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AUTOMOTIVE AND TRANSPORTATION

Hyundai Motor Group

Using model-based systems engineering to take a new approach to virtual NVH development

Product

Simcenter

Business challenges

Address complexities presented by integrated modular architecture

Achieve digital transformation by integrating data with correct infrastructure and expanding virtual development

Improve efficiency and credibility of virtual evaluation for driving comfort

Keys to success

Develop test models compatible with simulation models using test-data-driven MBSE

Use Simcenter to combine test and simulation to build a digital twin

Build custom methods and bench to perform test-based modeling of tire, suspension and body

Results

Attained highly accurate modeling of tire, suspension and body

Achieved highly accurate NVH performance predictions virtually by integrating test and simulation models

Developed roadmap for building digital twin of road noise refinement for electric vehicles with IMA

Hyundai Motor Group uses Simcenter to combine simulation and test to build a digital twin

Rethinking road noise

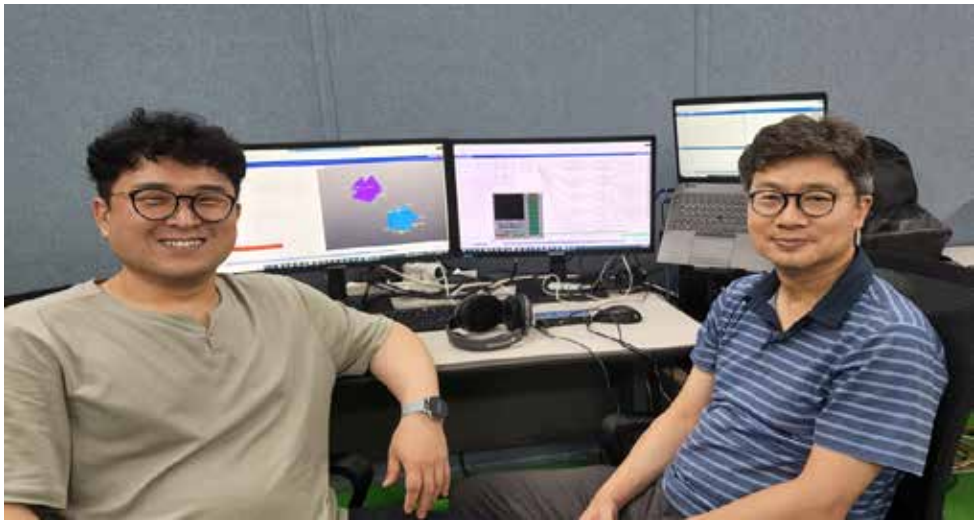
Since its founding in 1967, Hyundai Motor Group (HMG) has been committed to constant improvement. It has been a pioneer in many automotive technologies and is now considered a leader in the future of mobility. This spirit touches every aspect of HMG's business, from the company's vision for electrification to its best-in-class reliability. It also explains HMG's commitment to reducing road noise in its vehicles.

Original equipment manufacturers (OEMs) have tried to reduce road noise for decades and the increasing importance of electric vehicles (EVs) has only intensified that effort.

As part of its dedication to constant improvement, HMG decided to rethink its approach to road noise in all its vehicles because that change included transitioning to an integrated modular architecture (IMA) strategy. This enables OEMs to reduce development costs by using the same part in multiple vehicle models. This is particularly effective with EVs, as batteries can be developed to attach flexibly to any vehicle model. To address new complexities presented by IMA, HMG had been seeking to integrate data, supply proper infrastructure and expand virtual development.

More than just a software vendor

HMG's goal is to become the top EV manufacturer in the world. To achieve this, it needs to increase the efficiency and lower the costs of its vehicle programs while meeting road noise performance goals.

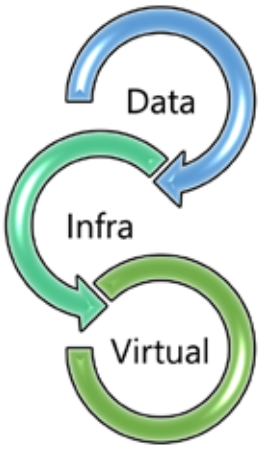


Engineers at HMG are pioneering test-data-driven MBSE for full vehicle road noise.

"When I suggested our idea for acquiring a suspension model, I wasn't sure it was achievable. However, Siemens integrated hardware, software and component-based TPA testing enabled us to design a very challenging jig flawlessly."

Sangyoung Park
Senior Research Engineer
Hyundai Motor Group

Digital transformation strategy in HMG



HMG's three-part strategy for digital transformation.

This led HMG to form a strategic partnership with Simcenter™ Engineering and Consulting services to reduce road noise in HMG's vehicles. Since 2019, the groups have worked closely to develop high-quality vehicles with optimal sound levels. Simcenter is part of the Siemens Xcelerator business platform of software, hardware and services.

Engineers at HMG knew they needed a commercial solution to balance accuracy and speed in its development process to optimize road noise. They also knew that virtual development in the early stages would be crucial, but wanted to ensure the best possible accuracy of simulations by incorporating test data.

"Three years ago we set out on a mission to define the test engineer's role for the virtual development environment," says Sangyoung Park, senior research engineer at HMG. "We began by focusing on developing test models that would be compatible with our simulation models. However, I faced significant obstacles when attempting to create perfectly compatible test models. For that reason, I turned to Simcenter Engineering and Consulting Services."

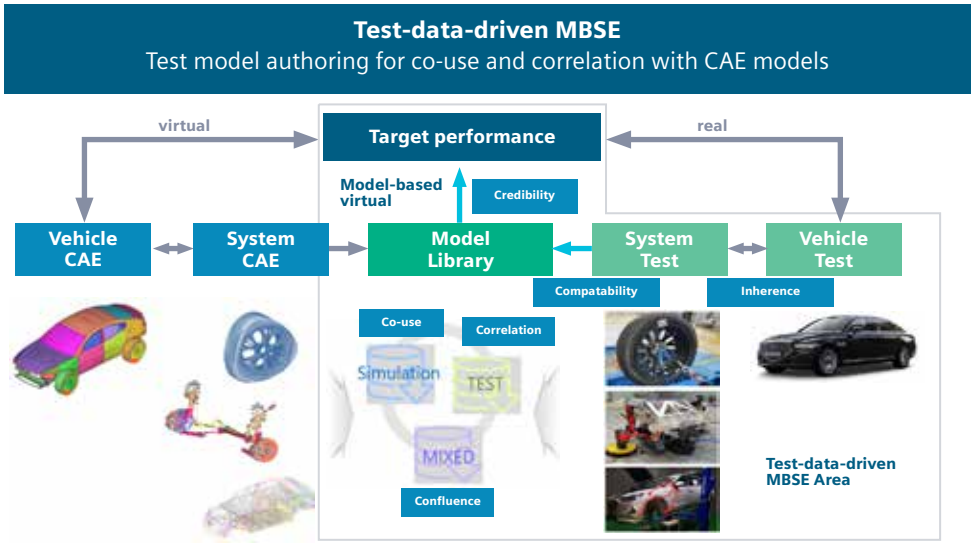
"We selected Simcenter Engineering because we knew they could help us transform our vision into an actionable, realistic roadmap for implementation," continues Dr. Jaehoon Jeong, senior research engineer at HMG. "They have developed proven methodologies and experience for integrating hardware and software to achieve balance between practical application and technology advancement."

This worked particularly well because HMG was already using the Simcenter portfolio of tools so Park and Jeong would not need to invest in, learn and implement new solutions.

"We realized that test and simulation technologies could be combined to create a more credible digital twin," states Park. "We refer

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Senior Research Engineer
Hyundai Motor Group



HMG's test-data-driven MBSE for authoring test models for virtual development.

to this process as test-data-driven MBSE and selected Simcenter Engineering to help us build test models that are representative, compatible and credible and that also contribute to the best possible accuracy."

As a result, HMG and Simcenter Engineering entered a multiphase project over the course of several years.

Invariant loads from the tire

Simcenter engineers worked with the HMG team to apply component-based transfer path analysis (TPA) technology at the wheel level to determine invariant wheel center loads. These invariant loads, sometimes referred to as blocked forces, are solely dependent on the wheels, invariant to the receiving structure.

These loads would give the team better understanding of a component's behavior and the ability to share clear component targets and additional information with their suppliers early in the development phase. Additionally, using Simcenter Virtual Prototype Assembly (VPA), the wheel-defined invariant loads could be used with virtual vehicle assembly variants to predict and evaluate road noise performance, reflecting HMG's desire to use test-data-driven MBSE at every step of its development.

To apply the invariant loads in HMG's development processes, Park and the Simcenter Engineering team needed to determine how invariants are experimentally identified loads that are evaluated on the tire, if the theory is practically applicable and how well could they predict the vehicle road noise performance.

The Simcenter Engineering team worked with HMG to validate the component-based TPA method on the tire. The teams were able to demonstrate the approach could work with HMG's current road noise evaluation process.



Studying invariant loads in the wheel level.

"We have worked with the Simcenter Engineering team to improve the tire model, make the suspension model more efficient and many more challenges. We are excited to have them as strategic partners in our MBSE journey."

Sangyoung Park
Senior Research Engineer
Hyundai Motor Group

> The outcome of our project with Simcenter Engineering is we can now make timely and reliable improvements during the early stages of vehicle development."

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A historical achievement: test-based modeling of the suspension

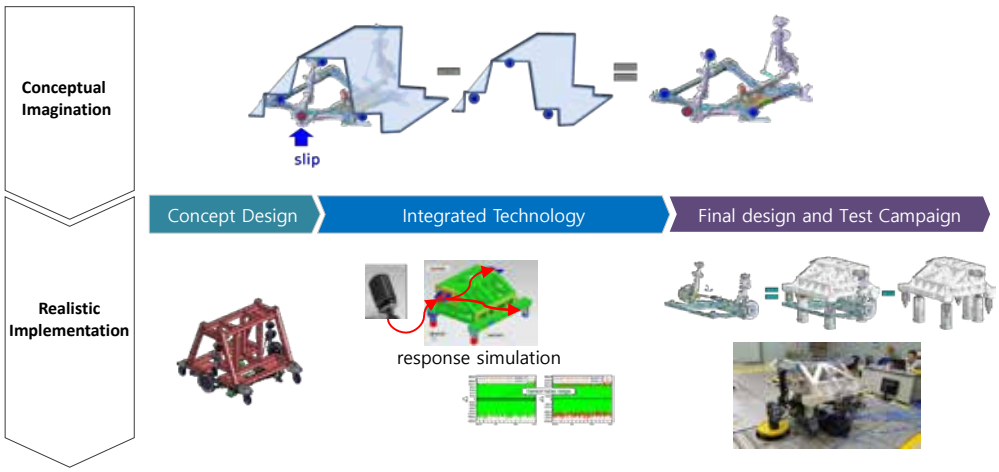
In the previous phase, the system consisted of only two components – the tire as the source and the rest of the vehicle, including body with suspension, as a receiver.

In the next phase, the Simcenter Engineering and HMG teams further split up the receiving structure into suspension and body with the mount in between. All components were experimentally characterized to enable engineers to later build models so they could construct a virtual assembly of the full vehicle.

This phase was particularly important due the electrification of the automotive industry. This transition has led to the drivetrain, road and wind noise becoming the main contributors to in-vehicle noise.

Component-based TPA is an effective method to allow individual characterization of substructures to be assembled into a virtual vehicle, allowing the system designers to switch between designs and handle the increased product complexity and increasing number of vehicle variants.

However, a major challenge of component-based TPA is accurately representing the subsystem in its realistic operational boundary conditions and preload. Additionally, to measure a component, it should be free at the connection interfaces, which presents significant challenges to create the required conditions during the test campaign. A solution for this challenge can be frequency-based substructuring (FBS) decoupling, a technique to characterize the vibrational behavior of an unknown component by subtracting the supporting structure



Designing the suspension jig required a combination of hardware, simulation software and component-based TPA.

from the complete assembly. FBS decoupling is a methodology to identify an unknown component's frequency response functions (FRFs) by removing the influence of the secondary structure from the two assemblies.

Prior to this project, test-based creation of a suspension model had been tested and applied at several companies with varying success. However, none of these models met the required data form for FBS and the frequency range for this project.

This is due to the particularly difficult nature of suspensions – they cannot be characterized separately because they are attached to a wheel on one side and the body on the other. This makes it challenging to replicate the operational boundary conditions during component-only characterization, including vertical preload due to vehicle weight and suspension in slip during driving. If the suspension is not modeled correctly, the results will not be accurate. The FBS decoupling approach had previously only been applied academically, but never commercially on a suspension. Using this method, the engineers were able to create a model that provided the accuracy and frequency range required for the suspension.

Next, HMG and Simcenter Engineering built a customized bench to accurately test the suspension and develop the requirements for and validate the bench design. The teams also recognized that repeatability would be key for this bench, so they designed it to make sure it could later be used in-house.

As a first step, the suspension was coupled with a test jig designed for allowing FRF testing in operational conditions. The test jig was designed and validated using a finite element (FE) model to limit strong dynamic behavior or excessive stiffness so it could be coupled with the target structure. Additionally, the jig allowed different suspensions to be mounted using adapter blocks at its interface points.

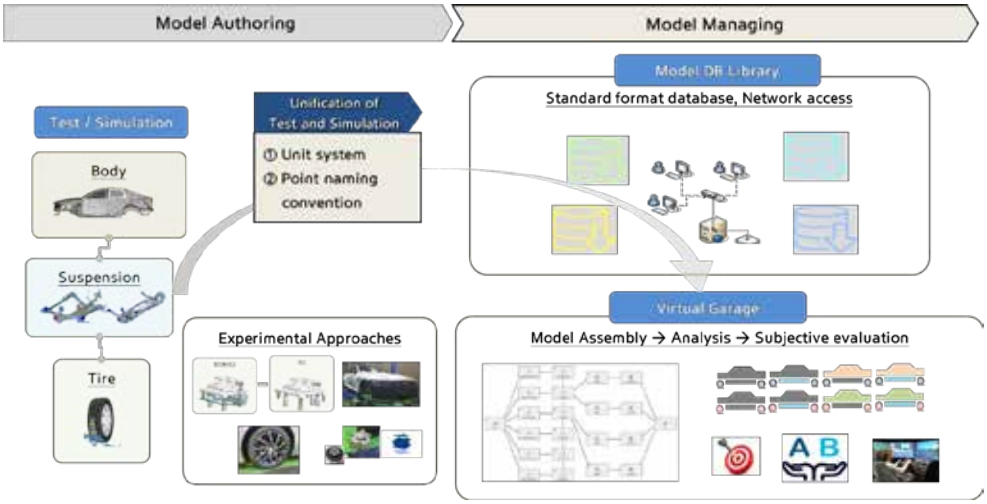
Park and the Simcenter Engineering team are the first group ever to successfully build a complete test setup for FBS-based assembly analysis. This setup enabled the identification of a representative integrated front suspension model with the correct operational boundary conditions.

"When I suggested our idea for acquiring a suspension model, I wasn't sure it was achievable," says Park. "However, Siemens integrated hardware, software and component-based TPA testing enabled us to design a very challenging jig flawlessly. Additionally, various techniques learned from other test campaigns were used to successfully make on-the-fly changes. The progress we've made is encouraging and will help us prepare future models to evaluate performance at the early stages of development."

Characterizing the suspension model

Once the bench was complete, the teams got to work characterizing the suspension model. Simcenter 3D, the computer-aided engineering (CAE) solution for multidisciplinary product engineering, was used to evaluate the ideal test setup, including sensor positioning, accessibility and compatibility for excitation with Simcenter for Qsources™ hardware. Simcenter Qsources is a suite of sound and vibration excitation hardware to measure frequency response functions.

Using Simcenter 3D also enabled easy communication between the simulation team in Leuven, Belgium and the test team in South Korea. In Leuven, engineers built, evaluated and validated computer-aided design (CAD) models for the accelerometers and the Simcenter Qsources shaker. Using these CAD models, the test engineers in South Korea could make instrumentations and measurements based on these CAD models. This provided a critical feedback loop between the Simcenter Engineering team and the customer to make changes and extract test geometry.



Deploying the technology and customization for model-based virtual vehicle development at HMG.

Once the sensors were placed, the Simcenter portfolio of testing solutions, including Simcenter Testlab™ software and Simcenter SCADAS™ hardware, were used to characterize the structural dynamics of the system on the test bench. The teams also used Simcenter Qsources shakers and excitation hardware to confirm the measurements were accurate.

The teams repeated these studies on the test bench several times. Approximately 31,800 transfer functions/FRFs (146 excitations and 132 responses) were acquired for this study. This suspension component contained a large amount of connection points that required interactions to be described and measured. As a result, a high number of frequency response functions (FRFs) were needed to characterize it, from inputs at the wheel hubs to the outputs at the connections to the vehicle bodies. This was a huge effort, but was necessary to ensure accurate model creation.

Their efforts were successful: After the tests, the teams were able to extract the dynamic behavior in a way that contributed to accurate modeling of the suspension system. After the project, the Simcenter Engineering team delivered the bench to the customer for future use on-site.

Deploying the technology and customization

Next, Simcenter Engineering and HMG partnered to deploy the techniques learned from the previous phases of the project using Simcenter VPA and Simcenter Testlab NVH Simulator.

"Using the models and techniques developed during the previous projects, we wanted to provide opportunities to our system designers to subjectively evaluate road noise auralization in various driving conditions such as roads and speed," says Park.

Using Simcenter VPA, Simcenter Engineering and HMG built a virtual vehicle assembly based on test and simulation models. The teams could now predict vehicle NVH performance virtually, confirming that transitioning to model-based virtual vehicle development was feasible and even more accurate.

The teams identified HMG's needs and goals for road noise analysis and defined a roadmap to enhance and customize Simcenter VPA to meet these needs. This included a dedicated graphical user interface (GUI) for data analytics and specific functions for complex multilevel vehicle assembly. The ultimate goal of this phase was to replay and listen to the sound of the vehicle in development before a physical prototype

Solutions/services

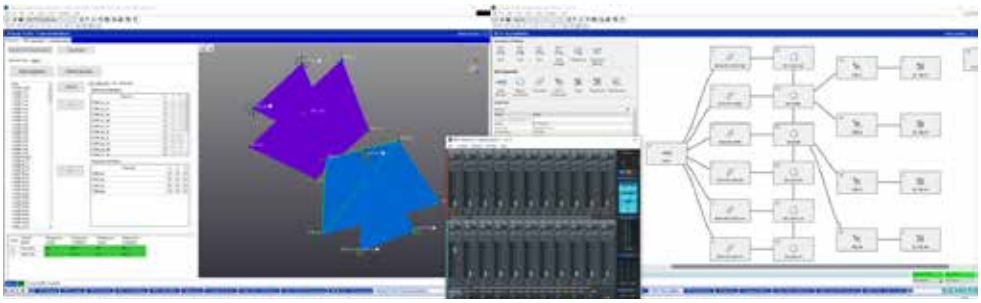
Simcenter
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Customer's primary business

The Hyundai Motor Group is a multinational firm headquartered in Seoul, South Korea. With about 250,000 employees worldwide, Hyundai Motor Group's mobility brands include Hyundai, Kia and Genesis.
www.hyundaimotorgroup.com

Customer location

Seoul
South Korea



Simcenter software and hardware were used together to help engineers achieve a digital twin of the vehicle's road noise.

was even built using Simcenter Testlab NVH Simulator. Simcenter Testlab NVH Simulator enables road noise to be combined with other normal noise contributors, such as wind, tires and the powertrain to make it more realistic. This helps engineers make more accurate noise predictions.

HMG engineers will be able to use the data obtained from Simcenter Testlab to perform detailed analyses, including identifying dominant sounds, where sound is coming from and more. Simcenter Engineering will also work alongside HMG to build a database of this sound information, including a component library for virtual assembly and sound information for Simcenter Testlab. This will enable HMG to reduce development time and costs.

Finally, Simcenter Engineering and HMG will fine-tune the tools and methodologies provided for HMG's specific needs. Because the goal is to incorporate this technology into HMG's development process, ensuring the tools are customized is crucial to achieve efficiency and ease of adoption.

A roadmap for the future

Park and Simcenter Engineering are collaborating on projects to incorporate this technology. In addition to improved accuracy, the HMG team expects to see reduced development time, as this project provided them with many test parts and models that can be used in vehicle studies. This will obviate the need to build and correlate simulation models every time a new vehicle is in development.

"We enjoyed close cooperation with the Simcenter Engineering team," says Park. "We are confident this project will help us improve our development efficiencies for HMG's new IMA strategy. We have worked with the Simcenter Engineering team to improve the tire model, make the suspension model more efficient and many more challenges. We are excited to have them as strategic partners in our MBSE journey."

Putting the customer first

True to HMG's commitment to constant improvement for its customers, Park and Jeong confirm this project will improve driver/passenger comfort by removing unwanted noise and vibration from the cabin. "The outcome of our project with Simcenter Engineering is we can now make timely and reliable improvements during the early stages of vehicle development," Park says. "This will increase driver and passenger satisfaction and make HMG vehicles more comfortable and enjoyable to drive."

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