An automotive OEM was faced with quickly having to reduce the noise, vibration, and harshness (NVH) levels of a new model that were above those of comparable vehicles. The problematic noise levels were about 6 dB higher on its vehicle than for the quietest competitor.

Company design engineers called in LMS International engineering consultants who used source ranking and benchmarking analysis, investigation of critical noise paths, and countermeasure evaluation by frequency response function (FRF) testing techniques to determine the root causes. They found primary NVH contributors were airborne noise and noise transferred through the engine mounts. A new bracket was developed to reduce the engine mount contribution, and trim materials were added to the floor, firewall, and hood. The result was that noise levels were reduced by 8 dB.

Here's how modern analysis tools allowed such a reduction.

**A severe noise problem**
Just before the subject vehicle was scheduled to go into production, the OEM identified a severe engine noise during full-throttle acceleration. The company turned to LMS to solve the problem while also providing other important information. The latter included an analysis of the best competitive vehicle to set targets for interior noise, especially during acceleration (see below).

![Graph](image-url)  
**The acoustic insulation of the subject vehicle was compared with best-in-class competitors to provide a design target.**
The OEM wanted LMS engineers to also identify reasons for the different noise levels and propose design changes to improve the car. Final requirement was for LMS to deliver a modified prototype that equaled the NVH performance of the competitive vehicle.

A sensor suite was used to measure interior noise.

For the project, LMS used a combination of advanced technologies and vehicle experience. The former included "fast" technologies, such as fast transfer path analysis (TPA), to quickly identify the general areas causing problems in the vehicle, and detailed technologies, such as TPA and acoustic source quantification (ASQ), to understand the noise mechanisms and determine the root causes of the difficulties. While overcoming engineering challenges, LMS engineers simultaneously transferred what it learned to the customer, making it possible to optimize the vehicle and subsystem development process.

Previous methods
The traditional approach to addressing interior noise problems uses physical tests that attempt to pinpoint noise sources. For example, a tube may be placed in the air intake in order to remove the nozzle noise from interior noise measurements. Or the intake manifold might be shielded to eliminate shell noise radiated from its housing.

Structure-borne noise coming from the driveshaft and propagated to the vehicle through the suspension.

A detailed transfer-path analysis allowed engineers to investigate the major power train
The fast TPA results showed that the airborne contribution was the largest at 49%, engine mounts contributed 40%, and the suspension accounted for the remaining 11%. The fast analysis technique also determined that the airborne contribution was higher on the customer’s vehicle because of a high basic noise source as well as a high acoustic transfer from the engine compartment to the vehicle cavity. Fast TPA, which was developed by LMS, relies on an advanced indirect source identification method in which each noise contribution is considered to be the product of an equivalent source strength and an equivalent transfer path. It does not provide details, such as which engine mounts are the primary contributors. Because the engine mounts were determined to be the primary contributor, a detailed TPA was carried out to obtain more information, particularly the contribution of each engine mount. LMS engineers measured the transfer path from the source to the interior by exciting each mount with a calibrated source and measuring the response in the interior. They quantified the source strength with acoustic measurements in the vicinity of the source (see below). Multiplying the strength of the source times the transfer path yields the contribution of the source to the interior noise.

Acoustic sensors quantified source strength. The relevant source strengths and transfer path analysis were also done on the competitive vehicles. The two vehicles were compared in terms of construction choices, such as engine mounting layout and trim materials, in order to gain an understanding of the differences. The detailed TPA determined that the right engine mount was the source of most of the noise. Determining critical noise transfer paths

Next, an investigation was performed of the critical noise transfer paths. Structure-borne transfer path analysis was performed by combining a force identification procedure with frequency response function (FRF) measurements. The quality of engine airborne isolation was evaluated by calculating a transmission coefficient based on FRF measurements. The FRFs were measured reciprocally by exciting the car cavity with a calibrated volume velocity source and measuring the response at various locations around the trim. Reciprocal measurements were performed by using calibrated volume velocity sources, which made the measurements faster. The volume acceleration sources were active and the panels were passive. Microphones were placed on the trim surface and below the trim on the sheet metal. The tests measured FRF trim pressure per volume acceleration, FRF steel and aluminum pressure per volume, and ratio averaged over surfaces and sources. The consultants then used acoustic source quantification (ASQ) to accurately identify the interior panels that contributed the most to noise. This was done using artificial excitation to reduce the time required relative to operational testing. Acoustic excitation was performed with an acoustic source and structural excitation with a shaker. The vibro-acoustic transfer function from the acoustic sound source on the engine surfaces to the panels that contributed to the interior noise (including the firewall, floor, front window, and side windows) was measured. Then the acoustic transfer functions from the radiating panels to the target microphone positions were measured. The ASQ showed the
key panels were the upper firewall and front floor. Once the critical panels were identified, their excitation was traced back to acoustic or structural resonance phenomena. Combining these sources with measured FRFs made it possible to quantify the impact of the different sources on interior noise. **Countermeasures**

The detailed investigation of the critical noise path showed that the acoustic transmission through the firewall was much higher on the customer vehicle than on the competitive vehicle. The resonant frequency of the firewall was higher on the customer vehicle so it only isolated high frequency noise. For a structural excitation, the upper part of the firewall and front floor contributed most of the interior noise. For an acoustic excitation, on the other hand, the upper firewall was the dominant source. At the critical frequency's structural modes, the firewall and front floor are again the largest contributors due to the high acoustic sensitivity of these locations. A running mode analysis was performed to identify the root cause of the right engine mount contribution. The results highlighted the large impact of structural modes on the part, indicating the need for stiffening. **Evaluating countermeasures with FRF**

The next step was making simple modifications to determine how they affected critical transfer mechanisms before investing the time and money needed to make realistic changes. Structural modifications were performed to try and change the acceleration levels of the panels in order to change the resonant behavior and radiation to the microphones. Acoustical modifications were also done to try to insulate the cabin by adding a mass-spring system on the vibrating panels. For example, engineers weakened engine mounts by drilling holes in them, added dampening treatments on interior trim panels, added a combination of foam and insulating fabric on the firewall to isolate the airborne noise from the engine, stiffened an engine bracket by welding a beam to it, etc. **Validation of countermeasures**

The simple countermeasures were then evaluated using FRF testing. The local damping layer had a minimal effect on FRFs but increasing the isolation with a combination of a layer of foam and a heavy damping layer had a major positive impact. Those simple modifications were then converted into realistic modifications that were acceptable from a weight, packaging, static stiffness, durability and other standpoints. In addition, a new bracket was designed to reduce the engine structure-borne contribution.

**Overview of the global noise level of the original vehicle vs. the final prototype vehicle highlights across the spectrum noise level reduction.** View a full-size image The results exceed the OEM's expectations, with the LMS delivered prototype vehicle exceeding its best competitor in NVH performance. The level of high frequency noise was substantially reduced. Levels of all engine
orders were also considerably lower. The overall noise level was reduced by up to 8dBA at the driver's outer ear. Rob Snoeijs is a technology writer for LMS International.