How Simulation Supports Systems Engineering

CIMdata Commentary

Key takeaways:

- *Companies are striving to apply simulation early in the product development cycle, where systems engineering is often used to allocate requirements and to define and evaluate multi-discipline tradeoffs.*
- *The majority of product lifecycle cost is determined by decisions made early in the development process. The decisions upon which costs are based become very expensive to alter or correct later in the process.*
- *Products are no longer simply mechanical systems. Model-based systems engineering can be used to enable collaboration across multiple engineering (e.g., mechanical electrical, software, and controls) and other enterprise disciplines (e.g., purchasing, finance, and project management).*
- *CIMdata believes that systems engineering will become the pervasive paradigm for product development, supporting and promoting a systems thinking mindset.*

Companies have always faced intense competitive pressure to develop products better, faster, and cheaper. Simulation is a key enabler to accomplishing this today and into the future. Improved software, better integration with design tools and faster response (turnaround) times for simulation enable it to be used earlier in the product development process.

Traditionally, simulation has been used to assess the performance of and validate completed designs. This function is no less important now, and it is well established at many companies. However, simulation "up front" involves a different set of issues.

The Systems Engineering Vee is often used to depict the complete product lifecycle—from concept through end-of-life, as shown in Figure 1. For mechanical product design, the base of the Vee is usually detailed design represented by CAD models of the individual components. The right side of the Vee is then the validation and integration of the components into subsystems and systems, ending with validation of the final product. Traditional simulation is used (along with physical testing) to evaluate components, subsystems and systems, and validate the final design.

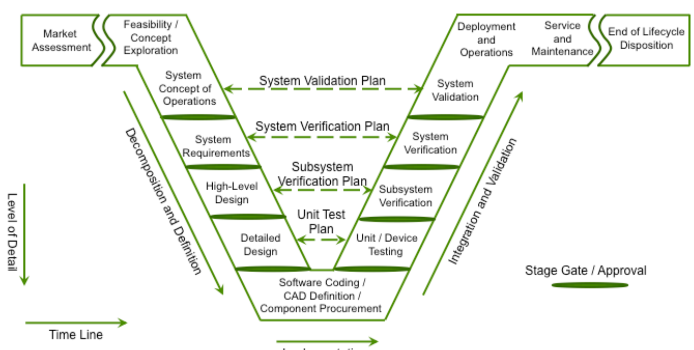

Figure 1—The Systems Engineering Vee[1]

[1] Adapted from: US Federal Highway Administration: http://ops.fhwa.dot.gov/publications/seitsguide/ "Systems Engineering for Intelligent Transportation Systems"

The left side of the Vee represents the process of capturing, defining, and understanding the product's requirements, and then specifying, in increasingly deeper levels of detail (decomposing and allocating), the requirements for product systems, subsystems, and components as well as the interactions among them. The left side of the Vee encompasses product ideation, concept selection, and the definition of overall product architecture.

One can see that the left side of the Vee is a systems engineering problem. It is here that decisions are made at the systems level that trade off between competing requirements like cost, weight, durability, performance, range, and fuel economy, among others. Simulation up front, on the left of the Vee, by necessity then requires a multi-physics capability within a framework of systems engineering. As simulation is implemented up front for balancing performance with other requirements (i.e., cost, weight, etc.), simulation must simultaneously comprehend load cases for different physics disciplines. For example, the design of a space optical device (e.g., telescope) demands that the structural, thermal, and optical analyses be coupled. Thus, as companies drive to up-front simulation to improve early product decisions, they are driving towards multi-physics, multi-domain simulation, and systems engineering.

The driving forces are program cost and product lifecycle cost, as suggested in Figure 2. Studies over four decades have shown that the overwhelming portion of total product lifecycle cost is determined by decisions made very early on in the product development lifecycle. Engineering on the left side of the Vee consumes only about 4% of the program cost, but determines about 80% of the product lifecycle cost. The implications are tremendous and early simulation can have a significant impact on the design and lifecycle cost.

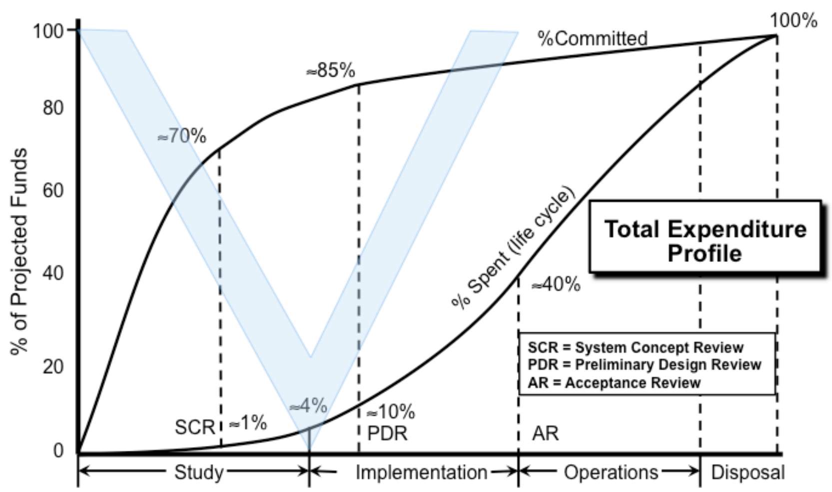

Figure 2—Most of the Product Lifecycle Cost is Committed on the Left Side of the Vee[2]

One might expect that good decisions made early during product ideation, architecture development, and concept development are critically important. Conversely, bad decisions are almost always very expensive or even disastrous to correct later.

This is confirmed in Figure 3, which shows that cost overruns correlate with fewer resources spent early in a product's development program. Getting it right on the left side of the Vee is crucial for product and program success.

[2] Adapted from: Forsberg, Kevin, Hal Mooz, and Howard Cotterman. "Visualizing Project Management." 2nd Ed. John Wiley & Sons, NY. 2000.

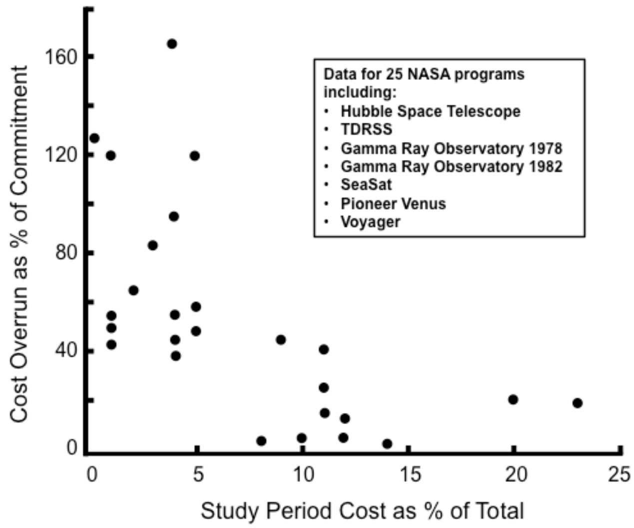

Figure 3—Cost Overruns Correlate with Hasty Project Starts[3]
(Data from 25 NASA Programs)

Systems engineering practices have been used for software development and for electrical system design for some time, much more so than for mechanical system design. Now, increasing product complexity and increasing interdependence is driving systems engineering across all domains, including mechanical, electrical, software, control systems, chemistry, physics, and others depending on the industry.

Products are no longer simply mechanical systems. A modern automobile contains fifty plus microprocessors and millions of lines of computer code. Systems engineering is a critical enabler for the concurrent design of mechanical, electrical, control systems, and other domains, and for the implementation of the concurrent engineering techniques of model-, hardware-, and software-in-the-loop. In this regard a model is a digital description of some aspect of a product. For example, a simulation utilizes a digital model to predict some aspects of product or manufacturing system performance. Such models are created for mechanical, electrical, software, and controls system behavior for products. Models from one domain can be used as surrogates in another domain, to enable concurrent engineering; for example, a control system can be developed before the availability of actual electronic or mechanical hardware. This is the basis for the evolving paradigm of model-based systems engineering (MBSE).

The International Council on Systems Engineering (INCOSE) has published a roadmap for MBSE that extends for more than a decade, beyond 2025. The move to systems engineering is not a fad or a short-term trend. In CIMdata's view systems engineering will be the framework for product development well into the future.

The move to systems engineering has a number of drivers, not just up-front engineering and MBSE. Among these are:

- *Focus on Systems, not Components:* The capabilities of most companies to design components have improved remarkably over the past few decades, to the extent that component design is no longer the driving issue. Rather, attention is being paid to component performance and interaction in the context of the systems and subsystems.

[3] Ibid

- *Optimization and Robust Design:* Robust design is a probabilistic method for design optimization. It seeks to maximize design performance and simultaneously to minimize the sensitivity of the performance with respect to variation in manufacturing and customer use, among other factors. Robust design and associated techniques explore the design space by assessing hundreds, or even thousands, of design alternatives.
- *Regulation and Compliance:* Systems engineering is virtually a requirement in highly regulated industries like pharmaceuticals, medical devices, and commercial aerospace, where companies have to document their development process in addition to meeting specific regulatory requirements. For example, the US Department of Defense (DOD) is now requiring that SysML models be used in its acquisition programs, to facilitate collaboration and improve communication between DOD and its suppliers. (SysML is a system modeling language.)

Companies are looking to their product development solution providers for the right offerings to support these more complex requirements.

CIMdata believes that systems engineering will become the pervasive paradigm for product development. Model-based systems engineering allows product knowledge to be captured in digital models for up-front decision making and to support concurrent engineering and collaboration across multiple engineering and other product related domains throughout the product's lifecycle. Compounding product complexity and increasing regulations and compliance requirements demand these fundamental changes in the processes used to develop products and manufacturing systems in the future. Experience shows that when systems engineering concepts are applied to product developments, the results are improved efficiency, higher quality, and shorter time to market.

About CIMdata

CIMdata, an independent worldwide firm, provides strategic management consulting to maximize an enterprise's ability to design and deliver innovative products and services through the application of Product Lifecycle Management (PLM). CIMdata provides world-class knowledge, expertise, and best-practice methods on PLM. CIMdata also offers research, subscription services, publications, and education through international conferences. To learn more about CIMdata's services, visit our website at http://www.CIMdata.com or contact CIMdata at: 3909 Research Park Drive, Ann Arbor, MI 48108, USA. Tel: +1 734.668.9922. Fax: +1 734.668.1957; or at Oogststraat 20, 6004 CV Weert, The Netherlands. Tel: +31 (0) 495.533.666.