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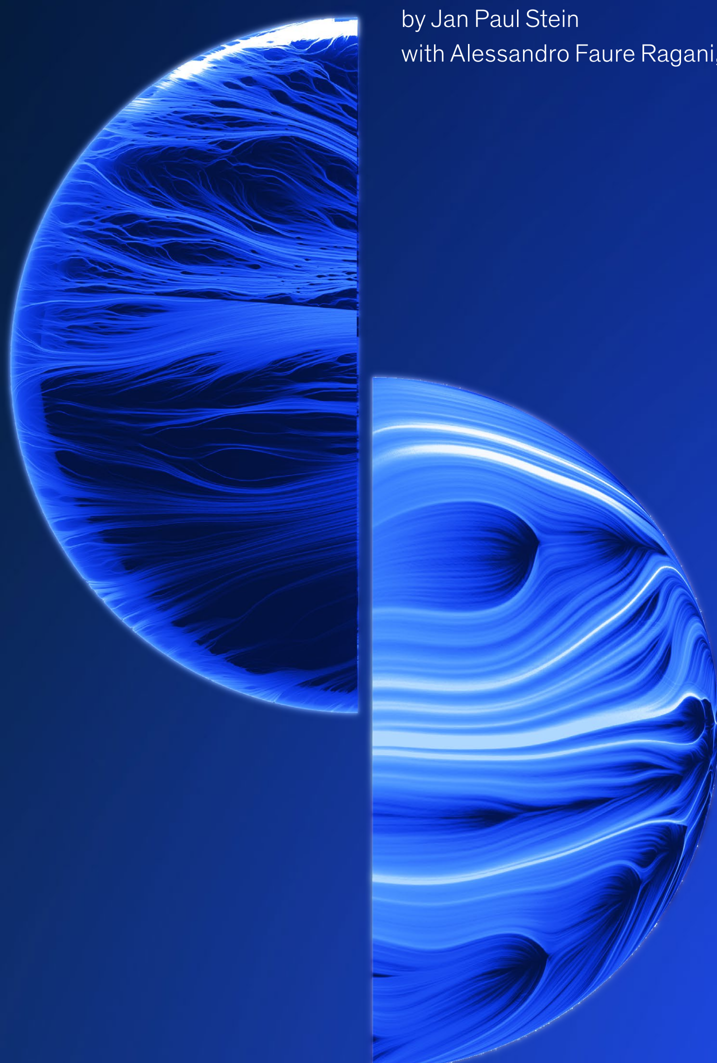
In collaboration with NAFEMS

On the brink of a revolution? Engineering simulation in the age of AI

by Jan Paul Stein
with Alessandro Faure Ragani, Joe Walsh, and Roger Keene



Digital tools have already transformed product development. Multiphysics simulation tools allow engineers to evaluate more options more quickly, improving product performance while reducing development time and costs. Today, artificial intelligence and machine learning (AI/ML) technologies have the potential to change the game again, promising faster time to market, better product performance, and disruptive improvements in simulation speed.

In 2023, a McKinsey survey conducted in partnership with NAFEMS showed that technological advances, changing market conditions, and increased confidence in advanced engineering simulation tools are shifting user priorities. Respondents told us that improved time to market is the primary value driver for the use of simulation in their organizations, surpassing better product performance for the first time.

That survey also revealed a high level of interest in the use of AI/ML simulation tools. Two-thirds of respondents said they had used AI/ML simulation, but only 5 percent reported using these technologies at scale. By comparison, the application of traditional simulation tools is ubiquitous in engineering organizations (99 percent), with just over half of respondents using them at scale.

A deeper look

Our previous analysis showed that engineering simulation has entered a dynamic phase of development. But it left some important questions unanswered: What types of problems are users solving with simulation? At what level of maturity? How well are simulation tools integrated into product development processes and engineering workflows? Where should companies concentrate their investments in digital product development and simulation to secure the best returns?

To address these gaps in knowledge, we collaborated with NAFEMS on a new study designed to take a deeper look at the use of simulation within a single industry. We chose the automotive industry for this analysis because its companies deal with a wide range of engineering problems across multiple domains and because our previous work has shown that the automotive industry is a leader in the adoption and integration of simulation tools, especially those using AI and machine learning.

Based on a survey and interviews with 50 professionals involved in engineering simulation in the automotive industry, we collected data on the use of simulation across a matrix of 28 vehicle subsystems (for example, seating, transmission, and lighting systems) and 11 performance attributes (for example, safety, aerodynamics, and durability). We asked respondents to rate the current state of the art in the application of traditional simulation tools across all relevant combinations of system and performance attributes, as well as the degree to which the toolchains behind those simulation systems were automated and integrated into product development workflows. For AI/ML simulation, we asked respondents to assess the relative maturity of these technologies compared with their traditional counterparts. The result is a granular view of the current state of the art and rate of evolution of advanced engineering simulation in real-world applications (for more details, see sidebar “Methodology”).

Our study reveals rapid but uneven progress, with some engineering domains and application areas benefiting more than others. We also found dramatic differences in adoption, growth, and business impact.

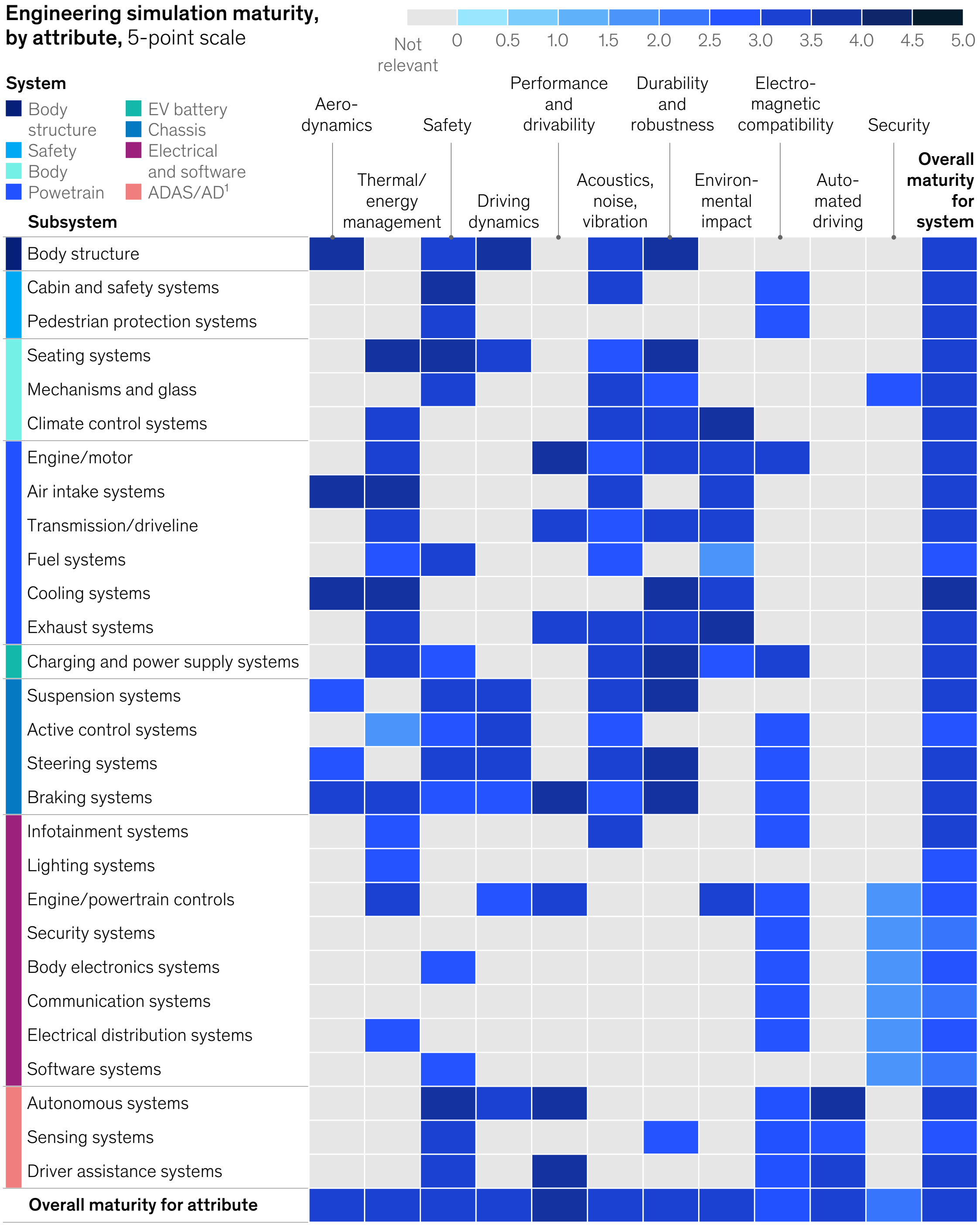
Traditional simulation sets the pace

The average state-of-the-art maturity level for traditional simulation tools across all combinations of systems and performance attributes was 3.2 out of 5.0 (Exhibit 1). However, our analysis revealed significant differences in maturity across vehicle systems and performance requirements. For example, among the most mature were exhaust system environmental impact and body structure system durability attributes, with scores of 4.0 and 3.9, respectively. Among the least mature areas were security aspects of various electrical and electronic control systems, with scores of 2.0.

These differences in relative maturity likely arise from a combination of technological and economic

Exhibit 1

State of engineering simulation maturity averages 3.2 across systems.



[1]Advanced driver assistance systems/automated driving.
Source: NAFEMS and McKinsey Digital simulation maturity assessment survey, automotive version, 2024 (n = 50); industry expert assessment (n = 2 automotive OEMs + 2 simulation solution vendors)

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Methodology

In the first quarter of 2024, we distributed a survey to members of NAFEMS, the international association for the engineering modeling, analysis, and simulation community. The sample group consisted mostly of members working in the automotive industry, including vehicle OEMs, tier-one and tier-two suppliers, and simulation tool and service providers.

Fifty respondents completed the survey. This sample represents a wide range of roles, from engineers to executives, in geographies including Asia–Pacific. Europe, Latin America, and North America. We also conducted face-to-face interviews with five industry experts.

We structured our survey to explore the use and impact of simulation at a granular level. We asked respondents to describe their experiences with simulation for eight major automotive systems, 28 subsystems, and 11 performance attributes. After eliminating irrelevant combinations of subsystems and performance attributes (for example, the climate control system has negligible impact on driving dynamics), we collected data on a matrix of approximately 100 combinations of systems and performance attributes. Our questions focused on vehicle development, not considering the use of simulation in related functions such as manufacturing and assembly processes.

For each combination in the matrix, we asked respondents to rate four attributes:

1. for traditional simulation, the state-of-the-art maturity level within their organization, with best in class defined as "Engineering simulation is used for all aspects of design, optimization, and validation. No physical testing, even for regulatory compliance"

2. the highest level of toolchain automation achieved within their organization, where best in class is defined as "Engineering simulation leverages a fully automated and integrated toolchain across use cases within a PLM system"

3. the relative maturity of AI/ML simulation compared with traditional approaches, where best in class is defined as "Engineering simulation leverages analytical simulation and AI/ML-based simulation on an equal footing and in a closed loop"

4. the business impact of simulation

Respondents rated the first three attributes on a scale of zero to five, comparing their organization's situation with textual descriptions of maturity levels ranging from nothing to best in class for the attribute. For the business impact attribute, we asked respondents to estimate the quantitative impact of simulation on engineering cost, engineering speed, and end product performance.

To inform our analysis of the rate at which the use of simulation is evolving in the automotive sector, we asked respondents to compare their organization's maturity in 2024 with its maturity in 2019. We chose this four-year span to provide a picture of recent progress in the sector while excluding the disruptive impact of the COVID-19 pandemic from respondents' assessments and allowing sufficient time for measurable changes in simulation maturity.

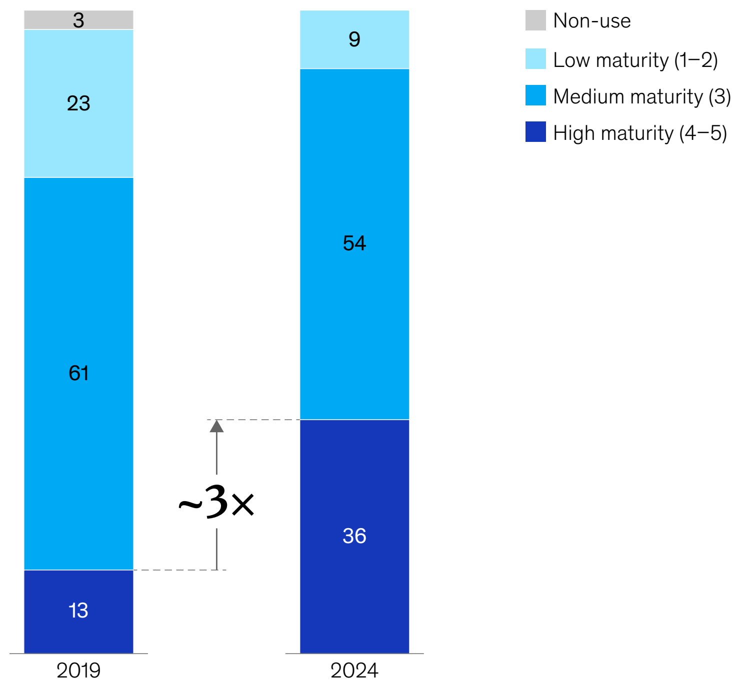
factors. Safety, durability, and performance/drivability attributes have the highest level of maturity across relevant vehicle systems, reflecting the significant attention to these aspects of vehicle design, the availability of robust simulation tools, and the clear cost and speed advantages of simulation over physical testing of prototypes. Notably, respondents identified only mid-ranking levels of simulation maturity as the current state of the art in battery- and software-related systems and performance attributes—two areas that play a dominant role in more recent vehicle developments.

Overall, engineering simulation maturity continues to grow. In 2024, 36 percent of respondents say their organizations achieved a high level of simulation maturity, a threefold increase from 2019. The share of respondents citing low or no maturity as the state of the art in their organizations has decreased from 33 percent to 12 percent over the same period. (Exhibit 2).

Exhibit 2

Between 2019 and 2024, the share of companies with high-maturity classical simulation techniques has tripled.

Level of maturity of classical simulation techniques, % of respondents



Note: Figures may not sum to 100%, because of rounding.
Source: NAFEMS & McKinsey Digital simulation maturity assessment survey, automotive version, 2024 (n = 39)

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AI/ML simulation enters the mainstream

AI and machine learning promise several types of benefits in engineering simulation (see sidebar "The evolution of engineering simulation"). These tools can automate and accelerate simulation model preparation or assist in the interpretation of results. Replacing computationally intensive equation solving with AI inference can speed up simulation runs, sometimes by several orders of magnitude. Reducing the time to complete simulations allows engineering teams to evaluate a wider range of potential designs and identify better solutions. At the forefront of this approach today is the combination of fast AI/ML simulation and generative design systems that iteratively adjust product geometry or other characteristics to produce optimized designs with little or no human input.

AI/ML simulation technologies are newer than their traditional simulation counterparts, so it's not surprising they have yet to reach the same level of adoption. The average relative maturity score across all dimensions was 1.7 on a five-point scale where 5.0 indicates the availability of AI/ML solutions for all simulation use cases within a category (Exhibit 3). The relative maturity of AI/ML simulation also varies widely by system and performance attribute. At the low end, pedestrian protection system safety had an average score of 1.6. At the high end, performance and drivability in autonomous systems scored 4.0, suggesting the approach is available for most simulation use cases.

While the overall maturity of AI/ML simulation is low, its acceleration over the past five years has been dramatic. Nine out of ten respondents say they use AI/ML simulation in some part of their product development activities, compared with less than one in ten in 2019 (Exhibit 4). For

Exhibit 3

State of AI/machine-learning simulation maturity averages 1.7.

[1]Advanced driver assistance systems/automated driving.
Source: NAFEMS and McKinsey Digital simulation maturity assessment survey, automotive version, 2024 (n = 50); industry expert assessment (n = 2 automotive OEMs + 2 simulation solution vendors)

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Evolution of engineering simulation

Engineers have always used mathematical models to make design decisions. Historically, these models were highly simplified representations of real products, used to make the necessary calculations manageable.

As computing power has increased, so has the complexity and fidelity of simulation systems. Classic simulation systems work by breaking down a complex product into simple elements and then solving partial differential equations to determine its likely performance and behavior. Advanced simulation systems can solve equations over tens to hundreds of millions of elements.

Today's traditional engineering simulation tools can address problems in a wide range of engineering domains, including but not limited to finite element analysis (FEA) for structural or thermal performance, multibody systems (MBS) for analysis of mechanisms such as suspension systems, computational fluid dynamics (CFD) for analysis of vehicle aerodynamics, and electromagnetic (EM) simulation to assess the increasingly complex electrical systems in vehicles.

More recently, approaches from other areas of mathematics and computer science have been applied to engineering simulation:

— Machine learning (ML) systems support engineering decision making by applying advanced statistical techniques to extract meaningful insights from complex data.

— Artificial intelligence (AI) systems are abstract models that can be trained to produce desired outcomes based on complex inputs.

These new approaches tend to augment rather than replace traditional simulation approaches. Today's leaders are applying AI/ML to automate simulation model preparation and assist in the interpretation of results. Advanced AI systems can create simplified models that dramatically reduce the computing effort required for highly complex simulations or keep the full complexity of the original simulation output while making high-fidelity predictions of the entire system's performance. Deep learning surrogates, for example, are AI models trained to replicate the results of traditional simulation systems in specific use cases. These systems can cut the time required to complete a complex simulation by a factor of 1,000 or more. They already are helping engineers explore more of the design space and identify better solutions to problems including tire–road interaction, brake duct design, and the cooling of power electronics.

almost a quarter of companies, AI/ML maturity reached at least a medium level, versus less than 3 percent in 2019. This rapid growth in adoption underscores the growing recognition of AI/ML's potential to improve simulation speed and efficiency.

AI diverges

Most AI and ML simulation technologies are extensions of traditional simulation technologies, building on the same underlying models and adapting traditional simulation workflows. This might suggest an evolutionary path in which AI/ML adoption follows the use of traditional simulation, with the highest maturity in areas where simulation is already established.

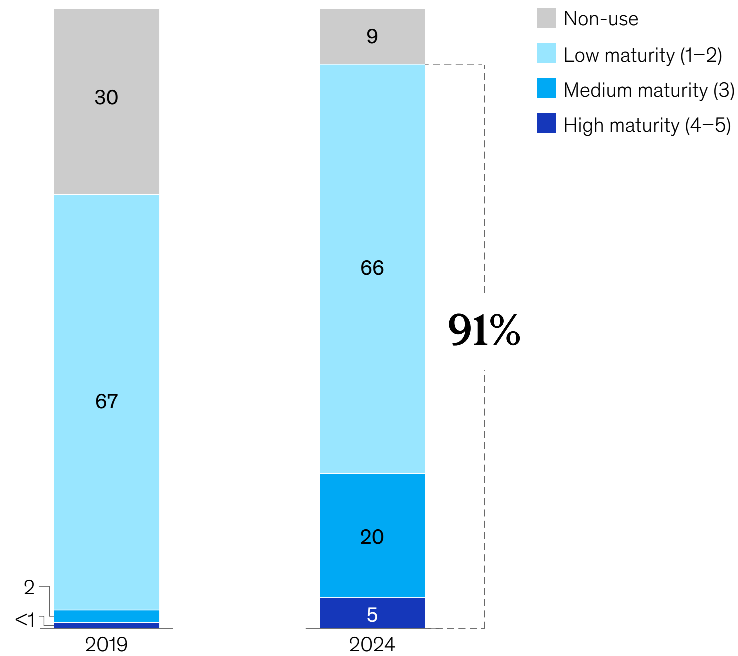
However, our research shows that this correlation between the relative maturity of AI/ML and traditional approaches is not always present. For example, aerodynamics has the highest level of AI/ML maturity but is in the middle of the pack for traditional simulation. Conversely, environmental impact attributes had some of the highest overall maturity scores for traditional simulation but some of the lowest for AI/ML.

This divergence is likely caused by a combination of factors. First, current AI- and machine-learning-based approaches may offer a clearer value proposition for problems where traditional simulations are computationally intensive and costly to run. Aerodynamic studies would fall

Exhibit 4

Nine out of ten organizations are already adopting AI/ML-based simulation techniques.

Level of maturity of AI/machine learning–based simulation techniques, % of respondents



Note: Figures may not sum to 100%, because of rounding.
Source: NAFEMS & McKinsey Digital simulation maturity assessment survey, automotive version, 2024 (n = 39)

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into this category, as would active safety and advanced driver assistance systems (ADAS), which need to be tested against diverse and complex input data. Conversely, where users perceive that traditional simulation approaches already meet their needs, they may not be convinced that AI/ML tools offer useful performance, cost, or speed advantages.

Tool chain automation—important but not essential

Simulation is not a stand-alone process within product development. Simulation tools draw data about product geometry, materials, and operating conditions from the company's product data management (PDM) system and other digital repositories. Simulation results must be delivered to engineering teams in the right format to support subsequent design decisions.

The exchange of data between simulation and other digital engineering systems such as product lifecycle management (PLM) can be a source of friction in the design process. Translating, cleaning, and manually annotating data to enable transfer from one system to another is time-consuming and error prone. High-maturity organizations seek to automate this activity wherever possible by creating toolchains that seamlessly integrate simulation into the broader product development workflow.

Our survey suggests that automotive companies have made significant progress in this area over the past five years. In 2019, only 20 percent of respondents gave their toolchain automation maturity a score of 3.0 or above. By 2024, that figure had risen to 50 percent.

Users should be cautious about fixating on their toolchains, however. While our survey found a correlation between toolchain automation and overall engineering simulation maturity, toolchain automation maturity varied widely among companies at each level (Exhibit 5). Several respondents achieved the highest level of simulation maturity despite toolchain automation scores in the middle of the pack, leading us to conclude that a toolchain automation score of 3.0 or higher is sufficient to achieve best-in-class improvements in time to market.

Business impact: Simulation pays

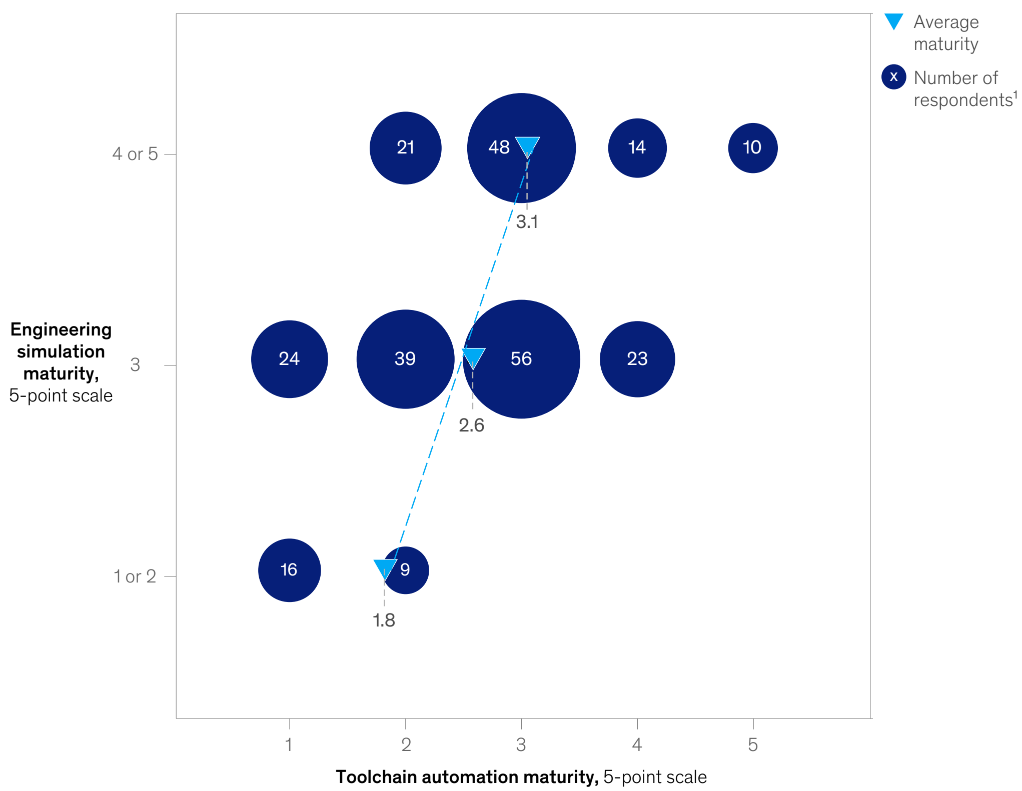
Product development teams are using engineering simulation to build better products faster and at lower cost. Our research suggests that most users are achieving these goals.

We asked respondents to quantify the business impact of simulation in their organizations across three key dimensions: product performance,

Exhibit 5

Tool chain automation maturity is loosely correlated with overall simulation maturity but varies widely among companies at each level.

Toolchain automation maturity vs engineering simulation maturity



[1]For subsystem–performance attribute combinations with at least 5 data points.
Source: NAFEMS & McKinsey Digital simulation maturity assessment survey, automotive version, 2024 (n = 50)

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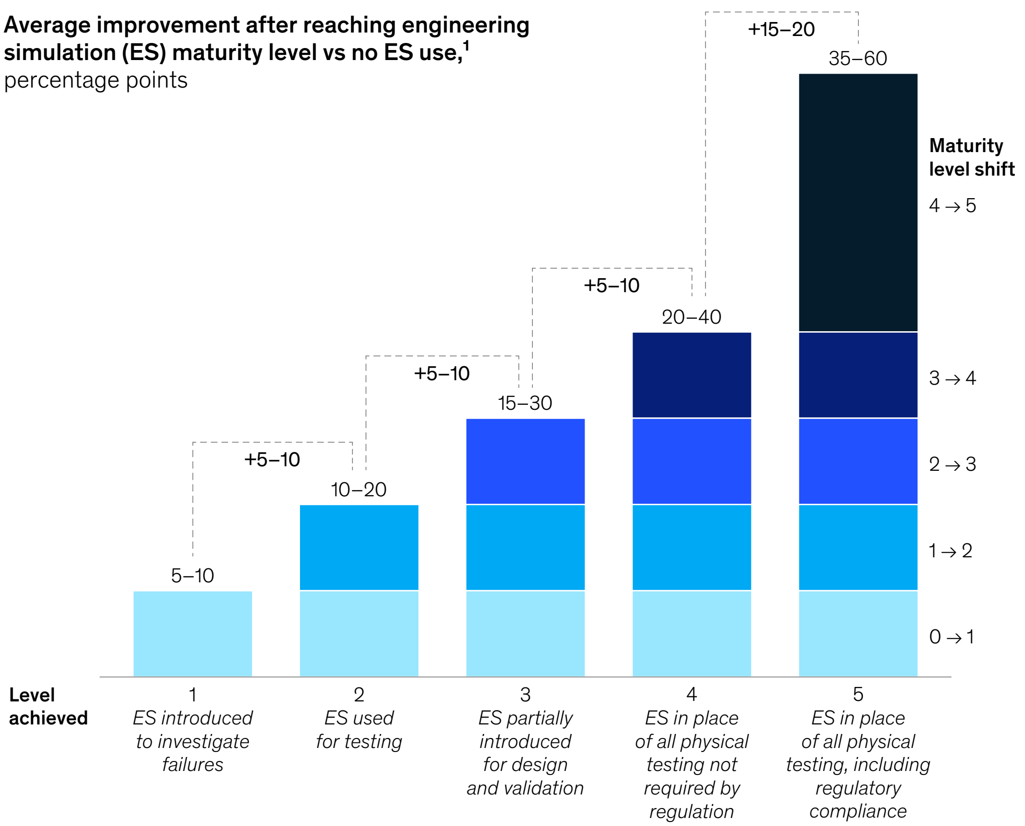
development cost, and development speed. The reported business benefits are broadly similar across these three dimensions, and they are closely correlated with the respondents' overall engineering simulation maturity scores, up to a point. For low- and medium-maturity organizations, an increase of one point on our five-point simulation maturity scale was associated with a five- to ten-percentage-point increase in business impact (Exhibit 6). However, at the highest maturity level (level 5), we saw a significant jump, with organizations reporting business impact 15 to 20 percentage points higher than for their level 4 counterparts.

This finding suggests that an ambitious approach to simulation is paying off for leading automotive companies. Simulation provides real value whenever it is introduced, but companies that build their end-to-end product development processes around digitization, virtualization, and simulation are pulling away from those that take a more fragmented approach.

Exhibit 6

As engineering simulation maturity increases, the business impact becomes substantial.

Average improvement after reaching engineering simulation (ES) maturity level vs no ES use,[1]
percentage points



[1]Business impact is measured through comparison of 3 dimensions (product design cost, product performance, and product design speed) currently vs 5 years ago and rated by its improvement in % intervals: <1%; 1–5%; 5–10%; 10–15%; 15–20%; >20% improvement.
Source: NAFEMS & McKinsey Digital simulation maturity assessment survey, automotive version, 2024 (n = 39)

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The barriers are human

Automotive companies striving to increase their simulation maturity face broadly the same barriers as other industries do. When we asked respondents to select the most significant barriers to the adoption of simulation, their responses followed the same pattern as last year's cross-industry survey.

Fifteen percent of respondents say available simulation tools are not accurate enough to model the phenomena they are concerned about. Twice as many (30 percent) identify a lack of trust in simulation results across the product development organization as a significant issue (Exhibit 7). Other issues highlighted by respondents involve workload and staffing challenges. One-fifth of respondents cite a lack of toolchain automation as a major barrier, and the same share cite a shortage of skilled simulation engineers.

Takeaways

Our high-resolution snapshot of the automotive industry shows that engineering simulation is thriving. Companies are applying simulation to more problems, using simulation tools across more of the product development life cycle, and adopting more advanced simulation tools. In return for their efforts, automotive companies are seeing real improvements in product performance, cost, and development speed, with outsize benefits accruing to those with the most advanced simulation ecosystems.

Zoom in, and the picture becomes more nuanced. Significant differences in simulation maturity exist across vehicle systems and performance attributes. Areas that lag in the simulation revolution could ultimately become bottlenecks, limiting the rate of improvement in the overall product development process.

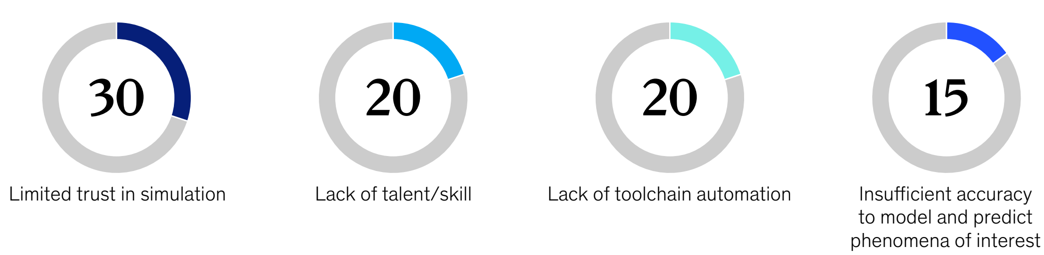
Closing these gaps will require effort from simulation system vendors, which have opportunities to develop more tailored offerings to address emerging demand in key areas such as electric powertrains and advanced electronic systems. End users, meanwhile, can use these findings to benchmark their own simulation practices against the current state of the art.

For some companies, this could also be the moment for a strategic shift. Islands of simulation can evolve organically to address the needs of

Exhibit 7

Insufficient talent and trust stand in the way of greater adoption of simulation.

Barriers at respondents' companies,[1] % of respondents



[1]Respondents were asked to choose the top 3 from a set of possible barriers.
Source: NAFEMS & McKinsey Digital simulation maturity assessment survey, automotive version, 2024 (n = 50)

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individual functions and specific engineering problems. A truly end-to-end simulation-based product development process, by contrast, demands centralized governance and coordination. Leading organizations are already taking a more holistic approach to simulation, often by establishing a center of excellence or similar function to develop technology and data standards, along with best practices for simulation-based workflows and data quality assurance.

A central function can also steer the development of simulation capabilities by understanding the relative maturity of simulation activities across different product development functions, identifying opportunities to capture more value, and launching initiatives to capture those opportunities. It can also help companies meet their talent needs through targeted recruitment and capability-building efforts with an emphasis on the development of a simulation workforce with the skills to bridge the gap between traditional and AI/ML simulation approaches.

To enable successful adoption and scaling of AI/ML-based simulation, organizations should focus on a strategic and integrated approach that aligns with both business priorities and technical feasibility. Rigorous prioritization is essential and should be grounded in a realistic understanding of the current state of AI/ML technologies as explored in this article. Developing a clear North Star vision with well-defined financial targets is critical for gaining alignment from business leaders. These targets should cascade into specific goals for engineering functions, incorporated into annual budget processes with a mix of impact metrics (such as cost savings) and progress metrics (such as adoption rates). Emphasis on change management including comprehensive upskilling initiatives, transparent communication, and showcasing lighthouses to build momentum will amplify success. Additionally, ensuring that foundational enablers like robust data management practices are in place will help streamline integration and maximize impact.

Our analysis of engineering simulation, toolchain automation, and AI/ML maturity in the automotive industry highlights the rapid progress made between 2019 and 2024 and the significant business impact achieved. The increasing maturity of these digital tools is clearly worthwhile, offering gains in cost, speed, and product performance. Given the current state of the automotive industry—marked by seismic shifts such as electrification, software-defined vehicles (SDVs), and intensifying cost pressures—it is more crucial than ever to harness the full potential of digital tools. The insights gained from the survey data not only can guide the automotive sector in advancing the impact of traditional and AI/ML-based simulation techniques in a targeted way. These insights also can be relevant for industries such as aerospace and defense, electronics, and medtech.

Jan Paul Stein is a partner in McKinsey's Munich office, **Alessandro Faure Ragani** is a senior expert in the Milan office, **Joe Walsh** is the founder of the NAFEMS ASSESS initiative, and **Roger Keene** is the chair of the NAFEMS ASSESS Business Theme Committee.

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