VDC Research
Insights for the Connected World

VDC White Paper

Accelerating Time-to-Innovation through Multi-Engineering Domain Integration

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Introduction

Over recent years, embedded systems have become increasingly complex. They are more intelligent, sophisticated, and connected. In this intelligent system ecosystem, software has become the chief currency of business operation and the primary vehicle of corporate differentiation. The emergence of this dynamic is not new, but the pace of its evolution has accelerated. Ever more software content is required to meet new, more sophisticated functionality specifications within shrinking time-to-market windows. This dynamic is especially pronounced in industries such as automotive where differentiation in the eyes of a consumer is now as equally driven by infotainment user experiences as by powertrain or suspension. In fact, many of these systems are now best described as complex systems-of-systems with it becoming increasingly common for cars to have greater than 100 Electronic Control Units (ECUs) and more than 100 million lines of software code. These marvels of mechanical system integration are now being reshaped by a new amorphous medium – the Internet of Things (IoT).

Product engineering organizations' desire to leverage interconnectivity has become a new catalyst for change, influencing design requirements and corporate business objectives. Connected embedded systems are not new; however, what is new is the frequency and depth to which Original Equipment Manufacturers (OEMs) and deploying enterprises are embracing these features as the foundation of their new product's value-add. Within the automotive domain, IoT has emerged as a key mechanism for systems integrators, OEMs, and dealers to deliver new services to improve end-customer experiences while developing new revenue streams through functionality-based upgrades, media or content distribution, and/or location-based concierge services.

Background on VDC

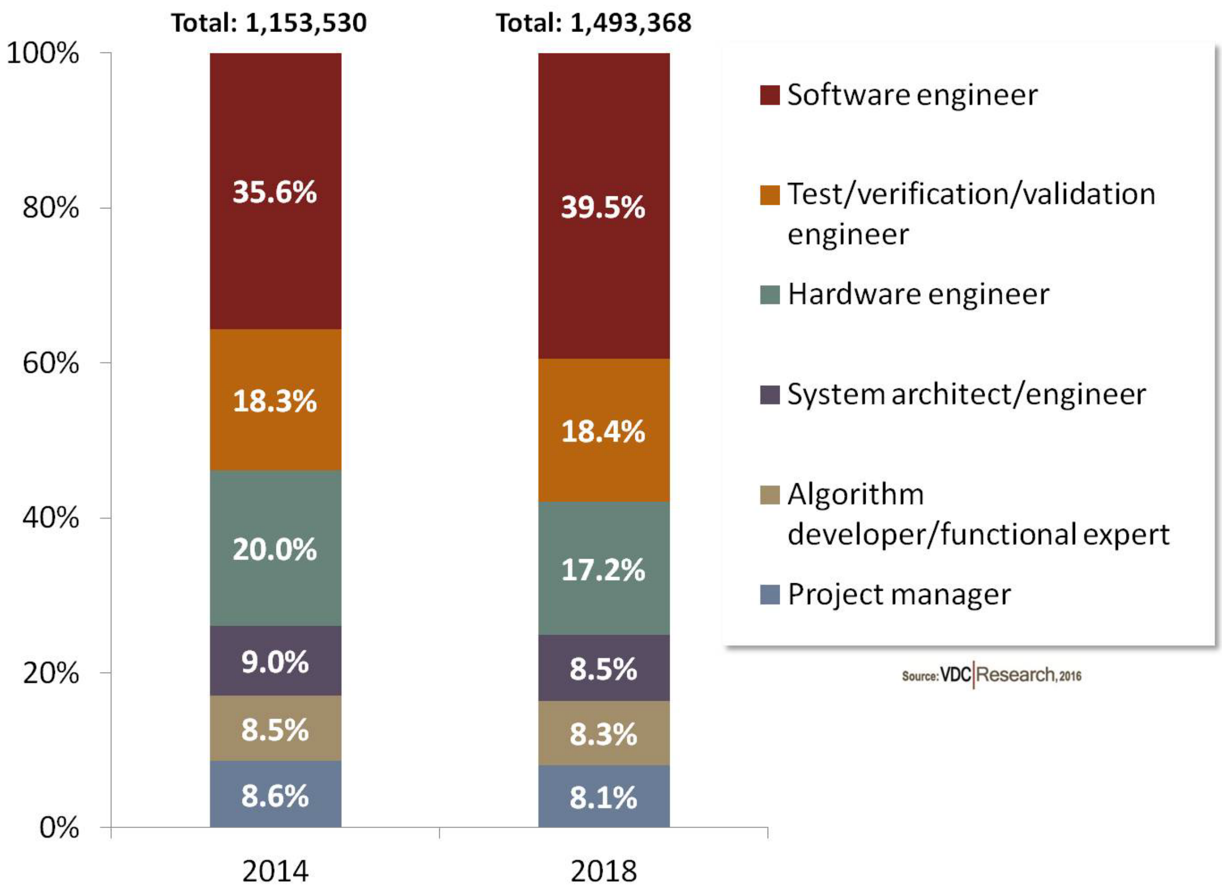
VDC has been covering the embedded systems market since 1994 and the use of lifecycle management solutions since 2000. The findings from VDC's 2015 IoT and Embedded System Engineering Survey capture the input from more than 800 engineers and form the basis of the data and charts used within this paper. The survey respondents are directly involved in software and systems development, across a range of industries such as automotive, aerospace and defense, consumer electronics, industrial automation, medical, and telecommunications.

New Product Innovation Requires Integrated Systems Engineering

New functionality goals and system requirements are making multi-domain integration critical for success. Traditional siloed workflows enabled by bespoke integrations and handoffs cannot provide the efficiency and visibility required to effectively respond to rapidly evolving market demands. Engineering organizations must identify new ways to improve schedule, agility, and end-product quality. To do so, they must reassess incumbent processes and tool infrastructures. New frameworks for integration are required in order to enable the reuse, coordination, and holistic lifecycle management needed to accelerate time to quality. Many traditional and incumbent solutions are simply no longer adequate.

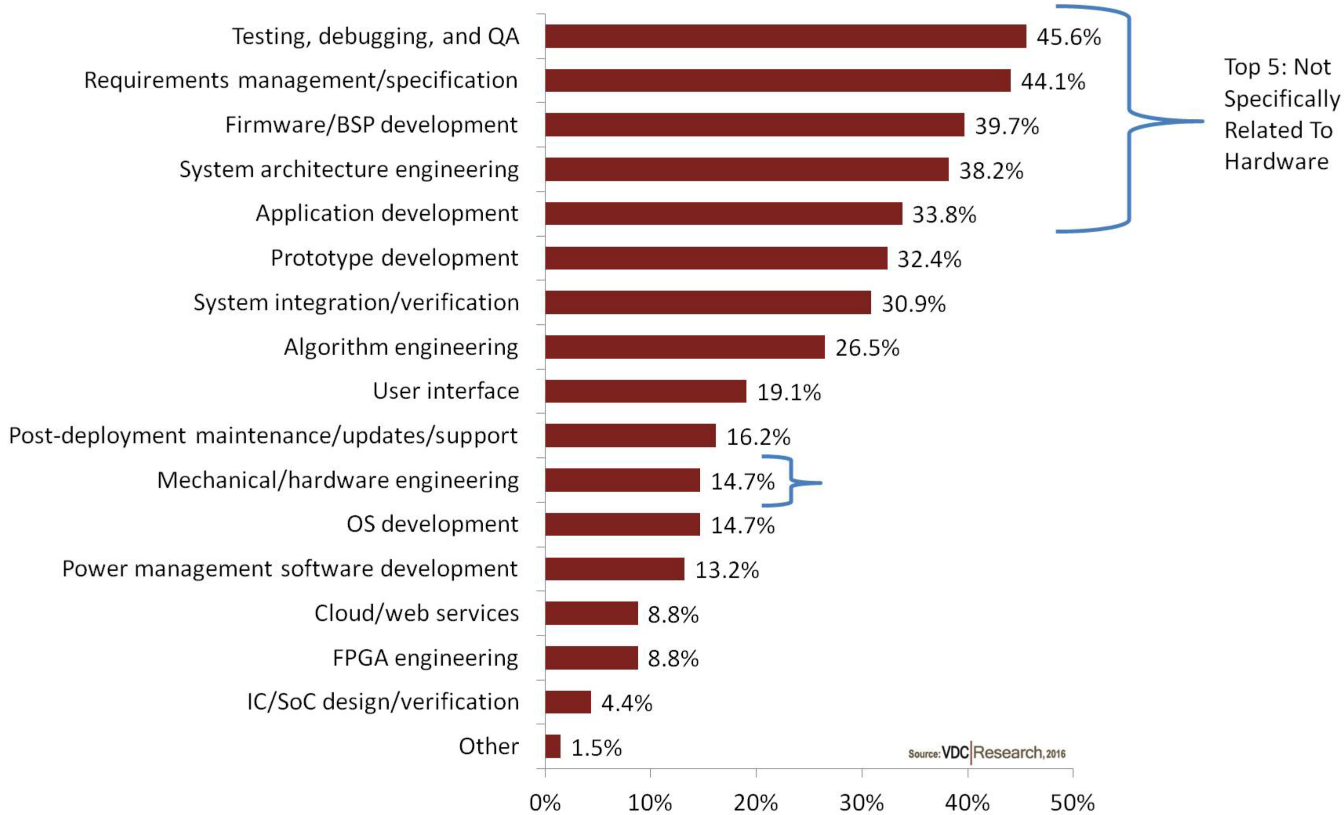
Exhibit 1: Worldwide Population of Embedded Engineers Working for OEMs, Segmented by Primary Engineering Role

(Percent of Total Engineers; VDC Estimates)



Consider that the overall embedded ecosystem is composed of billions of devices built by millions of engineers working for thousands of organizations. There are more than 1 million embedded engineers working at OEMs alone – a growing population that already translates to more than $100 billion dollars in labor spend invested annually by OEMs to bring their products to market. To build the next generation products, we estimate that embedded engineers will continue to invest more of their time on software engineering and less on hardware engineering roles and we expect that the trend will continue [See Exhibit 1]. We believe OEMs must optimize their Research and Development (R&D) budgets by finding ways to streamline productivity and development tools needed for the embedded engineers. As more organizations attempt to contend with and adapt to the dynamics required to be successful in the embedded market, it will be increasingly critical for them to identify the integrations and synergies needed to speed time to market and improve labor productivity.

Exhibit 2: Engineering Tasks Personally Involved in for the Current Project
(Percent of Automotive Respondents)



**Note: Sums to greater than 100% due to multiple responses.*

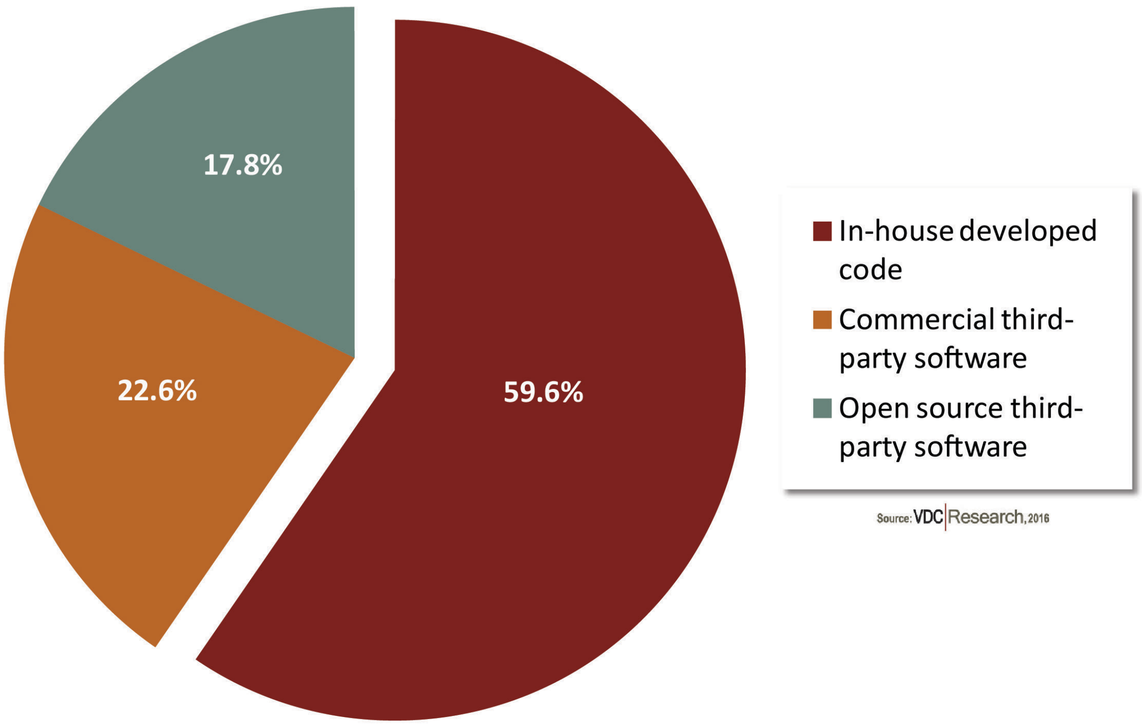
Furthermore, many engineering organizations are already undergoing a transformation. More engineers' roles have evolved to incorporate engineering tasks outside of their primary discipline, with many reporting time spent in a wide range of other functions [See Exhibit 2]. For example, mechanical engineers and Integrated Circuit/System-on-Chip (IC/SoC) designers now report spending an increasing amount of time developing software. As much as this shift is indicative of the increasingly amorphous job functions, it also demonstrates the need and value of bridging communication and skill gaps among cross-disciplinary teams. Out of design and necessity, more organizations are looking towards software/system models, platforms, and integrations to identify new areas of synergy and labor cost savings across these various engineering domains.

New System Requirements Magnify Existing Challenges

While emerging industry trends and pressures are creating new engineering and business challenges for development organizations, they are also amplifying existing problems. One of the largest and most persistent issues facing the industry is schedule adherence. In fact, over 40% of the surveyed engineers reported that their current projects are behind schedule. While delays are seldom caused by only one issue and often differ for each organization, there are consistent themes that highlight some of the challenges facing the industry. For example, “software complexity” is the most common issue cited as impacting schedule. This challenge is not a new obstacle; however, it has been cited by our survey respondents as the biggest challenge impacting schedule performance for years. The characteristics of embedded system design that led to many schedule shortfalls and fueled the development of unique processes and solution ecosystems will only grow more acute going forward.

The increasing complexity of embedded software development is placing even further stress on engineering organizations. No other engineering discipline (i.e., electrical or mechanical) must simultaneously balance requirements for creative innovation with sheer increases in productivity. The engineers we surveyed expect in-house code bases to grow by nearly 20% for their next project. This is a rate faster than for IT and far outpaces what could be expected through organic headcount additions or productivity gains. Although code growth rates from center-stack applications are a key driver in the automotive industry, code growth continues to increase across ECU types. The integration of more powerful microcontrollers in these designs provides the power and memory capable of running formal, third-party operating systems and more sophisticated software stacks. IoT initiatives are also driving more organizations to develop software components with which they have little, if any, relevant prior expertise (e.g., communications stack design). Furthermore, the IoT is enabling engineering organizations to pursue software as a new product offering itself – whether in the form of discrete applications or services, or through the evolution of existing product functionality via over-the-air updates.

Exhibit 3: Percent of Total Software Code in Final Design of Current Project by Origin
(Average of Automotive Respondents)



The distribution and sources of software code are also changing. In order to meet the content creation demands, organizations must leverage more sources, whether generated from models or other internal designs, or derived from third parties. While more organizations are embracing this diversification strategy out of necessity, it also creates additional supply chain management and potential quality issues. Code quality and intellectual property issues become an increasing burden, especially in automotive where the tiered, hierarchical nature of the supply chain can obscure visibility into development and process quality. Already, automotive respondents indicated that nearly 40% of their software code is being leveraged from from commercial or open source third parties [See Exhibit 3]. Managing the volume and compatibility of software content between sources – both during development and post deployment – further complicates the product lifecycle management process.

The changing composition of embedded software code bases is also augmenting security concerns. For one, the volume of software content now created devalues many traditional software quality assurance techniques. For example, traditional manual and dynamic testing do not effectively scale with code base size increases. The aforementioned expertise gaps also expose product development organizations not traditionally focused on security – or even on connectivity – thus making errors more likely to be introduced. In addition, the growing use of third-party software code can expose organizations to additional risk if the content is not sufficiently tested.

The growing security risk facing automotive systems is becoming increasingly apparent to both OEMs and end users based on recent high-profile hacking incidents. Poorly architected, designed, or managed software assets can have especially dire consequences based on the safety-critical and deterministic requirements for many automotive systems. The high number of ECUs, with multiple interfaces, often with overlapping software controls, further complicates this dynamic. Meanwhile, engineering organizations are under pressure to consolidate previously discrete ECUs into single integrated systems whose independent runtimes then need to co-exist on the same system-on-chip (SoC). This trend then introduces additional software and system architecture problems as well as further security risks. Many automotive firmware engineers simply lack the experience managing shared memory resources within asymmetric heterogeneous processing platforms.

IoT Market Dynamics Requires Process Change

The new IoT market dynamics and engineering requirements are challenging the efficacy of existing development processes. Time-to-market pressures and the increasing volume of software content being created for embedded devices are reinforcing the need for greater automation and collaboration between project teams. In order to accelerate development, OEMs are now looking for new ways to parallelize design tasks and focus resources on differentiating software feature sets. As in IT, these new development priorities have driven embedded engineers to adopt Agile methods in greater frequency.

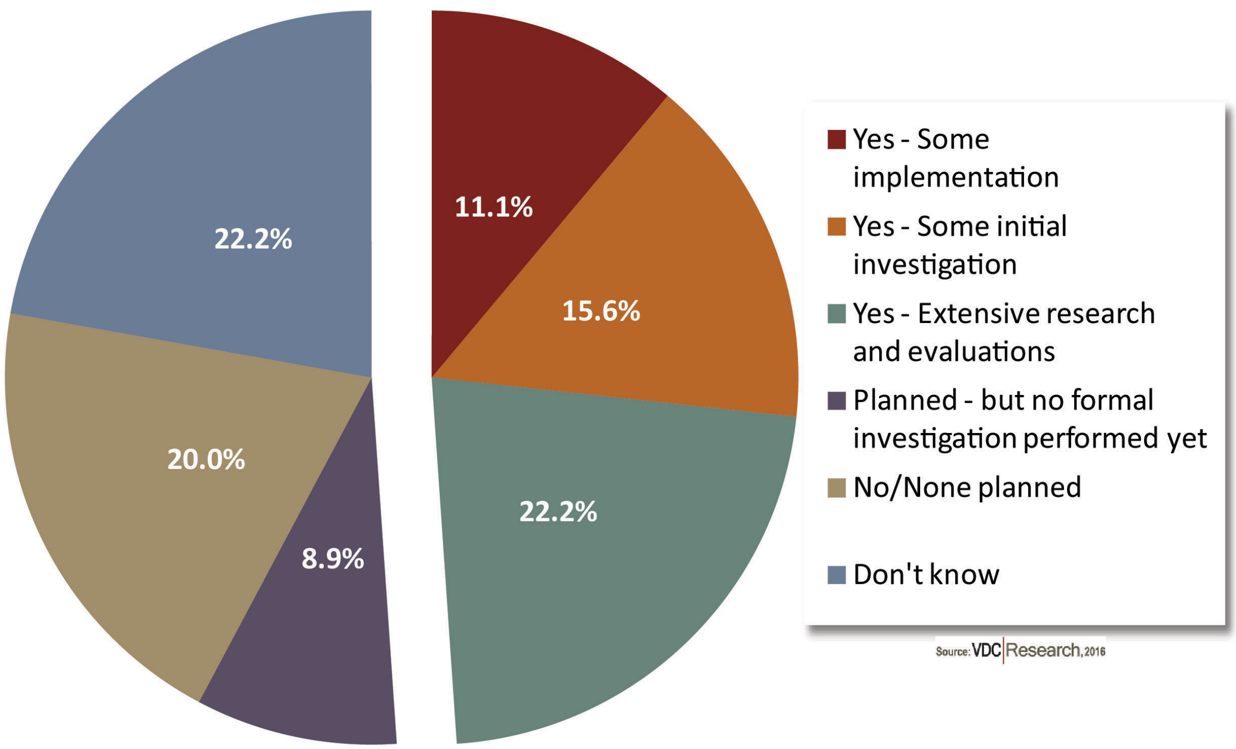
More Embedded Engineering Organizations Embracing Agile Development

Although Agile's adoption in the embedded market initially lagged that within the IT application development domain, more of these organizations are now experimenting with its implementation. The embedded system manufacturers, however, must contend with a variety of other challenges, such as safety-critical standards compliance, variant management, and multi-disciplinary systems engineering. Embedded OEMs must identify new ways to leverage best practices from iterative design, while maintaining (and often enhancing) the levels of engineering rigor within their development processes. In many instances, this more pragmatic approach to systems development has led to a hybridization of principles from Agile with traditional serial or V-model workflows. Even in safety-critical projects, more engineers are adopting aspects of iterative design. New frameworks have emerged for the safe and consistent application of Agile principles in this context, such as through Disciplined Agile Delivery or SAFe. Furthermore, the next generation of process standards, such as ISO 26262 for automotive and DO-178C for avionics, are now being written in more neutral language to support Agile development, whereas documented adherence to some prior standards essentially required traditional V-model milestones.

As previously discussed, embedded engineering organizations must contend with development requirements that span multiple domains, well beyond those of just software for which Agile was initially intended. The aforementioned time-to-market pressures only exacerbate the need to identify new areas of synergy between functional teams and to adopt more holistic system engineering approaches. The ability for OEMs to effectively manage and optimize this multi-disciplinary convergence is quickly transitioning from an exercise in strategic planning to one of tactical necessity.

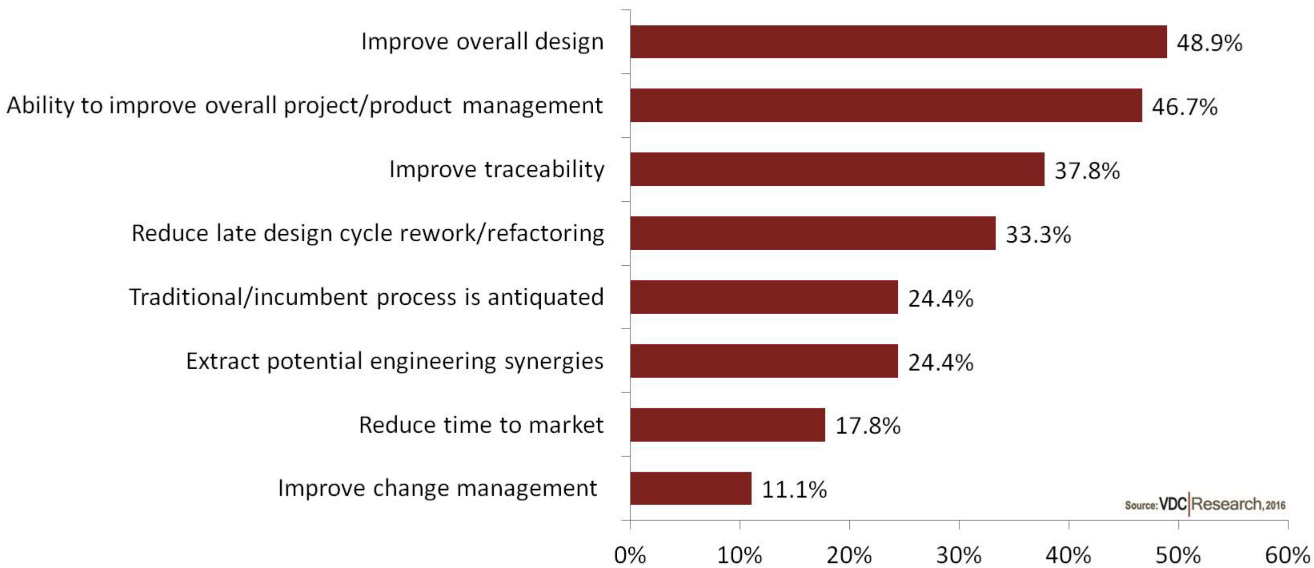
Almost 50% of Engineering Organizations Plan to Enhance Multi-domain Integration

Exhibit 4: Investigation of Methods to Enhance Multi-engineering Domain Integrations between Software/System Development, Mechanical Engineering/PLM, and/or Electrical Engineering/EDA
(Percent of Respondents)



System complexity is not only breaking down subsystem functionality silos, but it is also placing a premium on a higher level of hardware/software co-design. Engineering organizations can no longer afford to finish their work and then “throw it over the wall.” However, managing the complex system requirements and interdependencies creates big challenges. As such, more organizations are evaluating ways to integrate design and lifecycle management across all engineering disciplines. This increasing need for multi-domain systems engineering extends well beyond the integration traditionally offered between design and lifecycle management through product lifecycle management (PLM) tools. In fact, over half of the engineers surveyed indicated that they are currently implementing or planning to implement multi-engineering domain integrations [See Exhibit 4]. Within the automotive market, systems engineering is not a new development principle. However, mechanical design previously delivered the most value and was the primary gate to system integration and delivery. Now, the aforementioned importance of software-intensive systems is changing that dynamic, and driving more organizations to re-evaluate their incumbent design workflows as well as the depth of current multi-engineering domain integrations.

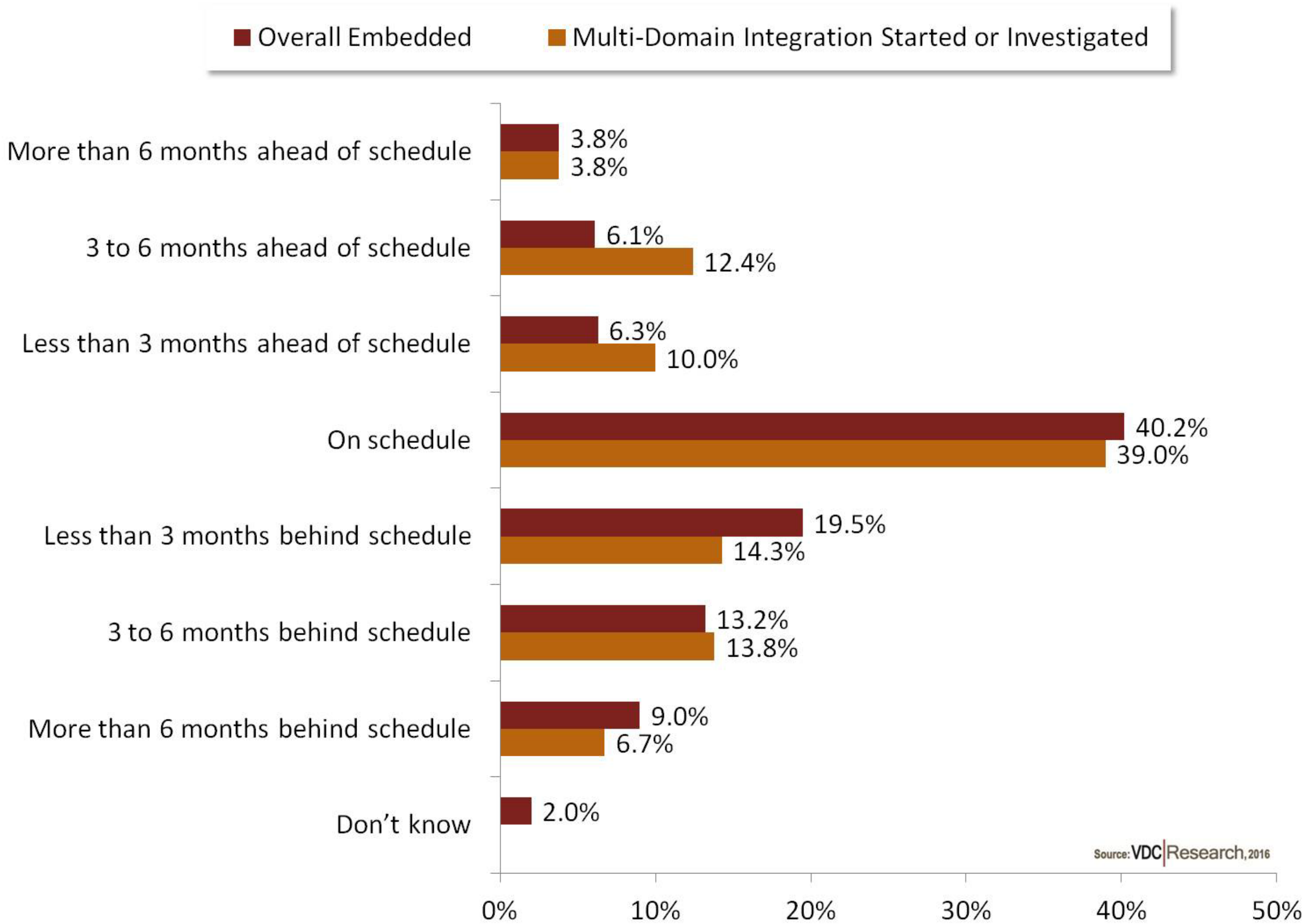
Exhibit 5: Biggest Advantages/Benefits of Multi-domain Integrations
(Percent of Automotive Respondents)



**Note: Sums to greater than 100% due to multiple responses. Not all response options displayed.*

The benefits of multi-engineering domain integration are multifaceted, offering both improved quality and time to market. And there is also growing recognition among engineers of the wide-ranging advantages cross-domain integration offers. For example, nearly 50% of automotive engineering organization respondents cite the "ability to improve overall project/product management" as a benefit to cross-engineering domain integration [See Exhibit 5]. This response is in stark contrast to results from just a few years ago in 2012 when only 27% of engineers cited this criterion. Going forward, we expect multi-domain integration to be even more important as a mechanism to improve time-to-quality/prototype. The tighter integration and management of multi-disciplinary models and requirements can ease system integration testing and validation. Facilitating and expediting this task can likewise speed defect mitigation and version iteration. In fact, engineers using cross-domain integration already demonstrate better schedule adherence than the embedded market overall [See Exhibit 6].

Exhibit 6: Adherence to Current Project Schedule
(Percent of Respondents)



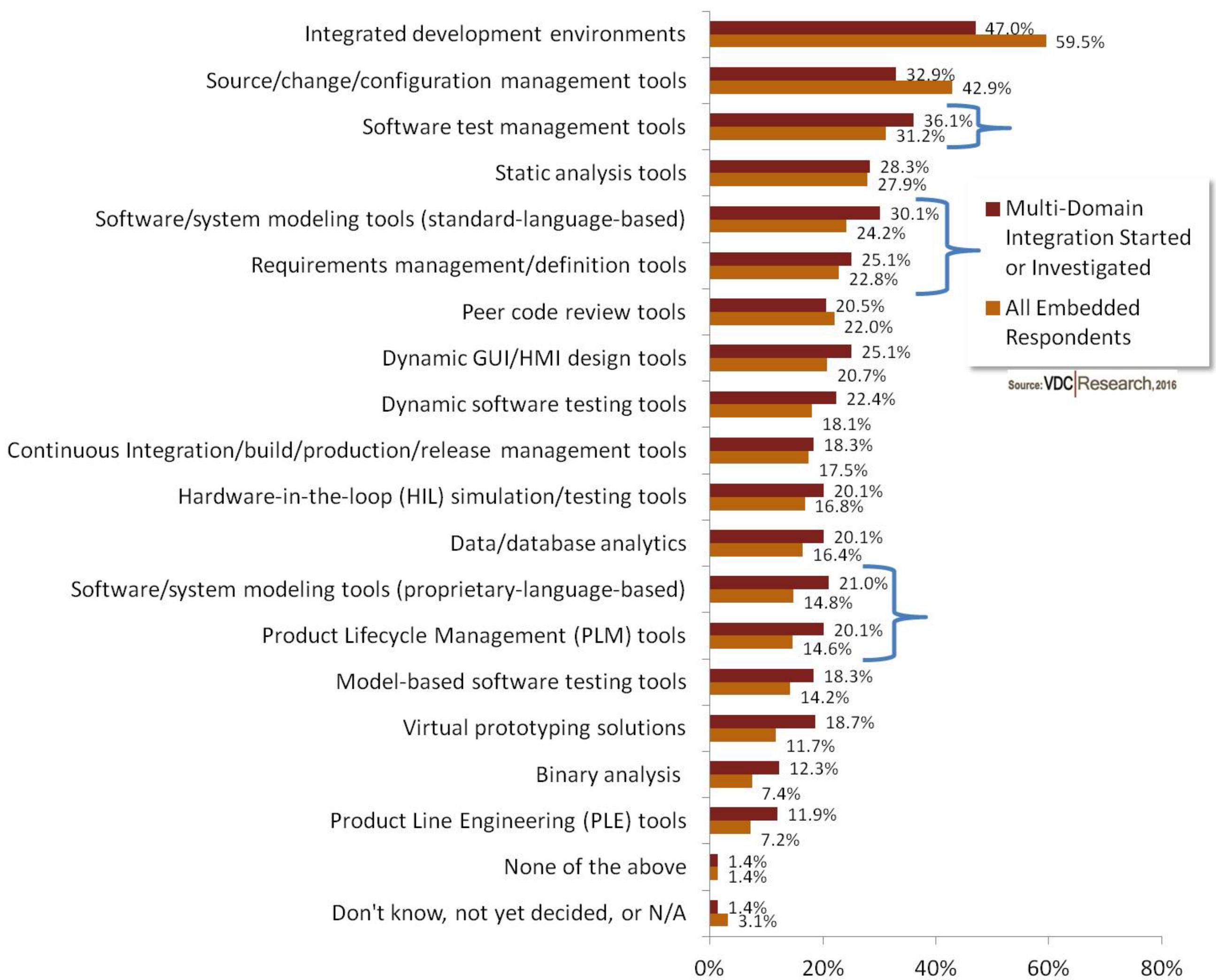
This ideal system engineering design paradigm, however, becomes even more complicated when added with the requirements of iterative design. Software innovation and development cadences are now simply much faster than traditional hardware design cycles. Bottlenecks similar to those that catalyzed the DevOps movement in IT can emerge if desires for more frequent software builds and continuous integration are paired with inadequate management of hardware requirements and changes. With Agile designs necessitating more multi-domain collaboration, engineering organizations must invest in the tooling infrastructure that can not only provide additional automation and integration, but also the framework for the traceability required for safety-critical system design.

Process Changes Require IT Investment

The need for cross-domain integration fuels requirements for more sophisticated tooling – and a more unified strategy across the enterprise – than many OEMs currently possess. Engineers implementing or planning cross-domain integration are already showing an increased use of higher-value lifecycle management solutions, such as software test/management tools, modeling tools, requirements management, and PLM tools [See Exhibit 7]. Traditionally, many OEMs have left some tool selection up to the product/project engineer level. However, siloed decision making and antiquated tooling cannot address all of today's engineering business goals.

Exhibit 7: Types of Tools Used on Current Project

(Percent of Respondents)



**Note: Sums to greater than 100% due to multiple responses.*

Successful multi-engineering domain integration requires the adoption of technologies that not only address the core development challenges that we discussed previously, but also the careful selection of solutions that align with process and industry best practice. As automotive organizations look to align themselves accordingly, we see four key trends emerging that highlight the growing importance of redefining IT investment strategies:

1. Open Standards Will Outshine Monolithic Proprietary Platforms

In the same way that isolated point tool selection can miss opportunities for broader organizational synergies, the realities of multi-engineering domain requirements limit the effectiveness of monolithic platforms aimed at addressing all engineering challenges. No single source of record or engagement can adequately scale in today's environment. OEMs must manage complex supplier ecosystems, and it can likewise be difficult to dictate or replace tooling across entire supply chains. Moreover, the complexity of and optimization required for designing today's systems-of-systems still necessitate the use of best-of-breed solutions. As such, we expect engineering organizations to place increasing value on solutions that embrace open frameworks and standards that facilitate integration, sharing, and flexibility.

2. Model-based Systems Engineering and Data-Linking Facilitate Reuse and Integration

For many organizations navigating the IoT, the transition to sophisticated code and data exchanges requires more managed analytics and automation, not less. For example, the complexity in software stacks has led to architectural flaws, which is only magnified in systems-of-systems designs. As such, modeling and simulation will gain greater importance to many organizations. These solutions help abstract system and enterprise architecture design and promote reuse.

The use of modeling solutions is already well established in the automotive industry. The use cases range from synchronous, discrete system simulation (e.g., Modelica, SCADE, or Simulink), asynchronous/system architecture design (e.g., Systems Modeling Language (SysML) and Unified Modeling Language (UML)), to mechanical Computer-Aided Design and PLM (e.g., Siemens PLM Software). The complex requirements and systems-of-systems designs in this sector will continue to reinforce the value of technologies such as modeling tools that simplify design and reuse. However, management and traceability of the content from these various design technologies, which can not only span engineering disciplines but also supply chain partners, requires evaluation of existing processes. A strategic priority is placed on integrating Application Lifecycle Management (ALM) and Product Lifecycle Management (PLM) solutions. Tool platforms that align with common and open data linking standards, such as Open Services for Lifecycle Collaboration (OSLC), ensure models can easily be shared and reused across projects.

3. Integrated Requirements Management and Automated Test Improve Quality and Traceability

Enhanced multi-domain integration is required to optimize lifecycle management for regulated industries. When working on or managing complex systems, the definition and management of product requirements is established as a foundational system engineering practice. However, recommended best practice extends beyond utilization of an integrated requirements management tool. Instead, organizations should look to link requirements through design components and to associated tests in an integrated automated test platform. This linking helps to provide end-to-end traceability that is not only important for visibility into requirements completion and change, but it is also a key tenet of design for safety-critical systems for process standard documentation purposes. Furthermore, traceability discovery and bi-directional referencing can be incredibly valuable to understanding interdependencies and conducting change impact analysis. Safety-considerations have always played a significant role in automotive ECU development, but now the distinction between safety-focused and consumer-centric software is becoming increasingly blurred in the automobile. The emergence of the center stack as the cornerstone of the automotive experience has fueled a new level of convergence between these once discrete domains, which makes managing and testing to safety and industry process standards such as ISO 26262 even more critical.

4. Common Change Management Practices Set Foundation for Efficient Product Line Engineering

More automotive companies are recognizing that multi-domain integration and the framework for collaboration it produces can serve as a foundation for needed improvements in portfolio and product line engineering. For example, while the growing volume of software content in today's in-vehicle infotainment (IVI) systems facilitates differentiation, it also complicates the management of the increasingly diverse code assets that are leveraged across product lines. Additionally, even within a given product, organizations need to look for technologies that can support variant aware design. The complex technology stacks required in the industry have been met with an increasingly complex array of localized, price-point, and consumer-controlled feature variations that can range from controlling the user interface language displays to managing wire harness variations. As such, it will become more important for engineering organizations to establish a foundation for change through common change management – not limited to software development – but across software, electrical, and mechanical domains.

Conclusion & Recommendations

Continued growth of more complex, intelligent embedded systems will not subside. Therefore, incumbent and antiquated tools and design methodologies will no longer suffice. Engineering organizations must reevaluate the status quo in order to improve – if not to simply maintain – schedule and quality goals amidst rapidly evolving customer requirements. Organizations unable to adapt quickly to today's engineering challenges will risk disruption and/or missed market windows.

Multi-engineering domain integration has emerged as one of the preeminent mechanisms through which development organizations are responding to these pressures. To maximize the potential benefit from these integrations, engineering organizations must commit to and invest in the supporting changes to their people, process, and tools. Based on this analysis, VDC offers the following summary recommendations:

- **Evangelize Change with Cross-Department Champions** – System complexity alone validates multi-engineering domain integration as a viable and needed solution. However, internal inertia and resistance to integrating previously discrete engineering disciplines remain significant obstacles to overcome. In some instances, organizations even need to consider fundamentally reorganizing the divisions within their engineering departments to remove barriers to improved collaboration. As such, it is critical to identify internal champions that can help evangelize and reinforce the principles of a multi-engineering domain approach within the ranks of each existing or traditional department division. Furthermore, this level of support, advocacy, and training must continue in the future, given the difficulties and associated learning curves that can arise from change of this magnitude.

- **Embrace Agile Software Development Principles for Systems Engineering** – Serial, waterfall development workflows no longer meet the needs of today's market place. The volume of software content to be created is too great, and the pace of change in market requirements is too quick. Agile and DevOps practices become even more valuable in the context of the Internet of Things marketplace. The continuous innovation required for success in the IoT ultimately requires a backbone of continuous integration and engineering. The IoT provides a new mechanism for feedback cycles and product use information that can be invaluable for engineering organizations to refine designs to better meet market needs. This type of shift in development methodologies, however, ultimately requires higher levels of automation and integrations across tool suites.

- **Adopt Tools from Vendors with Investments Across Multiple Engineering Domains** – More than ever, product engineering requires a focus of internal resources on points of differentiation. It is becoming increasingly difficult to justify spending time on custom point-to-point integrations instead of commercial tools with out-of-the-box functionality available. In this light, it is likewise important to recognize that not all third-party solutions are created equal. As such, we recommend that engineering organizations align their investments with those solutions that support future trends and whose vendors have invested, both internally and externally, to extend integrations beyond those within a singular, traditional engineering discipline.

These investments should also align with ALM/PLM engineering best practices and the technologies that support them (as described in greater detail in the preceding section). For one, organizations should look for solutions that utilize open lifecycle management tool standards, such as OSLC, SysML, or ReqIF. Solutions based on these standards can help ease adoption internally and provide needed levels of out-of-the-box integration with other incumbent or best-of-breed lifecycle management technology, such as modeling, requirements management, and test automation tools. When combined with a common change management infrastructure, these integrations are absolutely critical to manage the extended IoT software product lifecycles, as well as to meet the traceability and visibility requirements necessary for complex system-of-system and/or safety-critical product development.

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About the Author

Chris Rommel is responsible for syndicated research and consulting engagements focused on development and deployment solutions for intelligent systems. He has helped a wide variety of clients respond to and capitalize on the leading trends impacting next-generation device markets, such as security, the Internet of Things, and M2M connectivity, as well as the growing need for system-level lifecycle management solutions. Chris has also led a range of proprietary consulting projects, including competitive analyses, strategic marketing initiative support, ecosystem development strategies, and vertical market opportunity assessments. Chris holds a B.A. in Business Economics and a B.A. in Public and Private Sector Organization from Brown University.

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About VDC Research

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For more information, contact us at info@vdcresearch.com.