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OPTIMIZATION OF NVH TESTING AND ANALYSIS PROCESSES THROUGH THE INTEGRATION OF LEAN MANAGEMENT

Daniel Balc[1], Doina Banciu[2], Constantin Oprean[3,4], and Aurel Mihail Titu[5, 6]
[1]National University of Science and Technology POLITEHNICA Bucharest, 313 Splaiul Independenței, București, Romania, ORCID No. 0009-0004-9853-3039, danielbalc98@gmail.com
[2]Academy of Romanian Scientists, 3 Ilfov Street, Bucharest, Romania, banciu.doina@gmail.com
[3]Lucian Blaga University of Sibiu, 10 Victoriei Street, Sibiu, România, ORCID No. 0000-0002-1710-0660, constantin.oprean@ulbsibiu.ro
[4]Academy of Romanian Scientists, 3 Ilfov Street, Bucharest, Romania
[5]Lucian Blaga University of Sibiu, 10 Victoriei Street, Sibiu, România, Corresponding author, ORCID No. 0000-0002-0054-6535, mihail.titu@ulbsibiu.ro
[6]Academy of Romanian Scientists, 3 Ilfov Street, Bucharest, Romania

ABSTRACT: The paper provides an in-depth analysis of how Lean management principles can be applied within the framework of NVH (Noise, Vibration, and Harshness) testing and analysis, particularly in the context of braking systems. The decision to introduce Lean was driven by the need to streamline complex workflows, reduce repetitive or non-value-adding activities, and establish a more structured and transparent process for evaluating vibroacoustic behavior. Rather than approaching Lean as a rigid set of rules, the study explores its integration as a flexible methodology, adapted to the technical and organizational realities of engineering research and development. Special attention is given to the coordination between simulation and experimental testing phases, where clear communication and timely data exchange are critical. The study also considers how interdepartmental collaboration can be supported through Lean practices, particularly in multidisciplinary teams where responsibilities are often shared across modeling, measurement, and interpretation. Organizationally, the implementation of Lean required certain adjustments to working habits and task ownership, encouraging more structured planning and accountability without imposing excessive procedural overhead.
By focusing on the specifics of the NVH domain where small deviations in input can significantly affect perceived quality the research highlights how Lean can be tailored to environments that rely heavily on data accuracy, reproducibility, and cross-functional decision-making. This approach supports a more coherent and consistent engineering process, ultimately contributing to the development of more refined and technically validated products.
KEYWORDS: Lean Management, Coordination, Validation Workflow, Simulation, Integration

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1. INTRODUCTION

Alongside the growing technical complexity present in modern automotive systems, there is a noticeable shift within engineering organizations toward improving internal workflows, reducing development timeframes, and enhancing product quality through structured and incremental improvements. [1] These goals are not only driven by the increasing expectations of end-users regarding comfort and refinement but also by the operational need to manage resources more effectively and ensure repeatable, high-quality outputs. Within this context, Lean management principles are gaining relevance as a practical approach to organizing and optimizing processes that involve multiple iterations, data dependencies, and multidisciplinary collaboration.

Although originally developed for manufacturing environments, Lean has begun to find its place in engineering and research-based activities. Applying it in domains such as Noise, Vibration, and Harshness (NVH) testing requires a nuanced interpretation. NVH activities are inherently variable, often exploratory in nature, and rely on a continuous exchange between simulation and physical validation. [2] This makes direct transfer of Lean tools from production lines to engineering laboratories challenging. However, the fundamental principles of Lean such as reducing non-value-added activities, standardizing essential operations, and enabling a clear flow of information can be effectively adapted to support NVH processes.

The current work focuses on exploring how Lean principles can be introduced into NVH testing and analysis procedures, with particular emphasis on applications related to braking systems. It examines how the organization of tasks, allocation of roles, and communication among technical teams can be restructured to better reflect the dynamics of NVH work. In environments where small disturbances can significantly affect measurement quality or repeatability, maintaining clarity in roles, process boundaries, and expectations becomes essential. [3] Lean provides a framework for creating this clarity, allowing engineering teams to detect inefficiencies early and respond with minimal disruption to the overall testing strategy.

An important part of this integration involves rethinking the definition of performance in NVH activities. Unlike production settings, where volume and speed are key indicators, NVH engineering values the consistency, relevance, and traceability of data. The goal is not necessarily to test more, but to test smarter focusing on what adds clarity, enables better decisions, and contributes meaningfully to the validation or refinement of technical assumptions. In this regard, Lean becomes less about acceleration and more about precision in execution. The approach proposed in this paper suggests that by adapting Lean thinking to the realities of experimental and analytical NVH work, engineering teams can build more reliable processes that support long-term innovation and product quality.

2. LEAN MANAGEMENT

Lean is an integrated management approach centered on systematically eliminating waste while maximizing value for the customer, using minimal resources. Originating in the Japanese automotive industry, specifically within the Toyota Production System, Lean has evolved over time into a philosophy applicable across a wide range of sectors, including manufacturing, healthcare, services, research, and complex engineering domains such as NVH testing and analysis.

At its core, Lean emphasizes a clear understanding of what constitutes value from the customer's perspective and focuses on systematically eliminating all activities that do not directly contribute to that value. These non-value-adding activities referred to as waste include overproduction, waiting times, unnecessary transport, excessive inventory, inefficient movements, overprocessing, defects, and underutilization of employee capabilities. Each of these wastes can have a detrimental impact on process efficiency, product quality, and employee engagement.

Lean is not a rigid methodology but rather a flexible set of principles and best practices that can be adapted to the specific context of any organization. Its fundamental principles include customer orientation, value stream analysis, continuous flow, pull-based production (just-in-time), and a relentless pursuit of perfection through continuous improvement (Kaizen). Lean also emphasizes employee involvement, recognizing that those closest to the operational activities are often best positioned to identify opportunities for improvement.

To operationalize these principles, Lean provides a range of tools and methodologies. These include the 5S system for workplace organization, value stream mapping for identifying inefficiencies in the material and information flow, Poka-Yoke for error-proofing processes, Kanban for visual workflow control, and Just-in-Time and Heijunka systems for production leveling and demand-driven scheduling.

What distinguishes Lean from other process optimization approaches is its long-term vision. Rather than focusing solely on short-term gains, Lean fosters a culture of continuous improvement and systemic thinking, where all employees contribute to the development of robust, repeatable, and transparent processes. The emphasis is placed on creating process stability, standardization, and the ability to monitor and improve performance through structured, data-driven approaches.

Implementing Lean requires a thorough evaluation of existing workflows to distinguish value-generating steps from sources of waste. In many cases, this implementation involves a deep cultural transformation, supported by strong leadership, employee training, realignment of strategic goals, and a mindset oriented toward adaptability and lifelong learning. [4]

Ultimately, Lean is not solely about reducing costs or increasing efficiency. It represents a comprehensive framework for building sustainable systems where quality, customer satisfaction, and employee engagement are embedded into the organizational fabric. Regardless of the field of application, Lean provides a solid foundation for innovation, operational excellence, and long-term competitiveness.

3. OPTIMIZATION OF VIBRATION TEST DURATION

Within NVH testing activities, the analysis of vibrational behavior in mechanical systems represents a critical phase for ensuring both product performance and reliability. [5] This process requires the accurate capture of vibration signals generated by complex structures under variable and often difficult-to-reproduce operating conditions. To ensure that the data collected are both valid and comparable over time, it is essential to establish clear procedures regarding sensor positioning, measurement point classification, and the repeatability of the testing execution.

In this context, one of the most impactful interventions implemented during the project was the introduction of a standardized vibration sensor positioning table, developed in accordance with Lean management principles. [6] The need for this measure emerged following a series of tests where significant data inconsistencies were observed, despite apparently identical environmental conditions and experimental setups. A retrospective analysis identified the root cause as the absence of a systematic method for sensor placement each operator had relied on personal experience or general guidelines, leading to inconsistencies. This directly affected both the traceability of the results and the reliability of simulation models, particularly during advanced development phases.

The implementation of a positioning table, formatted as a technical document that was both accessible and updatable, represented a tangible step toward standardizing this process. [7] A portion of the table is illustrated in figure 1, where a series of positions along the Y-axis can be observed, along with the corresponding axes of interest for each position.

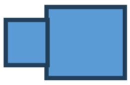
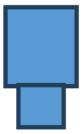
Sensor positioning	First axis	Second axis	Third axis
	Y	X	Z
	Y	Z	-X
	Y	-X	-Z
	Y	-Z	X

Figure 1. Impact Sensor orientation on the Y axis

This approach was the result of close collaboration between the testing team, NVH engineers, simulation specialists, and the project coordinator, who facilitated a shared working framework and ensured the integration of the document into internal procedures. [8] Unlike previous practices, where the organization of the test largely depended on the experience of the technician or engineer involved, this new method brought clarity, accountability, and a unified logic to the process.

From a Lean management perspective, the intervention targeted waste reduction across multiple dimensions. First, it minimized time waste associated with identifying appropriate sensor locations at the beginning of each test session. Operators no longer needed to interpret technical diagrams or search for historical documentation; all relevant information was consolidated into a single table, supplemented with QR codes linking to reference images and previous examples. Second, it reduced the risk of generating non-conforming data, which might have otherwise led to test repetition or inaccurate analysis.

In a process as complex as NVH testing, a failed test entails not only financial costs but also significant time and resource loss.

The impact of this initiative was quickly felt in day-to-day operations. The setup time for each test was reduced by approximately 10–15%, while data reliability improved significantly, as can be seen in the figure 2.

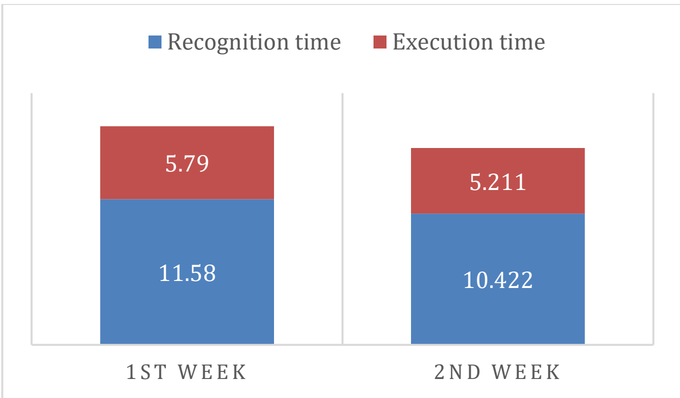


Figure 2. The improvement of execution time

Variability between identical test sessions fell below 5%, a meaningful threshold in vibration measurement. This increased consistency allowed for stronger validation of simulation models and provided clearer interpretation of test results in relation to the real-world behavior of the system under evaluation.

Beyond its direct benefits, this measure also fostered a cascading effect across the team, encouraging the expansion of standardization efforts to include other types of sensors (such as noise, temperature, or body-mounted acceleration sensors). As a result, testing activities began to be perceived not merely as a series of measurements, but as a well-structured, methodical process precisely the type of cultural shift encouraged by Lean philosophy.

Another noteworthy benefit was the contribution of this standardized table to the traceability and auditability of the testing process. In instances where results fall outside expected tolerances or diverge from anticipated performance, it is now possible to backtrack the full configuration of the test simply by consulting the positioning table. Each test session is associated with a specific version of the table, enabling quick identification of any deviations. Additionally, the integration of this information into data acquisition software allows metadata for each measurement file to be automatically populated, streamlining the post-processing work of analysis and simulation teams. [9]

The initiative also received strong support from the project management team, who recognized the strategic value of such standardization. [10] Especially in projects involving testing across multiple locations or conducted by external contractors, the availability of a sensor positioning table becomes an essential tool for ensuring consistency and product quality. Moreover, it serves as a foundational resource for training new team members, reducing the technical onboarding time and minimizing human error risks in the early stages of involvement. [11]

4. STRATEGIC DIRECTIONS FOR SUSTAINING LEAN IMPLEMENTATION IN NVH TESTING

Following the initial implementation of Lean principles in the vibration analysis process particularly through the standardization of sensor positioning and the optimization of test preparation a number of future directions have been identified to further validate, confirm, and expand this approach. These next steps are intended to serve a dual purpose: on one hand, to provide objective evidence of the positive impact that the new practices have on test performance; and on the other, to create a solid foundation for the controlled scaling of this methodology to other areas of NVH testing.

A first area of focus is the systematic monitoring of the performance indicators (KPIs) defined during the implementation stage. Special attention will be paid to trends in the average test preparation time, percentage variations in measured values between similar test sessions, the number of test repetitions due to sensor misplacement or improper mounting, and the consistency of the data compared to simulation models. These parameters will be tracked and analyzed over a minimum period of three months, under real operational conditions, in order to generate reliable and actionable insights.

A second direction involves extending standardization to other types of sensors, especially those used in acoustic and thermal testing. The plan includes developing similar sets of tables and technical guidelines for positioning microphones or temperature sensors, integrating them into a unified operational guide for NVH testing. This methodological unification is expected to minimize inconsistencies between test sessions conducted by different teams or operators, and to enhance the traceability of each measurement dataset.

A third initiative will focus on the development of a digital test management system, based on unique session codes that automatically link to standardized sensor positions, equipment configurations, and collected results. Such a system will streamline access to historical data, support cross-validation, and greatly enhance the ability to perform retrospective analysis. It will also facilitate better coordination between testing, simulation, and quality assurance teams.

Parallel to these efforts, dedicated training programs will be launched, both for current testing personnel and for new team members or external collaborators. These sessions will address not only the technical aspects of sensor handling and adherence to positioning protocols but also the foundational concepts of Lean thinking, aiming to reinforce team-wide understanding and long-term cultural adoption. Embedding these principles into day-to-day operations is viewed as essential for maintaining the sustainability of the improvements made.

Finally, a priority will be given to conducting a multi-criteria comparative analysis between the traditional and standardized methods, within structured testing campaigns. This comparison will incorporate not only quantitative metrics (such as execution time, standard deviation, or response time) but also direct user feedback from technicians, engineers, and project managers. The objective is to evaluate whether the Lean implementation has led to a clearer, more consistent, and more predictable workflow in the context of vibration testing.

Through these targeted directions, the aim is to solidify a well-tested and well-documented practice that is widely applicable and capable of becoming a standard component of internal NVH testing protocols. At the same time, these efforts contribute to the broader validation of Lean's applicability in high-variability, high-complexity technical environments such as those found in NVH engineering.

5. CONCLUSIONS

The implementation of Lean principles within the vibration analysis process has proven to be both relevant and effective, particularly in a technical context where precision, consistency, and efficiency are critical. By standardizing sensor positioning and introducing clear operational tools such as a structured measurement table the testing activity has become more predictable and controllable. These measures directly contributed to reducing test preparation time, improving data reliability, and lowering the occurrence of operational errors.

The conclusions drawn thus far suggest that applying Lean philosophy is not only feasible in engineering domains characterized by high variability, but also beneficial. The proposed approaches have had a positive impact on process traceability, clarity of responsibilities, and consistency of execution. In particular, the consistent reduction in preparation time without compromising result quality highlights the added value of standardization and systematic documentation in NVH testing procedures.

Another important outcome observed was the ability of this intervention to enable more effective cross-departmental collaboration. By involving testing, simulation, and project management teams in the development and use of a shared tool such as the sensor positioning table communication was improved, ambiguity reduced, and decisions were better supported. This synergy played a key role in establishing a coherent, adaptable, and repeatable workflow.

Moreover, within the involved team, the Lean implementation fostered a positive culture of accountability and active engagement. Rather than perceiving the intervention as an added constraint, employees viewed it as practical support in performing their tasks more efficiently. The clarity of instructions and quick access to essential information helped reduce operational uncertainty and increased trust in the obtained results.

While the current implementation directly addressed only one part of the testing process vibration sensor positioning the conclusions indicate strong potential for expanding Lean principles to other NVH testing components, such as acoustic analysis or thermal validation. This expansion will require tailored adaptations, but the lessons learned so far provide a solid foundation for future developments.

Overall, the Lean-driven intervention in vibration analysis represents not just a punctual improvement, but a genuine step toward building a robust methodology aligned with modern requirements of quality, traceability, and operational efficiency. This direction also resonates with current trends in the automotive industry and advanced testing fields, where validation demands are increasingly complex and development timelines are continually shrinking.

In the long term, the success of this approach will depend on the organization's ability to sustain continuous improvement and to adapt the implemented solutions to emerging technological requirements. Therefore, institutionalizing these practices is recommended not merely as a one-time efficiency tool, but as a core part of an organizational philosophy focused on value creation, quality, and ongoing learning.

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