Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139 USA
tel. +1 617 875 9598
fax +1 617 812 2443
www.oraresearch.com

Strengthening Simulation's Business Impact: New Strategies in the Automotive Industry

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By Bruce Jenkins, Principal Analyst, Ora Research LLC

Executive Summary

The world's best auto makers rely on digital simulation and analysis to deliver green, fuel-efficient, high-performing, high-quality vehicles faster and at lower cost than ever before. Nevertheless, these companies still experience program-gating constraints on getting the value they need from these technologies and the work processes that employ them. What are they doing about it? To find out, we interviewed experts at industry leaders around the world. We investigated business drivers for investing in simulation, current state of industry practice, chief constraints on maximizing simulation's value, and new strategies for overcoming these constraints.

This report summarizes our findings:

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P.O. Box 391227
Cambridge, MA 02139 USA
tel. +1 617 875 9598
fax +1 617 812 2443
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This report offers a practical, action-oriented analysis of new directions and emerging best practices for getting more value than ever before from digital simulation and analysis. Program managers, discipline leads and practitioners will find first-hand advice and lessons of experience for planning new and ongoing investments in simulation technology, and for managing these tools to exploit their organizations' simulation competencies to the fullest.

Digital Simulation and Analysis Investments: Business Drivers

What business goals are best-practice leaders seeking through more effective use of simulation and analysis? Increasingly central in today's environment is compliance with both regulatory mandates and consumer preferences for greener, more sustainable vehicles – key elements include more fuel-efficient, lower-emission powertrains; alternate-fuel engines; lighter-weight and more aerodynamically efficient vehicles; fabrication from recyclable materials, and more.

Sustainable mobility: It starts with fuel efficiency and emissions reduction

Hybrid and electric powertrains are key elements of the solution. Michael Abelson, Executive Director of Global Advanced Vehicle Development at General Motors, described to attendees at the *Automotive News* Green Car Conference[1] in November 2008 how GM plans to meet the business imperatives to improve fuel economy and reduce emissions, while moving to reduce and ultimately displace dependence on petroleum-based energy sources – "energy security" is the policy objective. The pathway he sketched begins with improvements to conventional internal-combustion engines and transmissions, moves through development of hybrid and plug-in electric vehicles, to extended-range electric cars, and ultimately to vehicles powered by hydrogen fuel cells.

Likewise at other car makers. This is how Josephine Cooper, Group Vice President for Public Policy & Government/Industry Affairs, Toyota Motor North America, put it for attendees at the Center for Automotive Research's Management Briefing Seminars[2] in August 2009:

> *"At Toyota, our top public policy priority is sustainable mobility. This means making vehicles that meet customer needs and expectations, while also being safe, sustainable, and better for the environment. We take a system approach to sustainable mobility, with four basic components. The first part involves our vehicles and the vast array of emerging automotive technologies. We must reduce CO2 and smog-forming emissions through pursuit of diverse and alternate technologies. The second component is the energy required to power these products. What sources and forms of energy will be sustainably available in the future? Which of these can be scaled up to accommodate hundreds of thousands, or possibly millions, of vehicles? Can we contribute to energy security? The third component is partnerships… The issues we all face – auto manufacturers, cities, states and countries – are so great that solutions require partnerships across many different sectors… Finally, our approach considers tomorrow's urban environment. For example, we know urbanization is increasing globally. This year, the United Nations*

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[1] *Automotive News* Green Car Conference/Exhibition, Novi, MI, November 13, 2008. http://www.autonews.com/Assets/html/08_angc/

[2] Center for Automotive Research Management Briefing Seminars, Traverse City, MI, August 4-7, 2009. http://mbs.cargroup.org/

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reported that half the planet's citizens now live in cities, for the first time in history. We need to address this trend with new kinds of vehicles. At the same time, we must localize production and ensure our business decisions result in sustainable communities in which our products contribute to improving people's lives." – Josephine Cooper, Group Vice President for Public Policy & Government/Industry Affairs, Toyota Motor North America

Systems complexity: Mechatronics However, all this brings a set of significant new development challenges:

"The name of the game in hybrid systems is integration. You can't make an engine and a transmission separately any more and then integrate them at the last minute. This has to be conceptualized as a family – as a system. If the system isn't conceptualized well, your end product's not going to work very well." – Kent Helfrich, Director of Software Engineering, General Motors Powertrain[3]

Hybrid powertrain and electric powertrain control systems, as well as the many other mechatronic systems being introduced or extended in new auto models to improve driver experience as well as vehicle performance and efficiency – drive-by-wire, automatic stability control, intelligent braking, active all-wheel drive – require new levels of coordination between design of hardware, electrical and electronic subsystems, and software control systems. Critical to answering these challenges is to move from slow, disjointed, sequentially bound physical prototype-based development processes to those grounded in digital simulation and functional modeling. Describing development of the hybrid powertrain control system launched in 2008 on the GMC Yukon and Chevrolet Tahoe SUVs, GM's Helfrich says:

"I don't think you could do a hybrid control system without model-based design and development…That really allowed engineers to do what they needed to do to ensure that the system actually worked, prior to even having hardware available." – Helfrich, GM Powertrain

The benefits? Lowering development costs and cutting weeks from control-systems development schedules, as well as reducing cycle time on design changes without sacrificing quality:

"We can now do those iterations virtually, and then commit ourselves to hardware later in the design center. It saved us a lot of money in terms of eliminated [physical] prototypes and rework." – Helfrich, GM Powertrain

Vehicle-level optimization and integration are the key pathways to improved fuel economy, GM's Ableson notes. The challenges include improving vehicle aerodynamics, reducing weight and achieving mass efficiency in every component and system, minimizing tire rolling resistance while meeting vehicle dynamics requirements, designing high-efficiency and low-loss electrical systems optimized for battery charging, and optimizing the control systems governing all these.

"Segment-leading fuel economy requires comprehensive reduction of energy losses with vehicle-level optimization during the early stages of design and throughout vehicle development." – Ableson, GM Global Advanced Vehicle Development

The crucial role of simulation and analysis in making total-vehicle optimization possible is evident.

[3] "GM Simulates Software to Speed Hybrid Development," *Automotive News*, December 15, 2008.

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Auto industry business crisis Of course the 2008-2009 recession, and the consequent collapse in vehicle sales worldwide, has put most every auto maker under pressure to slash costs across the board, while doing everything possible to make its products stand out in the market.

Cost A single physical prototype can cost $250,000 to $500,000 to produce, depending on complexity, and 100 prototypes or even more may be required over the 30-month development cycle for a new car model. The goal of lowering development costs by reducing prototype counts is a leading driver of simulation and analysis investments:

> *"The pressure is on to reduce and eliminate costly prototypes – they can cost anywhere from a quarter-million dollars to half a million, depending on whether you have a 'top hat' [new sheet metal on an existing platform] or a full brand-new platform. Because prototypes used in crash and safety applications are destroyed, demands for physical prototype reduction have been most severe on the crash and safety groups. [In all these cases], building fewer and fewer in hopes of someday having zero prototypes has always been the vision. [To make this possible], I and others in the analysis disciplines are always working to improve the methods." – Dr. bijan K. Shahidi, Principal Consultant, E.P.I. (Engineering Products Inc.)*

> *"…[there are two major constraints on product development]…first is quality but a close second is cost…simulation is a tool to reduce the number of physical prototypes and to reduce part count for the final product…" – Japanese automotive OEM*

Quality Equally critical is product quality. Here, the value of simulation and analysis lies in its power to help detect and correct failure modes before product ships. According to the Automotive Industry Action Group, a typical recall takes 250 days to complete, at an average cost to the auto maker of $1 million per day. Given the industry's history of recalls, physical test-based processes are clearly failing to find the failure modes – something more is needed.

Schedule Prototype fabrication and testing is a major factor that lengthens development schedules:

> *"…if we reduce the number of physical prototypes or overall development time, that's sufficient to justify the use of simulation…if you can save some prototypes, you can save a lot of money and time…" – German automotive OEM*

Simulation: Current State of Practice in the Automotive Industry

Against this background, we interviewed experts at industry leaders around the world to find out what best practices they have developed for using simulation and analysis to achieve the business objectives that they and all manufacturers face – to boost product efficiency, quality, performance and innovation, reduce development costs, shorten program schedules, and improve engineering productivity.

Focused on physical prototype reduction… Using simulation to refine designs, explore alternatives and detect failure modes; using physical test for final validation only – that's the goal of auto makers in all geographies. Companies we studied in Europe and Japan appear closer than North American firms to realizing this goal. But management awareness of CAE's potential to reduce prototype counts and shorten schedules is being leveraged by advocates in U.S. firms to weaken entrenched biases toward empirical approaches and strengthen trust in analytical methods.

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"The challenge, in essence, is to duplicate the physical phenomena virtually, so that you can eliminate costly physical prototypes. That is senior management's main driver [for adopting virtual methods]: their view is that, to the extent that analysis can reduce prototype counts, it's successful.

"But in reality there are many more benefits. CAE and simulation activities don't get the credit they deserve, because measuring the benefits is difficult. But the underlying promise of doing simulation is not only prototype cost reduction – it has also improved the quality of the product tremendously. For example, crashworthiness – cars and trucks have become much safer in each decade since the 1980s. This is not because physical prototype engineers have gotten smart, but instead through the use of crash codes, which originated in military and research labs and have now come into use throughout the auto industry.

"In addition to safety, look at noise and vibration. From the 1980s to the 1990s and beyond, cars [have become increasingly] quiet and vibration-free. All that comes from simulation and analysis.

"Yet despite all this, the auto makers' CAE organizations don't get due credit for these great improvements in vehicle quality – because prototype budgets are easy to measure, whereas quality is hard to measure." – Shahidi, E.P.I.

How and when CAE is used varies widely among the companies we studied in the U.S., Germany and Japan. We found that in Germany and Japan, simulation and analysis are seen as powerful means for design exploration and discovery, and are brought to bear early and pervasively throughout product development.

"…[simulation] is absolutely important. Our [product development] processes are based on simulation…in the first half of the development process you have a very close interaction between simulation and design. The product is built between those two groups, and all variants are calculated in close cooperation between design engineers and simulation engineers…" – German automotive OEM

"…the most important metric [for gauging simulation's value] is how many revisions to the design have to be made after the first [physical] prototype. The goal is to be successful in the first pass – the prototype validates the design…" – Japanese automotive OEM

"…[simulation] is used from the very beginning…our goal is to make sure that, on the basis of simulations, no significant problems occur during the [physical] test phase…" – German automotive OEM

This is less strongly the case in the U.S., where automotive engineering culture has long been oriented toward physical test and there remains some institutional discomfort with analytical results. In this environment, CAE is used more for late-stage design validation than for exploration and guidance early in design. Yet we found strong awareness in U.S. firms of the ability of simulation and analysis to have greater impact and value if initiatives to deploy and apply it more effectively continue making progress.

…but working to achieve still more: advance from physically led to virtually led development processes

"The number one challenge is the size of the problem: vehicles are getting a lot more complex, and now include a great deal of electronics. Drive-by-wire and other electronic controls are being introduced everywhere in the vehicle. Mechatronics is the new buzz word, although it's been around a long time – [simulation is key] in determining, for example, how fast the signal goes down the wire. This makes the design much more complex, and takes designers out of their comfort level. So increased problem complexity

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and problem size are the challenges." – Dr. Andreas Vlahinos, Principal, Advanced Engineering Solutions, LLC

In Europe and Japan we found high confidence that simulation provides a trustworthy assessment of product performance. The goal is to find all problems digitally, before the first physical test.

"…in former times we had the discussion whether simulation or test would be the better choice to do different things…there was a competitive situation between simulation and test…today there's no need for discussions like that…everybody knows you can do certain things on the basis of simulation…" – German automotive OEM

This is the goal at U.S. companies as well:

"…there's clearly an ongoing effort over the last ten years to displace physical test with CAE…" – U.S. Tier 1 supplier B

But progress appears less advanced:

"…[the U.S. auto industry is] clearly in a transition. There's a desire to do as little physical testing for discovery as possible, and only do test as final validation, but we're not there yet…" – U.S. automotive OEM B

One reason, we found, is that in U.S. companies, people at many levels – both engineers and program managers – sometimes remain oriented toward inductive reasoning, i.e., physical test. The issue is how well analysis results have been correlated with physical test results – and how well their fidelity has been communicated to stakeholders:

"…[how early in product development] analysis tools [are] used…depends on how well the tool is believed for a particular problem…correlation is the word typically used…" – U.S. automotive OEM B

One senior engineering executive at a U.S. OEM told us, "We do way too many physical tests, but because they are not well planned or well informed, they still miss the failure modes." The good news is that, as this executive noted, this is being widely recognized as far from best practice, and green/sustainability, performance, cost and consumer-differentiation pressures have begun driving changes in the culture. Ultimately this will lead to wider recognition that, beyond being a cheaper, faster substitute for physical test, simulation is a powerful tool for exploration and discovery of phenomena that would be cost- and time-prohibitive to find through physical test, if not impossible:

"…simulation is very important to discover and learn about new phenomena that can't always be seen at the testing phase…" – Japanese automotive OEM

But maximizing CAE's impact involves far more than simply buying the best technology and handing it off to an analyst or discipline lead. Contemporary best practice also focuses on making more efficient use of existing resources – both engineering staff and tool investments.

"…constraints boil down to expertise and cultural issues…" – U.S. Tier 1 supplier B

No one we interviewed named software budgets as a constraint on product development's ability to contribute to corporate business objectives – all identified time, human resources, and culture issues as limiting factors.

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Constraints on Maximizing Simulation's Value

What constrains automotive development organizations from achieving the goals laid out above?

> *"In vehicle engineering, analysts face high demand from the physical test organizations to correlate their analytical results with physical phenomena. So how do you do it – what technological shortcomings must be overcome? [For simulation to have maximum impact on product development], you must be able to transfer physical sign-off to analytical sign-off…The challenges are, first, to understand the physics, and second, to purchase or develop software that duplicates the physical results.*
>
> *"That raises the next business issue: is there enough funding to buy or lease the software? And enough time and budget to train your staff?*
>
> *"Finally there are IT infrastructure challenges – hardware capacity will likely need to increase. Many auto makers don't have enough computing capacity to run heavy-duty simulations such as virtual wind-tunnel tests. Remedying that requires getting buy-in from the company's IT infrastructure management." – Shahidi, E.P.I.*

We found that constraints fall into two primary categories: (1) technology constraints and (2) organizational and work-process constraints.

Technology constraints

A central problem is the need for better data integration among CAE tools for different disciplines, and also between CAD and CAE:

> *"…a major constraint is how well the CAE tools integrate with one another and with the CAD tools…[even where vendors have integrated their software with one another] you may have trouble getting CAD geometry into the CAE mesh, then getting CAE results back to the CAD model…in the CAD-to-CAE links, there's a lot of manual intervention in the meshing process…" – U.S. automotive OEM B*

CAD-CAE gaps A perennial constraint has been the technological gaps that exist between product definition geometry on one hand, and simulation models on the other – and the resulting penalties in time and, sometimes, accuracy exacted by the need to prepare geometric and functional models for input to analysis.

> *"When [our OEM] customers come to us, they have tight timing – they want prototypes quickly. But they are also regularly changing their design requirements, so the design can be evolving daily. At the same time, your CAD designers are trying to keep the drawings and models updated as the design evolves. Then the analysts are providing design input to the designers at the same time as customer requirements are changing. And those three things – CAD updates, design analysis, and customer requirements – need to be coordinated in real time. In the heat of the moment, with the drastically reduced prototype delivery times we're being asked for now, [response to design changes] needs to be daily, even hourly. We're not a large organization, so we have analysts running around from desk to desk talking to the various team members – coordinating changes in real time. It would be easier if we had a design that didn't change. But if even we had that, the constraints remain CAD and analysis – the biggest bottleneck is the fact that those activities take time, because CAD and analysis are not tied together." – U.S. Tier 1 supplier A*

> *"One big technological issue is also cultural: is the model CAD-centric, or node- and element-centric? If you bring in CAD geometry, you mesh it, and then you have nodes and elements. That is more common than letting the geometry remain CAD-centric. But it*

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is a very limited approach. We have morphing software [from various vendors] – everybody is trying to manipulate nodes now, which is very difficult. You perturb the nodes when you move them around in the process of morphing. It limits your creativity. You see a vibration mode; you say, 'That is too low; I need to move it.' You can do it in node-centric models, but it's very difficult. You need to do it in the CAD system – but that is a different system, often in a different building even – two different worlds. There's no synchronous communication between them at present." – Vlahinos, Advanced Engineering Solutions

Cross-discipline analysis gaps Similar barriers impede sharing of results between analysis tools in different disciplines:

"The next problem is the lack of interdisciplinary integration. For example, the vehicle dynamics guys, working on a suspension, take forever to make sure vehicle dynamics are okay. But they assume the chassis is rigid, not flexible – although in reality, it is flexible. Those two groups – vehicle dynamics and body-in-white – work independently. In turn, the body-in-white group doesn't see the real loads, the real driving cycle data, from the dynamics group, even though they need it to accurately estimate the fatigue life of the body-in-white. The challenge is to integrate multi-body dynamics and FEA: they should eventually be one. Practitioners should not have to choose between implicit FEA, explicit FEA, and multi-body dynamics codes; it should be all one code doing all three of those functions together. You talk to the dynamics group and say, 'You know, the frame there is actually flexible; you do all these fancy controls for vehicle dynamics, but you don't consider the fact that the chassis is flexible.' They answer, 'Well, the dynamics group isn't ready in time.' But vehicle dynamics, NVH and safety are the three areas that need to be brought together." – Vlahinos, Advanced Engineering Solutions

Need for better simulation data/process management Another chief constraint is the need for robust, capable simulation-specific data management and process management tools. Indeed, many name simulation data and process management as the biggest technological challenge constraining the value available from simulation and analysis today. Best practice centers on better managing and automating the flow of data between disparate simulation/analysis tools, and between CAE and CAD. It's also about developing ways to capture, archive and retrieve simulation models, input conditions and results, together with related assumptions and conclusions.

"As for technology constraints, computers could always be faster, but more to the point, it could be easier to get information into them. Our model setup is the big crunch now. Computing hardware is not the big barrier right now – it's having the experienced person who knows the software and understands the physics enough to tweak the CAD geometry and set up the model.

"Also, the software could be more customized for very specific products or areas. That's one way we could go forward: if there were analysis tools that were available out-of-the-box for doing, say, a shaft analysis, we wouldn't have to develop these specific capabilities ourselves. Today the software vendors offer generic tools, but it's up to us to define how to set up our problem, and how to make decisions from the results. If there were more standardization, it would help: maybe all the companies who do shaft design could get together, share their knowledge, and then roll out standard design analysis practices. That may not be realistic, but it would be a lot more efficient if we all standardized our methods. There are already a lot of standards for gear and shaft design, but still everybody has their proprietary methods for decision-making." – U.S. Tier 1 supplier A

What do practitioners see as the key challenges?

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"In our organization we've adopted a PLM system. The first phase of implementation is to manage the CAD part of the business. And we hope that, down the road, it will help us manage CAE data. But we're not there yet. A few years ago we bought a data management tool [from a CAE vendor], which promised usability out of the box. But even after a lot of customization, we still found it prohibitive to productivity. This reality probably had less to do with the product, than that we're small, we're lean, and we don't have a huge data management issue. We could always be better, but we found that after the customization work, the time-consuming step of inputting the CAE results into the PLM system just didn't add value to our workflow." – U.S. Tier 1 supplier A

We found a disparity of opinion as to whether CAD-CAE gaps are inherently technological, or are instead more a result of suboptimal data/process management tools and practices:

"[Traditional] PDM makes sense for CAD but not for simulation. You don't want to keep track of every simulation file you run; you need to keep the process, not the model – loads, boundary conditions, etc. – and it needs to be usable. Who needs the solver file? Even better would be an automatic reporting capability for simulations in which you publish the inputs, outputs, assumptions, and lessons learned. That's all you need to keep from a simulation. You don't need these old files. But because analysts in the auto companies are node- and element-centric, they go at it that way. If you ask four people, 'Give me a good control arm for a vehicle,' they'll all give you a node model. You cannot morph it, you cannot fix it." – Vlahinos, Advanced Engineering Solutions

This source further elaborates:

"Within the simulation area, the main challenge is not the CAD systems; CAD geometry can now come in very clean [for analysis]. But the analysis groups aren't given timely access to the CAD data. It's kept in a vault, and analysts don't have simultaneous access to the CAD data [as it's being developed]. They have to request it from this person, that person has to approve it, and so forth. Thus, the moment an analyst gets CAD data from the PLM system, usually it's already out of date. The released CAD models are not up to date with the current work being done in the CAD systems.

"This is very frustrating, but it is a cultural fact within the auto companies. Why is it this way? The design of cars happens with the CAD designers, the two-year-college workers. And there are, say, another 50 people who are the 'designers,' that is to say the industrial designers, who develop the outside envelope for the vehicle. The CAD designers then place components in the envelope. Then, when the CAD design is mature enough, they send that to simulation – but they keep going. In simulation, there are several hundred performance attributes we need to meet – NVH, safety, all the rest. We cascade them down, and by the time we get answers to all of them, and take them back to the design group, the CAD designers look at us and ask, 'Where have you been for the last two months? The design is entirely different now.' So the CAD and the CAE processes are entirely out of sync." – Vlahinos, Advanced Engineering Solutions

Organizational and work-process constraints

Culture and psychology can be big obstacles to improving work processes. One U.S. executive remarked that "people in simulation want to do a perfect job because it's their nature, but there isn't the time, so they miss impacting the product development cycle."

Culture gap: physical vs. virtual

"Wherever we think we can reduce physical test in favor of analysis – where we feel the risk level is appropriate – we do it. The areas we test for are the areas where we are not confident enough in our design calculations to test all the variables. We're always looking

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for opportunities here, but we don't ever expect to eliminate physical testing. It is usually a two- or three-year process, at a minimum, to actually reduce physical testing in favor of a set of analyses, on even a single component. To do this, we have to do a great deal of benchmarking and correlation and methodology development – it's a long road, and often you can't even be confident you're going to get there at the end. It's a lot of work, so unless the path is really clear, we don't take it on. The amount of work can parallel a PhD-level science project. You have thermal influences, lubrication influences, structural and materials influences.

"Which brings up the point that the multiphysics aspects of problems have traditionally been difficult to comprehend in analysis. A recent trend – with the maturity of software packages on the market and the increasing capability of hardware – is that people are going toward more multiphysics analyses. That's what it's going to take to reduce physical testing. For example, representing a bearing test in analysis can involve heat and lubrication as well as structural issues. To model all that together is difficult and time-consuming. It's challenging to get an answer you can trust from analysis alone, in the time frame needed to make a design decision. In cases such as that, physical test is still faster and higher-confidence." – U.S. Tier 1 supplier A

Organizational design Another constraint is the requirement to integrate the tools, intelligently and with forethought, into an organization's work processes – and effect the changes in culture, mindset, and institutionalized working habits necessary for the tools to have greatest impact:

"Organizational design [is key]. The organization and its design can produce good vehicles, or bad vehicles. [In contrast to some other geographic regions], in Detroit the problem is that the (former) Big Three – from senior management, through middle management, down to engineers – are driven by people who have little if any understanding of CAE. They don't come up through the ranks of the simulation activities. The president and vice presidents of engineering all come from the hardware side, the physical side of the organization. They haven't paid attention to how to organize the company in such a way that you can implement a virtual development process – virtual builds all the way to the end, with physical prototypes solely to support the virtual build.

"It's always been the reverse – the CAE- and simulation-based organizations support the physically based organizations. When someone wants to design something, he goes to the CAD system, models it, then goes to the CAE group and says, 'Is my design okay? Will it vibrate? Is it safe?' As long as that organization remains in place, it will limit the industry's progress toward a virtual engineering process." – Shahidi, E.P.I.

Learning curve – individual and organizational – is a related constraint on broader use of simulation and analysis:

"There is a training issue. Not just on the software, but on the disciplines – thermal analysis, structural, and so on, and on the physics side of it; it is a huge investment for people career-wise. You can't make good decisions if you don't understand your own product and the physics behind it, along with the software tools. You also need to understand, say, FEA and meshing and materials properties to do a structural analysis. And then you need to understand your product and how it's used in the field. Most of that knowledge does not come from college; it requires three to five years on the job. And then, when you start considering multiphysics, you need to understand thermal, and fluid, and the other disciplines. So the training barrier is a constraint on broader use of simulation. It's difficult to accelerate that accumulation of knowledge." – U.S. Tier 1 supplier A

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"It takes time to allow people's usage of newer software tools to evolve. We're at the point where the software is not the biggest hurdle any more – it's the learning curve on how to make design decisions from the tools. You have a tool available, and then you have some process you follow to use that tool to make design decisions; and if you want to switch tools, then you have to revalidate your metrics and revalidate how you make design decisions. And on top of that, you have the learning curve for the new tool – both for the individual, and for the organization, which has to learn to make design decisions with the new metrics and methods.

"Then you have to test before you can trust your new computational metrics. The way we learn to trust new tools is by physical testing, and then getting the product into production. That's the biggest challenge in changing tools: not the individual learning curve on the software, but in becoming able to make design decisions with the new tools. Any time we change how we do calculations, we have to re-benchmark and validate and correlate, to make sure the design is still acceptable." – U.S. Tier 1 supplier A

Procurement-bound constraints Simulation purchase decision-making processes are also sources of constraint:

"Basically [software tool procurement] is a cost-driven process. The U.S. OEMs, essentially to contain costs, have worked to move toward single simulation software suites, or at least toward greater uniformity of software packages. And now with PLM vendors increasingly offering one-stop shopping, buyers are starting to think in those terms. But a challenge arises in the organizational design – the CAD organization and the CAE organization are completely separate. And the companies' senior management is much closer to the decision-making processes in CAD than in CAE. Why? Because of the disparity in costs. A typical OEM's CAD-related costs may be in the tens of millions of dollars annually. By contrast, its CAE activities – FEA, CFD, NVH, thermal, 1D tools, all of it – cost in the millions of dollars, or very roughly one-tenth as much as the CAD budget. When you go to the vice president of engineering, he mainly wants to hear how the high cost of one CAD system compares with another…Because of this cost disparity, there has not been as much interest in the integration of CAE technology…From a technology point of view, you want all these tools to talk to one another seamlessly – that's always been the holy grail, to eliminate the gaps between the tools. But from a business point of view, there has not been much drive to do it." – Shahidi, E.P.I.

Overcoming Constraints: New Directions, Emerging Best Practices

Fortunately, our research identified significant progress now being made on all these fronts.

Overcoming technology constraints

Toolset integration: CAD-CAE We found substantial progress in efforts to narrow the gaps between design and simulation models. Best practice in overcoming toolset gaps is about finding – or developing – tools and processes to better manage and automate the flow of data between different simulation and analysis tools as well as between CAE and CAD. Where technological solutions are not yet available, best practice is to develop workarounds:

"…we would like to do analysis on incomplete models to make early decisions….[the] problem is that CAD tools are not structured to output an incomplete model…so to do early CAE you often use a surrogate from past work…something close enough…but it could be better…" – U.S. automotive OEM B

Best practice also involves understanding and optimizing program-level work processes that impact use of simulation:

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P.O. Box 391227
Cambridge, MA 02139 USA
tel. +1 617 875 9598
fax +1 617 812 2443
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"…[there are] bottlenecks in data movement….in some areas it's demanding…e.g., with body-in-white, spot welds are something you have to look at very carefully…is design aware of how the positions of the welds might influence the behavior of the overall structure, or will they adjust and finalize spot weld positions during the production process definition? You have to make sure that you get the correct data for simulation…" – German automotive OEM

Toolset integration: cross-discipline analysis Similarly, we found substantial progress in integrating the tools used in the various analysis disciplines:

"Multiphysics – multidisciplinary integration – is the next natural step from solvers. We should stop using specialized codes for specialized solutions just because that's now they grew. Some software companies started in structural, others in multibody dynamics, other still in crash and safety. Well, isn't it time to have one code for all this? The user should have one system, and be able to say: 'Here's my system; here are my performance requirements; give me a solution.' We do this with small problems, for example a heat exchanger. But that's not happening at the OEM in Detroit; it's at a facility in Torrance, California, which came out of the aircraft industry, so they know how to take a systems view and cascade targets down. The car guys don't know how to do this – even though they tell you, 'Oh, we've been doing this for years; we know what we're doing.' Their processes are still node-centric instead of CAD-centric, much less the next step, performance-attribute-centric. 'I want a car that goes this fast, with this much fuel economy, and so on' – and this knowledge, believe it or not, is there right now, but in the minds of the skilled practitioners. If you go to the powertrain guy at any OEM, he knows you need to use at least this transmission or that engine. I ask, 'How can we capture that knowledge for next time?' The knowledge of how to carry out performance-attribute-centric engineering is there in engineers' minds, but not in the software yet." – Vlahinos, Advanced Engineering Solutions

"It's definitely a trend that with multiphysics tools, it's getting easier to pass data around without two years of internal coding first. The commercial tools are more available and of higher-fidelity, to allow people to start evolving away from individual analyses, toward multiphysics analyses. But you have to re-learn how to make decisions with these new tools. And there are training issues. Before, you had people in silos – structural, thermal, crash, etc. – and now you're asking someone to do it all. In our small organization, we don't have those silos, but in huge organizations you have huge silos. The tools are becoming available and working better, but there are still a lot of infrastructure issues to overcome in order to make that happen." – U.S. Tier 1 supplier A

Simulation data/process management: mapping the way forward Practitioners we interviewed repeatedly described new initiatives to break through the two most frequently cited constraints on getting more value from simulation and analysis: (1) availability of trained, knowledgeable professionals and (2) time in the program schedule to do all the analysis they would like. Best-practice initiatives aimed at overcoming these constraints focus on tying existing design tools, preprocessors and solvers more closely together, and on using data/process management and knowledge capture technologies and methods to increase work throughput.

Another problem that better CAE data/process management can address is limited availability of people and time. Our research found that a key constraint on getting more value from simulation is the availability of trained professionals and time, not a shortage of software tools or budget. Best practice for overcoming these constraints is to use knowledge capture, data/process management and open tools to make more efficient use of existing

Ora Research LLC
P.O. Box 391227
Cambridge, MA 02139 USA
tel. +1 617 875 9598
fax +1 617 812 2443
www.oraresearch.com

investments in staff and technologies. While no one we interviewed has yet achieved this goal, all are striving for it.

> *"Solution [to today's constraints]? There are some software providers which do, today, have technology for synchronization of CAD and CAE. But they don't have it yet on the large scale required for a whole automobile design – the contacts, joints, etc. Some have introduced automatic contact detection and automatic joint detection, so I can automatically put in spot welds, say every 5mm – I can bring in the CAD design and automatically mesh it. Or if I bring in a suspension, and it has a cylinder inside another cylinder, the tool will assume it is a hinge joint. Or if it is not, I can tag it in some way – for example, if I give this condition a name such as 'ball joint' in the CAD system, the software will know how to model it for FEA. But even the most advanced software won't yet work at full automobile scale: capability today is around 250 components, not 2000 components. The goal is to automate more. Bringing CAD geometry into simulation today is trivial, but it is almost always a dumb model, and you have to spend hundreds of hours putting welds, joints, bushings and so on into it to make it intelligent. The CAD models can come in very clean today, but that is a small part of the story. Automatic contact and joint detection is a big issue today." – Vlahinos, Advanced Engineering Solutions*

How are industry leaders structuring and attacking the problem? A notable area of innovation contributing to improved process automation and integration, we found, is the accelerating implementation of tools and techniques for automating and speeding up the execution of simulation and analysis codes in order to more efficiently explore design spaces:

> *"[To do] systems engineering [efficiently], PIDO (process integration and design optimization) tools are the key to integrating all the disciplines involved. But PIDO needs to come from the CAE vendors, so that the integration will be easy. If you ask a systems engineer today, 'Can you give me the status today of all your design targets? Which targets are passing? Which ones are missing, and need to be worked on?' They can't tell you. Why can't we see on our screen a set of real-time performance metrics, so we can see what we need to work on? The process is very ad hoc today. The lack of synchronous, real-time performance attributes metrics is a dangerous thing, because it slips product development. Everybody says, 'I am red or yellow or green,' but there's no real time reporting. Every day, you should have a screen on your desk that says, 'From yesterday's CAD changes, this is what happened to our performance attributes.' That will come from the PIDO approach. If implementing this disturbs people, it will need management buy-in to succeed. But if you do it painlessly – if you extract their performance attributes from their simulations without their having to do anything – they won't object." – Vlahinos, Advanced Engineering Solutions*

These new tools and the methods they support – multidisciplinary optimization (MDO), design of experiments (DOE), robust design, Design for Six Sigma (DFSS) – are becoming feasible through improved approaches to better managing problem setup and problem execution, as well as data interchange between different simulation and analysis tools, and between analysis codes and CAD systems.

Overall, we found that practitioner priorities are focused on capabilities to:

- Automate data exchange between analysis disciplines, and between geometry modelers and mesh generators
- Ensure that CAD-CAE data exchange capabilities are multi-CAD – partner/supplier collaboration requires this
- Readily re-run or update analyses months or years later

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tel. +1 617 875 9598
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- Ensure that design changes trigger re-analysis; ensure analysts receive correct inputs from modified design; ensure re-analysis results feed back to design

Overcoming organizational and work-process constraints

Of course, with even the most optimal technology implementations, much of the progress in optimizing use of simulation and analysis and maximizing its impact has to do with organizational considerations and people factors:

> *"At the root of these toolset gaps is the organizational design. When the design is not a good fit, then what you see – even within the CAE activities themselves – is core rigidities. Core rigidity means the organization has becomne set in its ways in using a given toolset, and isn't open to other toolsets. If a manager only knows FEA and, within that field, considers one code the grail, he likely doesn't want to touch a competing code; if he comes from the CFD world, likewise he may not want to look at other tools…If you don't have an organization where top managers can help nurture and make flourish the different types of CAE, then fidelity and data sharing will be low.*
>
> *"When this core rigidity finally it hits its limits, then the CAE organization stalls. And the physically oriented customers in the company say, 'Well, the CAE organization can't do what we need.'*
>
> *"The organization should be designed so that it nurtures all types of CAE. Aerospace manufacturers are organized that way; as a result, you see a certain individuality of practice in CAE across that industry – a different flavor of how CAE is done from one company to the next. In the automotive business, by contrast, manufacturers more or less copy one another. There is a convergence of tools and processes – and not a lot of innovation. This all flows from people not being open-minded. And in this way, the core rigidity I mentioned takes hold.*
>
> *"Senior management should have begun focusing on this problem long ago, and should have been working to hire and develop more creative CAE professionals. But it doesn't happen because the organization lacks reward mechanisms to help bring it about. In aerospace there is more recognition and reward. I often hear aerospace companies say they're looking for more CAE people, because they want to do more simulation. You seldom hear this in automotive – 'I need somebody who understands bending moment,' for example." – Shahidi, E.P.I.*

One solution lies in making more use of system-level simulation tools:

> *"…the [CAE] tool may be powerful, but can it be partitioned to make the partial decisions needed early, using incomplete models? I only need a portion of the model or a certain level of detail to make a decision now, and then more complete definition of the product to make a more complete decision later. Some CAE tools have the ability to work with coarse concept models, then refine that as you go – for example the AVL system-level tools for predicting engine loads, oil paths, etc.…" – U.S. automotive OEM B*

Another best practice we found in both Europe and Japan is to locate design, simulation, and test departments close to one another – in one case, all three occupied the same floor of a building.

Ultimately, the aim of simulation work-process improvement is to reengineer program workflows to bring simulation to bear early in product development. When simulation is done late in the cycle, after the bulk of engineering decisions have been made, its impact on product development is much diminished – design changes can only be cost-justified if analysis identifies serious design deficiencies or failure modes.

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People factors Much of the challenge in optimizing use of simulation and analysis has to do with organizational, cultural and people issues. Our research found that best practice focuses on two objectives:

- Attract executive sponsorship
- Create incentives for discipline leads, analysts and engineers to take ownership

Attract executive sponsorship

> *"…what will it take [to tie simulation more closely to design, test, measurement and manufacturing]? In many organizations change is required, to break down the traditional barriers between these groups, where historically they have been defensive about their roles. This change needs to be driven from the upper level of organizations – it will not be as effective from a program manager level…" – Automotive engineering services firm*

How to drive change in the way U.S. companies deploy and use simulation is a conflicted subject, we found. Many feel that change will only occur if driven by management. But one cause of the problem – the relative independence of the analysis groups, who stand on the authority of their expertise to continue maintaining the status quo – makes it difficult to effect change.

> *"…more accountability for quality of work needs to be developed, where predicted results are suspect or later turn out to be incorrect – verification and validation efforts need to occur more regularly to build/rebuild credibility. This will reduce the independence and help bridge the gap…" – Automotive engineering services firm*

Nonetheless, the consensus seems to be that executive sponsorship is necessary though not sufficient to change cultures and work habits so that simulation is used earlier and more pervasively in product development.

> *"…change has to be driven from the top down. It boils down to a leadership issue. If the leader lays out what the vision and plan are, and gets everybody on board, then [change can happen]. But they have to get all the interested parties together and explain why they've got to do things differently. They may have to do skip-level meetings, going down several layers in the organization…they've got to engage passionately in communicating why…" – Automotive engineering services firm*

In Europe and Japan we found less evidence of these cultural impediments to optimal use of simulation and analysis:

> *"…all German auto industry executives are aware that the [product development] process would not work without simulation…" – German automotive OEM*

What is the best way to get executive sponsorship? Align simulation/analysis with key business drivers and ongoing company-wide initiatives and budgets – such as Six Sigma, Lean Design, quality and efficiency programs that directly impact:

- New-product cycle time
- Product development costs
- Product quality improvement, warranty cost/recall reduction
- Product differentiation, consumer appeal

Create incentives for discipline leads, analysts and engineers to take ownership

> *"…in early phases of product development you don't have 100% information…geometry may not all be defined…you certainly don't know all the loads…if you set the*

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Cambridge, MA 02139 USA
tel. +1 617 875 9598
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expectations correctly, [that] simulation is only directional at this phase and then you will get closer to the exact answer as you refine…it will go better…instead people get into this go/no go mindset…" – Automotive engineering services firm

While it is generally understood that simulation can provide a richer and more complete picture of product performance, there are unavoidable complexities that require analysts to be more comfortable doing analysis with partial information. We found that in some cases, analysts even want to see physical test data to see what "fudge factors" to put into their model to ensure correlation with test results. It's critical to tackle issues such as these head-on in order to fully understand what incentives will actually motivate the changes that need to be implemented.

One solution is to enlist "champions" who are currently using simulation and create incentives that enable them to focus their efforts to implement the change from the user level up. This can ensure a smoother transition and greater adoption of the technology.

Best practices also include deploying knowledge-capture tools and process templates that aid designers in performing first-pass analyses. This has the added benefit of raising the value of designers' engagement in product development and having simulation data and analysis to refer back to throughout the process. Best practices also focus on reengineering program workflows to engage discipline specialists earlier in design.

Next Steps

To drive change in an organization, a powerful call to action can be to benchmark the organization's maturity level against industry best practices. Using this report as a starting point, compare practices in your organization with those of your most successful rivals. Identify areas where more effective use of simulation and analysis would put you in the lead.

One way to begin is to assemble a multidisciplinary team – include representatives from the analysis groups, design, test, and program management – to audit current practices, identify gaps and bottlenecks, and develop recommendations for improvement. First review the constraints identified by practitioners in this paper. Determine which of these is most severely gating progress in your organization today:

Technology constraints

- *CAD-CAE gaps*
- *Cross-discipline analysis gaps*
- *Need for better simulation data/process management*

Organizational and work-process constraints

- *Human resource constraints*
- *Methods development, work-process integration requirements*

Then investigate sources of solutions for both classes of constraints.

Technology solutions Unlike CAD and PDM purchase decisions made by corporate committees with heavy IT involvement, analysts call the shots in simulation/analysis tool purchases.

"…the CAE groups decide which tools to use...it's not driven by the IT people...the discipline needs drive [the CAE] decisions…" – German automotive OEM

"…the engineers make the CAE tool choices. CAD is different – the decision for the CAD tool comes from above…" – Japanese automotive OEM

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Cambridge, MA 02139 USA
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Nonetheless, it's important that simulation/analysis purchase decisions be grounded in not only technical but also business criteria. Criteria for qualifying and selecting a solution provider, conditioned on what constraints you need to address first, include:

- *Functionality of solvers*
- *Functionality of meshers, gridders, other tools for problem setup and results execution*
- *Competence as integrator of diverse functionality – multi-CAD, multi-CAE, other product lifecycle functionality from requirements capture through manufacturing into service, support and sustainment*
- *Commitment to providing help with process change, people/cultural issues*
- *Commitment to providing:*
    - *Simulation data management framework*
    - *Process automation tools*
    - *Knowledge capture tools*
- *Reliability as long-term partner*

In your organization's next procurement cycle, revisit your qualification and selection policies for simulation solutions to ensure they address your requirements not just for superior point functionality but also for simulation data management, tool integration and process optimization. Factor in solution-provider stability, longevity and change management experience.

Organizational and work-process solutions

Optimize simulation/test tradeoffs Audit three past projects – one highly successful, one typical and one that could have gone better – to gauge whether superior management of the tradeoffs between simulation and test contributed to the success. Use the audit to map existing processes for design refinement and validation, and identify opportunities for improvement.

Manage people factors

Create incentives for discipline leads, analysts, and engineers to take ownership – Identify champions of advanced simulation and analysis within your organization. Engage heads of Six Sigma and Lean Design as advocates of best practices. Enlist professionals who enjoy strong peer respect to lead process improvement initiatives. Cultivate corporate and public recognition of these champions.

Attract executive sponsorship – Find an appropriate time and venue to brief VP-level executives on the business impact of the organization's simulation and analysis competencies. Reinforce the need for executive backing at the business-unit level, and enlist assistance in communicating the benefits of the technology and how it contributes directly to business-unit and program objectives.

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For information contact: Bruce Jenkins, Ora Research LLC
bruce.jenkins@oraresearch.com Tel. +1 617 875 9598
www.oraresearch.com