Introduction of Systems Engineering Practices in a Product Lifecycle Management (PLM) course for master students

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Introduction of Systems Engineering practices in a Product Lifecycle Management (PLM) course for master students

Krister Sutinen
Siemens Digital Industries Software
Box 141 53
SE-400 20 Göteborg, Sweden
+46 709 15 15 70
krister.sutinen@siemens.com

Abstract. This paper presents how a model-based system engineering approach was used to introduce to master students the strength of and the challenges with a Product Lifecycle Management (PLM) system. The students were introduced to use various authoring applications to build the product content to be managed by a PLM system.
Keywords. Product Lifecycle Management, Model-Based Systems Engineering, graduate course

Introduction

Chalmers University of Technology (Chalmers) in Gothenburg, Sweden, has provided a course in Product Lifecycle Management (PLM) for the students in the Mechanical Engineering, Production Engineering, and Mechatronics Engineering programs for more than 20 years. The content and the applications used in the course have changed over the years.

As part of the current course, the students are introduced to systems engineering practices; (1) to provide content to be managed by a PLM system, and (2) to address systems engineering practices, such as capture and manage requirements, define system models, and to verify the system design thru simulations and design validations.

This paper will address the benefits to use systems engineering content to address the capabilities of a PLM system. The core of a product lifecycle management is the creation, preservation, and storage of information relating to the company's products and activities of its lifetime, order to ensure the fast, easy and trouble-free finding, refining, distribution and reutilization of the data required for daily operations.

PLM has been part of the education curriculum for engineering students to prepare them for working in the industry. For example, a PLM curriculum was created to provide the industry with PLM Professionals. This initiative is also an example where the academia, software vendors and industry working together, (Burchardt, 2015). This is true also true for this course, where the author, working for a software vendor, provided the exercises to let the students to explore the capabilities of PLM.

The PLM Course

The PLM course is aimed for master students from the programs Product Development, Product Engineering, Industrial Engineering and Automotive Engineering. The course length is 7 weeks, where the learning activities are divided in about 30 hours lectures, 85 hours project work and 60 hours homework. The purpose of the course is to provide an overview of how IT tools and systems are used to create and manage product information and knowledge, from identification of customers' need to product retirement. The lectures are combined with academic lectures and industry lectures where industry experts present business challenges and experiences.

The main topic for the master course is Product Lifecycle Management (PLM), it doesn't cover systems engineering methodologies either thru lectures or using system engineering literature or practice, e.g. Systems Engineering Handbook (INCOSE, 2023). On the other side the students, especially those who have attended the bachelor program in mechanical engineering have learned product and system development methodologies.

The reason to add some elements of systems engineering practice in the PLM course, is that the deliverables for each activity are creating a digital thread and where the tasks are assigned to different disciplines, such as requirements engineers, systems engineers, CAD designers, and simulation analysts.

The project work is divided into two moments; (1) a PLM crash course, and (2) a computer lab where students utilize software from Siemens Digital Industries Software. The PLM crash course is an exercise where students will simulate a simplified design process, without system support by e.g., a PLM system. The purpose of the crash course is let students discover aspects and errors that are occurring in multi-team development. During the crash course the students are divided into teams, where they are assigned to develop a vehicle for different purpose, e.g. sustainability and circularity, for city, or for recreation purpose. Each student team get different assignments. In the first moment, they are performing conceptual design, in the next moment, addressing how they are going to build it when the limited material available, e.g. paper, scotch tape, and Lego. In the final step, they are going to build it. There is a twist, they aren't allowed to complete the assignment based on the first task. Between each task, the student groups are forced to handover their work to another team. In the end, they will have performed the task for three different vehicles. During this exercise, they will learn the importance to capture and share information. They will also be asked to reflect on the learnings based on the two moments of the course.

The computer lab is divided into four steps: (1) requirements management, (2) system modelling, (3) concept simulation, and (4) mechanical design. The exercises have been adopted and modified from a course at Purdue School of Engineering & Technology (El-Mounayri, 2021). The electric skateboard was selected as an example of a complex, multi-domain system, while simple enough for students to understand the product. Figure 1 is showing how the computer lab is supported by Siemens' software.

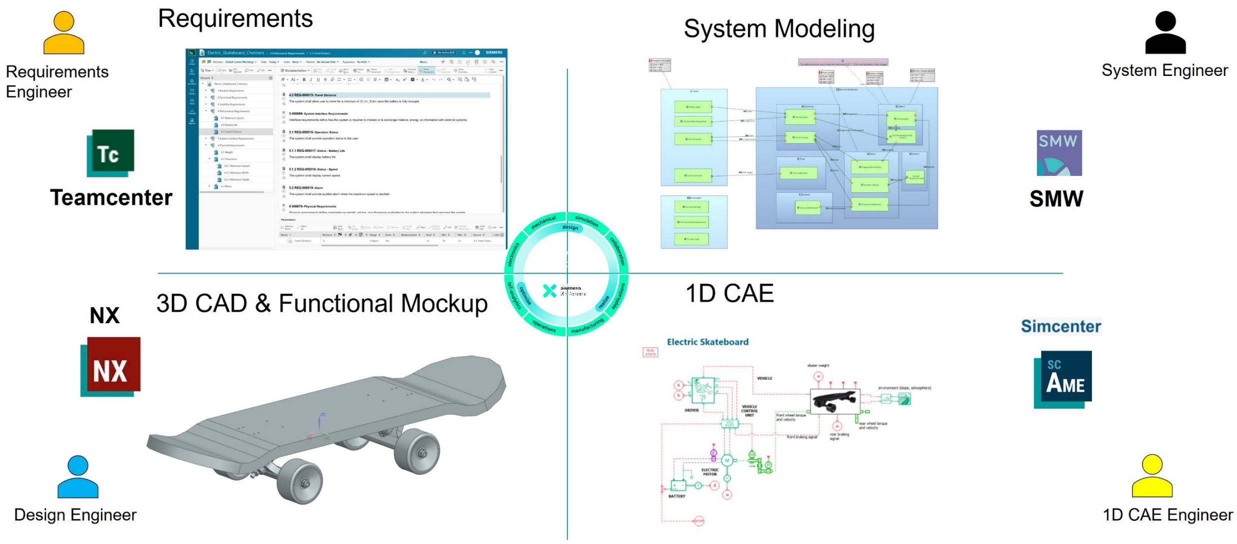

Figure 1. Siemens software used in the different steps for the computer lab

Requirements management

The students will capture and manage the requirements in Teamcenter (Siemens Digital Industries Software, 2023). Some of the requirements have quantitative values and for those requirements, the students will also assign parameter with goal, minimum, and/or maximum values. Some of these parameters will be used for simulations and geometric validations.

As mentioned in the earlier chapter, the PLM course doesn't cover any lectures of requirements engineering or requirements management. It is expected that the students already have learned to capture, elicit and write requirements. In the course, a requirements management application is introduced.

But students are asked to reflect of the completeness, coverage, and if the requirements provided the right information to system engineers, CAD designers or simulation analysts, to enable the perform their tasks. They will also create test / verification requests to assign requirements to define the system modelling and to assign requirements to be verified by simulation (performance) and to be evaluated by the design (geometrical constraints).

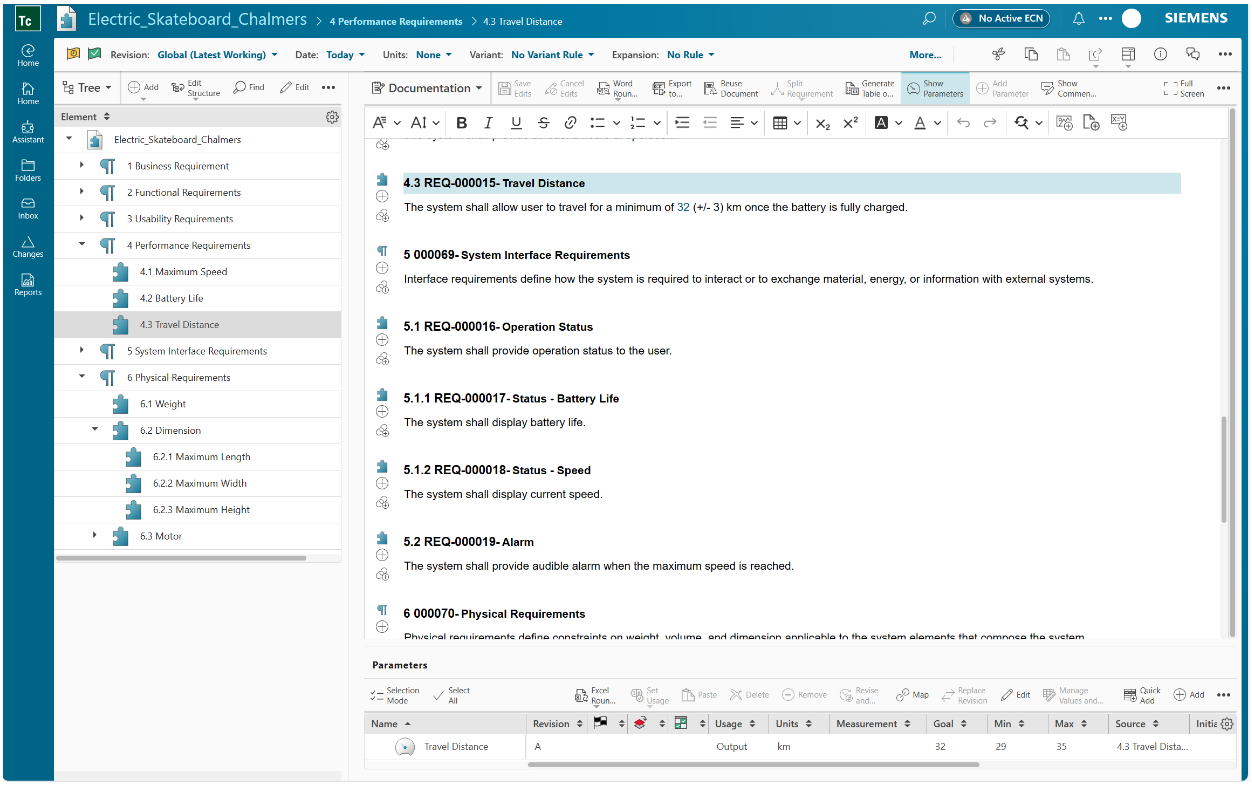

Figure 2. Requirements Management in Siemens' Teamcenter

System modelling

The next exercise for the students is to create system models with System Modelling Workbench (Siemens Digital Industries Software, 2023). Due to limited time allocated for the computer lab, there isn't any possibilities to build a comprehensive system model. For this exercise, the students were provided a detailed instructions to build a minimal valuable system model to be used in the following exercise. They will also link requirements to system model elements and later to evaluate the performance requirements with a 1D simulation model.

The students have experience of product development methodologies and practice from their previous undergraduate and graduate courses. To be able to create a good system model requires more practice and teaching in systems engineering. Chalmers University of Technology is providing a master level course in systems engineering and for graduate and Ph.D. candidates there is an opportunity to get a systems engineering certification (ASAP/CSEP).

There were two reasons why a Capella modelling tool was selected for system modelling, (1) its integration to the PLM application and (2) quick start to modelling together with a supported method, ARCADIA.

ARCADIA

ARCADIA (ARChitecture Analysis & Design Integrated Approach) is a tooled method to system and architecture engineering, supported by a Capella modelling tool. Siemens' System Modelling Workbench is a commercial Capella modelling tool. The method prescribes to use a layered model to capture different aspects of the system definitions from Operational Need Analysis (OA), System Need Analysis, Logical Architecture (LA), to Physical Architecture (PA).

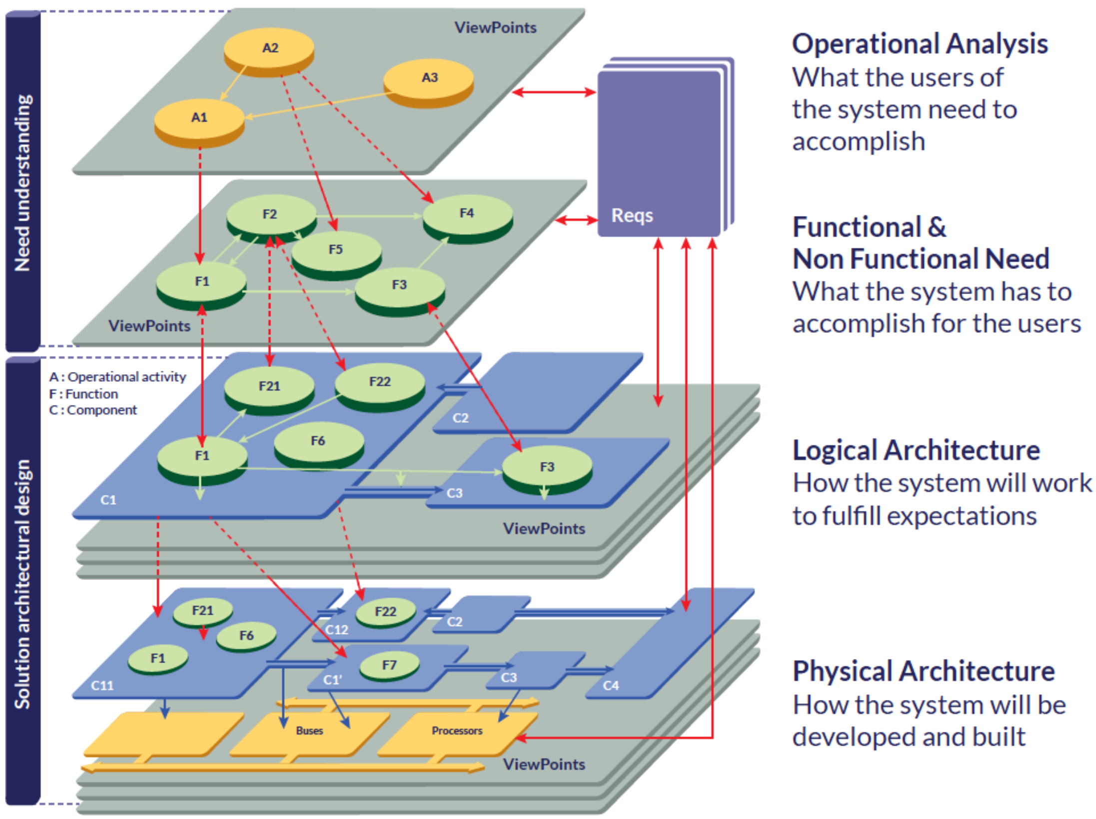

Figure 3. ARCADIA (Capella, 2023)

The students will create a capability diagram for Operational Analysis and allocate requirements to the identified capabilities. As part of the PLM course, this shows how requirements managed in PLM or a requirements management application can be included in a system model.

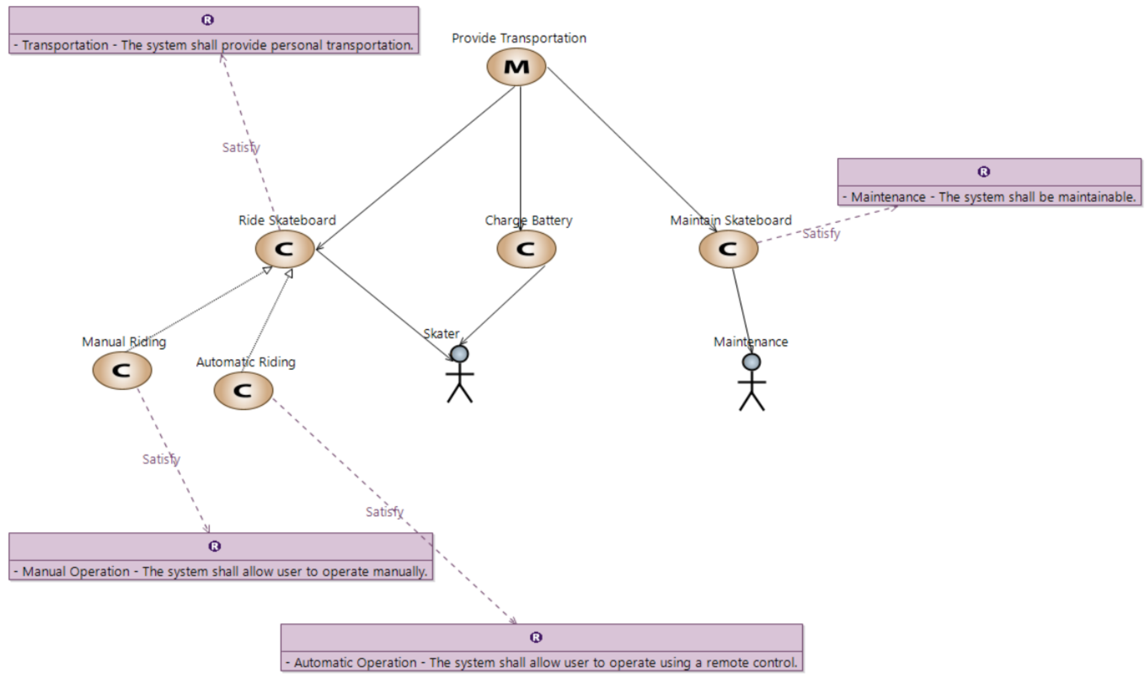

Figure 4. Capability diagram

Next the students will continue with Physical Architecture where they define the architecture of an electric skateboard by identifying components, allocation functions and define exchanges. The purpose of this exercise is to provide them understanding that the system model can and is the blueprint for downstream engineering activities. The analogy is how an architect's drawing guide constructors to build a house. The system model captures the intent and the purpose of a system, therefore guide the design of the system.

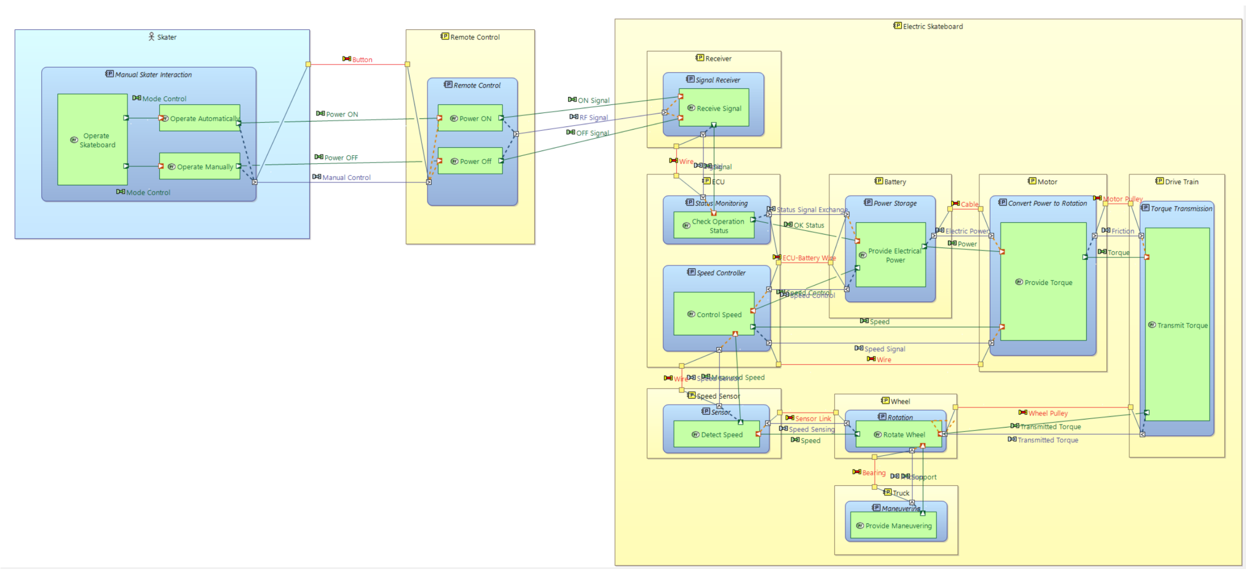

Figure 5. Physical architecture diagram

The requirements specification and the system model are two artefacts that are generated by system definition, that is described by the left-hand side of the systems engineering V-model. In this PLM course the student will also use a simulation model and to evaluate the spatial requirements with the CAD-tool, NX. These two examples will show the students how the right-hand side of the systems engineering V-model can supported by PLM-tools, especially thru verification management.

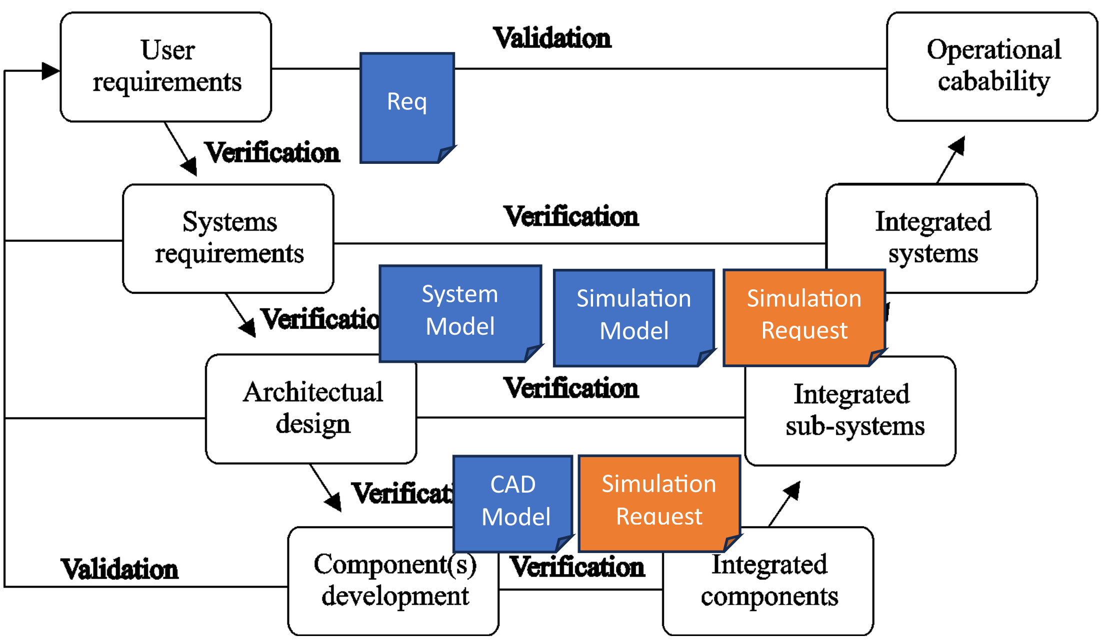

Figure 6. Systems engineering V-model with PLM course deliverables

Verification management

A PLM system has been developed to manage a product and its lifecycle including not only items, documents, Bill of Material's (BOM's), but also analysis results, test specifications, engineering requirements, product performance information, etc. Therefore, it is vital in a PLM course to address those capabilities. Secondly, verification management process is connecting the system definition and requirements to analyze and evaluate a systems performance, see figure 7.

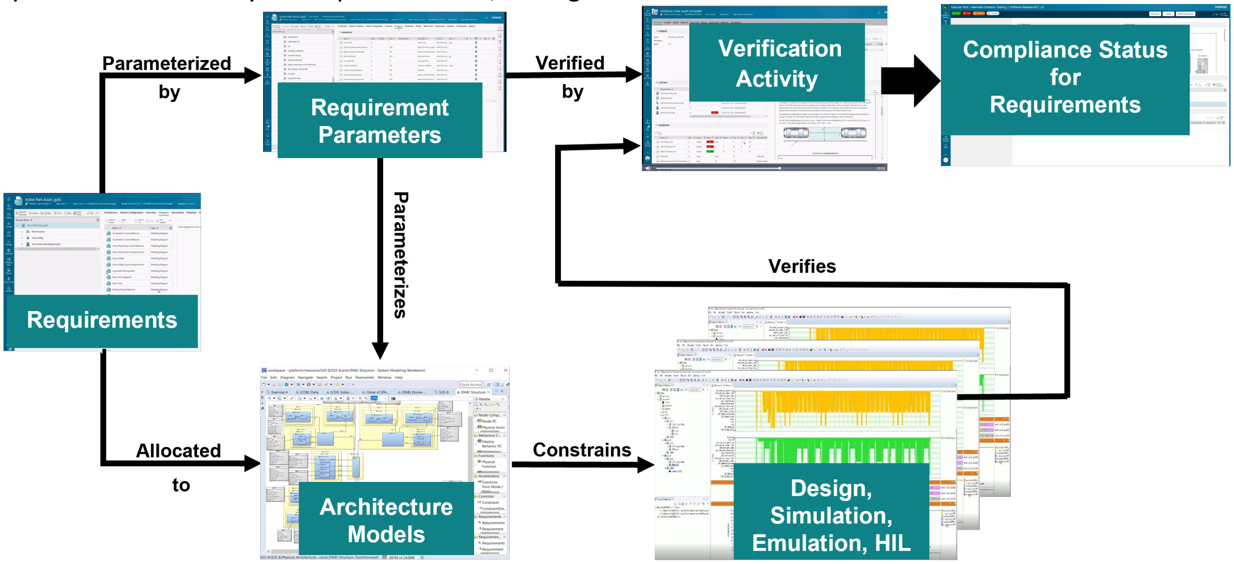

Figure 7. Integrated verification activities

In the verification process, the verification request will capture what will be verified (i.e. requirements), how it will be done (the verification method or procedure), what input and output parameters must be captured, and the evidence/result of the verification activities.

An example of a verification request is shown in figure 8. It is a simulation request, which is a specific adaption of a verification request. This simulation request is used to capture the relevant information for verification by simulation. Each field in the request is show specific information that is relevant for the simulation activity.

The fields can be automatically populated based on the relationship between the data. The requester (the person who is asking for a simulation) and the analyst (who is performing the simulation activity) will add additional information to the request, e.g. what simulation model was used and the results of the simulation.

The request will capture the evidence for compliance and the communication between the different teams that normally would have been exchanged, e.g. by e-mail. The verification request remains inside the PLM environment and thus the evidence thread is secured and maintained for e.g. auditing.

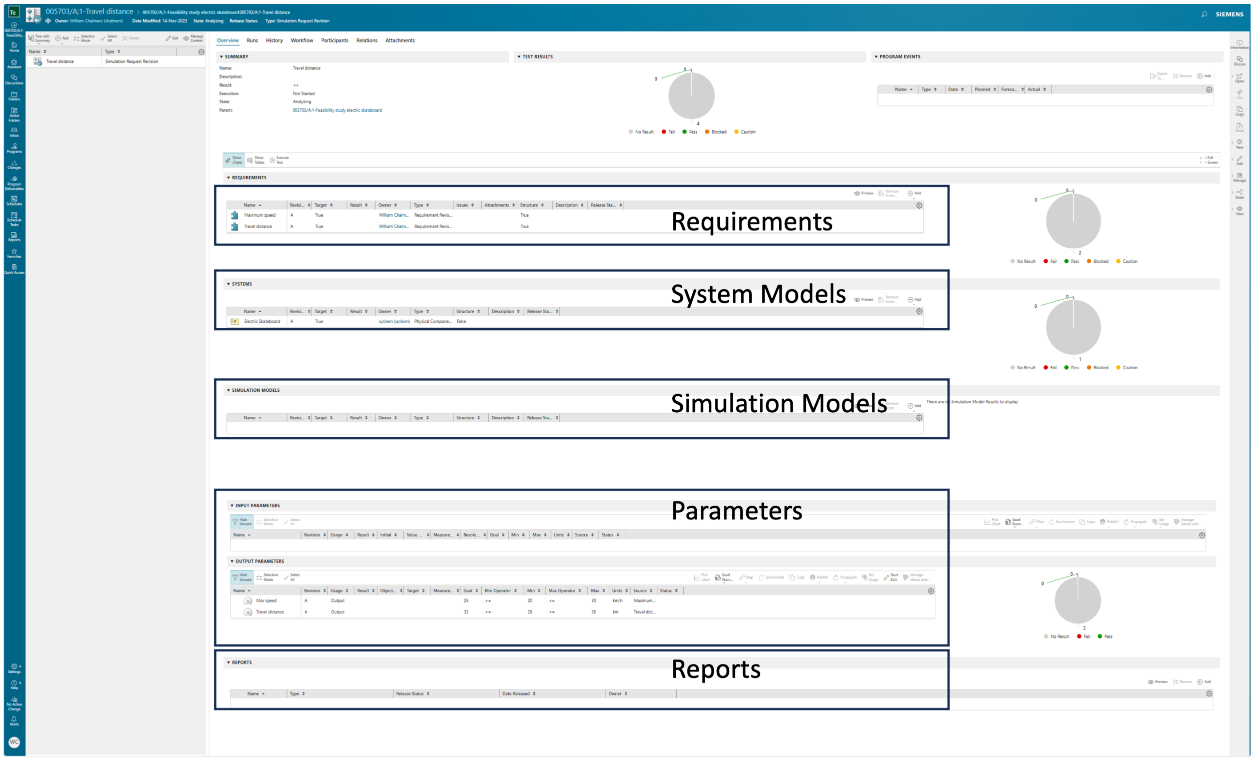

Figure 8. Simulation request

Add information about the 1D simulation and spatial geometry evaluation.

Using model-based systems engineering for introducing product lifecycle management

A model-based systems engineering approach to apply modeling to support system requirements, design analysis, verification and validation activities thru the lifecycle phases, has been successful to drive a complex PLM implementation project (Ciriello, 2012). For the implementation project, the technological and methodical approach satisfied the IT managements needs and created a common knowledge management environment to manage a PLM initiative.
The deliverables generated by model-based systems engineering approach will together with PLM application capabilities to create a digital thread, i.e. how the information is related to each other, to share and control data thru workflows, and how to use simulation and verification requests to manage the execution of simulations.
Post-course reviews by the students shows that it gave them insights of using a PLM-system, but the time allocated for the computer lab wasn't enough. "Needed more time than the allocated to work". "Learning how to use different software as a bit tricky, but it gave insight on a way to use PLM-system".

Conclusion

Using model-based systems engineering approach enabled the students to create content and relate it to other information stored in a PLM-system to support system requirements, design, analysis, verification and validation activities throughout the life cycle phases. It gave the students insight of the potential of a PLM system and to understand the complexity of integrating applications, to manage the data, and how a PLM system interacts with the business processes and users.

To provide students insights in systems engineering, it cannot be done by a single master course. It should be part of a bigger curriculum. There are universities that are providing systems engineering curriculum, often at master level, but there are examples at bachelor level, as the course at University of Michigan, Ann Arbor, MI.

As a general trend in the digitalization of business and industries, systems engineering as a discipline, methodology and practice is the enabler for digital enterprise and "shifting-left". This PLM course can only highlight aspects of the digitalization and how PLM can support it.

References

Burchardt, C. (2015). *Establishing product-lifecycle management education at university in industry context*. Paper presented at the 2015 IEEE International Conference on Engineering, Technology and Innovation/International Technology Management Conference (ICE/ITMC), Belfast, UK.

Ciriello, D. (2012). *Using MBSE Methodology to drive a PLM Initiative*. Paper presented at the INCOSE International Symposium 2012, Rome, Italy.

El-Mounayri, H. (2021). *Integrated Model-Based Systems Engineering (iMBSE) in Engineering Education*. Paper presented at the 2021 Annual INCOSE International Workshop.

INCOSE. (2023). *Systems Engineering Handbook* (5 ed.): INCOSE.

Capella (2023), http://mbse-capella.org

System Modeling Workbench (2023), Siemens Digital Industries Software

Teamcenter (2023), Siemens Digital Industries Software

Biography

Krister Sutinen. Senior Business Consultant at Siemens Digital Industries Software. He has expert knowledge in Product Lifecycle Management (PLM) and Systems Engineering. He has a Ph.D. from Chalmers University of Technology.