Tech-Clarity Perspective:

How Top Auto Companies Realize Innovation and Manage Complexity

Digitalization Drives Innovation and Program Performance in the Automotive Industry

Table of Contents

Executive Overview

The global automotive and transportation industry is experiencing a tremendous rejuvenation. The market is alive and sales and profits are growing. Within the last few years, automotive manufacturing has entered an age of innovation and witnessed unprecedented introduction of new models and advanced technologies to meet the challenge of doubling fuel economy and halving emissions.

In parallel with the booming auto market is a growing level of product development complexity. This increased complexity results from a variety of factors ranging from advanced materials for vehicle lightweighting to the increased role of software in product innovation and product performance. Some like to say today's cars are like computers driving around on wheels with over tens of million lines of code – but that's a huge understatement. Today's automobiles are an intricate orchestration of mechanical, sensors, controls, and software and are increasingly interacting with other vehicles and their surroundings. The resulting complexity is immense.

Top-performing automotive companies are going beyond today's best practices in manufacturing and leveraging digitalization to realize innovation.

How is the industry responding? Tech-Clarity analyzed survey data and reviewed automotive executive presentations to determine how automakers and suppliers address complexity and take advantage of the industry renaissance. We found that top-performing companies are going beyond today's best practices in manufacturing and leveraging digitalization to realize innovation. These companies have transformed their vehicle development processes to take greater advantage of digital product models and simulation, leading to growth and profitability.

Specifically, our research shows that Top Performers in the automotive industry are:

- Continuing their lead in collaboration and concurrent design
- Expanding their use of digital product models to optimize products early in design and better validate mechanical, electrical, and software systems
- Expanding their ability to synchronize and integrate design and manufacturing

To support these initiatives, Top Performers are leveraging digitalization to:

- Use more integrated, holistic PLM capabilities that allow early, model-driven systems optimization
- Integrate systems across the lifecycle to align and share design data from concept through production

Key Strategic Plans of the Auto Companies

A brief review of automotive strategies shows a continuing trend to compete and produce globally. This is characterized by companies aiming to launch new models on a global scale while accounting for local market requirements and preferences (Figure 1). In addition, the automotive industry is adopting higher levels of customization and embracing more variability in product configurations, enabled by flexible manufacturing capabilities that can rapidly accommodate change.

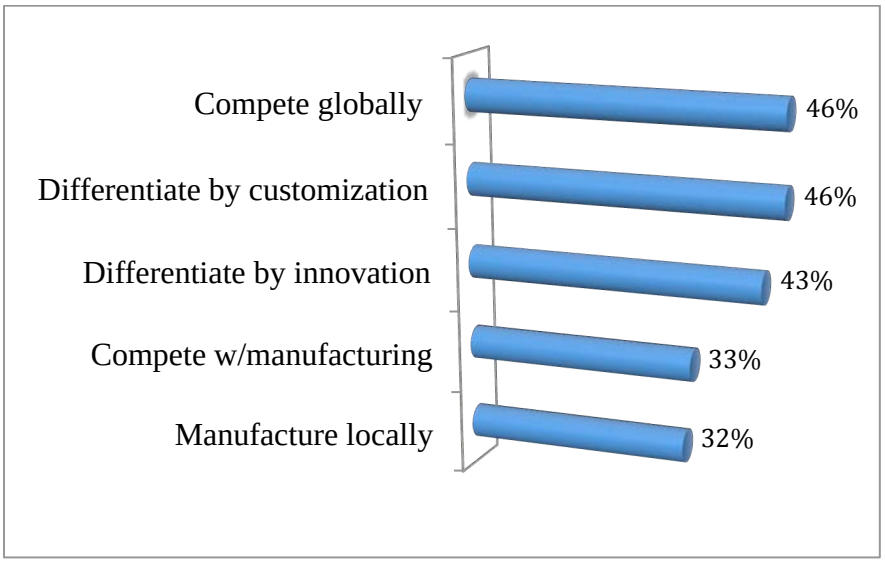

Figure 1: Strategic Initiatives in the Auto Industry

In addition, automotive and transportation companies plan to compete through innovation. This innovation comes in many forms including new materials and "smarter" vehicles. Innovation is also leading to an unprecedented number of models being introduced to the market. OEMs plan to introduce more new models to the market faster than ever before. For example, Nissan's "Power 88" plans (announced by Nissan in 2011) calls on them to deliver, on average, an all-new vehicle every six weeks for the next six years.

OEMs plan to introduce more new models to the market faster than ever before.

The global scale and speed of new product introduction touches many automakers' strategic plans. Some OEMs already have over 30 vehicle derivatives with more on the way. Volumes are also expanding, with some planning to double production by 2020. That represents significant complexity. These strategies place tremendous product design and development demands on automotive OEMs and the supply chain.

The Automotive Industry Faces Significant Complexity

Increasing complexity is a trend seen across the manufacturing industries. Tech-Clarity's The Five Dimensions of Product Complexity finds that "*the job of developing and delivering profitable products is more difficult*." Rising global production and faster model introductions are further challenging an already complex automotive product design and development environment.

Rising global production and faster model introductions are further challenging an already complex automotive product design and development environment.

The report shares various ways that complexity is expanding in product design and development, including:

- Increased mechanical complexity with mixed materials for lightweighting and substantially more models from base architectures
- Greater electrical and software complexity, such as smarter, more connected vehicles, infotainment, and software-driven product features and options

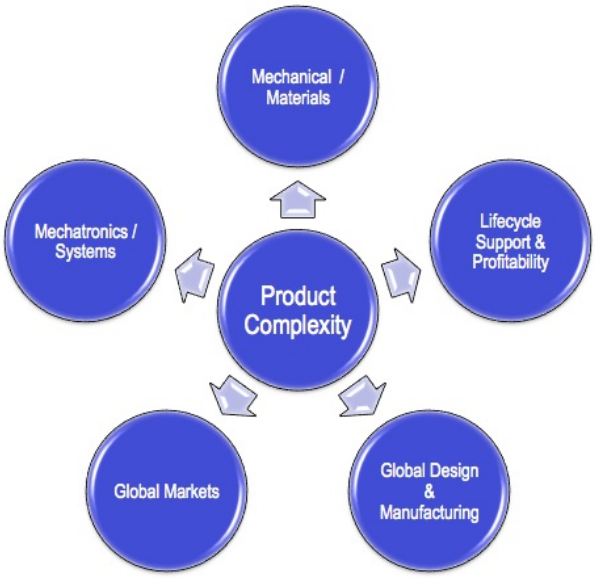

Figure 2: Product Complexity Framework

The report also shares that the business of manufacturing is also more complex due to:

- Globalization, including global markets, more stringent regulation, and worldwide design and production

For example, some automakers build tens of thousands of cars a day in more than 100 factories. This makes worldwide development and production a challenge. Today's OEMs may have more than five times as many facilities than they did a decade ago.

The transition to intelligent, interconnected vehicles … is forcing automakers to adopt a more systems-oriented view of product development.

The automotive industry has to deal with all of these challenges, with no reversal in sight. But perhaps the most challenging aspect of all is the transition to intelligent, interconnected vehicles that exist in a "system of systems" environment that includes C2C (car to car) and C2X (car to everything) interaction. This is forcing automakers to adopt a more systems-oriented view of product development.

Today's vehicles demand early attention to product architecture.

Today's vehicles demand early attention to product architecture. Otherwise, these interconnected systems can suffer from integration issues because a change in one area can ripple through others in unexpected ways.

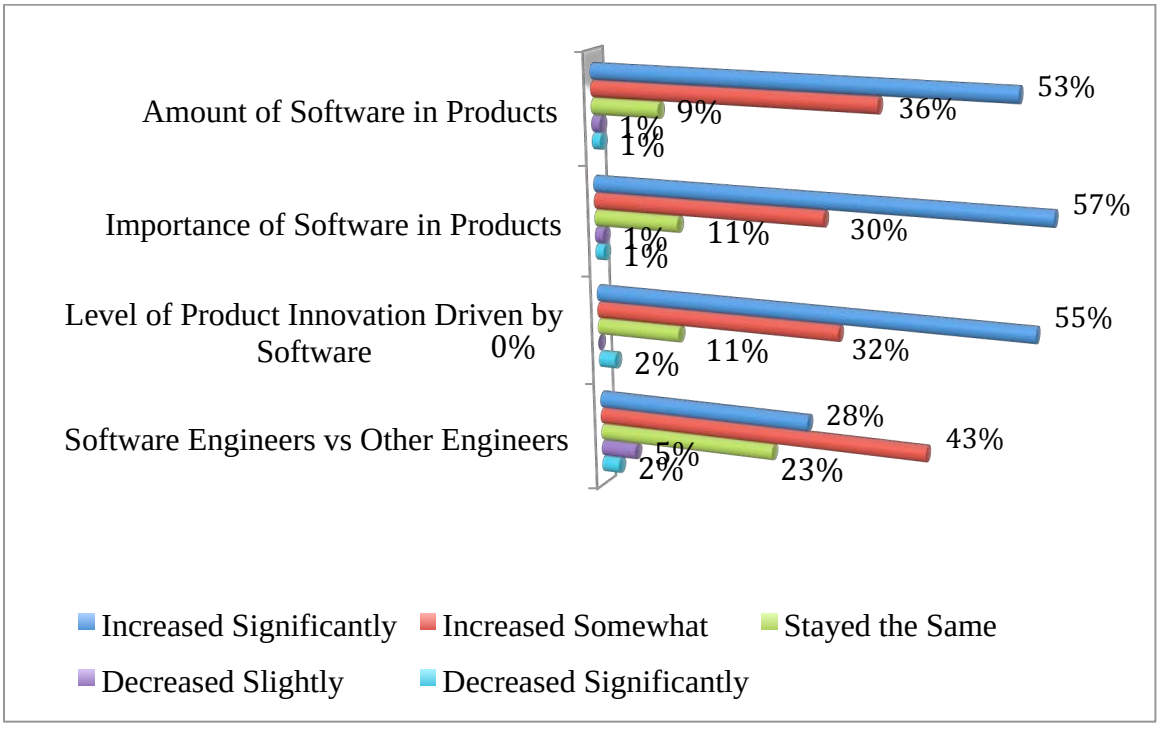

Figure 3: Change in Product Software over 5 Years

Mechatronic complexity in the automotive design will continue to increase and there is no foreseeable reversal in sight. In fact, Tech-Clarity's Developing Software-Intensive Products finds that manufacturers plan to significantly expand the amount of software in their products over the five-year period from 2013 to 2017. The study also finds, perhaps more significantly, that manufacturers are not only increasing the *amount* of software in products but the *level of product innovation* driven by software and it's importance (Figure 3).

Manufacturers are not only increasing the amount of software in products but the level of product innovation driven by software and it's importance.

The automotive industry also faces significant regulation including sustainability demands that drive significant product redesigns for light-weighting, fuel efficiency, and alternate drive trains. This furthers complexity and leads to more reliance on systems-level optimization.

The automotive industry faces significant regulation including sustainability demands that drive significant product redesigns for light-weighting, fuel efficiency, and alternate drive trains.

Due to this complexity, automotive companies report a number of significant product design and development challenges (Figure 4). Not surprisingly the most common challenge is meeting delivery schedules given the aggressive introduction of new vehicles. But automakers also suffer from challenges including sharing information and managing change. Globalization and increased supplier involvement makes it more difficult for everyone to be on the same page, particularly for engineering changes.

Today's customers are simply not willing to accept price increases so automakers must contain costs as cars become more complex.

Despite these challenges, automotive OEMs and the supply chain have to continue to improve performance. Today's customers are simply not willing to accept price increases so automakers must contain costs as cars become more complex.

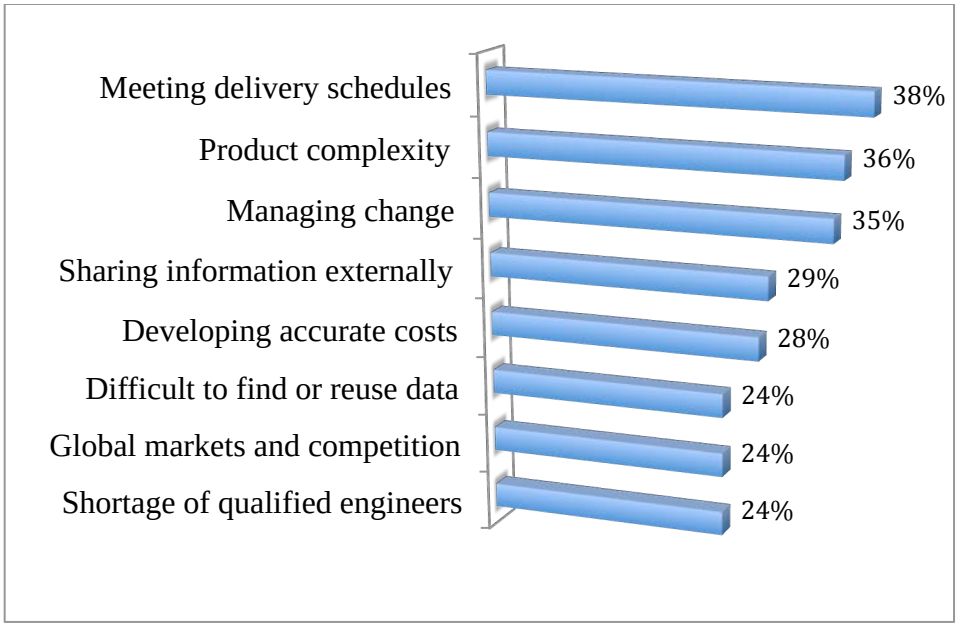

Figure 4: Engineering and Design Challenges in the Auto Industry

Identifying the Top Performers

Given the need to manage complexity and simultaneously control cost, product design and development performance must improve beyond the already high levels found in the automotive industry. To determine who is performing at this level and how they achieve their advanced levels of success, Tech-Clarity collected data from manufacturers on their strategies, challenges, processes, and technology.

Our researchers analyzed self-assessments for how automotive companies and suppliers performed in two metrics compared to their competitors:

- Revenue growth over the prior 24 months
- Margin growth over the prior 24 months

Not only are top performing automotive companies adopting best manufacturing practices, they are taking them to the next level.

These metrics reflect the end result of effective product innovation and product development – products that sell and products with optimized cost to drive margins. We selected the top 17% of the respondents and labeled them as "Top Performers." Then, we analyzed what these companies do differently in order to make recommendations to other companies. The data shows a number of differentiated processes and technologies, detailed in the following sections. One of the most interesting observations is that not

only are top performing automotive companies adopting best manufacturing practices, they are taking them to the next level.

Collaborate / Design Concurrently between OEMs and Suppliers

The research shows that the Top Performers adopt different product design and development practices. One of these is the adoption of more collaborative design processes. Top Performers work more closely with the supply chain and production to innovate at a fundamental level and ensure rapid production ramp. Even competitors are teaming up to research new technologies like alternate powertrains and batteries. This requires a much more collaborative approach to design.

Top Performers work more closely with the supply chain and production to innovate at a fundamental level and ensure rapid production ramp.

Automakers are very reliant on their supplier bases for individual parts, but also for knowledge, development, and experience. Suppliers are very involved from conceptual development all the way through production. Even internal organizations are more dispersed and virtual than before.

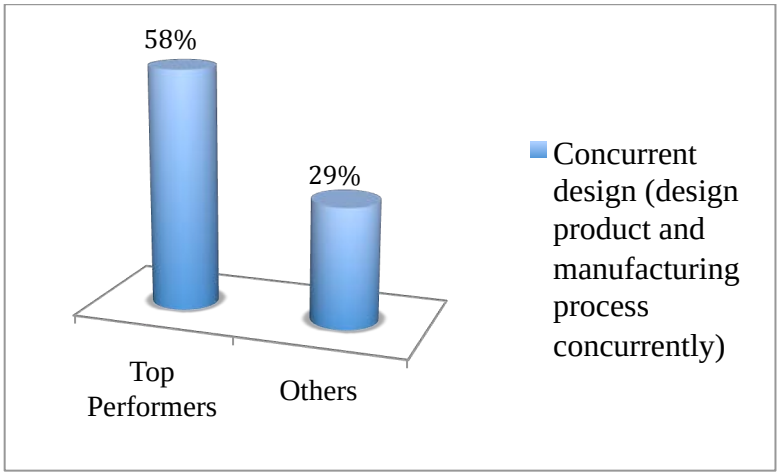

Figure 5: Automotive Use of Concurrent Design Processes

OEMs are integrating suppliers into their processes starting with early schedules down to the details.

Another difference is that Top Performers are twice as likely to practice concurrent design (Figure 5). Leading companies share models from early conceptual / systems design with extended internal and external teams. This allows downstream departments to provide early feedback on manufacturability and cost. OEMs are integrating suppliers

into their processes starting with early schedules down to production details. That helps prevent errors and compress timelines by getting downstream parties such as manufacturing designing processes, plants, and tooling early in the product lifecycle. The practices can help drive better products, optimize cost, and reduce product development risk and delays.

Adopt Next Level Simulation / Optimization

The research also shows that Top Performers are more likely to optimize products and their performance characteristics early. Specifically, Top Performers are 39% more likely to optimize products early in the design phase (Figure 6). Automakers are moving capacity and resources upfront so they don't face late changes.

Top Performers are 39% more likely to optimize products early in the design phase.

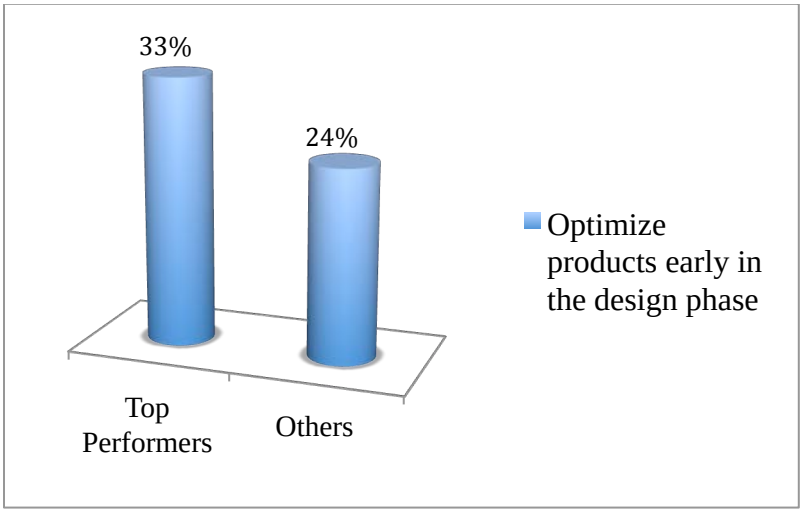

Figure 6: Automotive Use of Optimization Early in Design

This approach to front load design decisions and "shift left" is a good strategy to address complexity. For example, focusing on noise and vibration can help mitigate unintended consequences caused by lightweighting. Optimization helps get products right while they are still flexible, before design decisions are locked in (Figure 7).

The automotive industry is going well beyond part optimization and clash detection to model-driven optimization at a systems level to model behavior and driving experience early in design.

The automotive industry has embraced simulation as a key enabler and is taking it to the next level. They are going well beyond part optimization and clash detection to model-driven optimization at a systems level to model behavior and driving experience early in design. Automotive engineers use models of various types, such as 1D, 3D models, and simulations, but when dealing with controls even that is not sufficient.

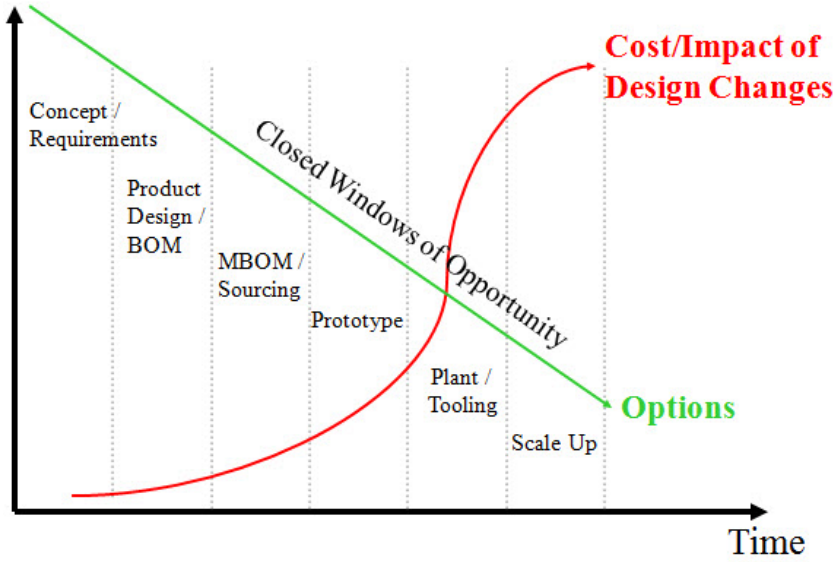

Figure 7: Open Windows of Design Flexibility

The automotive industry is also going beyond the use of simulation in design to a more holistic approach encompassing models defining requirements, functional, and design characteristics to actual operating conditions. Some automakers model across different stages of development starting from customer needs to the through validation and checking. It's important to connect physics / multiphysics to software.

Leading companies are using test results to refine models and increase confidence in predicted product performance and behavior, effectively closing the loop on simulation to gain better insights early in design.

One of the most exciting advancements is the adoption of model in the loop, software in the loop, and hardware in the loop to test real performance as deliverables transition from virtual to real. Model-in the loop can be used to test software connected to the physical model. Then, when the physical device is available you can introduce hardware in the loop to test and verify the system in a virtual environment. Leading companies are using

test results to refine models and increase confidence in predicted product performance and behavior, effectively closing the loop on simulation to gain better insights early in design.

Transform to Next Level Manufacturing Planning

As seen earlier in Figure 1, many in the automotive industry plan to increase agility in the plant. This requires collaboration and concurrent design, noted Top Performer strengths (Figure 3). Modularity in the plant is a very good approach to increase agility. Modularization allows automakers to build very different cars in the same plant. Another way to combat complexity in production is through increased automation and a move toward higher levels of intelligence and connectivity between equipment.

Leading companies are also using much more integrated views of product and production.

Leading companies are also using much more integrated views of product and production (see use of MPM technologies in next section). This includes a more connected view of the vehicle throughout the lifecycle including reuse and expansion of product models downstream through manufacturing planning to the shop floor, tool design, and CNC instructions.

Enabling Technology

Top Performers support their differentiated processes with the right technology. Ideally, this is a suite of next generation Product Lifecycle Management (PLM) tools that helps develop today's innovative intelligent and connected products. PLM is a solution that works with all disciplines starting with the concept design phase and spanning to manufacturing for tooling, manufacturing planning, and manufacturing engineering.

But let's start with the basics, and look at the current landscape of engineering tools that are prevalent in the automotive industry. It's not surprising that some of the most common technology used in automotive design is CAD (Figure 8). The shift to 3D is a pervasive change in the auto industry due to proven benefits including getting products right up front, sharing information directly with downstream functions, and more. It's also no surprise to see they are using spreadsheets and internally developed systems, that is simply today's reality.

There are some important differences in the technologies that Top Performers use compared to other companies.

But there are some important differences in the technologies that Top Performers use compared to other companies. Two items that are highly differentiated (if not the most commonly used) are:

- Simulation
- Manufacturing Process Management (MPM)

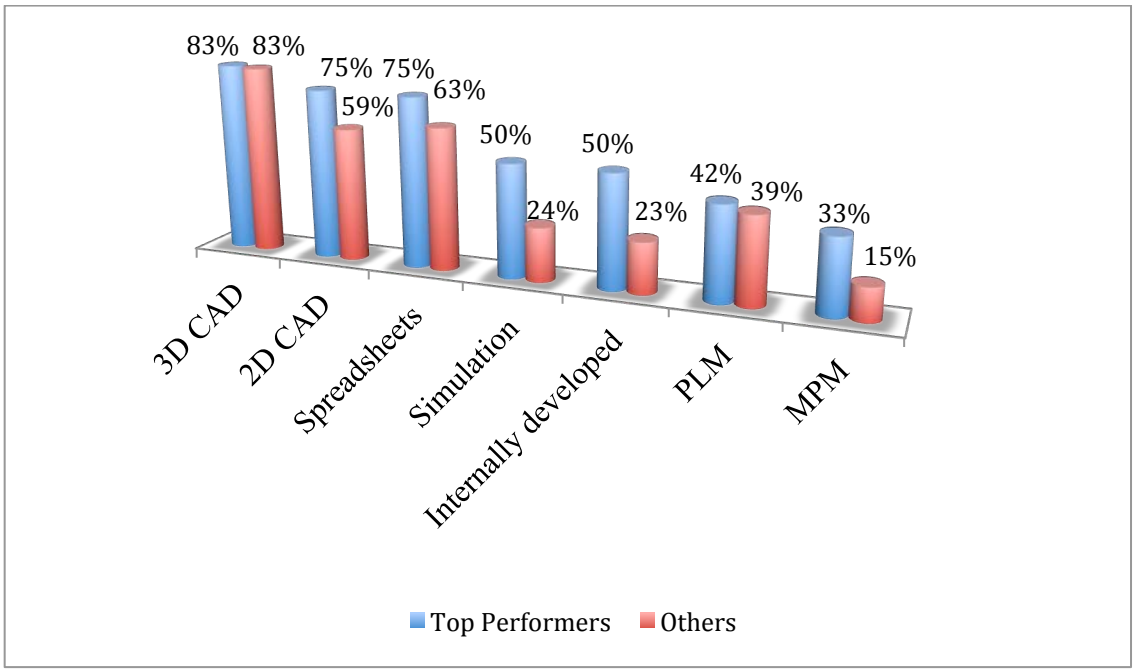

Figure 8: Design / Development Technology in the Automotive Industry

Simulation technology is used more than twice as frequently by Top Performers in the automotive industry. As discussed earlier, it helps them validate products early and optimize designs, which helps with initiatives like lightweighting and other approaches to improve fuel efficiency. While part and assembly simulation tools are becoming more standard in the manufacturing industries, the leaders are simulating at the systems level in the context of their entire vehicle architecture. This approach allows them to configure a digitized model of their product and validate its design, performance, and production requirements.

Leaders are simulating at the systems level in the context of their entire vehicle architecture.

MPM, although it is still only reported in about 1/3 of Top Performers, is used by over two times more of the Top Performers than the lesser performing companies. This helps

them design concurrently and ensure that manufacturing processes are well defined and aligned with the product. It allows them to optimize production processes early so they can eliminate errors before they occur and ramp up production very rapidly. Digital product and plant models allow manufacturing engineers to evaluate multiple models and variants on a single production line and validate processes across global manufacturing sites. Models can incorporate robotics, human ergonomics, and logistics planning early in the planning stages and prevent in-production stoppages.

MPM is used by over two times more of the Top Performers than in the lesser performing companies.

Not surprisingly, PLM is part of the list of technologies utilized. While PLM use doesn't appear to directly differentiate the Top Performers, the definition and implementation of PLM can vary. Tech-Clarity observes leading manufacturers are able to get more out of their PLM systems by taking a much more holistic, integrated approach.

Conclusion

The automotive and transportation industry is in a growth cycle. Volumes and profitability are strong for most in the industry. But the auto industry is facing unprecedented complexity due to growth, aggressive introduction of new models, regulatory pressure to improve fuel economy and safety, and increasingly intelligent / connected vehicles. They are also exploring and adopting innovations ranging from new drive trains and materials to new manufacturing processes including additive manufacturing.

Leading OEMs and their supply chains are actively addressing complexity through increased digitalization of their innovation process.

Leading OEMs and their supply chains are actively addressing complexity through increased digitalization of their innovation process. Survey findings and presentation reviews uncover a few significant trends. Top Performers in the automotive industry leverage digitalization to collaborate more, design more concurrently, take simulation to the next level, and integrate manufacturing planning with design.

Top Performers in the automotive industry leverage digitalization to collaborate more, design more concurrently, take simulation to the next level, and integrate manufacturing planning with design.

Top Performers support their advanced practices and performance with leading technology approaches. In addition to PLM, they are much more likely to use simulation

and MPM technologies. Leaders are taking simulation beyond best practices to the next level. They are incorporating advanced techniques like model/software/hardware-in-the-loop to validate system behavior, and using test results to "close the loop" on simulations and improve their ability to predict vehicle behavior early in design.

Recommendations

Based on industry experience and research for this report, Tech-Clarity offers the following recommendations:

- Recognize and address increased automotive industry complexity. Vehicles and the business of developing and producing them has become much more complex.
- Adopt best practices and technology for concurrent design and collaboration to support globally dispersed production and supply chain activities.
- Adopt (and go beyond) best practices in critical areas like simulation, expanding them to a systems level and adopting new approaches including model/software/hardware in the loop that allow better understanding and validation of systems behavior early and throughout design.
- Enhance manufacturing connectivity, leveraging digitalization to model products, predict their behavior, and streamline their production. Use MPM to plan production for multiple variants across lines and ramp up production faster and with fewer errors.
- Support best practices with enabling technologies including a more holistic, systems-driven approach to product development that leverages digitalization to improve collaboration, simulation, and MPM. Look for modular, integrated solutions that support digital product models starting at early concepts that can be expanded upon and detailed out during design, encouraging reuse and eliminating inefficient and error-prone handoffs and recreation of data.

About the Research

For this report, Tech-Clarity analyzed responses from a 2012 web-based survey, filtering the responses to focus only on those that serve the automotive industry. In addition, researchers attended 2014 conference presentations where leaders from a number of automotive groups shared their strategies, approaches, and enabling technology.