ATKearney

Digital R&D: When the Model Becomes the Product

A data explosion is changing the way companies research, develop, make, and service products. Continuous end-to-end integration will drive efficiency and innovation at leading manufacturers.

From the manufacturing of sports cars to industrial parts, R&D organizations are no stranger to using digital tools in development, having used computer-aided design (CAD) and software development environments for decades. The explosive growth in computational power and product connectedness, however, is opening up a world of new possibilities, where every aspect of R&D is going digital. Digital R&D can have a fundamental impact on how product development defines itself and how it will work in the coming months and years. We have seen companies that embrace digital R&D capture dramatic efficiency improvement to the tune of 15 percent in the requirement and system design phase, 30 percent in the hardware and software design phase, and up to 50 percent in the testing phase.

Digital R&D will be fundamental for most manufacturers' future innovation capability. For industrial and consumer-oriented manufacturers in Europe and across the globe, digital R&D will not only be a process of putting a number of integrated tools to work, it will also be a major transformation of the R&D operating model.

There is much to consider to maximize the benefits of digital R&D. In this paper, we discuss the rationale, its most important aspects relating to development and operations, how to set up digital R&D, and how to extend it into factories and the supply chain. We look at the relationship with lean and agile practices and offer a checklist for beginning a transformation.

Digital R&D offers exciting and crucial aspects for manufacturers to consider. Let's begin by looking at the most important reasons for shifting from traditional to digital development.

Why Move to Digital R&D?

R&D experts know that products are becoming more complex even as they face ongoing pressure to rapidly bring them to market. But these are not the only challenges R&D faces. Another set compounds the task, making it difficult to reach optimal development flow. Digital R&D addresses these challenges at every point of V model for product development, streamlining it to bring the next wave of efficiency and effectiveness to the process (see figure 1 on page 2). This is in contrast to traditional V-model processes, where system integration and testing is done toward the end of a project, risking the late discovery of deviations from requirements.

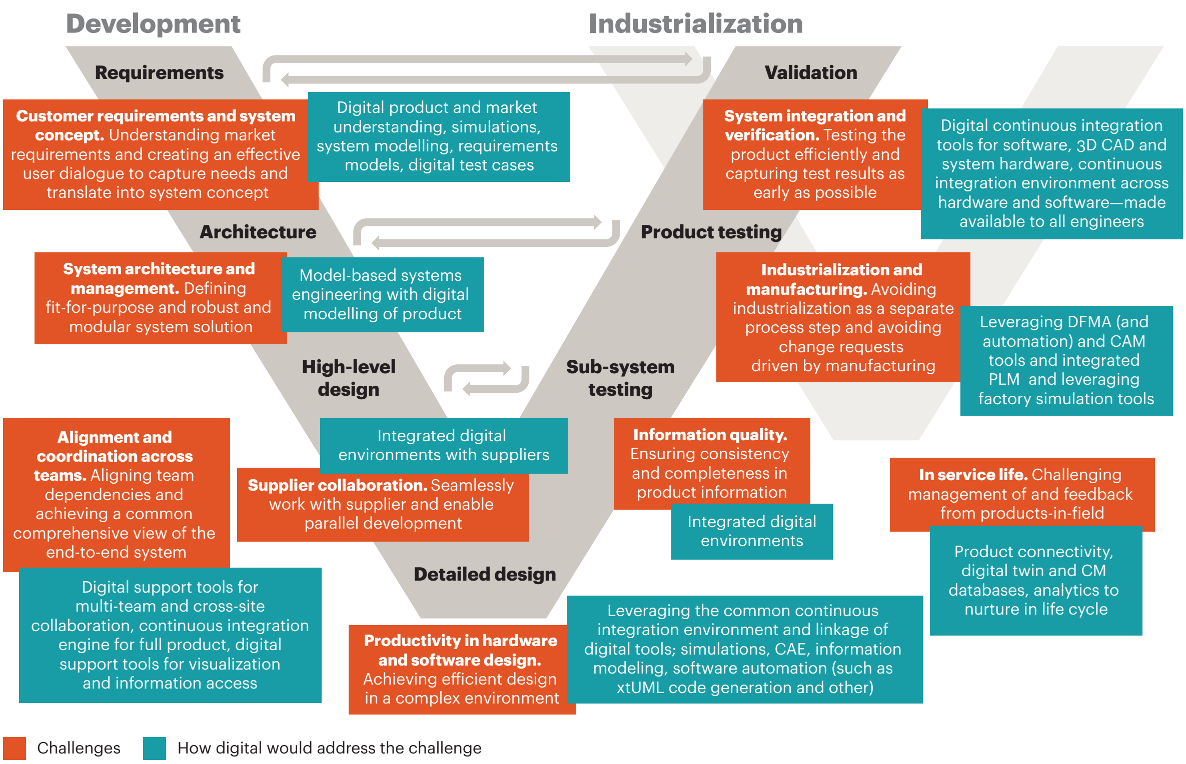
Challenge points along the V-model—and digital R&D's solutions to them—include the following:

Clarifying customer requirements and system concept. A product's requirements must be defined up front, but its true needs often do not become clear until the end of traditional development when R&D and other stakeholders see what it actually looks like. If it does not live up to expectations, there are costly change requests and delays. By using augmented reality (AR), virtual reality (VR), and simulations—three forms of digital R&D, the team can simulate use cases at the beginning, when concrete design input is crucial. Combined with more digital R&D tools—system modeling, requirements models, and digital test cases, the team can understand the product's market and communicate better with the end user to capture and translate needs into the product concept. Ideally, the team defines requirements as test cases and uses them throughout product development.

Smoothing system architecture and management. Just as it is challenging to predict all product requirements from the beginning, it is also difficult to foresee every design issue that may arise. Digital tools can help define fit-for-purpose and support the architecture definition, including a modular system solution. Model-based systems engineering, digital modeling, and

Figure 1

Digital addresses many challenges to close the "development V"



Notes: DFMA is design for manufacture and assembly. CAM is computer-aided manufacturing. PLM is product life-cycle management. CAE is computer-aided engineering. CM is configuration management.

Source: A.T. Kearney analysis

product simulation (for example, through systems modeling language) can help R&D evaluate alternative architectures and validate them early on.

Coordinating across teams and sites during design. Engineering teams are often spread out across multiple sites, as are team members from other disciplines, such as manufacturing and supply chain. Coordinating them takes a lot of active management and communication. Using integrated digital environments gives engineers and other stakeholders access to the design baseline. Digital support tools can help them visualize the product, share vital information, actively contribute, and achieve a comprehensive view of the entire system.

Collaborating efficiently with suppliers. R&D often spends significant time and effort developing detailed specifications for suppliers. Then, while suppliers are producing parts according to those specs, product designs shift and create a disjuncture between what suppliers have made and what the company now needs. Digital R&D enables much closer collaboration with suppliers, ideally making them part of the project and giving them access to the same tools as the rest of the team. There is tremendous potential here to avoid the typical challenges that arise with suppliers in the later stages of development.

Boosting hardware and software productivity during detailed design. Integrated digital environments let hardware and software developers be fully productive, too. The status-quo way of working, with its manual tasks, inconsistencies in information, unclear ways of working, and indecisiveness, can be detrimental to individual productivity, especially in a complex R&D

environment. Continuous integration is important here. Full use of linked digital tools, such as computer-aided engineering (CAE) and an integrated development environment, can make the process flow more efficiently. Accurately using simulation tools can cut lead time to nearly zero by eliminating prototyping and lab stages. Focusing on model reuse allows developers to skip manual recreation of the same information for different purposes.

Continuously integrating and verifying the product and its subsystems. When subsystems are developed independently and integrated late in the process, there is a high probability that pieces of the puzzle will not fit, leading to needed design adjustment. Digital R&D emphasizes the use of continuous integration at the system level. This ensures product information is consistent and complete, and minimizes late change-requests. It is important to build continuous integration into new-product development as well.

> Digital R&D makes it possible to connect to products and realize the full benefits of that connection, from remote maintenance to upgrading of functions, supplementing it with value-adding information.

Smoothing industrialization and incorporating manufacturing. The industrialization process can generate change requests when components do not fit together well or assembly orders are too cumbersome. Standard digital tools support technology such as computer-aided manufacturing (CAM), but full digital R&D makes industrialization a part of the design process (through design for manufacturing and assembly), using the same models as the design engineers, including product life-cycle management (PLM) and simulation tools. Manufacturing, assembly, and automation become part of the overall design, which becomes full digital manufacturing.

Making product information consistent and complete. Slightly disjointed systems often require a human touch in data management, cleanup, and transfer between systems. Digital R&D uses a single source of truth for information, with sets that are seamlessly exchanged and reused across the business.

Managing the installed base of products. Getting feedback on how products work in the field and establishing an efficient process for maintaining them is often a challenge. Digital R&D makes it possible to connect to products and realize the full benefits of that connection, from remote maintenance to upgrading of functions, supplementing it with value-adding information.

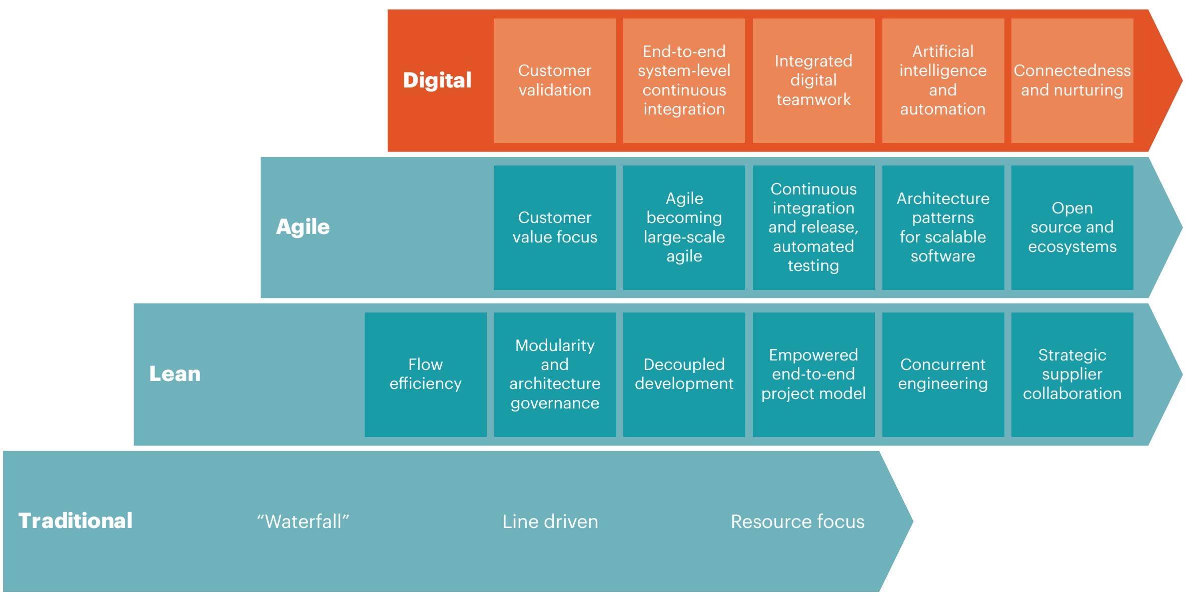
All in all, digital R&D can cut development lead time in half with a more seamless design process, smoother collaboration, better decision making, and less cumbersome use and reuse of information.

Digital R&D Takes Lean and Agile Even Further

Digital R&D's benefits complement those that lean and agile practices brought to R&D in recent years. Those practices greatly improved its efficiency and continue to be important in areas including cross-functional teamwork and concurrency across development flow.

Beyond lean and agile, digital R&D takes efficiency to a new level in five stand-out areas (see figure 2):

Figure 2
Digital adds a new level of efficiency to R&D



Source: A.T. Kearney analysis

Captures and validates customer needs and requirements. Everything that a manufacturer can do up front to make a new system or product feature come alive for a customer improves a specification's accuracy and success. Digital R&D lets developers simulate and demonstrate a product to them and thoroughly outline use cases. It can also capture and analyze a large amount of information on a product, its surroundings, the market, and other factors, all of which forms a fact base for improving requirements. Then, as development progresses, the product can be continuously validated because it is accessible through gradually improving models. This approach minimizes late surprises and the risks they pose.

Continuously integrates end to end (e2e). Digital R&D brings agile development to the full system—for both the hardware and software components. Teams access one another's designs and have testing capabilities at their fingertips. This can markedly improve outcomes because team members receive continuous feedback on designs, which helps make the e2e system robust and high quality. It also supports the ongoing validation with customers and reduces the need for change requests. Continuous integration works in a software-only environment as well, where individual pieces are integrated and tested in the larger system.

Drives teamwork, which is crucial for an improved process. A fully digital e2e system that is accessible to the entire development team is essential for efficient teamwork. Members work concurrently across system hierarchies, subsystems, and modules. They can carry out concurrent functional work that includes downstream activities, such as industrialization, in parallel with the product design. A fully integrated environment guarantees information quality and helps ensure a single source of truth.

Makes full use of artificial intelligence (AI) and automation. Digital R&D focuses on automation and leverages AI and analytics to improve decision making. With full digital modeling, there are plenty of automation possibilities in simulations, analysis of physical phenomena, and tests. In fact, testing in continuous integration flow can be fully automated. Much of software development can be automatic, such as staging or code generation from xtUML modeling. Developers can save model databases for reuse. They also can construct AI-supported design rules so the vast knowledge base about successful and producible design is accessible and shared. In this way, AI and analytics contribute to better products by improving foundations for design decisions. All of this contributes to R&D efficiency.

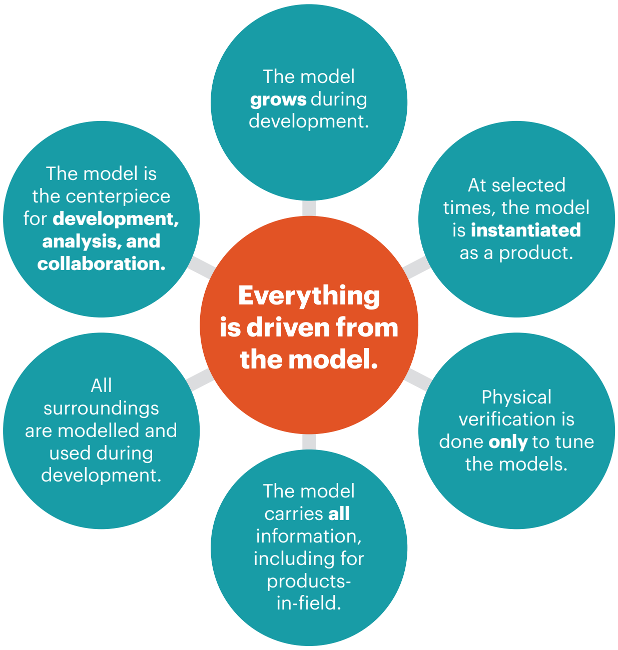
> Manufacturers will have an ongoing relationship with products, nurturing them over time by capturing information to use in future designs.

Leverages product connectedness and nurtures products during their life cycle. More products will be connected in the future. Digital R&D allows manufacturers to leverage this now and goes far beyond remote maintenance to fundamentally change how they consider products. Instead of viewing a product in isolation, manufacturers will see it as part of a larger system (for example, interfacing with other products or running network-based applications). They will also have an ongoing, interactive relationship with products, nurturing them over time by capturing product information to use in future designs, for maintenance, to provide value-adding applications and information, and constantly upgrade (perhaps allowing for the early release of functionally incomplete products). Consequently, setting up digital R&D to support long-term product relationships will generate the most long-term benefits.

What Can Be Digitized and Modeled?

Digital R&D means everything is digital, which requires a substantial yet worthwhile change in mind-set. Among the biggest shifts, the model drives everything as the centerpiece for development, analysis, and collaboration (see figure 3 on page 6). It lives in surroundings, which also are models, and grows as development advances. A physical prototype is built mainly for tuning digital models, not for product testing, as it is in traditional development. Now, almost all product testing is done with the digital model. What's more, the model contains all information for a product in development as well as those already in the field, which supports the ongoing relationship.

Figure 3
Digital R&D means everything is digital



Key benefits

- Allows designers to quickly get feedback on their work through interactions with the models
- Enables use of automation and AI for design, analysis, and verification
- Keeps order and transparency in all information, reduces misunderstandings and double work, and brings useful input to designers' work

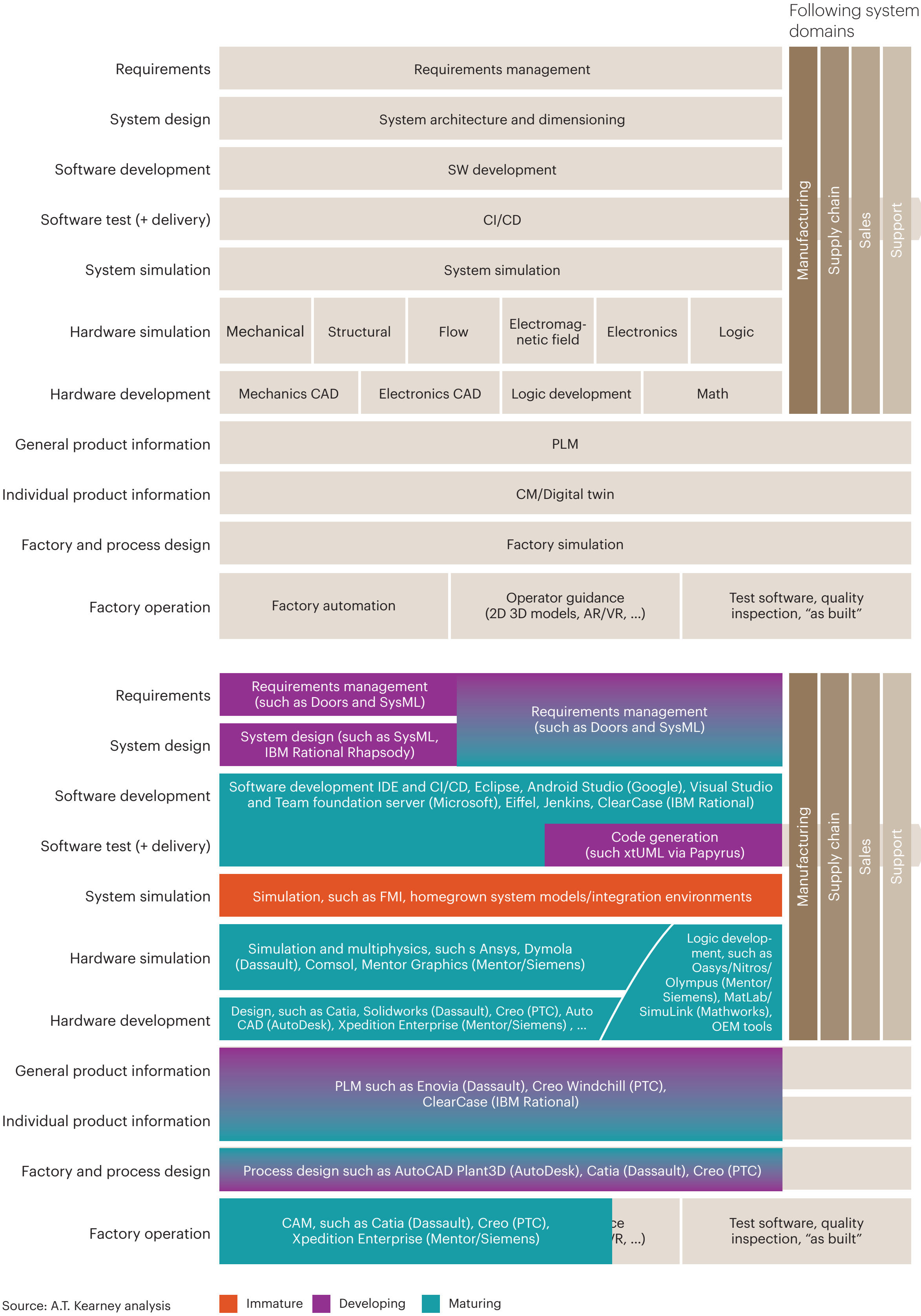
Source: A.T. Kearney analysis

Such a major mind-set shift requires a new system built for the job. While R&D organizations already use many digital tools, one that adopts digital R&D integrates them as much as possible (see figure 4 on page 7). The biggest IT challenge for a company that wants to fully adopt digital R&D is to create a cohesive system stocked with the right digital tools that allow easy transfer of the more detailed hardware and software models into the larger continuous-integration environment. Most companies lack this capability.

Some manufacturers, however, are leading the way by developing a full, continuous system-integration and simulation environment as a part of the development of a next-generation product. It uses a state-of-the-art model of the product as well as the typical environment that it is operating in. The system allows each engineer to integrate a new module, software, or modeled hardware, into the e2e integration environment, which runs simulations and tests to verify the new design (valid for hardware only, hardware- and software-embedded systems, and software-only systems). This can be done from each engineer's own desktop.

Many off-the-shelf tools have simulation capabilities for parts of designs. Simulia by Dassault can simulate mechanical designs. Modules with complex control logic, including hardware and software, can be designed and analyzed using the MatLab tool suite. Software can be modeled in xtUML, which can even autogenerate code from these models. Continuous integration and deployment for software is supported by an integration environment such as Eiffel and Jenkins. Advanced electrical circuit design can be modeled and supported by tools such as Simulink. Complex hardware can be modeled and analyzed using advanced CAE tools, such as Ansys or Dymola, while the regular design and drawing of a new hardware part is handled by competent CAD/CAM tools such as CATIA or Creo. The latter system also provides excellent process and factory simulation capability to secure best-possible design for manufacturing and assembly.

Figure 4
Digital tools can be integrated across the R&D landscape



Source: A.T. Kearney analysis

To capture correct user requirements, companies are investing in user-centric simulation capability. Some companies operate systems that allow customers to test new product features—before they have been designed and integrated. This ensures that the specifications and requirements for new functionality and features are as good as possible. In white goods, developers use AR and VR to closely approximate the look and feel of a new product. They can capture the requirements later in a dynamic object-oriented system.

Finally, PLM systems are crucial to keep track of items including system and product configuration, change orders, bills of materials, and bills of processes. There are several competent systems available, including Enovia and Windchill.

Revamp the Operating Model to Reap All the Benefits

Assuming R&D has become as efficient as possible through lean and agile practices, there will be further adjustments to gain the full benefits of digital R&D (see figure 5). The most substantial changes reflect the five characteristics of digital R&D discussed above:

Capturing and validating customer needs and requirements. Digital R&D lets developers closely manage the customer dialogue from the requirements through validation phases in a structured way by collecting constructive input. There is also an explosive amount of data available from customers as well as from products in the field and the surrounding environment. R&D will need the ability to capture and draw conclusions from this data for product and system design, and later for optimization purposes.

Figure 5
Gaining the full benefits of digital will require changing the R&D flow

Customer validation	End-to-end system-level continuous integration	Integrated digital teamwork	Artificial intelligence and automation	Connectedness and nurturing
• Customer dialogue at requirements phase and when development is done for validation	• Sub-system level development and testing, in separate domains • Final testing done on first prototypes	• Domain specific system landscape • Domain-separated development • Design-sharing "when done"	• Capturing automation capabilities in domain specific systems • Patchwork of handover between systems	• Limited interaction with released products • Product maintenance and lifecycle management left to separate organizations
↓	↓	↓	↓	↓
• Modelling flow aimed at customer interaction (for example, create early visualization) • Customer involvement through the entire process to ensure early validation	• All development in a fully soft model environment • Use of system level continuous integration environment • Final testing used to improve continuous integration environment	• Integrated system landscape • Concurrent design work across multiple system levels • Broad cross-functional collaboration • Open eco-system with close supplier collaboration	• Leverage of automation and AI tools • Continuous investment in enhancing automation and AI and applying automation and AI to the integrated systems landscape	• Organization to "live with the product" in an interactive product lifecycle, with continuous updates • Systematic and ongoing capture of product feedback

Source: A.T. Kearney analysis

Continuous e2e integration. R&D will translate continuous integration, which is common in agile ways of working, to the entire system. It would use increment planning in design projects to accommodate the different design cycles of hardware and software across subsystems. This approach helps bridge gaps that appear when large projects with many teams have to coordinate, and it reduces instances of people entering information twice. All teams support a common baseline by committing to continuous delivery of improved models of their subsystem. They will then have access to the baseline for their own testing and verification.

Teams would organize their work in sprints, where each delivers an updated model. (Hardware teams may not participate as often.) Teams come together for joint planning at regular increments, which they can also use as deadlines for having new functionality in place to cross-test and establish the most optimal order for function growth. This methodology streamlines the V-model for product development we discussed earlier. Verification and validation at the system-integration level can now be done continuously and in parallel with lower-level design activities.

To support all of the above, the company will strengthen key roles, including chief architect, chief engineer, and the increment-planning functions. (Empowering these positions may alter the traditional roles of line managers, who will need to focus more on skill building and supporting activities.)

Driving teamwork. Project teams should be staffed to enable them to work concurrently across the system, subsystems, and modules. While the whole system and product should grow more or less concurrently, some architecture work still needs to be completed up front to lay the foundation. All team members work on the same information set, and different organizational functions contribute as the product models mature. For example, industrialization engineers can help lay groundwork for manufacturing. Sales can prepare customer material and after-sales processes and documentation. Suppliers are invited into the same digital environment, where they can contribute to the growing model in real time.

It will be just as important for engineers to expand their role to support efficient, concurrent teamwork as it is for them to broaden their skills by training in the new digital tools and operating model. All the while, they will need to maintain their expert status.

Full use of AI and automation. There are many ways R&D can automate and use AI, with an explosion in yet more ways coming. Continuous adjustment is the best way to capture these opportunities. For example, remove manual steps, automate test coverage, and reduce paper-based working, because the model will be the document. These changes will have a substantial impact on the organization's capabilities and require skill-building in new tools, and new ways of working and approaching design. Perhaps the biggest change will be establishing the capability to build, improve, and refine AI, analytical tools, and the automation R&D adopts. Traditionally, the R&D organization focuses on applying available tools. In digital R&D, it will also need to work with them continuously.

Product connectedness and nurturing. The Internet of Things (IoT) and the ability to connect to the product are driving fundamental changes. To keep an ongoing relationship with the product, R&D will adjust to accommodate these technologies. Products can be released as "minimum versions" that are upgraded later with new functionality. The software design flow can release updates and upgrades periodically, and there can be dedicated R&D flows for adding other value, such as information, to the products. Quality management and product maintenance can be more targeted and proactive. Connected products will also generate massive data volumes, as we mentioned in this section's first point, so adequate capacity to capture and manage its value will be vital.

Use Digital R&D to Drive Digital Manufacturing and Supply Chain

Ultimately, manufacturers that want digital R&D to work fully for them will have it drive digital manufacturing and supply chain as well. Taking these areas digital offers even greater flexibility, automation, and agility (see figure 6).

Figure 6
Digital R&D is the engine that drives digital into manufacturing and the supply chain

Digital factory design

Enable flexible production: batch size of 1:

- Digital model of factory
- Simulation of production flows
- Simulation and design of flexible production
- AI for factory optimization
- Manufacturing simulations

Product configuration

Enable "design to order":

- Tools for automatic design customization: configurators, parametric design, AI supported, algorithmic design
- Feasibility, design simulation
- Automatic setup and programming of machinery and assembly lines

Digital manufacturing

Enable "lights out" manufacturing:

- Design for manufacturing, assembly, and automation
- Additive manufacturing
- Automatic setup and programming of machinery and assembly lines
- AI for machinery training
- Exhaustive monitoring and feedback from manufacturing into design
- AI for design improvement

Digital supply chain

Enable agile supply chain:

- Information transparent
- Flexible, with capability to re-plan
- Short lead-times
- Seamless to product configuration

Source: A.T. Kearney analysis

Start with a digital factory and process design. In the same way a product can be built and simulated digitally, so can a factory. Simulate, using CAD, AI, and analytics as needed to determine assembly station setups, and production flows and processes—all for planning a factory that is as flexible and capable as possible for managing different products and batch sizes.

Optimize manufacturing, assembly, and automation as products are designed. Industrialization issues would be worked on concurrently with product design thanks to cross-functional teamwork. Use the product model in the factory. For example, simple 3D viewers or more sophisticated AR/VR assembly instructions could guide factory workers. Use additive manufacturing to realize drastically different designs. Fully connect machinery for seamless transfer of networked computer instruction as well as for health monitoring and control. Connected machinery can also capture quality and other forms of data vital for design updates. Ultimately, digital manufacturing can create a fully automated "lights out" factory.

Digital goes to the supply chain, too. While its flexibility and agility are dependent on many things, digital R&D can be instrumental for making information transparent, shortening lead times, and seamless product configuration. Exchange information with suppliers, especially when using multi-sourced parts in a design. Use AR/VR to view field-installation instructions.

Finally, there is product configuration. Many products are configurable (automotive, for example), and their modular architectures and variants can be managed in the digital R&D system for design-to-order capabilities. A combination of reused models, configuration rules, and highly integrated links with product configurators and sales systems open up a realm of possibilities for reconfiguring products. Then there are product types based on parametric design or more freeform design, such as construction of buildings. For these, the product is created during the sales process with the customer, and the digital R&D systems seamlessly forward the designs and assembly instructions to manufacturing.

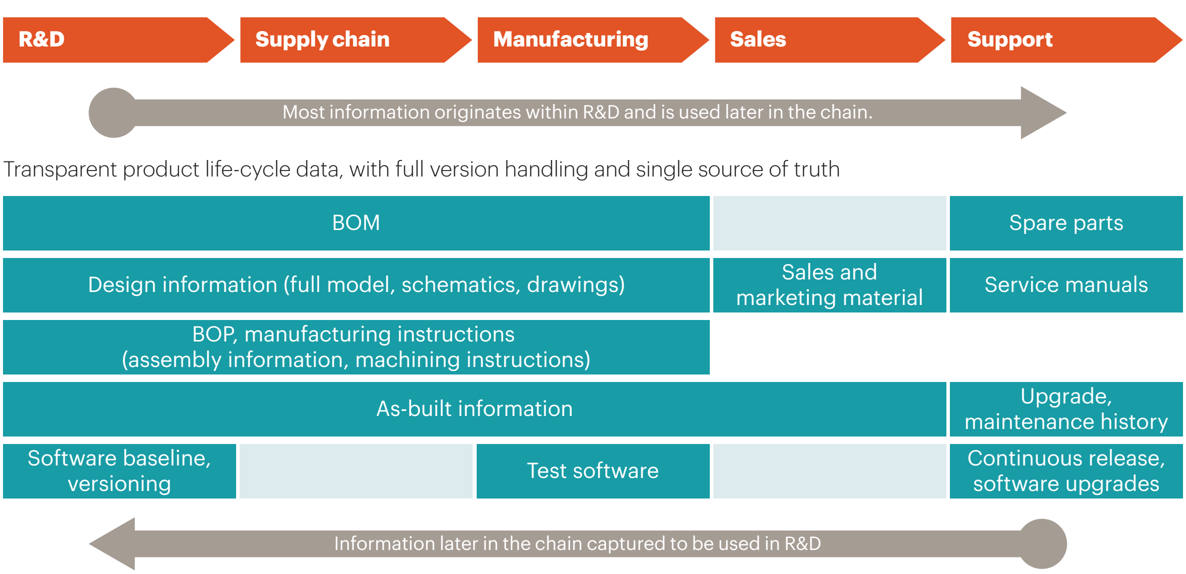
Digital R&D Touches the Entire Product Life Cycle

Digital R&D's influence extends further down the chain. We mentioned that IoT and connectedness will present new possibilities for the installed base of products. Sales and marketing will draw on the product models and designs. Installation organizations will get pedagogical and visually appealing instructions. Service and maintenance organizations will connect directly to products and receive an up-to-date view of how they are configured and what version they are so they can perform remote maintenance and provide proactive support.

At the foundation is a comprehensive and integrated PLM system, which ensures a single source of truth and quality of information. Comprehensive use of a PLM system improves efficiency at the R&D stage and throughout the entire product life cycle (see figure 7).

Figure 7
Digital R&D ensures efficient management of the product throughout its life cycle

Integrated PLM system for efficient information flow



Notes: PLM is product life-cycle management. BOM is bill of materials. BOP is bill of process.
Source: A.T. Kearney analysis

There should be great respect for the large amounts of data that R&D and the whole company will capture, treat, and manage, to the extent it will become a specific capability—through analytics and AI—to gain the most benefits from the resulting data explosion.

How to Implement Digital R&D

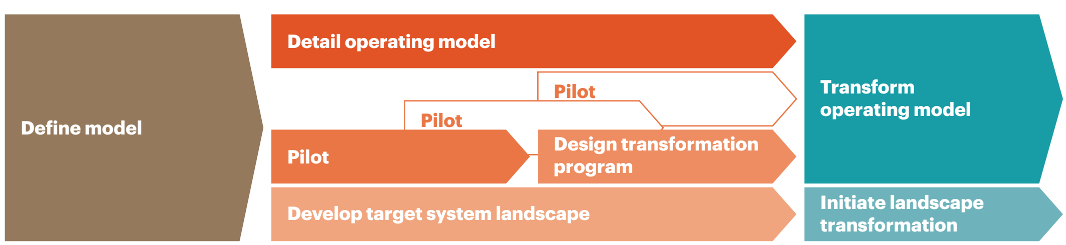
Digital R&D is a crucial, comprehensive transformation of the R&D organization. It is not only about adopting digital tools, but is a fundamental shift in the operating model that will let the organization reap the full benefits of going digital.

A transformation of this magnitude takes substantial effort and requires a long-term mind-set. Hence, it is worth investing in a thorough definition of the transformation program, using a comprehensive model that is piloted and tested first (see figure 8).

Figure 8

A typical transformation would build a comprehensive model that is then tested through piloting before rollout

Typical approach



Key activities

Define model

- Assess the development challenge.
- Map out current development model (project structure, roles, project portfolio, development approach).
- Review best practice model.
- Develop new high level model.
- Make broad outline of transformation program.

Detail operating model

- Identify gap between target and current model.
- Detail elements that do not require pilot testing, such as governance and organization.
- Identify potential transformation initiatives.

Pilot

- Identify pilots on isolated aspects of the targeted model, such as specific use cases and process development.
- Run pilots.
- Extract learnings and adjust.

Design transformation program

- Draw implications of pilots.
- Draw implications of model detailing.
- Translate into transformation program.
- Develop a target tool landscape.
- Identify gaps.
- Identify transformation needs.
- Analyze logical order for IT transformation.

Develop target system landscape

- Draw implications of model for tools landscape.
- Map out current tools landscape.

Transform operating model

- Run transformation initiatives.
- Track results and adjust.

Initiate landscape transformation

- Initiate activities for key system transformations.
- Identify transformations that can be made in isolation, to reduce complexity.
- Identify potential tools suppliers.
- Initiate transformation process.

Source: A.T. Kearney analysis

Key steps include the following, some of which are done in parallel:

- Define the targeted operating model for digital R&D (how to work, not the system landscape).
- Pilot key components of the targeted model to test them (for example, run development projects).
- Detail the targeted model in parallel with the piloting and based on the pilot results.
- Map out the current system landscape and build a target system landscape. Identify needed changes.
- Identify transformation initiatives, and plan a program for changing the operating model.
- Run the operating-model program and track results.
- Run the program for transformation of the system landscape and track results.

There are a number of areas to address when designing the new operating model, including governance, ways-of-working, and organizational needs.

Here is a checklist:

- R&D strategy: how to define, implement, and maintain it
- Key performance indicators, other measurements, and continuous improvement processes: what to measure and how to continuously improve
- Requirements handling: how to define requirements and manage them (together with customers) throughout the development
- Architecture management: how to define, implement, and maintain it
- Product development processes (hardware and software): all governance and ways of working with these processes
- Model and module repository handling: how to work with them for reuse and long-term evolution
- Development and simulation environment: how to set up and maintain the tools landscape
- Documentation and product information: how to document and support quality of product information through the life cycle
- Industrialization: how to leverage digital R&D to efficiently industrialize into digital manufacturing and supply
- Process repository: how to work with production processes for reuse and long-term evolution
- Ecosystem: how to leverage eco-systems within the product and as complements to the product
- Launch management: how to ensure that all aspects of a launch are in place when the product is ready
- Team: how to ensure efficient teamwork
- Culture: how to build a culture that embraces Digital R&D

Addressing all these aspects is not an easy task, nor is changing the system landscape. We are convinced, however, that fully implementing digital R&D is not only necessary for manufacturers to remain competitive in a more digital world, but it will also be rewarding and fulfilling for the R&D departments that will work in these new ways.

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