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A Brief Discussion on Modeling and Simulation

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ABSTRACT:

Simulation and modelling are essential to system engineering. They are effective instruments for designing, evaluating, and optimising complex systems before they are constructed or put into use. The conception and design of systems are aided by modelling and simulation. They let engineers to examine various configurations, designs, and parts by building virtual models of the system. Engineers are able to evaluate the viability, performance, and reliability of alternative design solutions by modelling the system's behaviour and interactions. Models and simulations aid in assessing a system's performance characteristics. Engineers may examine how the system responds to various input situations, operating scenarios, and stress variables. Early in the development process, possible bottlenecks, weaknesses, or places for improvement might be found thanks to this study. System engineering requires the use of modelling and simulation extensively. They provide engineers the capacity to create, examine, enhance, and verify systems, which boosts efficiency, dependability, and performance. System engineers may shorten development time, minimise costs, and limit hazards related to complex systems by efficiently using these techniques.

KEYWORDS:

Acquisition, Computer-Aided Manufacturing, Simulation, Virtual Replication.

I. INTRODUCTION

Fundamental methods used in system engineering to examine, comprehend, and forecast the behaviour of complex systems include modelling and simulation. Before systems are developed or put into use in the actual world, they provide a virtual environment for researching and analysing the functionality, interactions, and features of such systems. Modelling entails employing logical, physical, or mathematical structures to create minimalistic representations of systems. Engineers and analysts may examine and modify the system under different circumstances thanks to these models, which encapsulate the fundamental components, connections, and behaviours of the system. In contrast, simulation entails using these models in a virtual or computer-based environment to track and examine the system's behaviour over time [1], [2].

There are several advantages to using modelling and simulation in system engineering. It helps engineers to understand system dynamics, spot possible problems or constraints, and investigate various design solutions. Engineers may assess the effects of numerous elements, such as changes in parameters, inputs, or operating circumstances, by simulating the behaviour of the system under various scenarios and settings. Simulating and modelling systems can aid in anticipating their performance and capabilities, offering useful data for decision-making. Engineers may use them to evaluate the viability, efficiency, and efficacy of suggested system designs and configurations. Engineers may make educated judgements, optimise system designs, and reduce hazards by analysing the simulation data [3], [4].

Additionally, regulated and economical system testing and validation are made possible through modelling and simulation. System performance, dependability, and safety may be evaluated using virtual simulations rather of costly and time-consuming physical testing. This lessens the need for physical prototypes and enables iterative design optimisation. Additionally, modelling and simulation facilitate stakeholder engagement and communication. They provide stakeholders a visual depiction of system behaviour and performance that makes it simple for them to comprehend and offer suggestions for improvement. This encourages clear communication, reduces misconceptions, and makes it possible to reach agreement. Overall, by offering a virtual platform for analysing, projecting, and optimising system behaviour, modelling and simulation play a vital role in system engineering. They help engineers make decisions by enabling them to comprehend complicated systems, assess design alternatives, forecast system performance, and evaluate system performance. The proper design, implementation, and operation of complex systems may be ensured with the use of modelling and simulation, which are useful tools [5], [6].

II. DISCUSSION

Acquisition, Simulation, and Modelling

All phases of the acquisition cycle and all applications, including requirement definition, programme management, design and engineering, effective test planning, result prediction, supplement to actual test and evaluation, manufacturing, and logistics support, now heavily rely on modelling and simulation. The four main advantages of M&S cost savings, expedited schedule, enhanced product quality, and cost avoidance can be attained in any system development when used properly since there are so many possibilities to employ it. These prospects have been seen by the DoD and business throughout the globe, and many are using the growing capabilities of computer and information technology. Now that M&S is able to prototype whole systems, networks, link numerous systems, and integrate their simulators, simulation technology is advancing in every manner imaginable [7], [8].

A system entity, phenomena, or process is represented physically, mathematically, or logically by a model. The application of a model over time is called a simulation. A simulation demonstrates the behaviour of a certain item or phenomena by bringing a model to life. When a model can represent real-world systems or ideas, it is helpful for testing, analysis, or training. Modelling and simulation (M&S) allow for the virtual replication of goods and processes and portrays them in settings that are both conveniently accessible and operationally sound. The cost and risk of life cycle activities may be decreased by using models and simulations. Figure 1 illustrates how the benefits persist throughout the life cycle [9], [10].

Limitations On Simulations

Virtual, constructive, and living models and simulations are divided into these three categories:

1. Systems are represented both physically and electronically in virtual simulations. Examples include the Battle Force Tactical Trainer from the Navy, the Close Combat Tactical Trainer, and built-in training.
2. Useful simulations depict a system and its operation. They consist of IDEF, Flow Diagrams, Mockups, Computer-Aided Design/Manufacturing (CAD/CAM), Computer Models, Analytical Tools, and Mockups.
3. Live simulations include simulating activities using actual personnel and actual equipment. Fire drills, operational testing, and the first production run with soft tooling are a few examples.

Virtual Simulation

Virtual simulations include the human being. The physical interface between the operator and the system is cloned, and the simulated system is engineered to behave exactly like the genuine system. An environment that resembles the actual world in appearance, feel, and behaviour is shown to the operator. The virtual prototype is a more sophisticated variation of this that enables interaction with a virtual mockup running in a lifelike computer-generated world. A virtual prototype is a system or subsystem that has been computer-simulated with functional realism on par with that of a physical prototype.

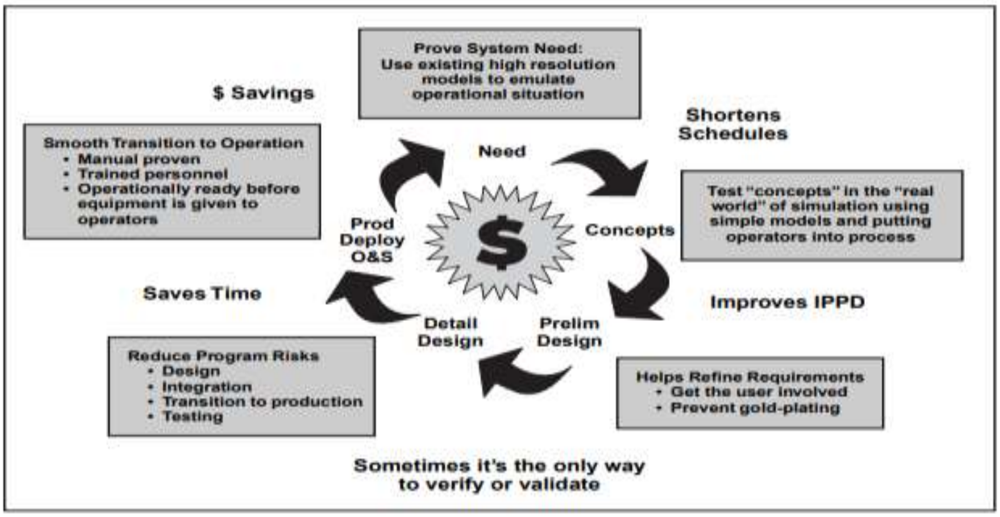

Figure 1: Advantages of Modeling and Simulation [ocw.mit.edu].

Building Simulations

The creation of descriptions of system solutions is the goal of systems engineering. Constructive simulations are crucial products in all essential system engineering jobs and operations, as a result. Systems engineers are particularly interested in computer-aided engineering (CAE) techniques. Early in the design process, computer-aided techniques may provide a more thorough and comprehensive examination of system requirements.

They may lead to better communication because information can be delivered quickly to several people at once and because design modifications can be quickly implemented and distributed. CAD, CAE, CAM, Continuous Acquisition and Life Cycle Support, and Computer-Aided Systems Engineering: Computer-Aided Design (CAD) are important computer-aided engineering tools. Electronic product descriptions created using CAD tools are used to assist and facilitate design choices. It may simulate a variety of system elements, including the layout of components on electrical or electronic circuit boards, the routing of pipes or conduit, and diagnostic procedures. Using two- or three-dimensional displays, it is used to arrange systems or components for size, placement, and space allocation. It makes sure that assemblies, surfaces, intersections, interfaces, etc. are precisely described by using three-dimensional "solid" models.

The majority of CAD software automatically produce isometric and exploded views of intricate dimensional and assembly drawings as well as calculate the surface areas, volumes, weights, moments of inertia, centres of gravity, and other properties of the components. For the purpose of analysing man-machine interfaces, many CAD programmes can also create three-dimensional models of buildings, operator consoles, maintenance workstations, etc. There are many distinct CAD tool options, each with varying levels of functionality, realism, and price. The Boeing 777 was developed using the commercial CAD/CAM application Computer-Aided Three-Dimensional Interactive Application (CATIA), which is a prime example of modern CAD technology.

Engineering using a computer (CAE).

For the purpose of supporting trade studies, CAE offers automation of requirements and performance analysis. Technical assessments like stress, thermodynamic, acoustic, vibration, or heat transfer analysis would typically be automated by it. Additionally, it may provide automated procedures for doing functional evaluations including failure mode, safety, and fault isolation and testing. The automation of lifecycle-oriented analysis that is required to support the design may also be provided by CAE. With CAE technologies, it is possible to do maintainability, producibility, human factor, logistics support, and value/cost studies.

CAM, or computer-aided manufacturing.

CAM solutions are often created to provide automated assistance for both the project management process and the production process planning process. Establishing Numerical Control settings, operating machine tools with pre-coded commands, programming robotic equipment, managing materials, and ordering replacement components are all aspects of CAM's process planning capabilities. The production management component of CAM gives management control over production-related data, uses historical actual costs to predict costs and plan activities, monitors metrics for procurement, inventory, forecasting, scheduling, cost reporting, support, quality, maintenance, capacity, etc., and identifies schedule slips or slack on a daily basis. Manufacturing Resource Planning II (MRP II) is an illustration of a commonly used computer-based project planning and management application. Some CAM software may directly take data from CAD software. By integrating the CAD data directly into the CAM programme, this kind of tool, also known as CAD/CAM, automatically generates a significant amount of CAM data.

CASE stands for computer-aided systems engineering.

CASE tools provide automated assistance for the Systems Engineering process and related ones. The integration of system engineering activities, carrying out the systems engineering tasks specified in earlier chapters, and carrying out the systems analysis and control activities may all be supported automatically by CASE tools. In addition to offering technical management assistance, it is more capable than CAD or CAE. As more products enter the market as a result of competition, there is an expanding selection of CASE tools, many of which complement the industry's "best Systems Engineering practices."

CALS stands for Continuous Acquisition and Life Cycle Support.

CALS refers to the use of computer technology in planning and carrying out support services. Information about upkeep, supply support, and related tasks is the major focus. Importing data created during design and production is a crucial component of CALS. Supporting the maintenance of the system configuration throughout the operation and support phase is a crucial duty of CALS. Data transfer from CAD or CAM programmes to CALS has been difficult since DoD CALS services the logistical community rather than a single programme office. As a consequence, standards development for suitable data sharing is now prioritised. Two- and three-dimensional models (CAD), ASCII formats (Technical Manuals), two-dimensional pictures (Technical Manuals), and engineering drawing formats (Raster, Aperture cards) are only a few examples of the formats that are important. The Integrated Data Environment (IDE), which is required for usage in DoD programme offices, will make use of these formats.

In-person simulation

Live simulations include simulating the use of actual systems by real people in real-world circumstances. The idea is to simulate various situations and surroundings to create a realistic working scenario while putting the system and its operators through it. Live simulation examples include fleet exercises and fire drills. Live simulations must eventually be conducted to verify constructive and virtual simulations. Live simulations are often expensive; thus, trade analyses should be carried out to support the program's choice of a variety of simulation kinds.

Software vs. Hardware

The choice of whether to employ hardware, software, or a hybrid method depends on the complexity of the system, the flexibility necessary for the simulation, the degree of accuracy required, and the possibility for reuse, even if the focus at the moment is on software M&S. As software capabilities grow, software solutions become more affordable for massively complicated projects and repetitive tasks. Hardware approaches are especially helpful for software M&S validation, small or one-time initiatives, and speedy tests on production system modifications. The price of M&S procedures will vary greatly. To assist planning choices, a cost-benefit analysis of prospective M&S techniques should be carried out.

Accreditation, Validation, And Verification

How can you believe the simulation or model?

Through formal verification, validation, and accreditation (VV&A), instill trust in your model or simulation. Although VV&A is often associated with software, the same idea also holds true for hardware. The fundamental distinctions between the words (VV&A) are shown in Figure 2.

More particularly:

1. Verification is the process of confirming that a model implementation faithfully reflects the conceptual description and requirements that the model's creator intended for it to.
2. In order to define the amount of trust that should be put on this assessment, validation is the process of verifying the way and extent to which a model is an accurate representation of the actual world from the viewpoint of the intended applications of the model.
3. Accreditation is the official declaration that a simulation or model is suitable for usage in order to achieve a certain goal. The organisation in the greatest position to determine if the model or simulation in issue is appropriate grants accreditation. Depending on the goals pursued, an organisation could be an operational user, the programme office, or a contractor.

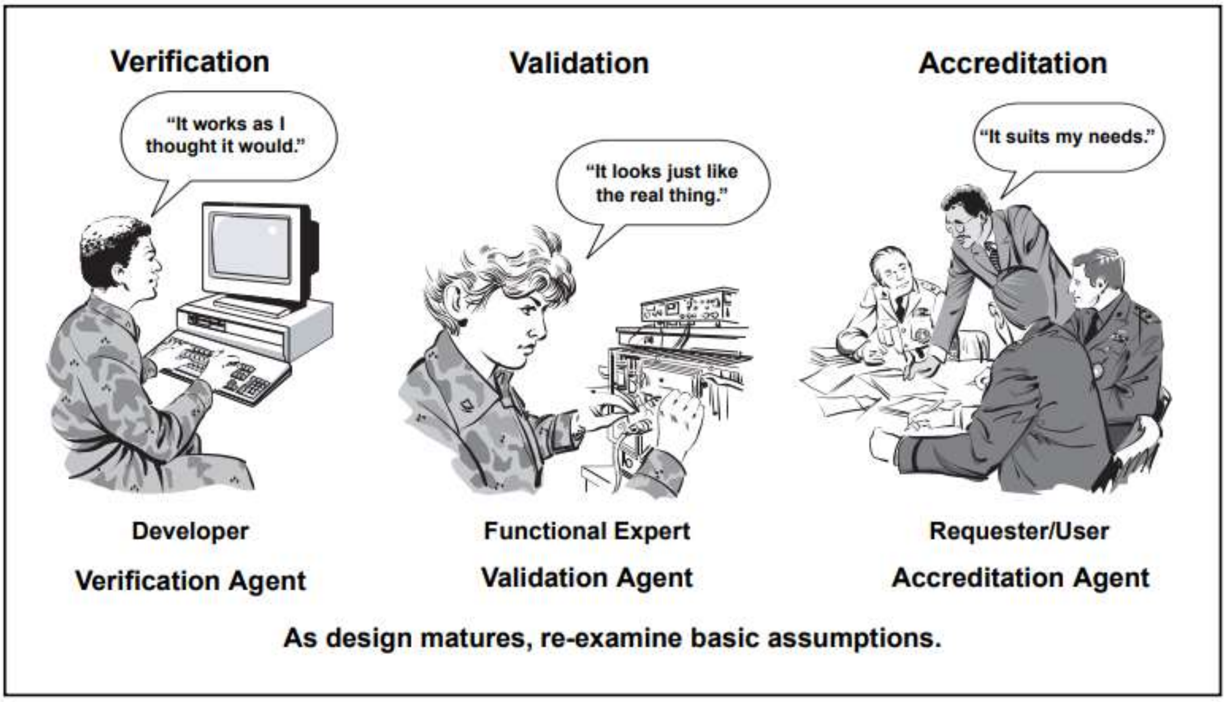

Figure 2: Verification, Validation, and Accreditation [ocw.mit.edu].

VV&A Currency

At the beginning of development and usage, VV&A is used. All DoD simulations must go through the VV&A process, which should be repeated every time an existing model or simulation receives a significant update or change. Additionally, VV&A must be repeated each time a model or simulation deviates from its specified methodology or from the inherent constraints that were utilised to validate or verify it via a new application. As long as its usage or what it mimics doesn't change, accreditation, however, may continue to be valid for the particular application until it is withdrawn by the accreditation agent.

CONSIDERATIONS

Decisions on the procurement and use of modelling and simulation in defence acquisition management should take a variety of factors into account. Cost, integrity, planning, balance, and integration are a few of these issues.

Cost Versus Fidelity

The degree to which elements of the actual world are reflected in M&S is known as fidelity. It serves as the basis for the model's development and later VV&A. With simulation fidelity, cost efficiency is a significant problem since fidelity may be a strong cost driver. The outcome of a simulation requirement analysis should be the ideal balance between expense and realism. When more is enough, M&S designers and VV&A representatives must decide. Throughout the simulation, fidelity requirements may change. Analysis should be used to find this variation, and it should be prepared for.

Not to be confused with the quality of satisfying simulation demands is the display quality! A well-known flight simulator employing a PC and a basic joystick as opposed to a complete 6-degree of freedom fully-instrumented aircraft cockpit is an illustration of fidelity. Both are useful at various phases of flight training, but their costs which range from hundreds to millions of dollars—are plainly quite different. Based on fidelity, or the degree of real-world realism, these costs change.

Planning

M&S should naturally include planning, thus it must be proactive, early, ongoing, and consistent. Balance, beneficial reuse, and integration may all be achieved with early planning. Planning is an active process since computer and simulation technologies are developing so quickly. To make the most of new capabilities, the process must be ongoing, and it is crucial that the right simulation specialists be engaged. All accountable organisations should participate in M&S activities as part of the integrated teaming. Integrated teams are required to create their M&S plans and include them into all programme planning activities, such as the TEMP, acquisition strategy, and others.

M&S preparation should consist of:

1. The assignment of responsibilities for each VV&A component in each model or simulation; and
2. Extensive VV&A estimates that have been explicitly accepted by all M&S-related operations, including T&E commitments from the operational testers, developmental testers, and distinct VV&A agents.

As part of routine planning, those in charge of the VV&A operations must be designated. According to Figure 2, the user serves as the accreditation agent, the functional expert as the validation agent, and the developer as the verification agent. This is often suitable for virtual simulations. However, the creator of a constructive simulation would often be required to support or guarantee the usage of their software for a certain purpose. The solution to the issue of who should carry out VV&A is one that is addressed in planning. Contracts and tasking papers should expressly include VV&A requirements. When applicable, VV&A should be discussed and included in the contractor's bid before the contract is awarded.

Balance

Balance refers to the use of M&S across the various stages of the product life cycle and across the range of concerned functional specialties. The phrase may also be used to describe the usage of hardware as opposed to software, fidelity level, VV&A level, or simply use as opposed to non-use. Cost-effectiveness research should always be the foundation of balance. Comprehensive cost-effectiveness evaluations should be performed, which means that M&S should be adequately taken into account for usage in all concurrent applications and during the whole life cycle of system development and use.

III. CONCLUSION

As a result, modelling and simulation are effective tools for system engineering that provide crucial information for analysis and decision-making at every stage of the system development lifecycle. They make it possible for engineers and other stakeholders to analyse, assess, and comprehend complex systems' behaviour, performance, and features in a safe and economical way. System engineers may depict the system's structure, components, relationships, and behaviours by using mathematical or computer models. These models depict the system virtually and enable the investigation of various scenarios, design alternatives, and what-if analysis. These models may be executed using simulation methods, which provide dynamic simulations of the system's behaviour over time that are realistic. System engineers may examine and evaluate the performance of the system, find possible bottlenecks, confirm design choices, and optimise system parameters using simulations.

By providing quantitative and qualitative evaluations of system performance, dangers, and trade-offs, modelling and simulation assist in successful decision-making. They enable engineers to choose the best option for attaining the required system goals by permitting the examination of different designs, configurations, and operating methods. In conclusion, modelling and simulation are crucial tools in system engineering that support complex system analysis, optimisation, and decision-making. They provide an affordable way to evaluate system performance, confirm design choices, optimise settings, and spot possible problems. Modelling and simulation help stakeholders communicate and work together effectively while promoting successful system development, integration, and testing.

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