Impediments and Enablers for Shared Modelling and Virtual Verification in Automotive Model-Driven Software Ecosystems

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Abstract—Virtual verification promises huge gains in productivity of automotive systems development, especiallyl if supported by shared modelling throughout the automotive ecosystem. Yet, adoption of such techniques has proven difficult. By mapping out benefits, critical impediments, and crucial enablers, we provide help to overcome such difficulties.

1 Introduction

THE development of automotive control architectures is increasingly dependent on the use of modeling and simulation technologies. Unfortunately, the history of automotive OEMs (original equipment manufacturers) as large systems integrators of pre-allocated functionality to ECU (electronic control unit) hardware, often results in modeling and simulation technologies being deployed late in the development process, and customized to specific use cases, domains, and/or organizations. There is a lack of standardized processes for tool/model integration and management across the OEMs' engineering organizations. Understanding the underlying ecosystem of cross-organizational collaborations will allow us to properly articulate the benefits, impediments, and enablers of designing electrical control architectures using shared modelling and virtual verification methodologies.

Virtual verification based on shared models is a strategy to manage the cone of uncertainty [2], which says that uncertainty is gradually reduced as development progresses, more information about the system becomes available, and system integration aspects can be tested. Many decisions need to be made in the beginning of the development process, though, when uncertainty is greatest. Thus, the ability to give early feedback about design decisions is an important asset. Consequently, any model characterizing hardware performance before the actual silicon hardware exists can be valuable in helping to develop the embedded software earlier.

Leveraging these potentially large benefits requires change throughout the *automotive ecosystem* (see *Box 1: Ecosystem Background*). This paper presents benefits, enablers, and impediments to adoption by relevant stakeholders in the ecosystem that we found helpful to articulate the value proposition and to overcome the resistance to change, or at least possible ways to sell the value proposition. For this, we build on our experiences over the last decade, with the automotive industry in North America and Europe, the research presented in this paper is based on semi-structured interviews with a large North American OEM, its suppliers, and tool vendors, and a follow-up workshop with OEM personnel, focused on the benefits and challenges of enterprise-scale deployment of MCU (microcontroller unit) and ECU simulation models.

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2 Benefits

The potential benefits of shared modeling and virtual verification fall in two categories: testing efficiency and collaborative advantages *throughout the ecosystem*.

2.1 Testing Efficiency

Shared modeling and virtual verification will allow to:

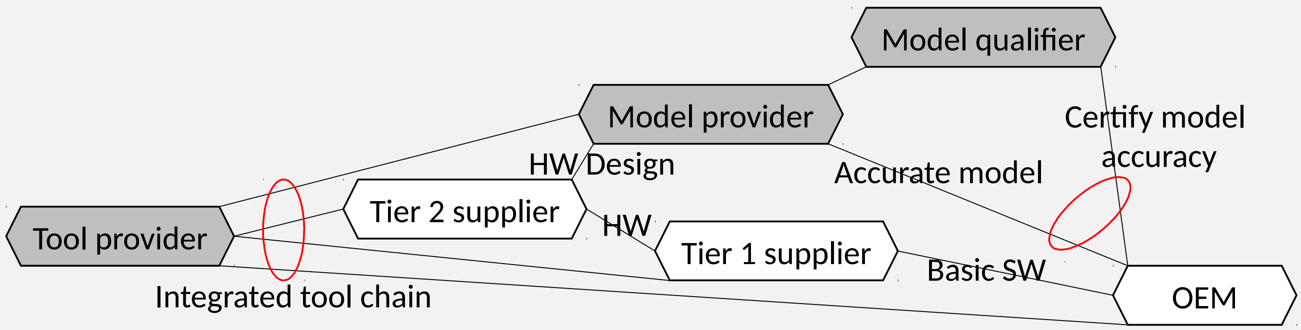
- Perform testing earlier.
- Uncovering more faults.
- Increase repeatability of tests.

Earlier Software Integration Testing

The main goal of virtual verification is to provide a means for testing the integration of software before the specific ECU/MCU hardware is available. Earlier testing could also prove very valuable by identifying issues with the microcontroller specification while it is still evolving.

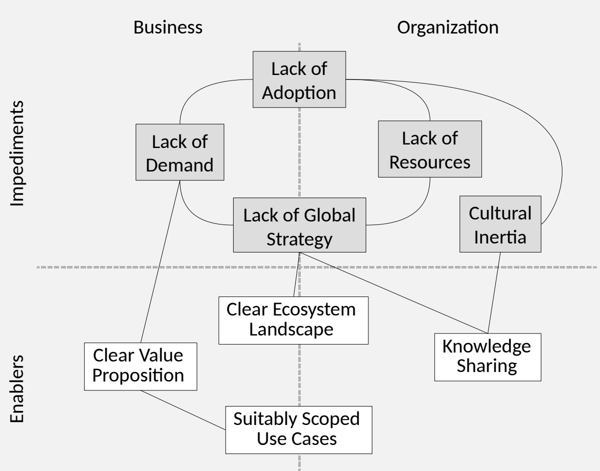
Hardware test benches are typically a heavily shared resource, resulting in scheduling conflicts and other logistic difficulties. Using models, with sufficient fidelity, reduces the need to build and physically access hardware-based test benches, in turn reducing scheduling problems. Virtual boards also support parallelization, allowing for many tests to be executed in parallel assuming the host computers have enough processing power. This could provide additional cost and time savings when compared to running tests on a physical board.

Figure 1: Ecosystem Background



The virtual platform technology ecosystem involves the model/tool suppliers, software/hardware IP suppliers, users, etc., and is described in [1]. The ecosystem is complex and may also involve the creation of new roles and responsibilities, e.g., the standardization of the microprocessor model certification process for accuracy and performance. Ecosystem roles and responsibilities are similar in nature to those found in the ECU hardware ecosystem, because there are mixed hardware and software IPs. In the hardware IP case, often times the microprocessor core provider is a Tier-3 supplier providing this device to a microprocessor provider, a Tier-2. The same scenario applies to software IPs, with platform software modules sold by one vendor, device drivers by another vendor, and the microcontroller abstraction layer provided by the chip provider. On top of these software layers, an OEM performs the overall integration.
A potential ecosystem for virtual platforms is shown. The degree of granularity and the integration levels of the different IPs, e.g. integration of peripheral models into a microprocessor model, integration of microprocessor models and ASICs into an ECU model, determines its complexity.

Figure 2: Map of Impediments and Enablers



Uncovering More Faults

Virtual testing will allow engineers to monitor, control, and observe the testing environment in a more comprehensive manner than currently possible on physical hardware. This includes easier ways to inject faults so that more thorough testing can be accomplished.

Repeatable Testing

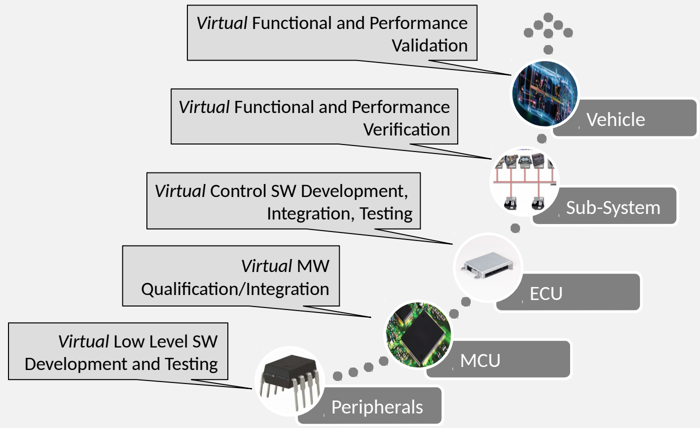
Virtual testing would simplify software regression tests on multiple (virtual) hardware platforms, that do not need to be maintained across the entire product lifecycle. This could provide a cost-efficient way to ensure backward-compatibility for software patches, or evolve software components in a product family. Running regression tests more often in a defined environment could make it easier to find bugs earlier and reduce expensive recalls.

2.2 Collaborative Advantages

In addition to increasing testing efficiency, shared modelling and virtual verification promises to support collaborations throughout the automotive value chain. For example, if suppliers are encouraged to provide models and virtual assets early in the process to their customers (other suppliers and OEMs), then they would likely embrace a model-first approach, where models of their product are delivered first, integrated and verified upstream, before the development of hardware and low level software starts. This would also benefit suppliers because it would encourage them to utilize model-driven development and virtual verification for their own internal processes. By improving the awareness and the attractiveness of virtual verification technology across the complete ecosystem, the overall process and product quality can be improved, enabling Tier-1 and Tier-2 suppliers to fully benefit from model-driven engineering.

In addition to facilitating collaboration between ecosystem actors, a shared modeling and virtual verification capability may also help facilitate the exchange of conceptual knowledge. This would provide feedback on system and software design and integration before hardware is available, significantly shortening the feedback cycle and enabling effective collaborative engineering much earlier in the design process.

Figure 3: Technology Background



Virtual platform technology is a key aspect of the ecosystem for model sharing and virtual verification, as it extends concepts such as HIL (hardware-in-the-loop) and SIL (software-in-the-loop) benches to include microprocessor models. This enables early software integration for OEMs, as well as early software development of basic software by Tier-1 suppliers. Enabling the parallel usage of these processor models among OEMs and their suppliers, can achieve parallel rather than sequential software development, whereby synchronization points are established for integration tasks and feedback loops between OEMs and suppliers.

The Virtual platform technology consists of two parts, a virtual chipset and a virtual platform for software development, integration, and testing. The virtual chipset consists of a high-fidelity microprocessor model, including peripherals and other resources that execute the target embedded software. Extending the virtual chipset with additional models of off-chip devices essentially realizes the concept of a virtual controller. Other models, similar to those required for HIL systems, are also required in order for the virtual controller to be able to emulate the behavior of the real controller's functionality and performance within a HIL bench. These include models representing incoming serial data traffic, typically in open loop, plant models (e.g., an engine), simulating ASICs running microcode, interfacing high power interfaces such as inductors to the controlled loads (e.g., electric motors, fuel injectors), vehicle dynamics, environment, etc. The degree of modeling around the virtual chipset depends on the use case at hand. In order to perform a full functional and performance verification of the controller, all the aforementioned models are needed. For use cases involving only low level software development, an open loop model providing hardware IOs or serial data traffic may be sufficient. Finally, tools for configuring software via calibrations and for software variable/signal recording may also be needed. The integration of several virtual chip sets may be necessary for sub-system and complex ECU software verification, and may require high-performance computing platforms to achieve acceptable simulation runtimes.

3 Impediments and Enablers

In our experience, any effort to introduce shared modelling and virtual verification needs to take large parts of the automotive ecosystem into account. When reasoning about ecosystems, we found it useful to follow advice from Christensen et al. as well as Tamburri et al. and analyse business aspects, social aspects (to which we refer as organizational), and technical aspects explicitly [3], [4]. Figure 2 presents an overview of impediments and enablers that we found in the business and organizational areas. We deliberately left out technical impediments and enablers, which we found to be of secondary importance. If the organization is aligned on adopting virtual verification of ECUs, any technical challenge should be surmountable, as long as resources are made available. In particular, we did not identify any insurmountable technical impediments for deployment of virtual verification platforms. Awareness of these impediments is still needed, since they will become more prevalent when deploying at scale.

Potential technical impediments include lack of *model interoperability*, challenges to *keep models up-to-date* with evolving hardware, lack of *trust in model fidelity*, and lack of protection of *intellectual property*.

Conversely, **foreseeable technical enablers** include a shared and standardized *modeling platform*, *reusable model templates* for handling product line variation points, and, standardization of for example computational ECUs, at the *system architecture* level.

With respect to **business- and organization-related impediments**, Figure 2 shows an undesirable circular dependency: Since there is *lack of demand* for high fidelity modeling technology, there's also a *lack of global strategy* for the use of virtual platform technology. Without such a strategy, there's limited personnel available (*lack of resources*), which leads to *lack of adoption*. Consequently, there is no clear value proposition for widespread adoption of virtual platform technology, therefore making it difficult to generate enough demand.

The lack of adoption is further increased by a hardware-centric, conservative *culture* that is accustomed to use HIL benches with physical controllers – indeed mature technologies.

As **business- and organization-related enablers**, we see a *clear value proposition* as crucial to breaking the circular dependency, and creating more demand. This will be helped by clearly articulating customer value, and by *properly scoping use cases* based on a *well understood ecosystem landscape*. These enablers also need to be mapped to a company strategy in order to facilitate wider adoption.

A *clear ecosystem landscape* and *knowledge sharing* will in addition mitigate the lack of global strategy. The foundation of this is sharing knowledge about what works in this area and which concrete benefits have already been achieved as well as by combining related knowledge from different initiatives. This will encourage grass-root adoption (e.g., from visionary engineers) and may in turn trigger wider adoption and then resources toward mainstream adoption. Transparency about benefits will also help to mitigate the cultural impediments.

3.1 Impediment Details

Lack of Demand

For a typical supplier, providing modeling support for users at the next higher development abstraction level would require a major investment, and would depend on customers requesting – and paying – for it. Even within the OEMs engineering community, there is no universal demand for such a virtual verification and model exchange platform. In a typical OEM, there is lack of agreement on whether such capabilities would yield a positive ROI. For example, in-house component level software development aims at being hardware independent.

Lack of Global Strategy

Without a global strategy, an OEM is very prone to the negative effects of engineering silos. In addition, knowledge is also widely spread over the different ecosystem actors.

> ”No one will ever have all the IPs at any given time. So new IPs will always have to be created/modeled costing time and money. The question is: who will model it?” – Tool Vendor Marketing Director

Lack of Resources

Ideally, the lack of a global strategy would be addressed by an explicit model team that supports modeling (maintenance, evolution, etc.). However, as our interviews show:

> ”Everybody is always focused on the ’current’ development objectives. Introducing new capabilities from a model-based engineering (MBE) perspective and institutionalizing them is very time consuming, and people have no time.” – OEM Software Development Leader

While there may be some strong support within an OEM to pursue such a strategy, resources maybe lacking especially if there is support from engineering without strong backing from leadership.

Lack of Adoption

In addition to a lack of a support organization, we found that all three ecosystem actors (OEM, Tier-1, Tier-2) are lacking expertise and experience as well. The usage of virtual prototyping tools and models, however, requires a high degree of understanding of the execution platform that needs to be modeled.

Cultural Inertia

Having mechanical roots, the automotive domain has traditionally little or no trust in virtual verification. Instead, there is a bias towards tangible ”real” hardware assets. It’s also uncommon for an OEM and its suppliers to share models. While an OEM could ask for access to a suppliers high fidelity model, there is no clear understanding on why or whether this should be done. As suppliers typically target multiple customers, their designs may have hidden functionality not in line with a particular customers data sheet, adding difficulty to sharing models currently intended for internal use.

3.2 Enabler Details

Clear Value Proposition

It’s critical to define a compelling value proposition for investing in virtual prototyping models and tools. The value proposition changes depending upon the problem to be solved, however. For example, during the initial phases of software development, the value proposition is that integration and testing activities can start earlier in the design process.

> ”Virtual prototyping means virtualizing everything in the development process, not only the MCU digital hardware. The definition of success should not be how accurate the model is, it should be whether the project objectives have been achieved, e.g. software developed and tested early in the design process.” – Tool Vendor CEO

In order to make a sizable initial investment in virtual software development palatable to ecosystem actors, incentives would need to be provided by the OEM, both internally to foster good practice, and towards suppliers that could support virtual software development. These incentives could then spread throughout the value chain.

Properly Scoped Use Cases

To support the definition of a clear value proposition, properly scoped use cases need to be communicated, so that tradeoffs such as fidelity vs. speed or functional vs. timing accuracy become well understood. Overexpectation on the level of fidelity required for models to be useful can lead to a belief that virtual verification is unfeasible. A constructive approach is to investigate whether models really need to be highly accurate, and offer guidance for a cost/benefit tradeoff. In order to realistically implement virtual platform technology, the scope must be manageable while also large enough to engage various aspects of the ecosystem, e.g., cross-organizational collaboration and new business models of ecosystem actors.

Clear Ecosystem Landscape

Many impediments relate to missing competencies and resources throughout the automotive ecosystem. Without detailed knowledge about potential business models of various ecosystem actors (e.g. hardware suppliers, tool providers, model providers, see Box 1) it is hard to define a suitable global strategy.

Knowledge Sharing

Since smaller scale pilots have been successfully implemented, one major enabler is awareness. This can be achieved through establishing transparency about the virtual verification ecosystem, its challenges and difficulties, but also its benefits and successes. Pilot studies and increasing adoption with OEMs should include documenting the experience with suppliers who are able to support virtual verification, so that it can be shared throughout the ecosystem. A strong value chain that can support one of the use cases will be a great enabler for further adoption. Specifically, the following knowledge needs to be shared:

- End users should share model requirements (e.g. speed and fidelity) that allow virtual verification of software.
- Tool vendors should share knowledge of the simulation technology.
- OEMs should share knowledge about their specific software customizations.

4 Conclusion

The focus of this paper is the ecosystem for model sharing and virtual verification. As the emerging ecosystem is still in its early stage, we share a map of impediments and enablers that we found most useful to plan the activities needed to bring about the technical and collaborative benefits. Specifically, we recommend to:

- Choose starting use cases, to clarify the fidelity needs.
- Define the value resulting from solving the chosen use case.
- Bootstrap the ecosystem by sharing knowledge and clarifying the actor – role mapping [5] .

Our findings indicate that virtual verification is a promising approach, that could improve automotive software development across organizational boundaries.

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