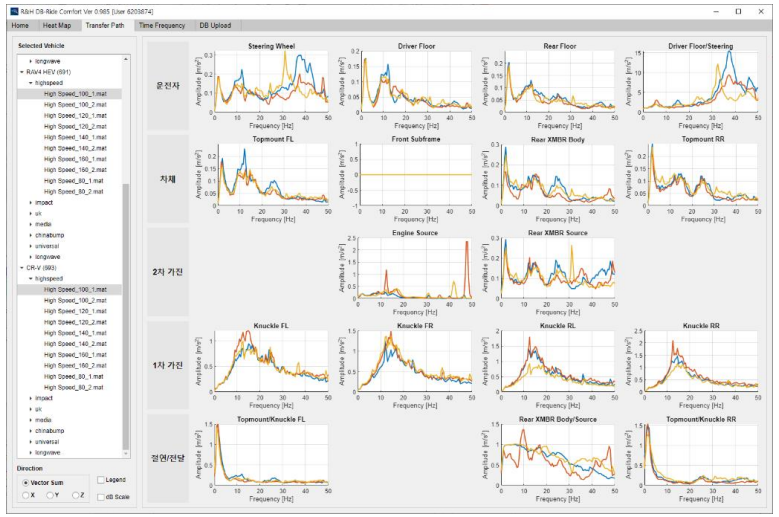
Ride DB

- **Heat map**: compare / identify overall vibration trend by road surface/speed/frequency/sensor location
- **Transfer path**: vibration path, transmissibility analysis (knuckle – strut – body – PT/PE – floor – steering)

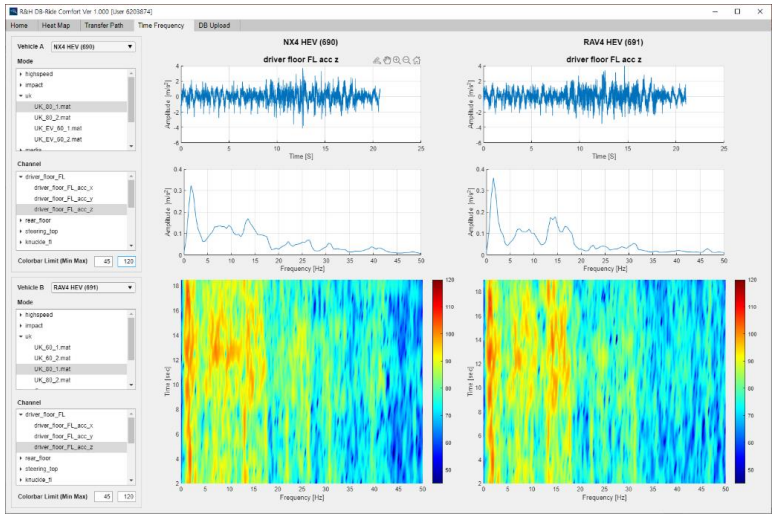
  → vibration root and main cause analysis
- **Time-frequency**: analyze the transient frequency characteristics according to the time change



[Heat Map Analysis]



[Transfer Path Analysis]



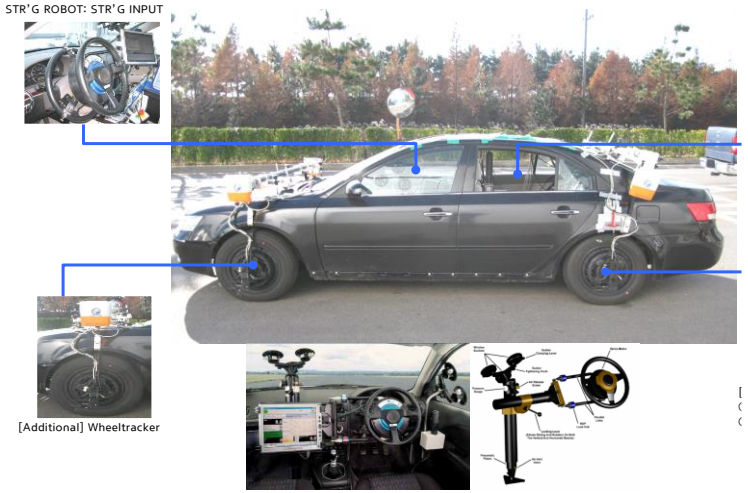
[Time-Frequency Analysis]

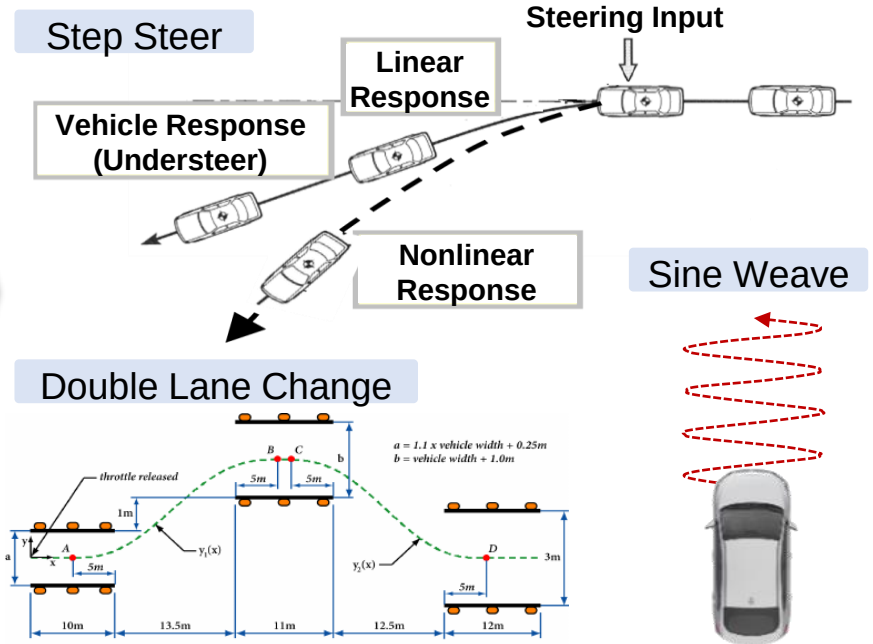
Handling/Steering DB

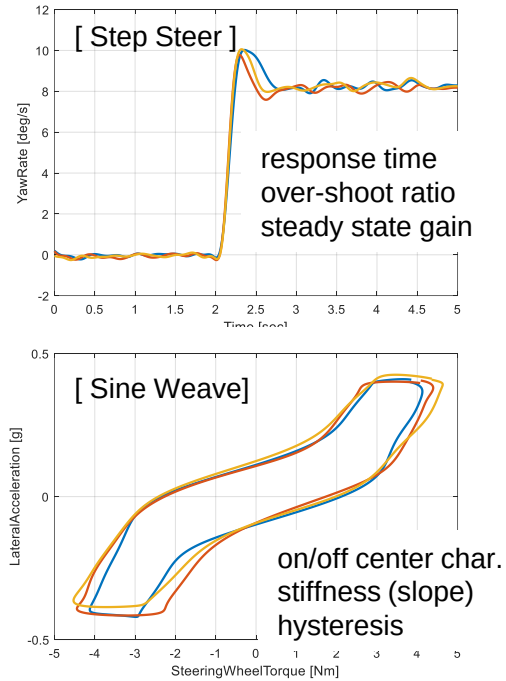
- Evaluation method: vehicle or steering response by specific / defined steering input
- Test mode: open-loop (step steer/series, sine sweep, sine weave, …), closed-loop: double lane change
- Measurement: steering wheel angle/torque, cornering status(lateral acc., yaw rate, side slip, roll angle, …)
- Specific objective index and processing method according to each test mode

Measurement Set-up ***Test & Measurement*** ***Data Analysis***

Steering wheel robot (for open-loop test)
gyro sensor

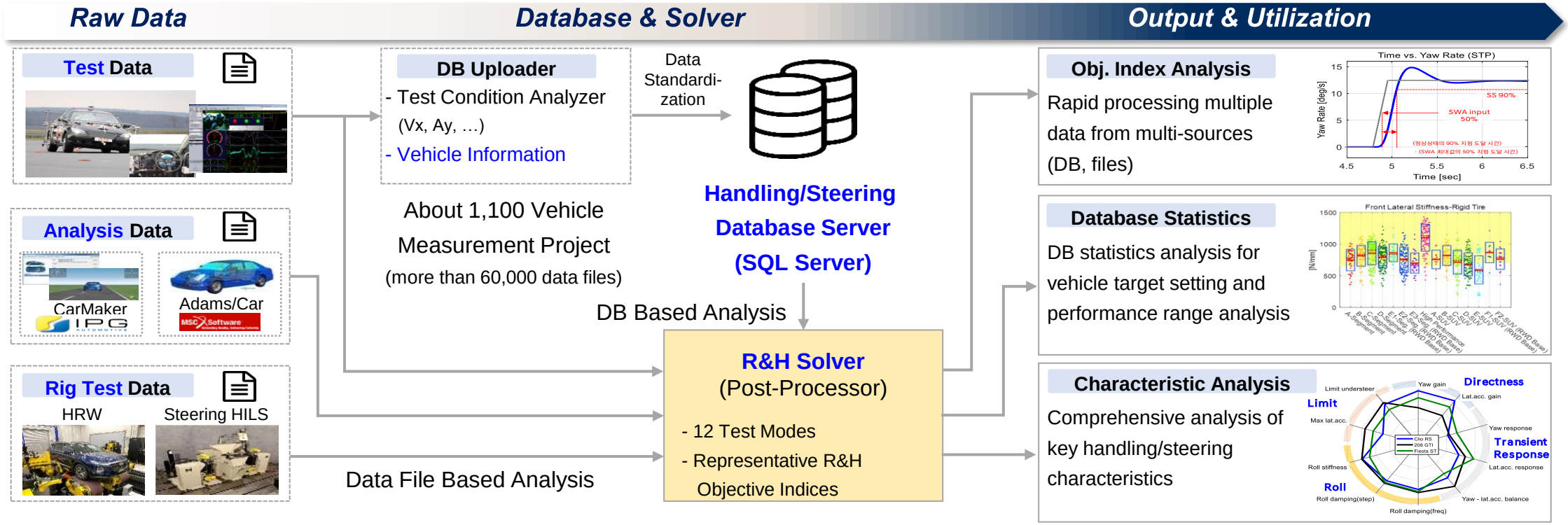






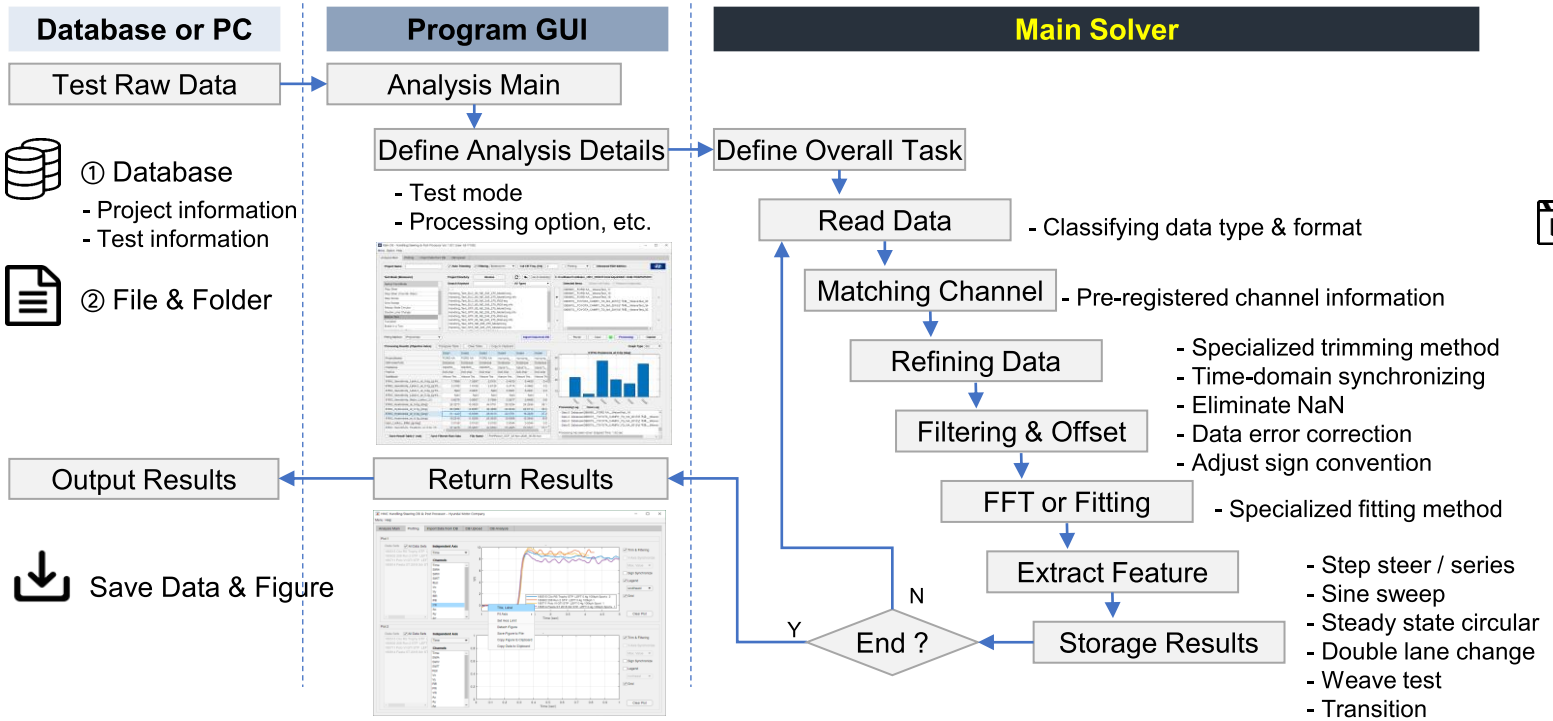
Handling / Steering DB

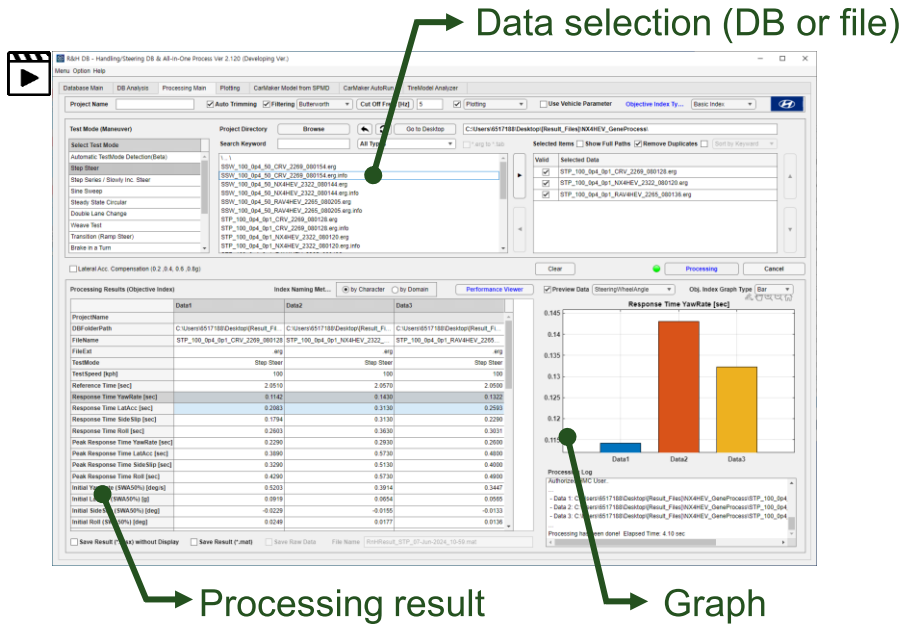
- Development concept: data post-processor with database
- Objective analysis for any types of data regardless of it type and format (from mea., analysis, rig-test)
- Among them, vehicle measurement data are uploaded to database through standardization (DB uploader)

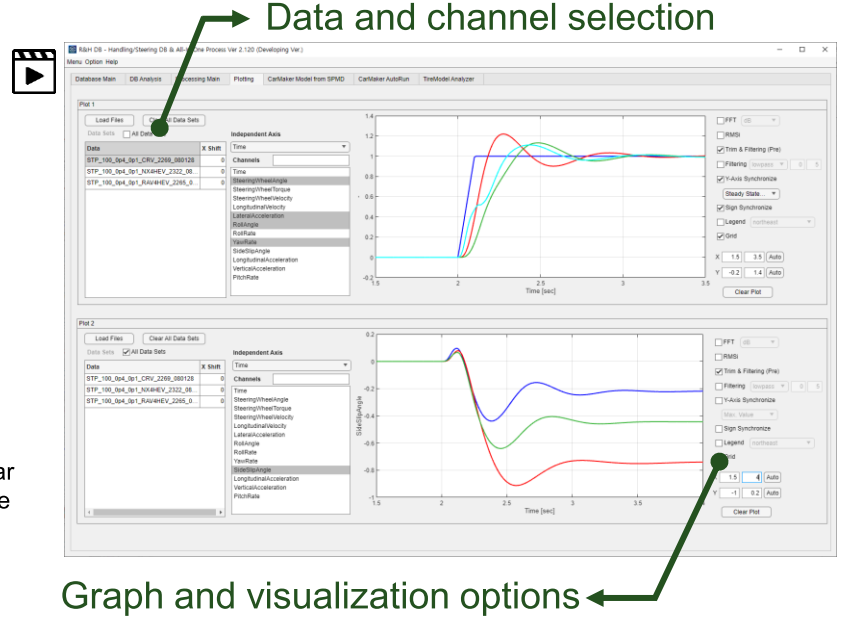


Handling / Steering DB

- **Processing main(R&H solver) and plotting**
  - ✓ Extract objective index with custom data processing algorithm
  - ✓ Automatic data adjusting, trimming, filtering, fitting, offset…

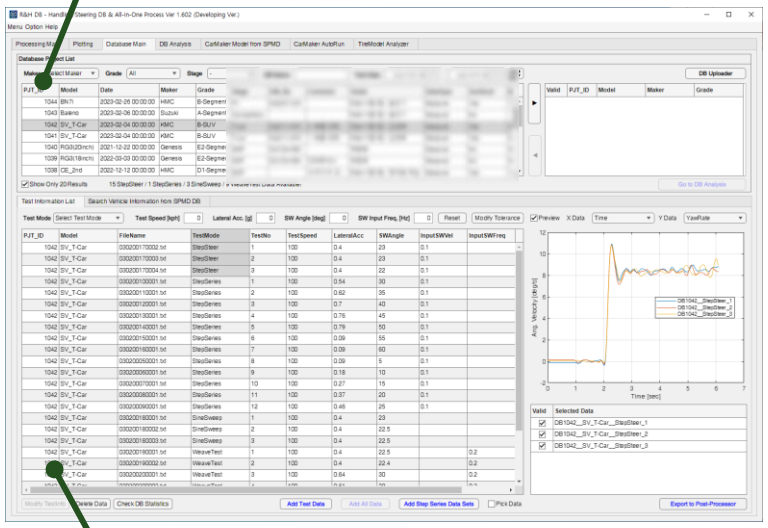




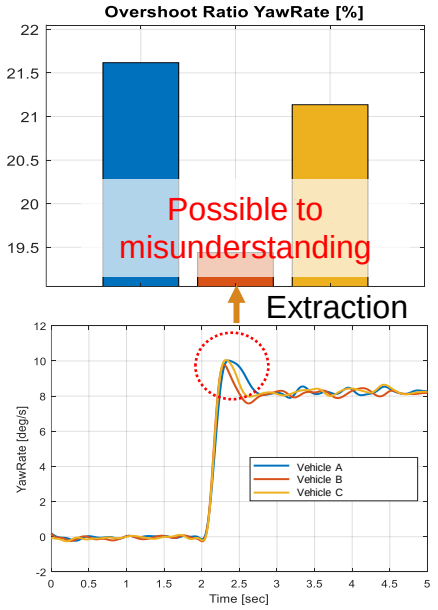


Handling / Steering DB

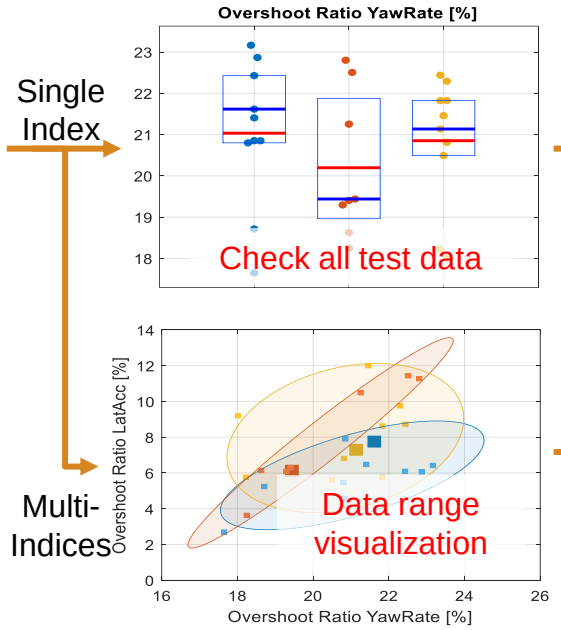
- **Database main**: search mea. project with vehicle and test information
- **Project based analysis**: Summary of handling/steering indices
  - ✓ Data recommendation algorithm closest to the mean/median
  - ✓ Performance positioning in DB distribution



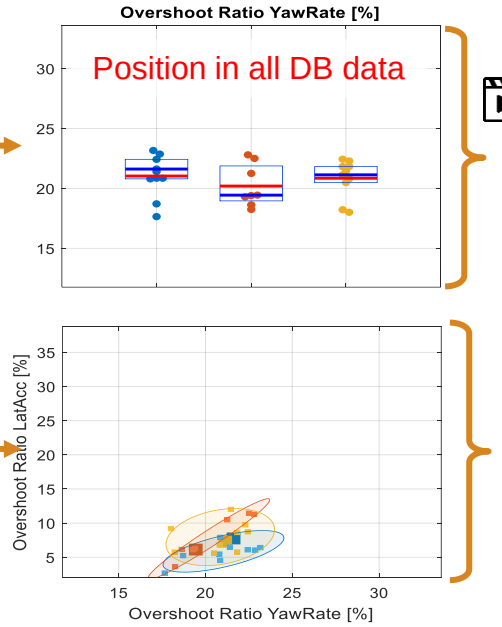
[① Single Test Data]

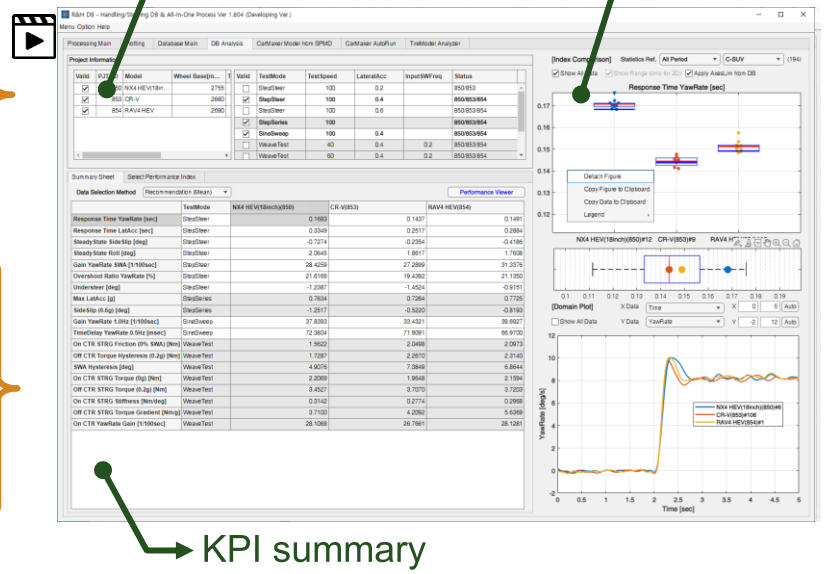


[② Multi-Test Data]



[② + with Statistical Range]

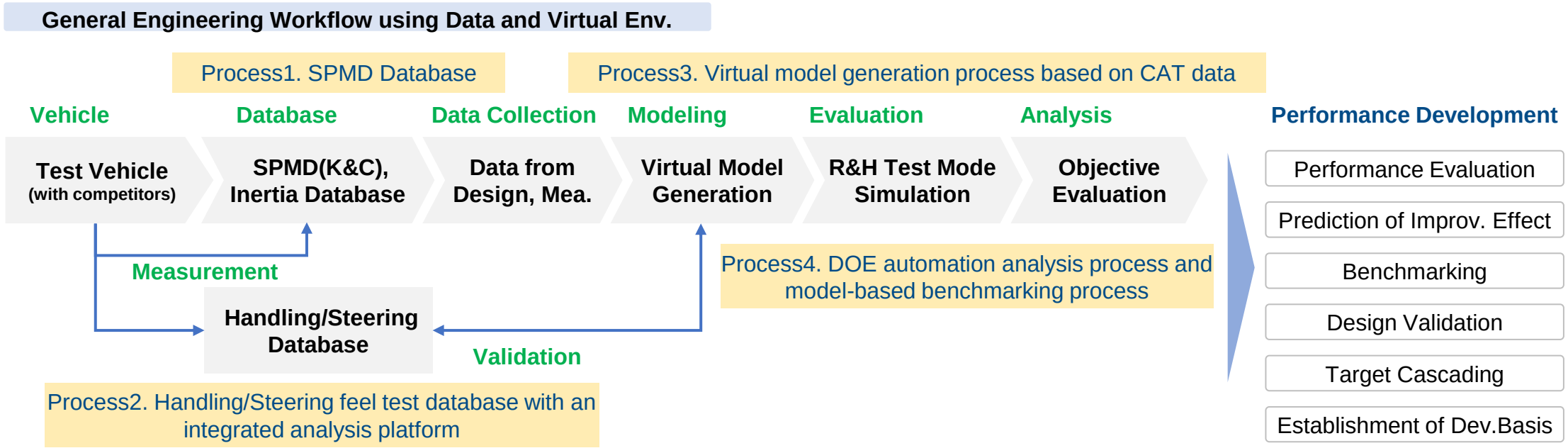




R&H Virtual Process Associated with DB (Overview)

- Efficient and integrated evaluation process on general engineering workflow
- Consist of separated process (4 sub-processes) and linked each other

  : Database (system, vehicle) → Modeling/Validation → Simulation → Evaluation → (Decision Making)
- Support to focus on performance development and decision making



R&H Virtual Process Associated with DB

- **(Modeling) Virtual model generation process based on test data**
  - ✓ Directly connected modeling process with K&C database(SPMD)
  - ✓ Customized modeling algorithm for using test data (e.g. wheel-rate decomposition)
  - ✓ Easy and quick process to get specific vehicle model already measured

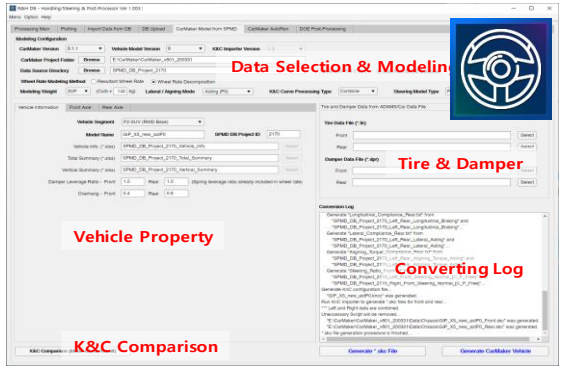
System Char.(K&C) based Evaluation → ***Virtual Model Generation based on DB*** → ***Vehicle Perf.(R&H) based Evaluation***

Relative determination of vehicle performance based on K&C char.

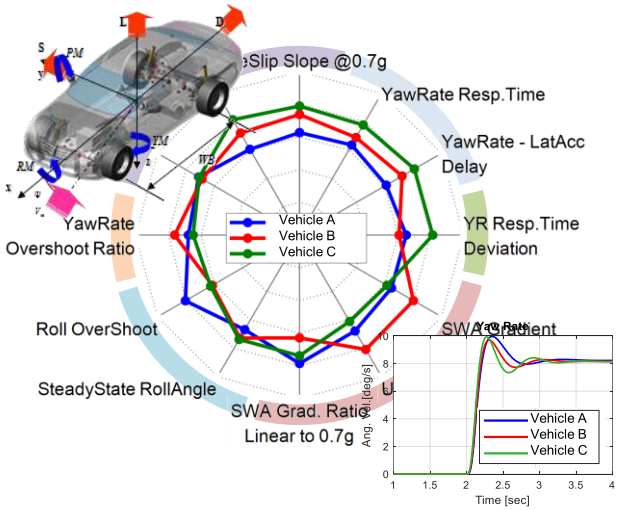
Immediately generate a virtual model with SPMD data that is analyzing system characteristic

Virtual evaluation of vehicle level performance affected by complex char.

SPMD DB

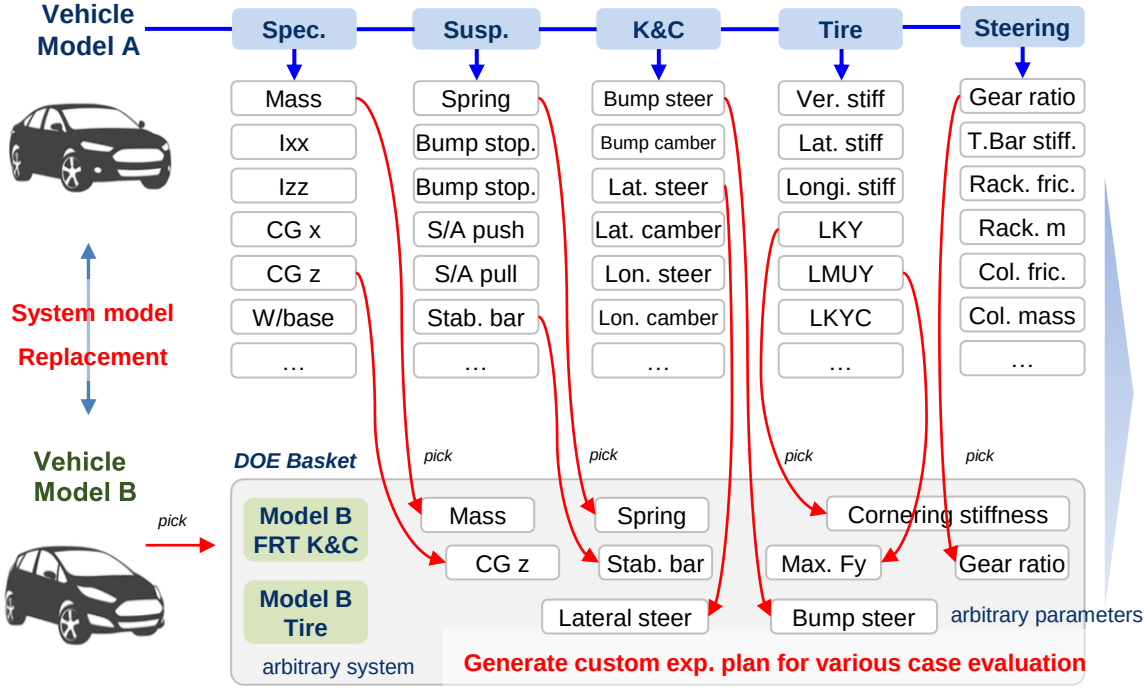


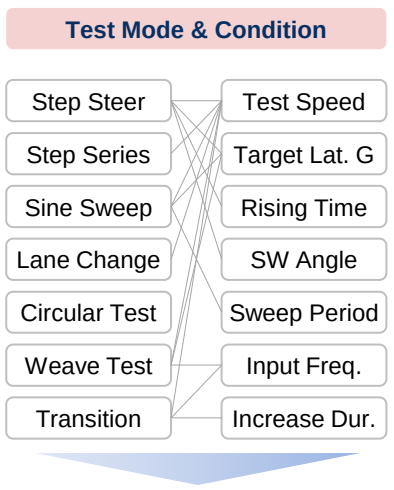
CarMaker Model from SPMD DB **CarMaker**



R&H Virtual Process Associated with DB

- **(Simulation) DOE automation analysis process**
  - ✓ Evaluate effect of various parameters and its combinations on R&H performance
  - ✓ User defined DOE for multi-vehicle / system / parameter / test mode / test condition
  - ✓ Directly connected with post-processor (Handling/Steering DB)

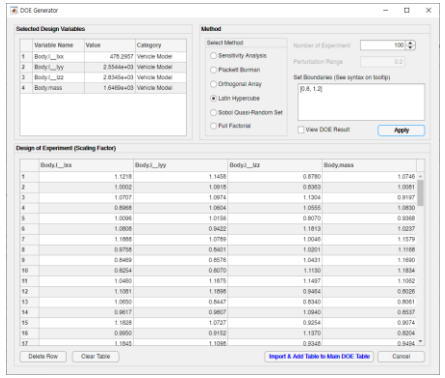


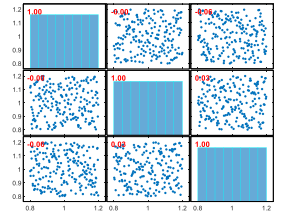


R&H (Handling) Objective Index

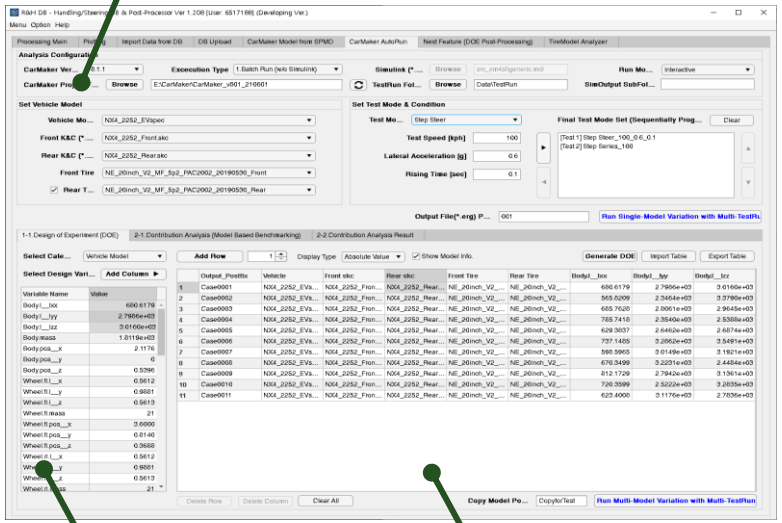
Gain
Response Time
Overshoot
Steady State
…

[DOE generator]





Vehicle model & test mode/condition



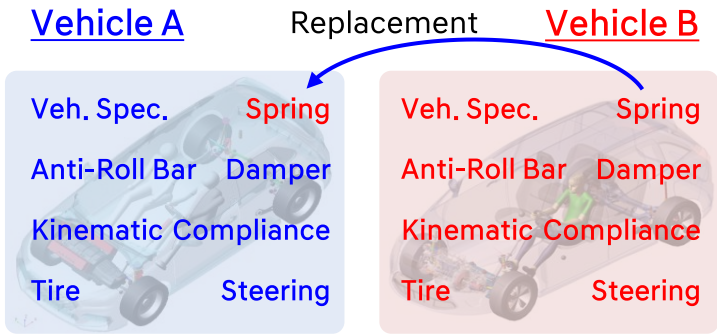
Model parameters

User defined DOE

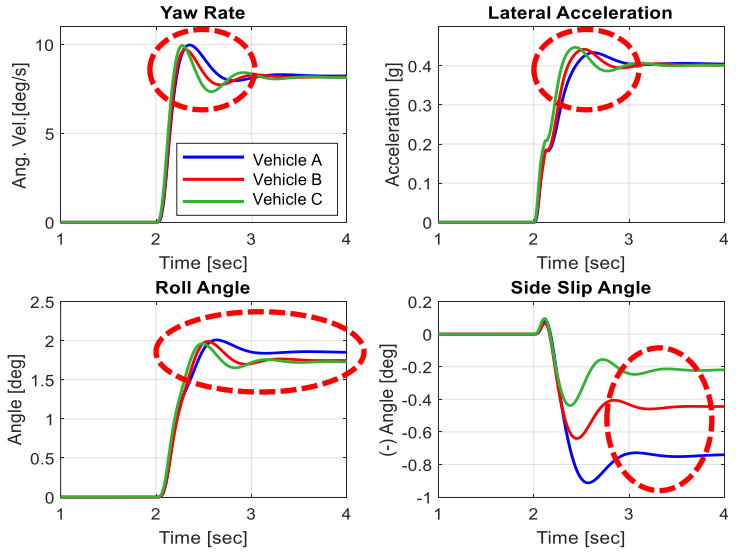
R&H Virtual Process Associated with DB

< Vehicle A > < Vehicle B >

- **(Evaluation) Model-based benchmarking process (1/2)**
  - ✓ Method that is possible to explain reason of performance differences
  - ✓ Using hierarchy of vehicle model(vehicle – system – subsystem), contribution and reason of performance differences can be analyzed

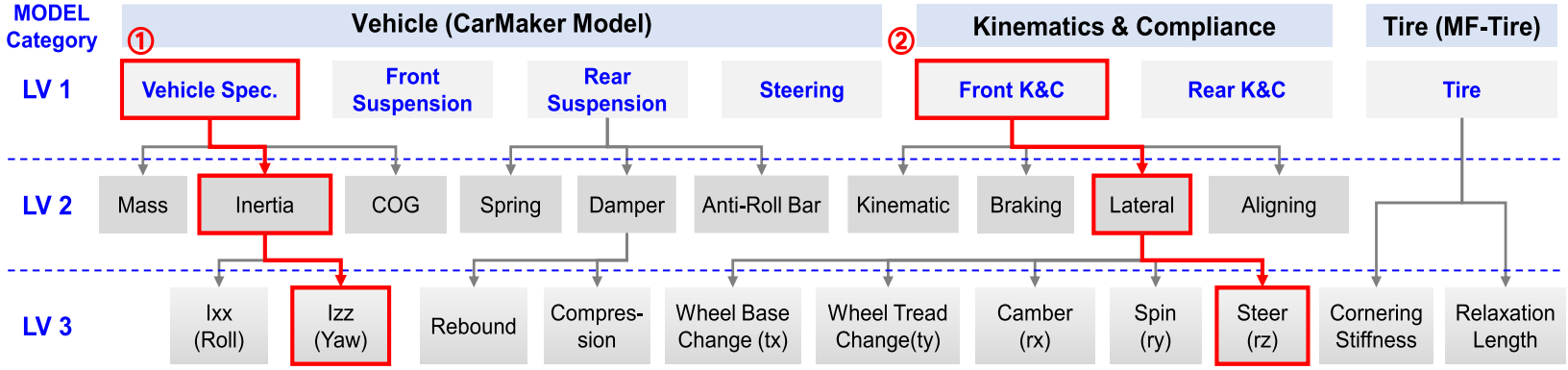


Which factor contributes the most to the yaw rate overshoot difference? and other?



What if spring of vehicle B is installed at vehicle A?
What if whole suspension are replaced?

☞ **Easily Possible in Virtual Environment!**

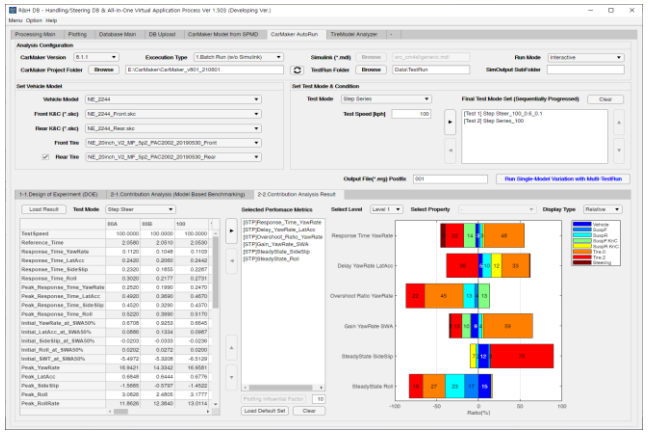


Ex.① Vehicle Spec. > Inertia > Yaw Moment of Inertia(Izz)

Ex.② Front K&C > Lateral Compliance > Lateral Steer

R&H Virtual Process Associated with DB

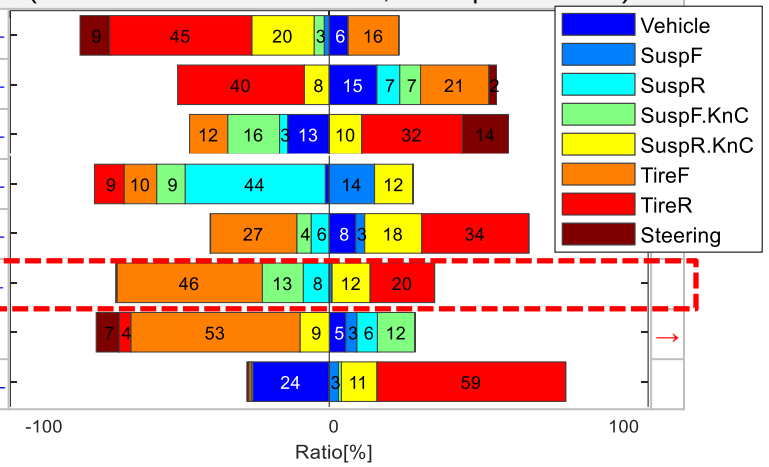
[Model based benchmarking]



- **(Evaluation) Model-based benchmarking process (2/2)**
  - ✓ Evaluate effect of various system based on objective index systematically
  - ✓ Cascade and extend to lower level (vehicle → system → subsystem)

Contribution of each performance index

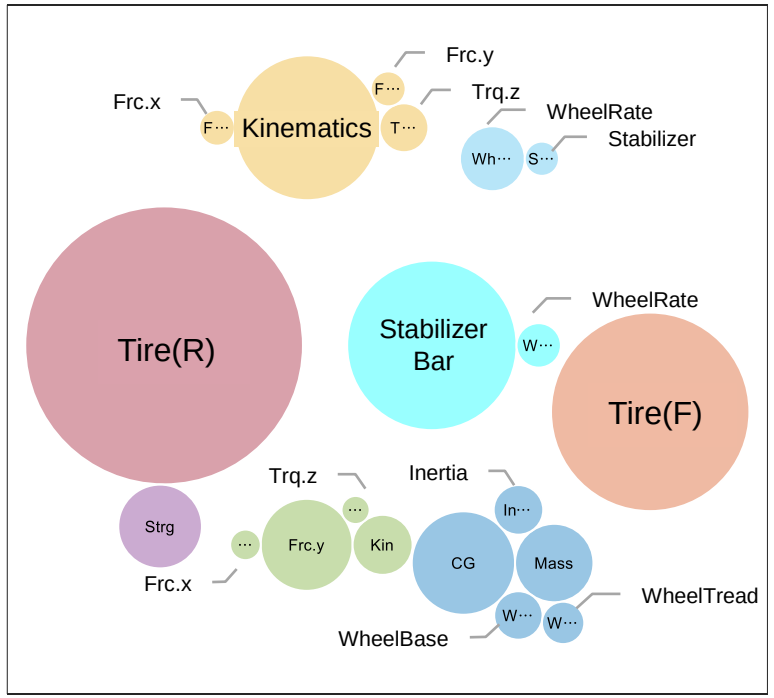
	Key Performance Index	Veh. A	Veh. B	Contribution analysis (Vehicle A → B) (Arrow direction: US reduction, better performance)
	YawRate Resp. Time [sec]	0.143	0.132	←
	YawRate - LatAcc Delay [sec]	0.170	0.127	←
	SWA Gradient [deg/g]	64.3	42.9	←
	Steady State Roll [deg]	1.852	1.746	←
	Roll Overshoot Ratio [-]	8.48	13.98	←
①	YawRate Overshoot Ratio [-]	21.14	18.93	←
	Max Lat.Acc. [g]	0.817	0.801	→
	SideSlip @0.7g [deg]	-1.63	-1.15	←



① Contribution of yaw rate overshoot decrease (21.1 → 18.9)

: Tire(Front) 46%, K&C(Front) 13%, Tire(Rear) -20%

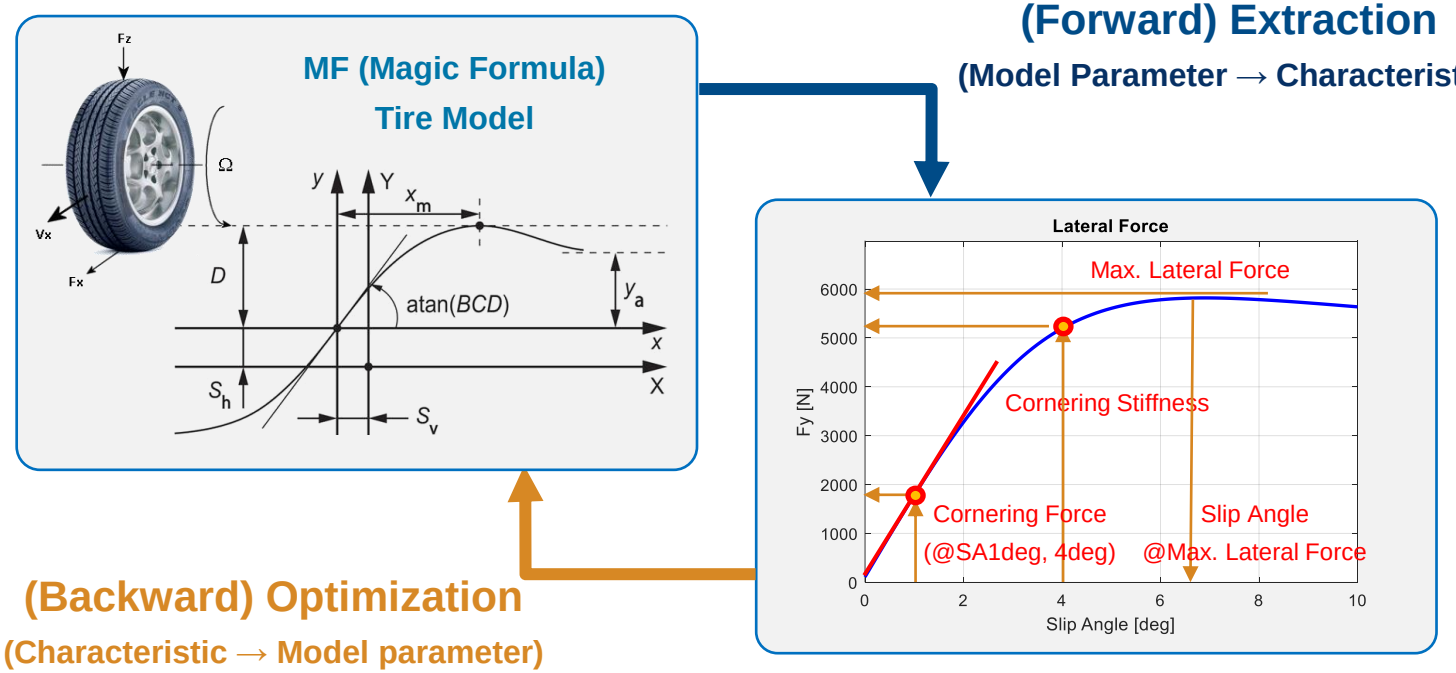
Overall contribution



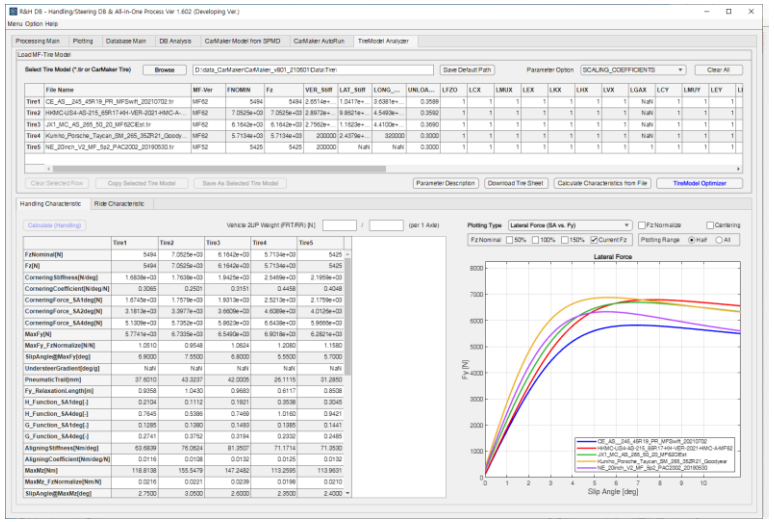
(*Tire: Cornering Stiffness, Max. Fy, Relaxation Length, Camber Stiffness…)

R&H Virtual Process Associated with DB

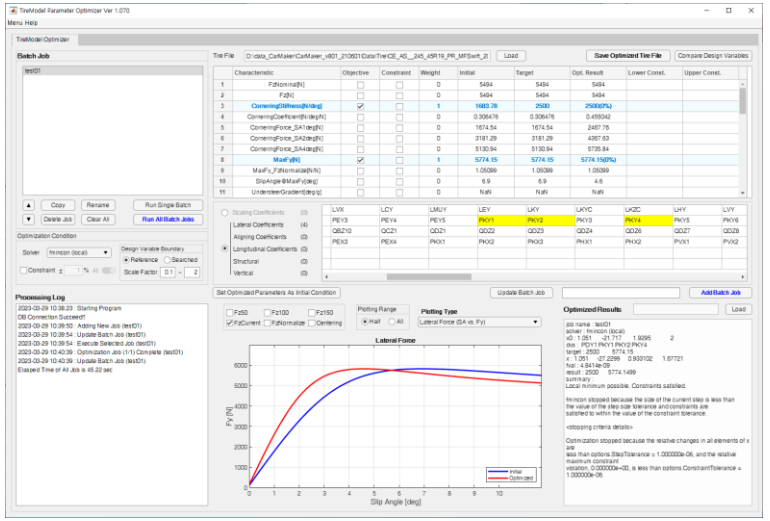
- MF(Magic-Formula) tire model: empirical model(equation + coefficient)
- **Tire model analyzer**: tire characteristic extraction from MF (Magic Formula) model equation and parameters
- **Tire model optimizer**: model parameter optimization to achieve target tire characteristics



[Tire Model Analyzer]



[Tire Model Optimizer]



R&H Virtual Process Associated with DB

- Vehicle handling performance evaluation and benchmarking application: C-SUV vehicles

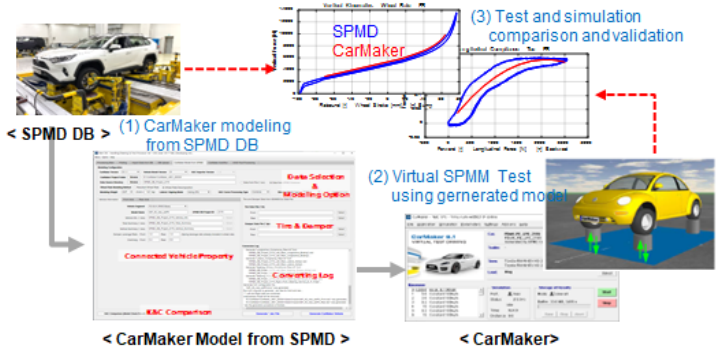
① Setting benchmarking vehicles

- K&C, inertia, tire, handling measurement

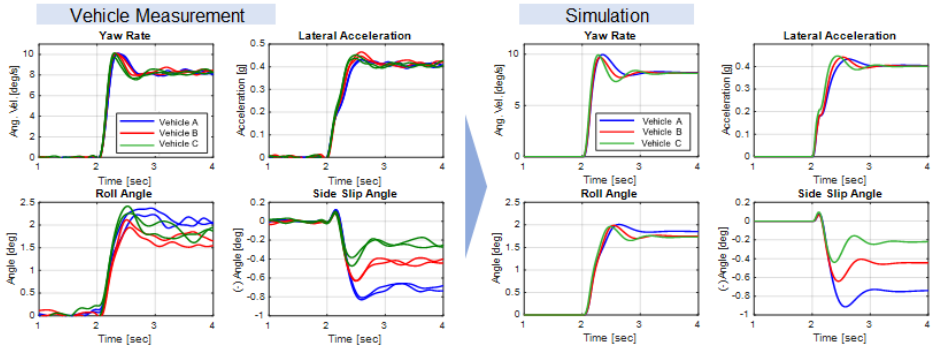
< Vehicle A > < Vehicle B > < Vehicle C >

Vehicle	ENG/TM	Drive	Suspension	Tire	Weight	Wheel Base	Wheel Tread	TGR	Steering
A			FRT: MacPherson RR: Multilink		16,301N (60.4 : 39.6)				
B			FRT: MacPherson RR: Multilink		17,058N (55.5 : 44.5)				
C			FRT: MacPherson RR: Multilink		15,505N (58.1 : 41.9)				

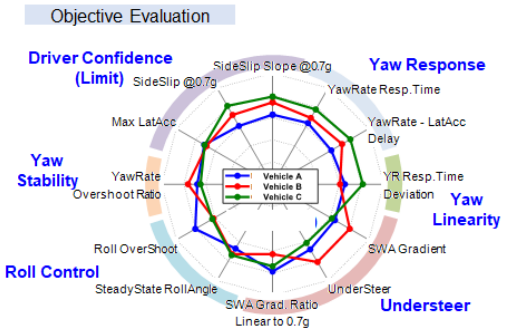
② Test & CAT based virtual modeling



③ Model Validation with test result



④ Comparison of objective / subjective results

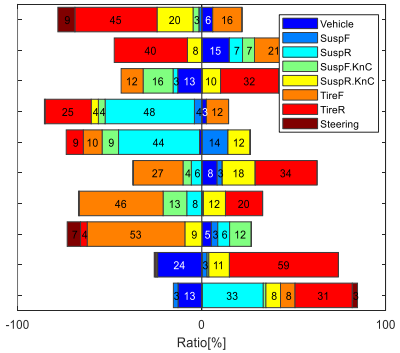


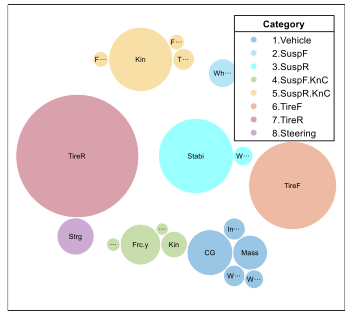
Subjective Evaluation

Similar tendency with obj. evaluation (virtual)

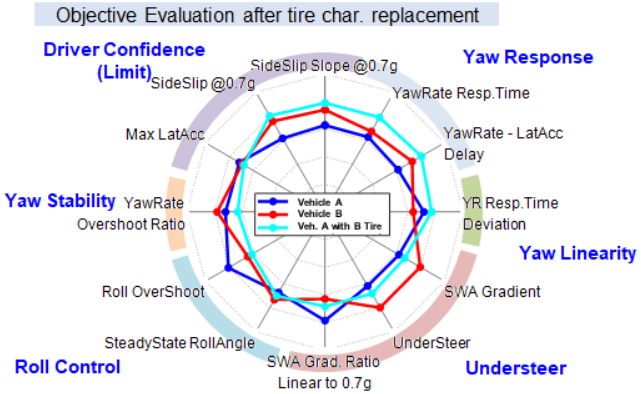
Handling Related Perf.	Subjective Rating		
	A	B	C
Yaw Response	7	7~7+	7+
Yaw Linearity	7	7	7~7+
Understeer	7	7	7
Roll Control	7	7~7+	7
Yaw Stability	7	7~7+	7~7+
Driver Confidence	7	7~7+	7~7+

⑤ Performance contribution analysis



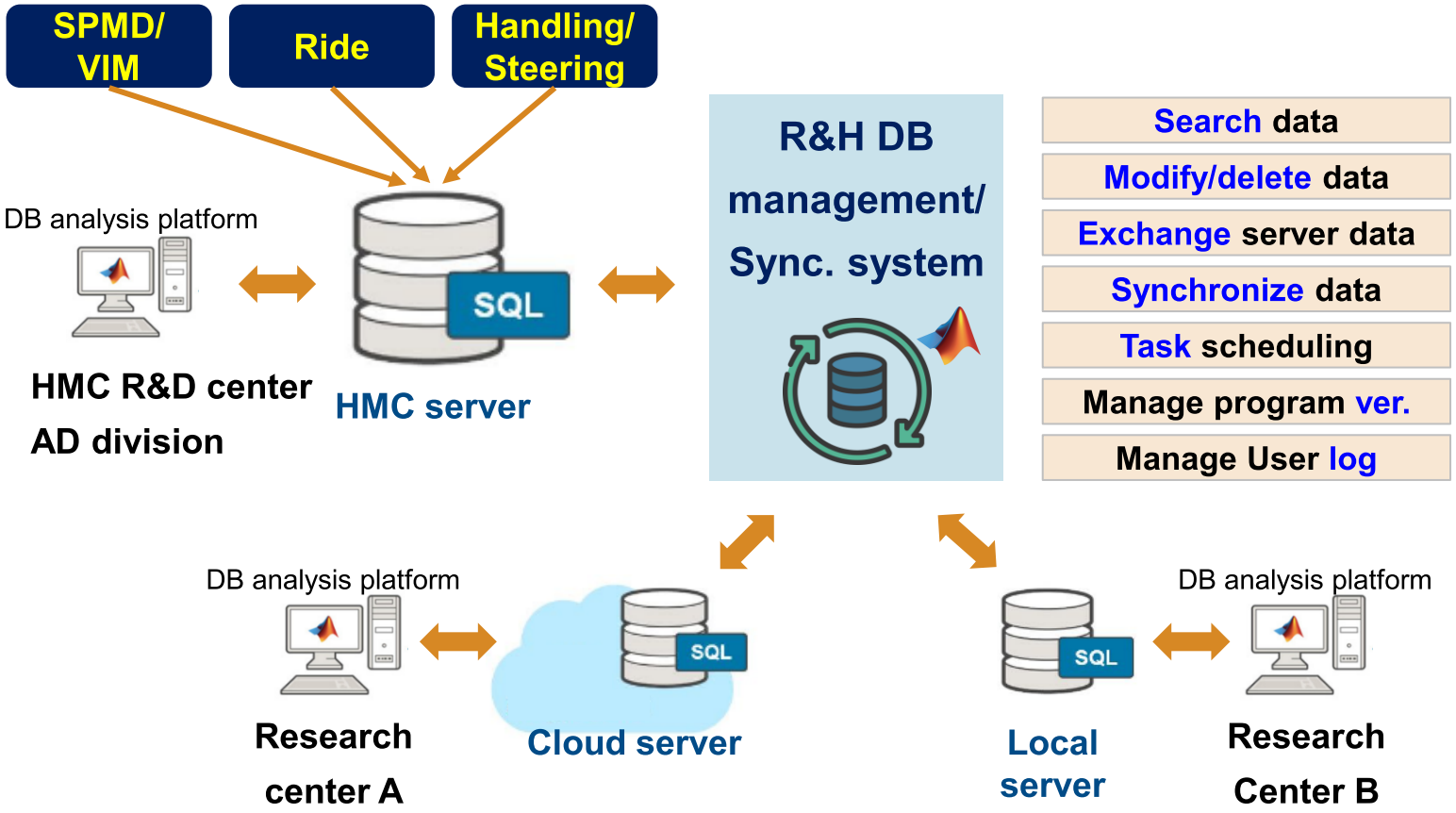


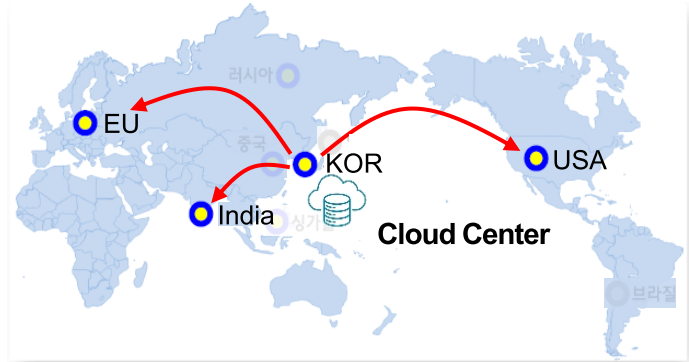
⑥ Virtual improvement & verification



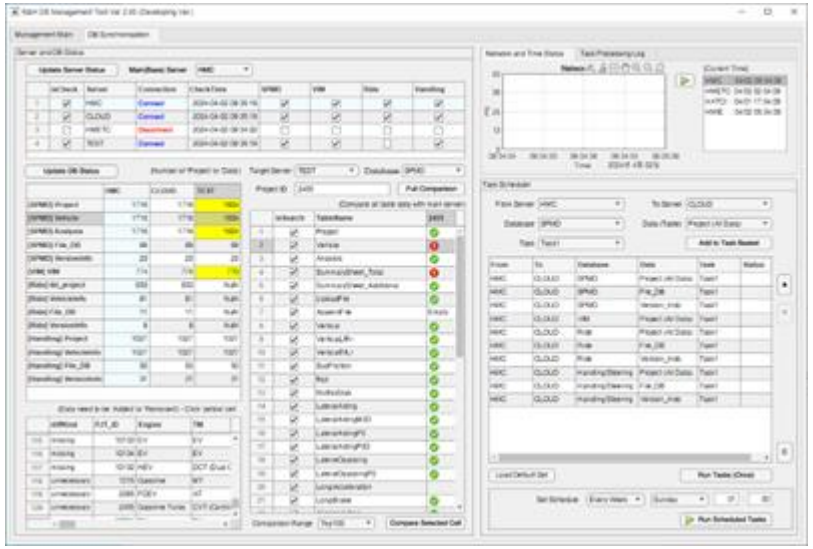
Others – DB Management Process

- DB management process for data sharing and synchronizing between global research centers
  - ✓ Task scheduling automation, data update / exchange, …





[DB Management, Data Share Program]



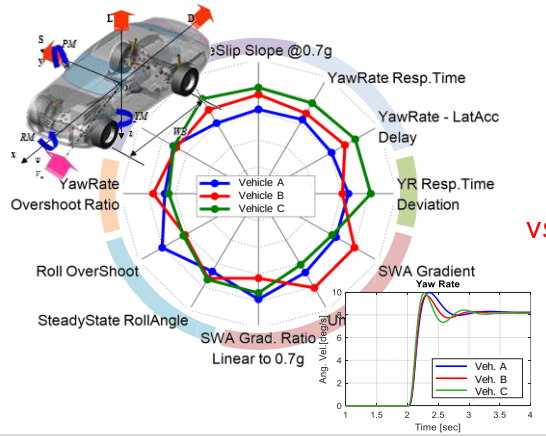
Others – ROM (Reduced Order Model)

- DB-based performance prediction platform using NN, ML (Database to Performance)

  ✓ Input: vehicle parameters, Output: performance index or vehicle status

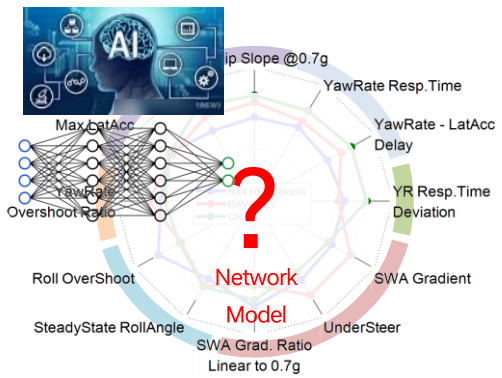
	Vehicle	Database	Data Collection	Modeling	Evaluation	Analysis	Engineering
As Is	**Test Vehicle** (with competitors)	**SPMD(K&C), Inertia Database**	**Data from Design, Test**	**Virtual Model Generation**	**R&H Test Mode Simulation**	**Objective Evaluation**	**Performance Development**
To Be			**Performance prediction/evaluation using ROM (All intermediate procedures omitted)**				**(Decision-Making)**

Actual virtual model evaluation result

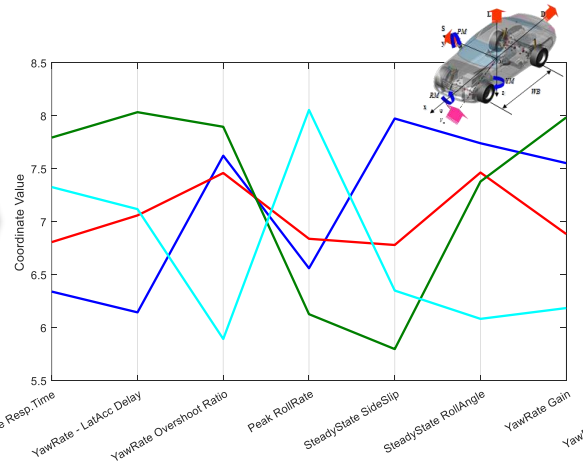


vs

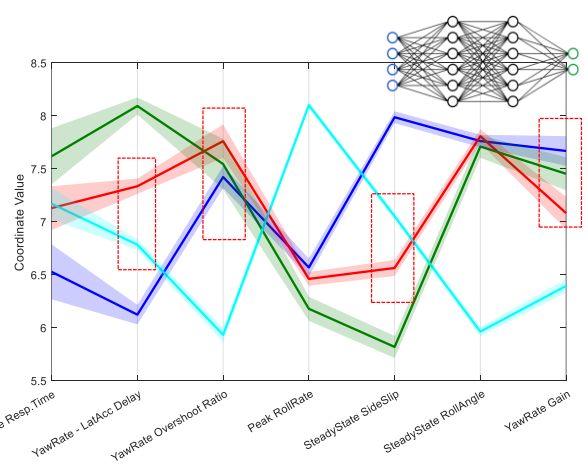
DB + ROM Model



Simulation Result



Predicted Result with Uncertainty

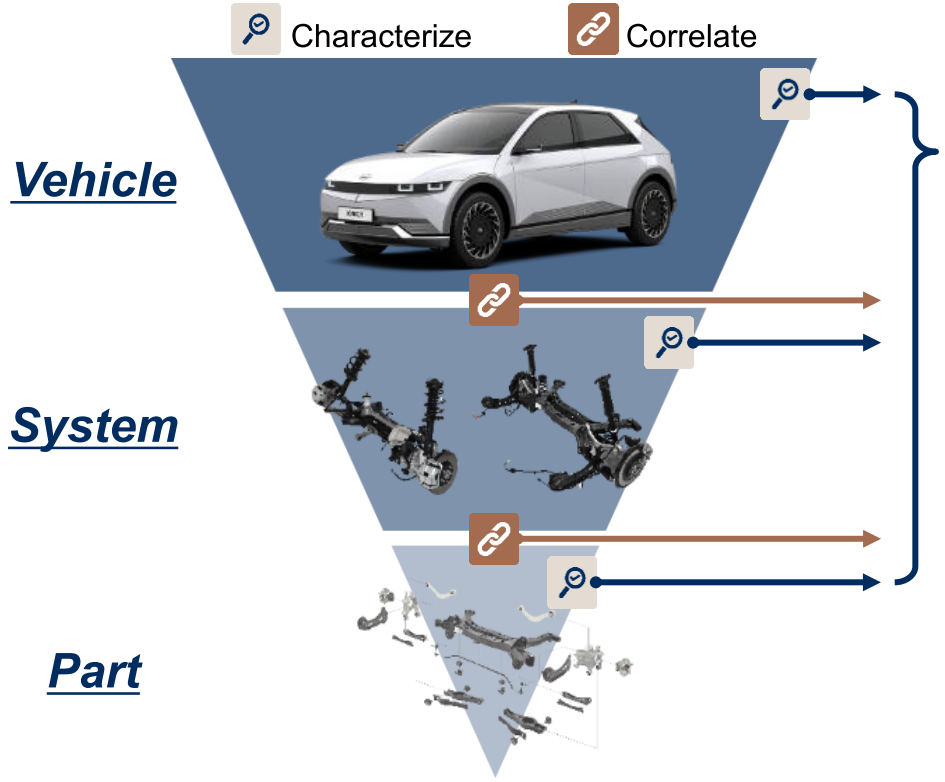


Contents

- Introduction & Purpose of R&H Database
- R&H DB & Analysis Platform
  - ✓ SPMD (Suspension K&C)
  - ✓ Ride
  - ✓ Handling/Steering
  - ✓ Virtual Process (Modeling, Validation, Simulation, Evaluation)
  - ✓ Other Applications - DB Management System, ROM(Reduced Order Model)
- Use Case and Values
- Conclusion

Basic Role as an Engineering Database

- Provide vehicle performance / characteristic information and advanced analysis process to various performance development fields for both general and specific R&D purpose
- Enhance development & engineering efficiency and effectiveness



Engineer in Various R&D Fields

Design (Chassis, Steering, Tire, Brake, etc.)		
R&H Test	**Virtual**	**Architecture**
Control	NVH	Safety
Autonomous	Adv. Dev.	Digital Eng.

- ✓ Sharing vehicle / system characteristic information
- ✓ DB statistics
- ✓ Target cascading
- ✓ Data engineering
- ✓ Virtual development

Performance / Characteristic / Design Guide

- Presenting the range / tendencies by characteristics through statistical analysis
  - ✓ Chassis design guide, vehicle performance index guide
  - ✓ Vehicle / system level target setting, development status & level check

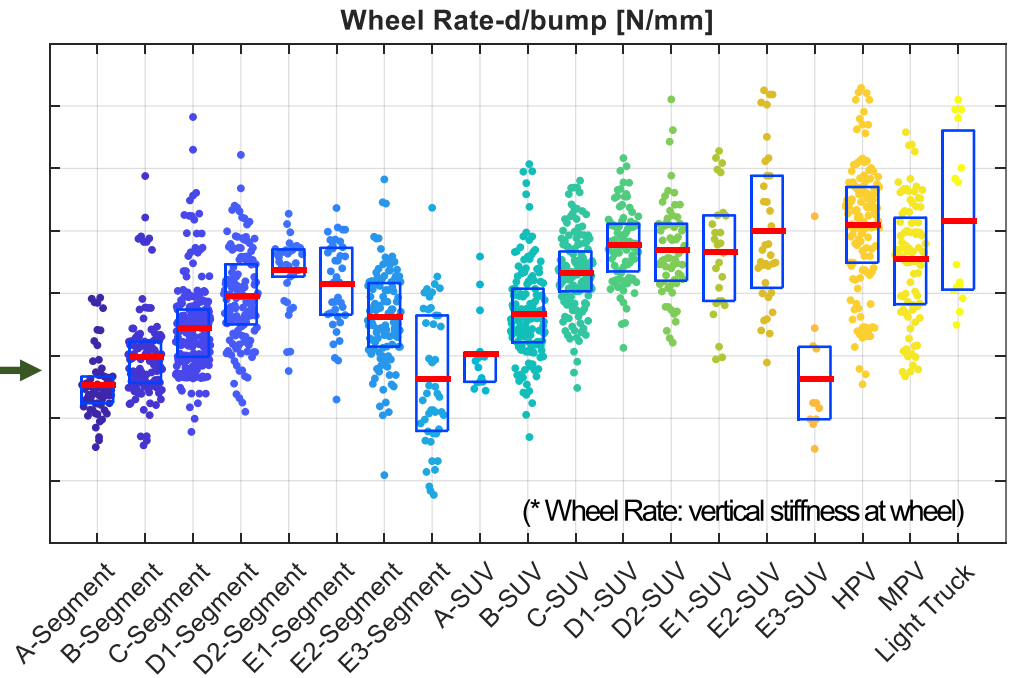
R&H Related Characteristics Index

Suspension (K&C)
- Wheel Rate
- Lateral Stiffness
- :

Handling
- Response Time
- Overshoot Ratio
- :

Steering
- Steering Stiffness
- Steering Sensitivity
- :

Statistical Analysis Results by Segment



< Segment >

Expanding Perspective with Statistical Distribution

- Performance / characteristic positioning comparison in DB statistical range
- Understand the performance level from a macro perspective, derive optimal development directions, and establish efficient goals

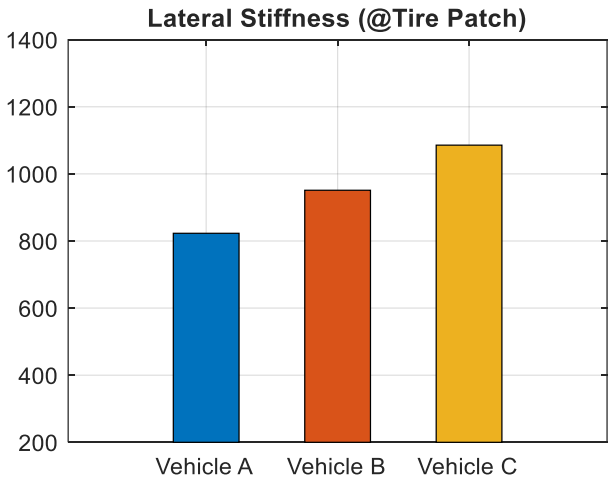
R&H Related Characteristics Index

- **Suspension (K&C)**
  - Wheel Rate
  - Lateral Stiffness
  - :
- **Handling**
  - Response Time
  - Overshoot Ratio
  - :
- **Steering**
  - Steering Stiffness
  - Steering Sensitivity
  - :

As Was

Relative comparison of 2~3 data

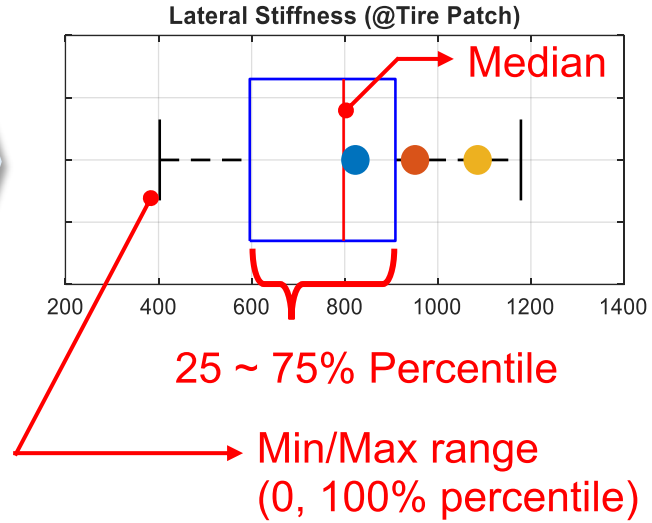
✓ ***Veh. A is the worst***
✓ ***Should be improved***



To Be

Compare level within a statistical range

✓ ***Char. of A is relatively small***
✓ ***But, more than segment median lv.***



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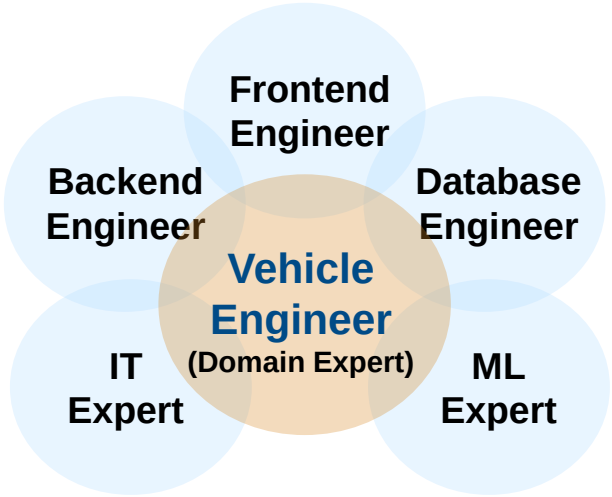
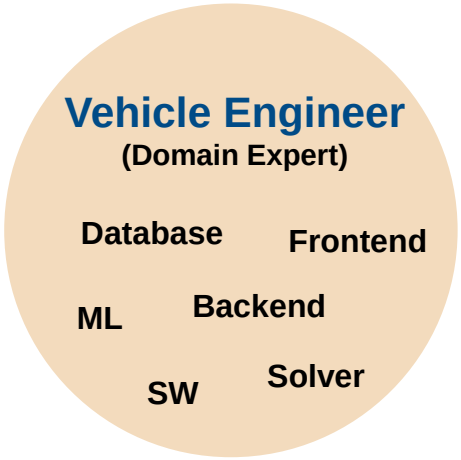
- Conclusion

Conclusion

- Benefits of building DB infrastructure within vehicle performance development field
  - ✓ **Specific**: the most detailed outcomes in the most effective manner by performance dev. engineer
  - ✓ **Agile**: immediate response to a variety of needs and issues
  - ✓ **Interactive**: communicate, interact and develop within various performance development fields
  - ✓ **Sustainable**: build a sustainable system based on internal capabilities and skills



General Roles and Relationships



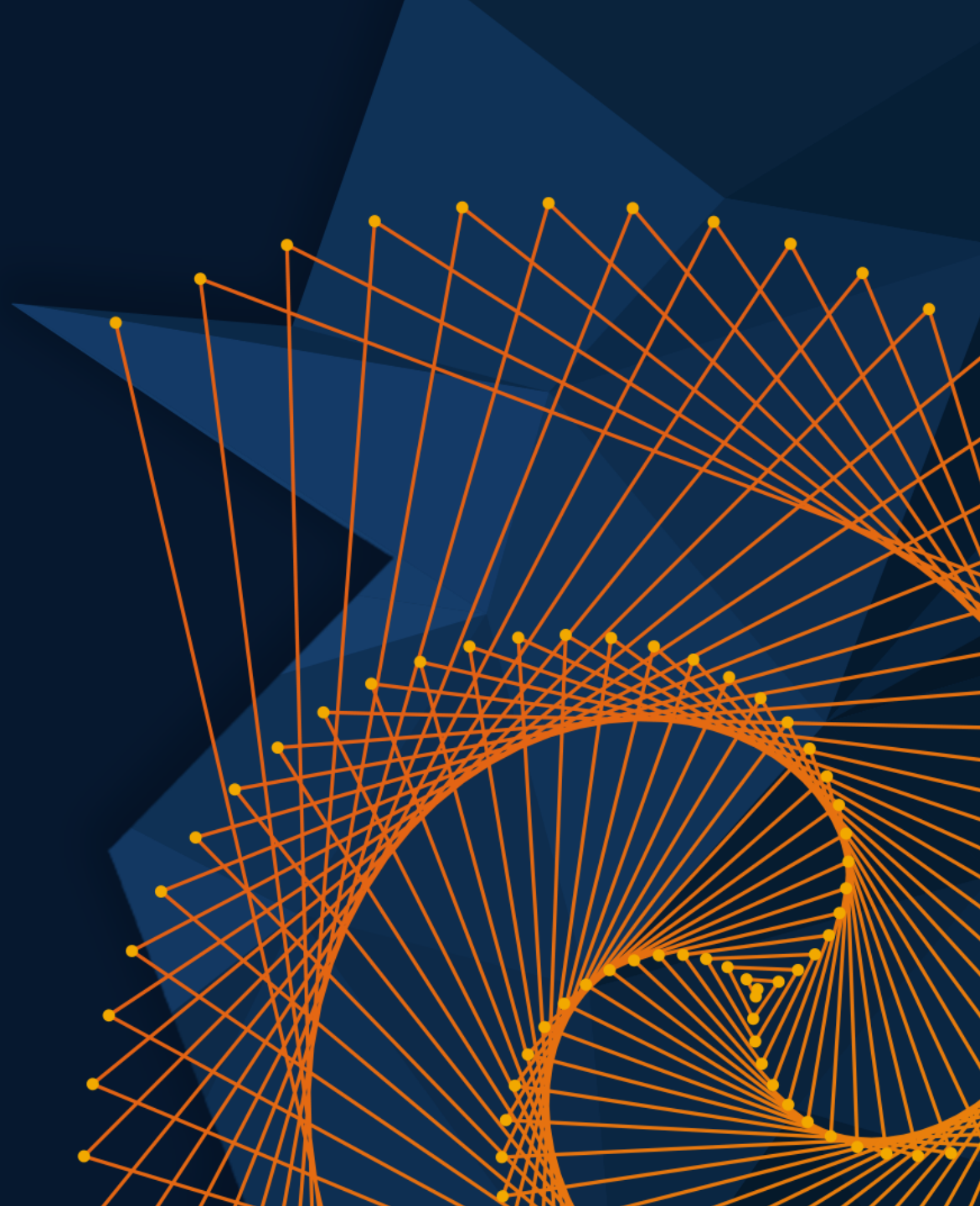
Domain Expert-led DB Development

Improve internal data engineering capabilities based on domain knowledge

Future Work & Vision

- Building an ecosystem where various kinds of DBs, data analysis/virtual processes related to vehicle performance (R&H related and others) are gathered and interconnected

MATLAB EXPO



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