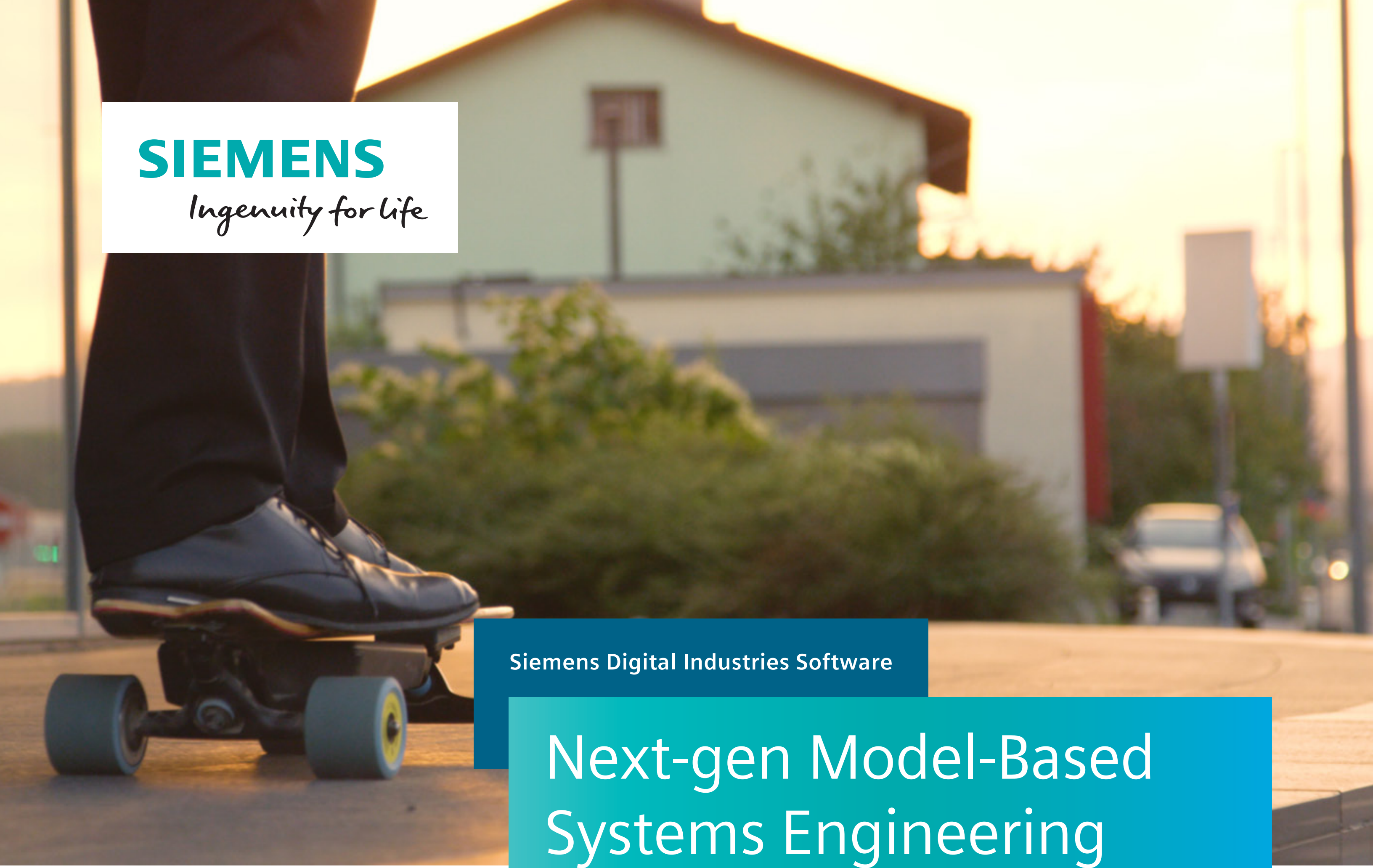

SIEMENS

Ingenuity for life

Siemens Digital Industries Software

Next-gen Model-Based Systems Engineering course

A holistic model-based approach to developing a multi-domain system

Executive summary

In the age of digitalization, traditional product development approaches are unsustainable. We need to make a fundamental change in the way we realize complex modern products and educate the engineers of tomorrow to be proficiently skilled for the technologically challenging jobs of the future.

This white paper introduces a 40-hour coursework on Model-Based Systems Engineering (MBSE) applied to a real-world example using the Siemens Digital Industries Software tool suite.

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Introduction

Rationale

21st century product development is by no means limited to a single discipline as product complexity is evolving rapidly. Moreover, the increasing realization of futuristic technologies like rapid prototyping, artificial intelligence (AI) and the Internet of Things (IoT) has resulted in a plethora of technological functionalities that can be offered within a product.

Remember when Batman could command the Batmobile to pick him up? That this science fiction is close to becoming a reality is not the most astonishing part of the story. Rather, the astonishing part is that you won't have to be Batman or own a real Batmobile to experience this. Yes, self-driving cars are in sight! But what does this imply? These cars would be made up of sophisticated mechatronic components coupled with embedded software running millions of lines of code per second and intelligent AI algorithms making decisions simultaneously, all linked together in a highly complex fashion. This is just one example among the myriad of multi-domain products being manufactured in various industries.

Hence, it has become inevitable to have a holistic, multidisciplinary perspective while developing these products. We need to make a fundamental change in the way we design and manufacture products. And indeed, a fundamental change in the way we educate college students to adapt to this revolution.

Engineering skills gap

In 2017, Tech-Clarity conducted a global survey of 201 companies to research the gap between the skills graduating engineers have and the skills companies would like to see. A majority of these companies (69 percent) projected their engineering department needed to grow in the next five to 10 years, and the top challenge of managing the engineering workforce is finding the engineering staff with the right skills. In the published report from Tech-Clarity[2], systems engineering was identified as one of the top 10 skills that students are not properly prepared in at engineering schools.

The 1989 Batmobile from the Batman film was one of the earliest pop culture references to autonomous driving.[1]

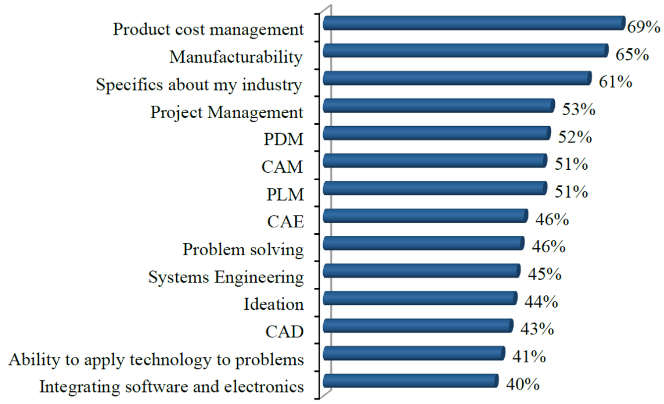

Figure 1: Top skills students are not properly prepared in at engineering schools.[2]

Systems engineering is an interdisciplinary field of engineering and engineering management that focuses on designing and managing complex systems over their lifecycles. MBSE is a formalized approach to performing systems engineering activities using computerized models. Enabling students to gain early exposure to MBSE during their engineering studies will contribute greatly to narrowing the systems engineering skill gap. Towards this goal, Siemens Digital Industries Software has designed a next-generation MBSE course that will provide engineering students the necessary insights into modern product development approaches and first-hand experience in using the digital tools that support those processes, with a real-life product example.

The scope of this course is to provide a thorough and simplistic view of the MBSE approach used in modern product development to academia, based on which university professors can develop their own sets of curricula. Students can gain the necessary insights that will prepare them well for the technologically challenging jobs of the future.

This course aims to achieve the following objectives:

1. Provide an overview of the generic product development process using systems engineering currently practiced in industries
2. Introduce MBSE as complementing the current product development process
3. Demonstrate MBSE in the context of product lifecycle management (PLM)
4. Implement the Siemens MBSE approach using an electric longboard system example

Introduction to Systems Engineering

"The whole is more than the sum of its parts."

Aristotle

Developing a systems mindset

Traditional engineering education has been very effective at instructing students in various specialties. However, focused education has led to promoting a reductionist approach to problem solving wherein students with a specialized education in an engineering discipline can hardly contextualize a problem outside of that particular discipline. To cope with increasing challenges in developing modern cyber-physical systems, it is crucial to develop a systems mindset of looking at problems that promotes pursuing a multidisciplinary approach. A systems engineering education would be a natural addition to the existing engineering curricula so as to inculcate such a systems mindset.

"Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem. Systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs."

-Definition by INCOSE[3]

Systems engineering is based on the foundation of "systems thinking." Systems thinking is a unique perspective of looking at reality. According to systems thinking principles, our world is composed of various kinds of systems like economic, social, biological, and infrastructural, to name a few, that are interconnected and form systems-of-systems. Every system is made up of various elements and subsystems that interact with each other, their environment, and the elements and subsystems of other systems. A major implication of this interconnectedness is that no single element or subsystem has an independent effect on the behavior of the complete system. Rather, their interdependencies define the system's behavior.

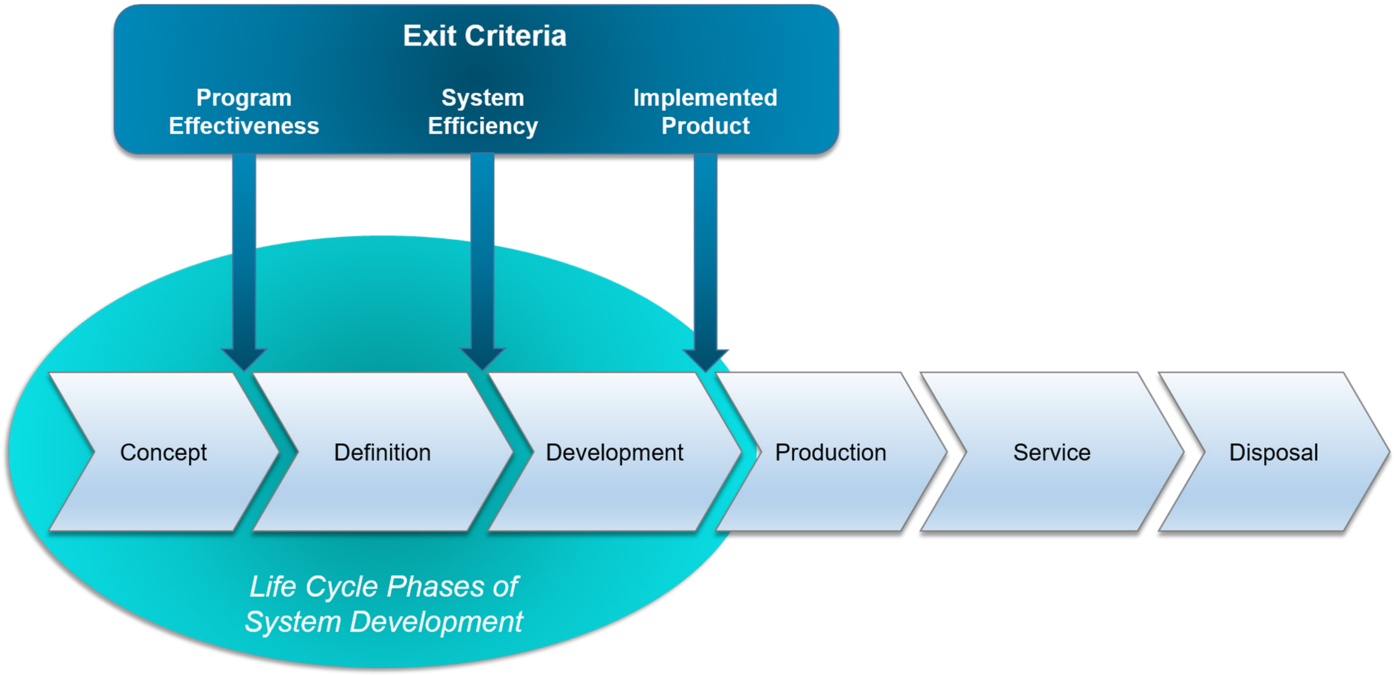

Figure 2: System life cycle stages.

The same principles can be applied to engineered systems and hence the discipline, systems engineering. In classical systems engineering, every product that is being realized is considered a system having various components and subsystems linked together, which is intended to perform a certain required function or functions.

Chapter 1 of this course focuses on a preliminary introduction to the systems engineering discipline that has been employed in manufacturing industries over the past several decades. Beginning with a set of common systems engineering terminologies, the chapter introduces the systems engineering life cycle (figure 2).

Systems engineering life cycle is a term used in systems engineering to describe the process of a system's evolution through different phases, starting from its conception all the way to its disposal. The course follows a simplistic approach to system development such that the system development subprocesses of the life cycle are mapped to the traditional systems engineering "V" diagram. Chapters 2 and 3 of the course cover the specifics of implementing a model-based approach to systems development, including exercises on using Siemens software tools to implement the approach.

Model-Based Systems Engineering

Why MBSE?

The systems engineering activities discussed in Chapter 1 of the course have been performed on many large-scale projects in industries, mostly aerospace and defense and automotive. These projects have employed the document-based systems engineering approach. This approach is characterized by the generation of textual specifications and design documents, in hard copy or electronic file format, and then exchanged between customers, users, developers and testers. System requirements and design information are expressed in these documents as text descriptions, graphical depictions generated from drawing tools, and tabular data and plots that may result from executing analysis models or derived from databases.

MBSE is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later lifecycle phases.

The output of MBSE activities is a coherent model of the system where emphasis is placed on evolving and refining the model using model-based methods and tools. An MBSE approach focuses on creating a system model that would act as a single source of truth for product information. A system model can be created using a modeling tool and stored in a model repository.

Implementing an MBSE approach provides numerous benefits to an enterprise including:

- Better communication among development teams
- Improved product quality
- Reuse of system specification and design artifacts across a product's lifecycle
- Enhanced knowledge transfer across domains
- Increased productivity

By leveraging MBSE, anyone touching a physical design can understand what functions the design supports and the role each component plays in fulfilling a requirement. This is especially valuable in projects that span mechanical, electrical and software engineering where complete traceability is crucial for facilitating collaboration and knowledge reuse.

It is worthwhile to mention that moving to a model-based paradigm does not restrict the use of documents. In fact, automatic generation of documents such as requirement specification, traceability reports, design specification, etc., from the models is one of the key improvement factors expected out of effective MBSE.

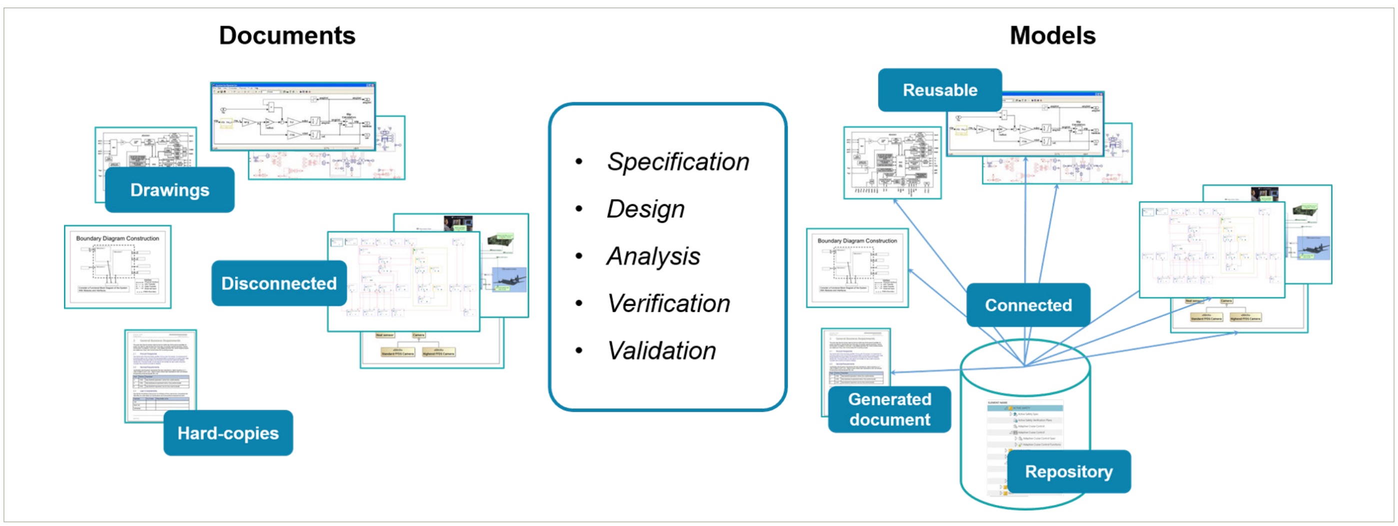

Figure 3: Systems engineering from documents to models.

MBSE in the Context of Product Lifecycle Management

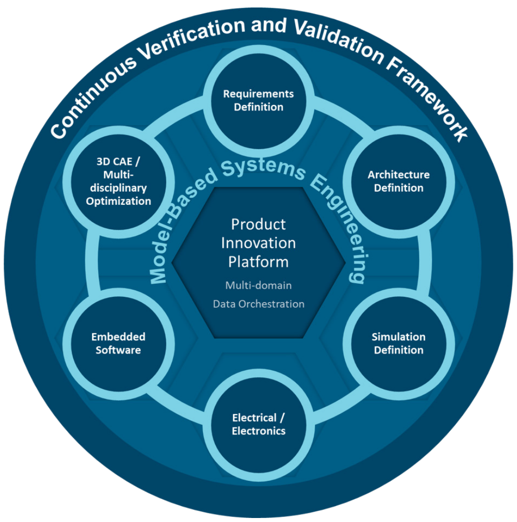

Figure 4: MBSE in PLM context.

PLM framework

PLM is the process of managing the entire lifecycle of a product from inception, through engineering design and manufacture, to service and disposal of manufactured products. PLM is usually supported as an information management system that integrates data, processes, business systems, and people in an extended enterprise.

PLM software allows you to manage this information throughout the entire product lifecycle efficiently and cost-effectively, from ideation, design, and manufacture to service and disposal.

MBSE in PLM context

PLM and MBSE are seen as two different approaches to product development, evolved from different requirements. MBSE is applied in the early stages of product development and is usually disconnected from the PLM systems. This has shaped the way these technologies have been implemented in many pilot projects across industries. With the increasing use of system modeling for systems engineering processes, there is an equally increasing need to integrate these processes with the PLM systems for coherency in lifecycle management of various engineering artifacts. Thus, it would be logical that future PLM systems are implemented using model-based approaches, or, in other words, model-based PLM.[4]

Siemens provides a PLM-based product innovation platform that supports the multidomain data orchestration that MBSE requires. Figure 4 shows the six key phases in our closed-loop approach to MBSE in the PLM context. This starts with defining system requirements, creating system architectures, simulating the system for performance optimization, developing the electrical and electronic architectures along with embedded software development as part of development sub-processes, and finally 3D product design and multidisciplinary optimization.

It is to be noted that MBSE is a framework, not a discipline. Hence, to successfully implement this framework, collaborative effort is required from people with different roles in an organization spanning multiple domains. Throughout this course, students will gain exposure to multiple roles that participate in the MBSE framework as they undertake the exercises.

Some of these key roles include:

System analyst
Responsible for planning, designing, and implementing systems.

System architect
Responsible for planning the architecture and defining the reuse of parts and assemblies.

System designer
Responsible for implementing the system architectural, logical, and physical designs.

System tester
Responsible for verifying that the system meets defined requirements.

Domain engineer
Realizes the system model according to an expertise area (mechanical, software, electrical, simulation).

Case Study: Electric Longboard Development

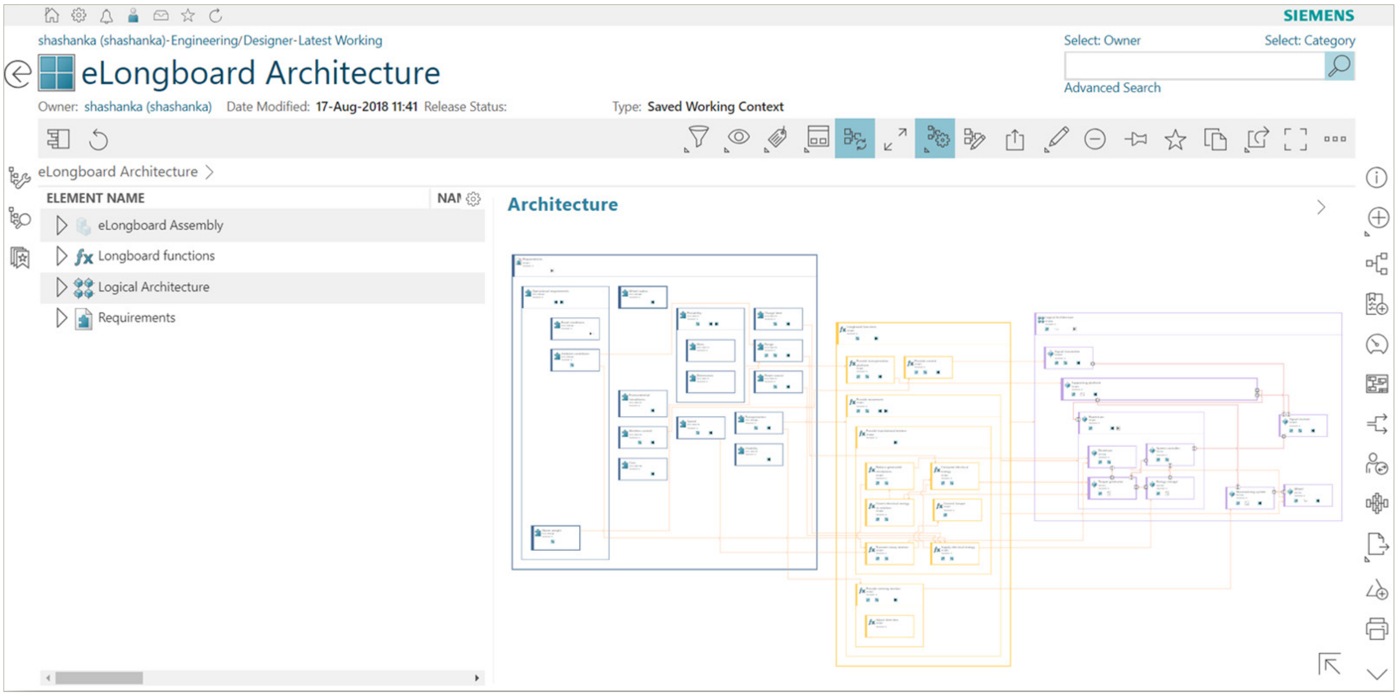

Figure 5: RFL multi-domain architecture in Teamcenter.

Business case

An established skateboard company has identified a business need to manufacture an electric longboard because of an increasing demand of longboards as a preferred means of short-distance transport for high-school and college students. The company wants to develop a comprehensive digital twin of the product that will allow them to simulate and optimize the product's physical design before proceeding to the production phases with the least consumption of its resources and maximum engagement of its employees during the development phases.

Approach

The students would implement the MBSE approach to develop an electric longboard using Siemens' software suite, mainly the Teamcenter® portfolio, Simcenter™ Amesim™ software, NX™ software and Simcenter™ 3D software. Teamcenter, Simcenter and NX are a part of Xcelerator, a comprehensive and integrated portfolio of software and services from Siemens Digital Industries Software.

An electric longboard is a fairly complex system that includes mechanical and electrical/electronic subsystems. These subsystems interact continuously with each other to perform a certain function or functions that satisfy the system requirements. To deal with this complexity, we develop an eLongboard system model using the Teamcenter Active Workspace architecture modeler.

This system model acts as a single source of truth for product information across its entire life cycle containing system requirements, functions, logical architecture and physical design (RFLP data).

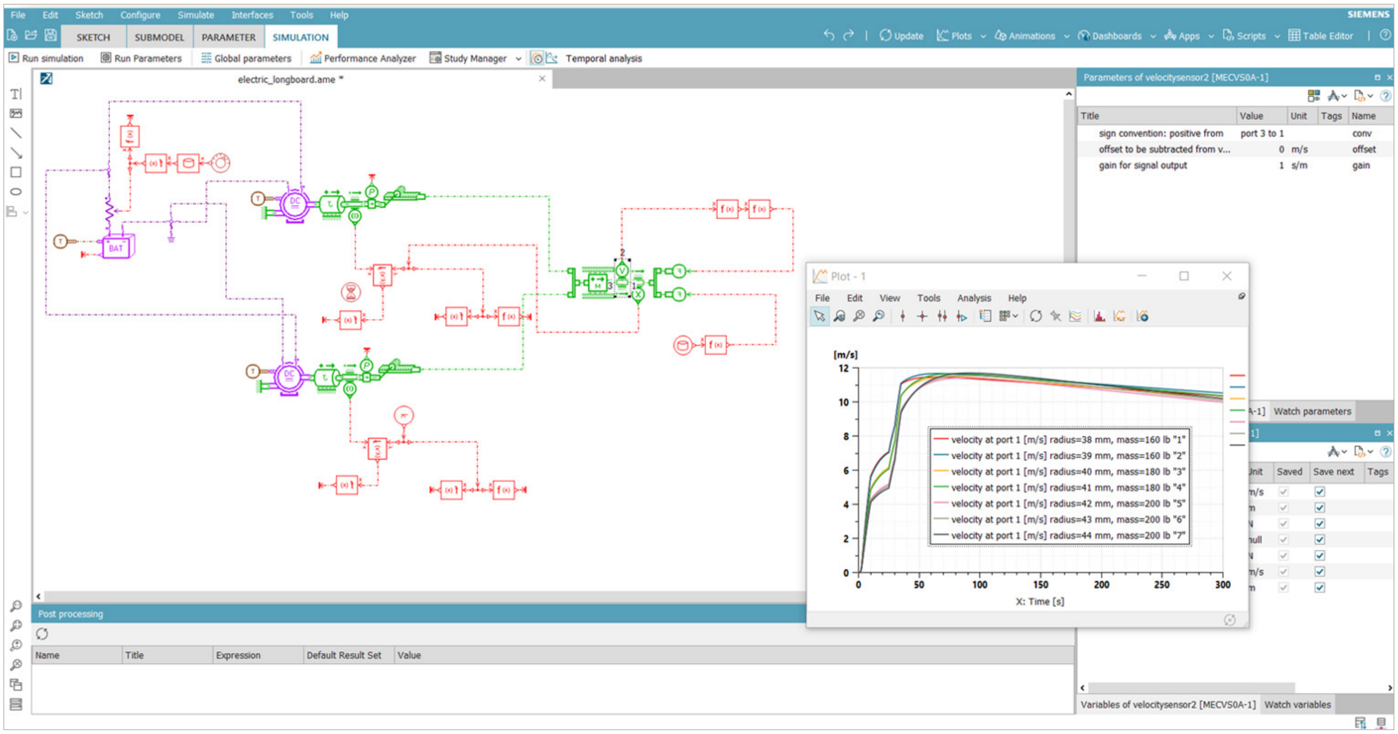

Figure 6: Simulation definition in Simcenter Amesim.

The system RFLP definition helps better understand the complete problem and finds innovative solutions.

Figure 5 shows the RFL architecture as represented in Teamcenter Active Workspace. The RFL architectures provide a basis to a simulation engineer working in the same context to model a physics-based simulation architecture that analyzes and monitors the system's performance under operating conditions and virtually validates the system's performance requirements. This is also referred to as frontloading design decisions. Based on the RFL architectures, we analyze the system performance using Simcenter Amesim to identify system specification like the size of the motors, battery and wheels. Figure 6 shows the multiphysics simulation definition in Simcenter Amesim.

The simulation gives an initial idea about how the system performs in response to certain inputs, after which we create the product structure in Teamcenter and specify and design the physical components in NX. An interesting part here is that we save the computer-aided design (CAD) product definition in Teamcenter and link it to the RFL artifacts, which is a powerful feature for managing change and product configuration. This adds the physical aspect to the system model thereby making it the RFLP definition. We can call it the RFLP 3D definition. The RFLP 3D progression in Teamcenter is shown in figure 7. As a result of such linking, we can automatically validate the design requirements elicited in the system definition in Teamcenter Active Workspace from within NX. We then perform structural finite element analysis of the longboard deck using Simcenter 3D to automatically validate a component design requirement. We can perform multidisciplinary optimization of the 3D geometry depending on the different subsystem requirements.

At this point in the course, we have a tightly integrated comprehensive digital twin of the electric longboard in place built on a cross-domain data orchestration platform thereby creating a digital thread from the beginning of the development process. The RFLP artifacts have several interdependencies that enable anyone touching a physical design to understand the functions that each component or subsystem

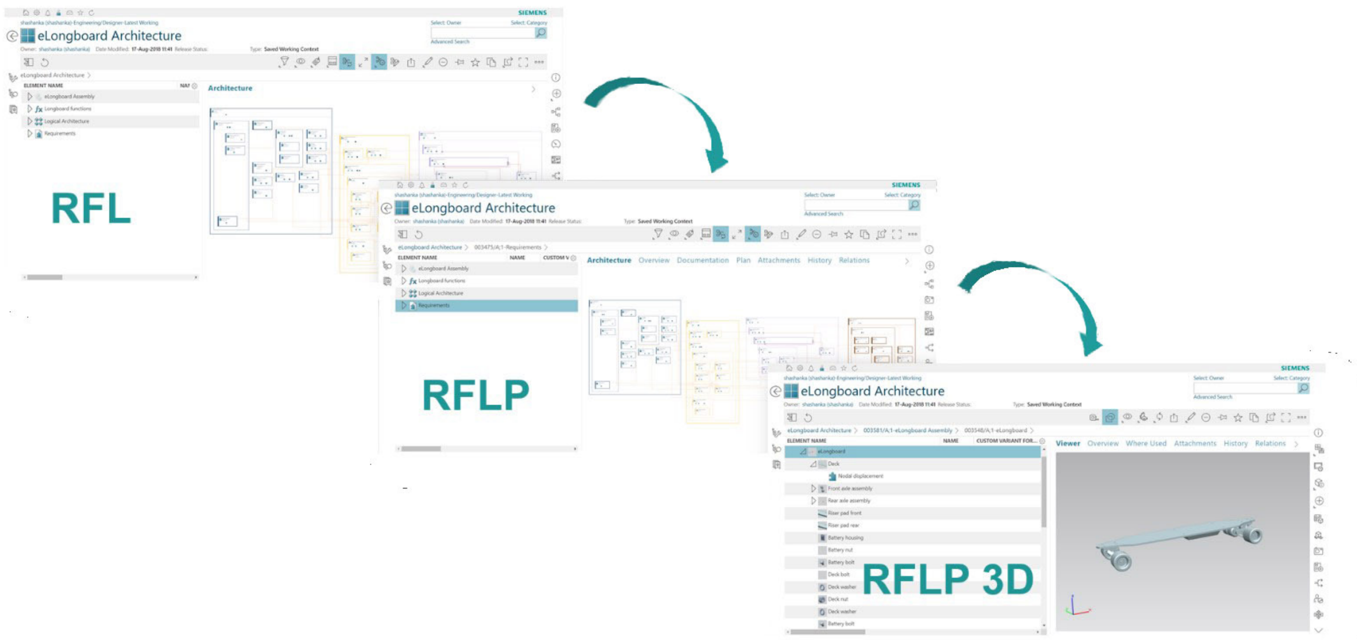

Figure 7: RFLP progression in Teamcenter multi-domain architecture.

is intended to perform. The eLongboard design is now ready for virtual/physical prototyping and manufacturing.

In this way, we successfully implement the MBSE approach in the context of Teamcenter Active Workspace using a Siemens tool suite. Some of the main advantages realized while implementing this approach include but are not limited to:

- Capturing the voice of the customer as requirements
- Shared understanding between different team members using a common language
- Generating solutions at every step by understanding the complete problem
- Frontloading the design decisions by early validation of system performance
- Design specification generation based on system architecture
- Faster design innovation
- Integrated design optimization and validation
- End-to-end requirements traceability
- Traceability of system/subsystem/component requirements across the development phase
- Enhanced communication and coordination between people from various disciplines

Conclusion

The fourth industrial revolution is happening already. Industrial manufacturers are revolutionizing their product development strategies in anticipation of the potential challenges in the coming decade, leading to a foreseeable rise in demand for a pertinently skilled workforce. As Siemens is one of the major corporations leading the charge for Industry 4.0[5], it is our obligation to help narrow the bridge between industry and academia with a shared vision of enhancing the employability of future engineering graduates.

This next-gen MBSE course attempts to provide an educational resource with a proven approach to systems engineering problem solving using a practical engineering case study. In a nutshell, the key aspect addressed in this course is that the whole product development process can be driven by one master, the system definition in Teamcenter, enabling efficient traceability and collaboration between people from multiple domains developing the product concurrently.

A successful implementation of the case study during the course provides the following key learning outcomes:

1. An overview of the current business processes for product development used in various industries. This helps students define a context for implementing a systems engineering approach.
2. An understanding of applying systems engineering to enhance the traditional development processes. Students are introduced to the systems engineering definition, terminologies and development process.
3. A review of the benefits and challenges of implementing an MBSE approach in product design and development. Students implement an actual case study to witness the benefits and challenges first-hand.

"This is going to be a revolutionary way of realizing modern products. It's quite fascinating that Siemens provides end-to-end digitalization solutions that will enable true realization of Industry 4.0."

Shashank Alai
Global Academic Student Intern, Summer 2018 [6]

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