Live, Virtual, and Constructive Models and Simulations for Test and Evaluation

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Test and Evaluation (T&E) is a fundamental aspect of developing a new product and is conducted in some form on almost all the products we buy and use. Models and Simulations can be used to make the T&E process quicker, cheaper, and more effective. This chapter will show how Live, Virtual, and Constructive M&S can be used to provide the consumer a better product that costs less.
1.1 What Is Test and Evaluation?

Lesson Objectives

- Define Test Evaluation (TE), and explain why it is conducted on a new product
- Understand the difference between a test and an evaluation
- Describe and give examples of technical TE
- Describe and give examples of user TE
- Describe effectiveness and suitability
- Define risk as the term is used in the TE process
- Discuss the need for test planning

Vocabulary

developer
A person who designs and manufactures a product or system. May also be the one selling the product to a customer. For example, the developer may be a car manufacturer or the maker of electronic games and software.

customer
The person who buys the product and actually uses it. In the context of this lesson, the customer can also be called the user.
effectiveness
The extent to which the goals of the system are attained, or the degree to which a system can be used to achieve its intended purpose or a specific set of requirements.¹

empirical information
Information gained by means of observation or experimentation. Empirical data are data produced by an experiment or observation. A central concept in modern science and the scientific method is that all evidence must be empirical, or empirically based. Evidence or consequences must be observable and repeatable.²

environment
The range of conditions under which a system can be expected to operate. This can mean adverse weather, heat or cold, rough terrain, or poor lighting conditions. The environment can also include various systems and components that are needed to complete a larger system or product, such as a satellite that is needed to send a GPS signal to a navigation system in your car. In the context of TE, environment will include the actual conditions in which and under which a product will be used and the interrelationships that exist among them.³

integrated testing
A process meant to put the product in a "real-world" environment as soon as possible and emphasize the early integration of user testing into technical test planning and execution.⁴
suitability
The qualities of a product or system that makes it appropriate for use by a customer. Some examples would be initial cost, reliability, ease of use, cost to operate, cost to maintain, and length of time it is able to perform its stated task, among others. Suitability for a customer should be considered as part of a product’s overall effectiveness.

system under test (SUT)
The actual thing that is to be tested. It can be new hardware, updated software, or a component of a larger system. When it is an integral part of a larger system or family of systems, the overall interaction as a unit is referred to as a system-of-systems. We will discuss more of this system-of-systems concept in the lesson “Introduction to TE of System-of-Systems and Interoperability,” below.

qualitative data
Information based on some characteristic rather than on some quantity or measured value. In TE, qualitative data may be based on subjective inputs or, in some cases, opinions; for example, ease of use, comfort, and aesthetics.

quantitative data
Information based on quantities or quantifiable inputs. Quantitative data has objective properties and is based on specific and observable measurements; for example, dimensions, weight, and capacity.

Check Your Understanding
Test and Evaluation (T&E) is a fundamental aspect of developing a new product. T&E is conducted in some form by the developers of almost all the products we use. T&E can be a simple and inexpensive process, or it can be complicated and expensive. Most of us are exposed to the effects of T&E, but many do not understand why or how it is conducted. To understand how live, virtual, and constructive models and simulations can be used for T&E, the student will first need to understand the basics of T&E.

Introduction
This lesson will introduce the student to the basics of Test and Evaluation (T&E). It is not meant to provide detailed knowledge of the T&E process, but rather to expose students to the necessary aspects of T&E, so they understand the relationships of T&E and live, virtual, and constructive simulations. We will discuss live, virtual, and constructive simulations in lesson two of this chapter.

Lesson Content
Overview
Test and Evaluation (T&E) is generally conducted by the developer of a product on behalf of the customer, or the person who will actually buy or use the product. The developer does not want to sell the customer a product that does not work, and that developer wants to make sure the product works as intended. So the developer tests his product to ensure that the product works in the conditions, or environment, in which the customer will actually use it.
developers will follow a defined TE process so they can identify deficiencies and problems with their products and then correct those problems before the product is released or sold to the customer.

**What Is a Test?**

Technically speaking, a test is a procedure designed to obtain, verify, or provide data for the evaluation of the performance and **suitability** of systems, sub-systems, components, and other equipment items. In short, a test is an event that obtains raw data to be used to measure specific or individual performance factors. A test can be very resource intensive, in that it can require a large amount of manpower and equipment to obtain adequate and credible data.

Discovering problems when building complex products is a normal part of any development process, and testing is perhaps the most effective tool for discovering such problems. Testing is the main instrument used to gauge the progress being made when an idea or concept is translated into an actual product. Ideally, testing progresses from early laboratory testing of technologies, to component and sub-system testing, through testing of a complete system, and finally to trial use in the customer’s hands.\(^5\)

http://www.youtube.com/watch?v=5xIObdXF8VE Go to this link to view the TE process for a new commercial jet aircraft engine. GE90-115B Gas Turbine Jet Engine Testing Evaluation.

http://www.bfbs.com/news/england/military-testing-facility-where-bullets-meet-their-match-45508.html Go to this link to view the process for testing new and upgraded body armor used by British troops in combat.

**What Is an Evaluation?**

An evaluation refers to what is learned from a test. An evaluation denotes the process whereby raw data obtained during a test are logically assembled, analyzed, and compared to expected performance to aid in systematic decision-making. An evaluation results in analyzed information and may involve the review and analysis of **qualitative** or **quantitative data** obtained from design reviews, hardware inspections, modeling and simulation (MS), hardware and software testing, metrics review, and actual use of equipment. An evaluation can be intellectually intensive and is used to draw conclusions by analyzing data to determine how the data from tests, models and simulations relate and interact. In general, most evaluations result in a formal written report on findings and recommendations to the developer.\(^6\)

The Federal Aviation Administration evaluated data from their tests and from Boeing tests of the 777-200 airliner to make the decision to issue a certificate of airworthiness needed to sell an aircraft on the commercial market. Automobile manufacturers evaluate data from tests of their products before they decide to release those products for sale. They want to avoid recalls such as have been experienced by some companies over the last few years.
What Is Test and Evaluation (T&E)?

When test and evaluation are put together, it becomes a process by which a system or components are exercised and the results analyzed to provide performance-related information. Test and Evaluation (T&E) is used at a variety of levels, including basic technology, components and subsystems, a complete system or product, and even several systems working together. The information has many uses, including design decisions, production decisions, risk identification, risk mitigation, and gathering of empirical data to validate models and simulations. T&E is a process that ensures a product or system meets its designed capability by enabling an assessment of technical performance, specifications, and system maturity. This allows the developer to determine whether the product or system performs correctly and is appropriate for use by the customer. The T&E process is often repeated as the system evolves from models to components to production articles and complete systems.\(^7\)

It is important that the T&E is conducted using the intended operating environment for the product as early in the design process as feasible. That will present challenges for those who plan and conduct the T&E, but if T&E is not done under realistic conditions, then problems with the product may not surface until the product is in the hands of the customer. If this occurs, the developer will have the additional expense of correcting the problem after the product is on the market for sale to the customer.

Many commercial companies have found innovative ways of conducting T&E that help them avoid being surprised by problems late in a product’s development. In general, most product testing is conducted by organizations separate from those responsible for managing product development. The intent is that the separate or independent organization will be more objective in T&E of the product than the developing organization.\(^8,9\)

What Is the Purpose of T&E?

The fundamental purpose of T&E is to provide knowledge to assist in managing the risks involved in developing, producing, operating, and sustaining systems and capabilities.\(^10\) T&E is generally done by the developer, but sometimes can be done on behalf of the customer who will actually use the product. T&E provides knowledge of system capabilities and limitations to the developer for optimizing product performance and suitability in real world use. T&E enables the product’s developers to learn about limitations (technical or operational) of the system under development, so that they can be resolved prior to production and deployment of the product or system to the customer.

Commercial companies have learned to make T&E an integral part of their product development process. For example, Boeing experienced significant problems with the 747-400 airliner due to ineffective T&E planning. Adequate T&E was not accomplished early in the developmental process of the new aircraft and caused the company to deliver the aircraft late and to assign 300 engineers to solve problems not found earlier in development. For the 777-200 airliner (Figure 1.1), Boeing included aggressive T&E from the very beginning of the aircraft’s design and development. This approach was so much more effective that the 777-200 program reduced design changes, errors, and systems rework by more than 60 percent. In addition, the Federal Aviation Administration certified the initial aircraft for overseas flight on the basis of Boeing’s T&E results. The certification normally requires two years of actual flight service.\(^11\)

After a flaw in the original Pentium® microprocessor cost Intel about $500 million to replace products for customers, the firm approached the T&E of subsequent microprocessors differently. The quality of these microprocessors, such as the Pentium® Pro and Pentium® III, has significantly improved, yet they were developed in the same amount of time as the original Pentium® microprocessor, despite being many times more complex.\(^12\)

In sum, the ultimate goal of T&E is to make sure the product works as intended before it is provided to customers. This saves the company time and money in the long run and makes a better product for the customer.
1.1. What Is Test and Evaluation?

What Types of Test and Evaluation Are There?

There are various types of T&E depending on the system being developed, its use, and the intended customers. T&E activities might be called technical specification testing, acceptance trials, advanced technology demonstrations, verification testing, or product quality testing. Some developers conduct what they call certification testing to "certify" that the product is ready for customer use, and some companies use the term "user testing" for the same purpose. The popular magazine *Consumer Reports* conducts what they call "consumer product testing." They do not develop or sell the products; they conduct TE and report the evaluation to the consumer via the magazine. Sometimes, there is more than one type of testing done on the same product or system. For example, many large commercial airplane builders will conduct in-house testing, followed by the Federal Aviation Administration conducting separate certification testing. At times, models and simulations may be required to test certain capabilities and testers will have to decide whether those simulations should be live, virtual, or constructive, or a combination of those three. We will discuss live, virtual, and constructive simulations further in the next lesson.

While there are many names for the various types of T&E, companies will generally think in terms of using T&E to ensure that a product is working as intended or maturing in accordance with an expected schedule. Most products will have three basic levels of maturity: components working individually, components working together as a system in a controlled setting, and components working together as a system in a realistic setting. Thus, the focus is on attaining the knowledge necessary to ensure that their products meet a basic set of standards at a given point in time.\(^{13}\)
Each type of T&E has its purpose in the development of a new product. In order to understand how live, virtual, and constructive models and simulations are used for T&E, we will discuss two types of T&E: technical T&E and user T&E.

**Technical Test and Evaluation**

Technical T&E (Figure 1.2) supports the design and developmental process used to build new systems and products and is generally used in the first two levels of product maturity: components work individually and components work together as a system in a controlled setting.

Technical T&E is done to provide information about risk and risk mitigation, as well as assessing the technical performance parameters of the system under test. Technical TE also provides empirical data to validate models and simulations and information to support periodic technical performance and system maturity evaluations. Robust technical TE reduces technical risk by discovering problems early during the product’s development, when they are less costly to correct. This in turn increases the probability of a successful program. During early technical testing, the product developer will focus on testing technical performance specifications. Follow-on technical testing events should advance to robust, system-level and system-of-systems level testing to ensure that the system has matured to a point where it can meet the requirements of use in a realistic environment.
1.1. What Is Test and Evaluation?

User Test and Evaluation

User T&E can be considered a test using representatives of typical customers or users, under realistic conditions, of any system or key component for the purpose of determining the performance of the system or product for use in real life by typical users. A user test will generally focus on the third of the three product maturities: components work together as a system in a realistic setting, also called the product’s environment.

A user type of testing should generally include interfacing systems and sub-systems to provide as real an environment as possible for the system to perform in. User T&E can be conducted early in a product’s development to provide insight into potential real-world problems and progress toward meeting performance and suitability requirements. Real-world problems might be those caused by operating a product in harsh weather or driving a vehicle over rough terrain. Another real-world example is a product being used by a customer who lacks detailed technical knowledge of how a product works. Most companies will delay a product’s release until the developer is confident the product or system is effective and suitable for use by the customer.

User T&E will generally include using only production representative systems, operated by representative users (Figure 1.3). The early planning for user testing should consider any special user requirements, such as the need for large or unique test areas, supporting capabilities and systems, necessary models and simulations (to include simulators), or other unique requirements to put the system under test in as realistic an environment and as close to realistic conditions as feasible. An environment is simply the surroundings in which a system or product must operate, and can include weather, terrain, dust and dirt, heat, cold, air quality, darkness, high humidity, etc. The product should be tested in an environment as near to the actual conditions it will be used in as possible.

This link demonstrates one company’s process for what it calls “usability testing,” which is part of user testing. http://www.youtube.com/watch?v=l9sYeP0z78k

What Is Risk Reduction?

Risk is a measure of future uncertainties in achieving a system’s or product’s performance goals and objectives within a set of defined cost, schedule, and performance constraints.14
"Late-cycle churn" is a phrase one commercial company uses to describe the scramble to fix significant problems or flaws that are discovered late in a product’s development. The "churn" refers to the additional, unanticipated time, money, and effort that must be invested to overcome the problem. Problems are most devastating when they delay product delivery, increase product cost, or "escape" to the customer. Usually, it is a test that reveals the problem, hopefully early in the product’s design and development when the problem is easier and cheaper to correct.15

Risk reduction is the activity that examines identified risks at various stages of a system’s or product’s development to isolate the cause and allow the developer to take the most appropriate corrective action to mitigate that risk (Figure 1.4). Mitigating and reducing risk has obvious consequences in terms of a system’s performance, development schedule, and cost. Risk reduction can be applied to all aspects of a program (e.g., technology, maturity, supplier capability, design maturation, performance against plan) and should be of great interest to TE planners. TE is a vital tool not only in mitigating known risks to a product, but also in identifying unanticipated risks and discovering previously unknown problems. The proof of successful risk reduction in TE can be found in the degree to which a product experiences "late-cycle churn."

**FIGURE 1.3**
This is an early permanent wave machine. Technical testing might find that it met all technical specifications. User testing might find that it was effective and worked just fine, doing a wonderful job of making wavy hair. But, would it be found suitable for use at home? (Courtesy of Consumer Reports magazine)
1.1. What Is Test and Evaluation?

A significant method to minimizing surprises and "late-cycle churn" in developing new products is to integrate technical and user testing for product maturity early in a product’s development. If the risks to "components working together as a system in a realistic setting" are identified early in the developmental cycle, they are much easier and cheaper to correct. Consequently, many companies and product developers place a high value on conducting user T&E early, often embedded into technical testing events, and using the results to save time, money, and assets as well as to make the product better. Examples of integrated testing will be discussed in the next lesson, "Live, Virtual, and Constructive Simulations in Test and Evaluation."

Integrated testing is not an event or separate test phase, nor is it a new type of test. Integrated testing is a process meant to put the product in a "real-world" environment as soon as possible and emphasize the early integration of user testing into technical test planning. The goal of integrated testing is to conduct a seamless TE program that produces credible qualitative and quantitative data useful to all evaluators, and to address developmental, suitability, and customer use issues. Integrated testing allows for the collaborative planning of test events, where a single test point or mission can provide data to satisfy multiple objectives without compromising the test objectives of participating test organizations.16

There is no single implementation of integrated testing that will be optimum for all products, but planning and conducting the T&E program in a collaborative manner will result in a more effective and efficient test effort. Such a structured approach also ensures that all test activities are necessary, duplication is eliminated, and that no areas are missing in the overall T&E effort. If done correctly, the enhanced operational realism in integrated testing provides greater opportunity for early identification of system design improvements, and may even change the course of system development during its early stages. Integrated testing can increase the statistical confidence and power of all T&E activities. Most obviously, integrated testing can also reduce the number of T&E resources needed in user T&E.

How Do You Plan for T&E?

Planning for T&E should be within the product’s overall development strategy and allow for a realistic period of time to accomplish the planned test events, evaluations, and report preparation. Planning for T&E should first identify
technological capabilities and limitations of alternative concepts and design options under consideration to support cost-performance tradeoffs. For instance, what is the minimum number of test runs needed to collect the right amount of data necessary to conduct an adequate evaluation of a system? Given that light bulbs cost money and that it takes time to test new ones, how long do you need to leave a particular light bulb on to evaluate its reliability? Also, how many light bulbs do you need for an individual test? Those are cost-performance factors a test planner must consider. Test too many light bulbs for too long, and you waste time and money. If you test too few or for too short a time, your test data may be unreliable. There are several T&E planning strategies used by various developers. Most will include a process that begins with identifying what facets or capabilities of the product need to be tested. Then T&E planners will continue by identifying how they will do that: what resources will be needed to test, how the data will be gathered and analyzed, and how the data will be reported.\(^{17}\)

T&E planning should also:

- Identify and describe design technical risks to the system.
- Develop a test that will stress the system under test to at least the limits of the expected product operating limits — and for some systems, beyond the normal operating limits — to ensure the robustness of the design. This testing will reduce risk of poor performance in the expected operational environments.
- Consider using early test activities, where appropriate, prior to conducting full-up, system-level testing, such as flight-testing, in realistic environments.
- Include technical and manufacturing risks in the required assessment of technical progress in order to mitigate technical risk.\(^{18}\)

Part of the T&E planning process should consider modeling and simulation. Test planners should collaborate early on the planned use of models and simulation to support or supplement their test activities or analyze test results. When actual system testing is not possible to support a T&E event, test planners may use computer modeling and simulations, preferably with real operators involved or “in the loop”). Should these capabilities be live, virtual, or constructive? We will discuss more about live, virtual, and constructive simulations in the next lesson.

It is important to identify gaps in planning that will prevent the test from achieving the desired results. Test planners must ensure that each T&E event will satisfy the objectives the developers need to assess the product maturity level for the system under test.

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**Test Planning Questions to Consider**

- Who and what are the participants and capabilities needed to satisfy data requirements?
- What locations, facilities, or products will provide the capabilities that are needed for the Test?
- Do I have everything I need to support my test in a single location?
- Should these capabilities be live, virtual, or constructive? (more on this in the next lesson)
- What are the “best” options for the type of test and maturity level of the product?

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**Lesson Summary**

- A test is an event that obtains raw data to be used to measure specific or individual performance factors.
- An evaluation denotes the process of analyzing data obtained during a test. Simply put, an evaluation refers to what is learned from a test.
1.1. What Is Test and Evaluation?

- Test and Evaluation (TE) is a process by which a system or components are exercised and the results analyzed to provide performance-related information.
- There are many types of TE, depending on the developer, the product, and the product’s use. The two most recognized types are described here as technical and user TE.
- Risk reduction can be applied to all aspects of a program (e.g., technology, maturity, supplier capability, design maturation, performance against plan) and should be of great interest to TE planners.
- The ultimate goal of TE is to make sure the product works as intended before it is provided to customers. This saves the company time and money and makes a better product for the customer.

Review Questions

1. Describe the differences between test and evaluation.
2. What are two attributes of technical T&E?
3. What are two attributes of user T&E?
4. What are some points to consider when planning a T&E on a new product?
5. How can an effective T&E reduce risk in developing a new product?
6. What is the ultimate goal of T&E?

Further Reading/Supplemental Links

http://www.youtube.com/watch?v=VdlaQTS76VU This link provides a tongue-in-cheek demonstration of the lengths some companies will go in user testing of their product.

Points to Consider

For this lesson, points to consider are provided as an aid to the instructor to stimulate critical thinking among the students. These questions have no right or wrong answers, but may help further the student’s understanding of the material. Suggested responses are provided to help the instructor guide the discussion.

T&E is a proven and accepted methodology used to make sure new products work as they are intended to and are ready for use by customers.

- Based on the picture of the landing gear and flaps of the Boeing 777-200, shown in Figure 1.4, what risk would the developer incur if adequate technical and user TE were not conducted on this complex system? (Suggested responses: The safety consequences of a failure of the gear or flaps to extend or retract are obvious. However, additional risk incurred by inadequate TE might include cost overruns in developing, or delays in fielding, the new airplane; expensive corrections to the landing gear after it is fielded; or excessive maintenance required of the user to keep the landing gear working properly. Aggressive testing might show that there was no problem with the landing gear itself but that the light bulb that indicates the gear is down is faulty and unreliable. So, early integrated testing might help avoid an unnecessary re-design of the system.)

- Based on what was learned in the "Introduction to Modeling and Simulation" chapter, how can MS techniques be applied to TE? (Suggested responses: Modeling and Simulation can be used to replicate the operational
environment for the product and thus allow for early input of user testing. Testing of actual hardware can be very expensive. MS can be used to help reduce some costs by replicating all or part of a system under test. MS techniques could simulate components of a system that has not been completed yet, so TE can be done before actual components are built.)

References

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7 ACQNOTES.COM (http://imap.acqnotes.com/Attachments/Lesson%2018%20Test%20and%20Evaluation%20Overview.pdf)
9 DoD 5000.59-M (DoD Modeling and Simulation Glossary), December 1997
16 Defense Acquisition Guidebook, July 2011
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Lesson Objectives

• Describe the categories of simulations
• Describe what a systems integration laboratory (SIL) does
• Explain the need for verification and validation of models and simulations used in Test and Evaluation (TE)
• Describe live, virtual, and constructive (LVC) simulations and how they can be brought together for a distributed test event

Vocabulary

constructive simulation
A simulation that involves simulated people operating simulated systems.¹

distributed
Originally referred to a computer network in which at least some of the processing was done by separate workstations and information was shared by, and often stored at, the individual workstations. The term is used today in a much wider sense, even referring to autonomous processes that run on the same physical computer and interact with each other by message passing. In the context of this lesson, the term is not limited to computers, but also refers to a network where individual systems and capabilities are physically separated across some geographical area and are connected to provide an environment needed to test a product. These systems can be individual components that are linked to simulate a "whole" system, or can be capabilities such as simulated adverse weather or terrain linked to the cockpit of a flight simulator. Thus, using Modeling and Simulation, a distributed environment can be developed from geographically separated systems providing all the components and capabilities needed to conduct a realistic test of a product.

hybrid simulation
A simulation that combines constructive, live, and/or virtual simulations, typically in a distributed environment. Such simulations typically combine simulators with actual operational equipment, prototypes of future systems, and realistic representations of operational environments.²

live simulation
A simulation involving real people operating real systems.³

virtual simulation
A simulation involving real people operating simulated systems.⁴

middleware
Middleware is the data exchange software used by laboratories and simulations to send and receive data. It provides a common functionality (data distribution, filtering, etc.) to exchange data/information between systems. Middleware provides a means of assuring that test sites with different data formats, structures, sampling rates, and so forth will be able to communicate meaningfully with each other.
Wide-Area Network (WAN)

A communications network designed for large geographic areas. A WAN is used to connect various systems such as cell phones, computers, and other devices.

Check Your Understanding

After gaining a basic understanding of the test and evaluation (T&E) process in the previous lesson, the student will now need to apply that knowledge to the application of the various categories of models and simulations to the T&E process. As shown in the "Introduction to Modeling and Simulation" chapter, there are a wide range of models and simulations, and not all will be applicable to T&E.

Introduction

This lesson will identify the categories of simulations appropriate to Test and Evaluation (T&E). The lesson will then examine some basic requirements that must be met before models and simulations can be used for testing and describe some direct applications, such as hardware-in-the-loop (HWIL) and systems integration laboratories (SIL). The lesson will then address how these applications can be connected to form a distributed environment. A distributed environment is a crucial element in using live, virtual, and constructive (LVC) modeling and simulations to support T&E. In subsequent lessons, we will show how this distributed environment applies directly to making improvements in T&E capabilities.

Lesson Content

How Does Modeling and Simulation Apply to Test and Evaluation?

Modeling and Simulation (M&S) is used to develop data as a basis for making managerial or technical decisions. However, it is essential to apply M&S appropriately to achieve an effective and efficient Test and Evaluation (T&E) program. M&S capabilities and limitations are often inadequately understood, and M&S is sometimes planned for with insufficient attention to detail. A M&S capability in T&E involves not just the software tools themselves, but the data that feed them; the computing platforms that execute them; the standards, middleware, and networks that may interconnect them; the encryption capabilities and security constraints that protect them; and, most importantly, the people that plan, develop, integrate, verify, validate, accredit, and use them. Deficiencies in any of these can present a risk for using MS incorrectly, thus obtaining unreliable and invalid test results. This, in turn, can result in poor decision-making on the part of the developer in designing and producing a new product. So, while MS will be an integral part of many TE programs, test planners should plan carefully for the use of MS.

A wide range of models and simulations are used in T&E. The specific method used for a particular application should depend on the requirements of the T&E planning, the capabilities needed, the product maturity level and, in particular, on what aspects of the system or systems being modeled need to be represented.

Go to this link to view how computer simulations are used in crash testing of a new car. Think about how much it costs to run a real crash test versus a simulated crash test - they run the real crash to verify the models used in design.
What Is a Model?

As discussed in "Introduction to Modeling and Simulation," a model is simply a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process. A model can be a representation of an actual or conceptual system that can be used to predict how the system might perform under various conditions or in a range of "real-world" environments.

What Is a Simulation?

As discussed in "Introduction to Modeling and Simulation," a simulation is an implementation of a model over time. That is, it is a way to examine how a model behaves over time. More precisely, it is the process of conducting experiments with a model for understanding the behavior of the system modeled under selected conditions. Simulations may include the use of computer inputs, laboratory models, or mock-ups of actual products. Simulations are often programmed for use on a computer; however, in the broadest sense, live military exercises and war games are also simulations.

What Are the Categories of Simulations?

There are three basic categories of simulations: live, virtual, and constructive. These are often combined and referred to as LVC simulations.

**Live simulation:** A simulation involving real people operating real systems. Live simulations may use equipment that is representative of an actual product and can be connected with other systems such as virtual and constructive simulations.

**Virtual simulation:** A simulation involving real people operating simulated systems (see Figure 1.5). Virtual simulations sometimes replicate or use actual equipment in a central role by exercising motor control skills, decision skills, or human-generated communications. In many virtual simulations, the operators are immersed in a virtual environment that looks, feels, and behaves like the real thing. Virtual simulations can enable the testing of "dangerous" tasks at no risk to the operator, and hopefully at no risk to the equipment.

**Constructive simulation:** A simulation that involves simulated people operating simulated systems. Real people stimulate, or make inputs, to such simulations, but are not involved in determining the outcomes. Constructive simulations cover the range from a simple single system simulation to complex multi-simulation interactive configurations.
What Is Verification and Validation?

Product developers must be confident that the models and simulations they use for T&E are credible and will perform as intended. Verification and validation of a model or simulation helps to answer the questions, “Are we using the right one?” and “Is it built correctly?” Credibility within the development community can only be achieved through a robust verification and validation process, followed by an acknowledged willingness by the developer to accept the subject M&S for their T&E requirements. Therefore, the product developer should identify the intended use of M&S and any specific requirements early so that resources can be made available to support development and verification and validation (V&V) of these M&S tools.

- **Verification:** Verification is concerned with functionality, answering the question, “Does it work the way it was designed?” Verification in the context of this lesson is the process of determining that a model or simulation and its associated data accurately represent the developer’s conceptual description and specifications. It is often summarized as, “Did we build the model right?” For instance, a model of the Boeing 777-200 landing gear system might include a green light that is supposed to come on in the cockpit to indicate when the gear is fully extended. When that model is tested, if the green light doesn’t come on in the cockpit when the landing gear is fully extended, then the model has failed its verification. If the model fails its verification, then of course it has to be corrected or it will be of no use. Verification should be a continuing process; the analyst should not wait until the entire model or simulation is complete to begin the verification process.

- **Validation:** Validation is concerned with fidelity, answering the question, “Does it look and act like the real world?” Validation in the context of this lesson is the process of determining the degree to which a model or simulation and its associated data are an accurate representation of the real world from the perspective of the intended uses of the model or simulation. It is often summarized as, “Did we build the right model?” Primary questions for validation to answer include, “Does model match real world?” and “Can the model be substituted for the real system for the purposes of the test?” Using the same example of a model of the Boeing 777-200 landing gear, if the model was designed to have a red light come on when the landing gear was fully extended, the model might pass a verification test as it is operating the way it was designed. However, airplanes generally have a green light come on in the cockpit when the landing gear is fully extended, not a red light. So this model would not pass a validation test, as it would not be representative of the real world. If the model fails its validation, then of course it has to be corrected or it will be of no use. Validation is the precursor to approval to use the model or simulation, and there are many methods for performing validation. If there is an existing system, an ideal way to validate the model is to compare its output to that of the existing
What Is Hardware-in-the-Loop?

Hardware-in-the-Loop (HWIL) is another category of simulation that is known as a hybrid simulation. It usually consists of the actual hardware and software and external stimuli/drivers used to test the system’s or sub-system’s capability to operate in an environment simulating actual conditions. For the purposes of this lesson, HWIL simulations will be considered a methodology to integrate actual system or sub-system hardware in conjunction with other LVC models, and should not be limited to defining a specific laboratory or system. HWIL simulations place prototype or actual products and working components in the simulation to demonstrate their capability to operate within a selected environment that closely replicates real-world operating conditions. This may be just a single, small sub-system, or it could be very large and complicated, like a cockpit simulator of a Boeing 777-200 commercial airliner. The HWIL provides a system environment for the subsystem hardware to operate in.

It is much easier to control a HWIL system environment than a live system in an open air environment. Individual parameters can be controlled in the laboratory. The hardware performs the normal role that it would have operating in a real environment. Runs can be repeated, parameters can be changed as required, and the hardware is never destroyed in the test. Examples of HWIL simulations include dynamic engine test-benches, control systems, development test platforms, cockpit mockups, avionics integration systems, operational flight program simulations, and flight simulators.

Using HWIL, T&E can be conducted early in the development process, even before the product is completely developed. The degree of realism provided is dependent on the test requirements and based on the product maturity level discussed in the previous lesson. LVC simulations, especially HWIL, can be used to include a real-world environment and components into early maturity testing. That is why testing is done — to determine if components work individually and also together as a system. A realistic, simulated representation of the intended operating environment can be injected into the test. This gives the product developers and test planners early insight into how the components will work together as a system in a realistic setting. This early insight is especially important in allowing the developer to correct problems and faults before the product design is finalized.

There are also circumstances where the majority of T&E can only be accomplished by M&S. For example, there is no option but to rely on M&S to verify that a robotic Rover system landing on Mars is going to be successful. Test designers cannot create all of the environmental conditions in an Earth-based test, such as Mars’s gravity, magnetic field, atmosphere, and pressure. A significant portion of the T&E conducted for such missions are performed in HWIL tests using modeling and simulation to replicate environments encountered by the rover on Mars. These tests will generally use real Rover Hardware-in-the-Loop connected to various M&S laboratories to provide the needed realistic environment.

http://www.youtube.com/watch?v=F4bULefbhKg Go to this link to see HWIL TE demonstration in automobile testing. Note the car industry wants to test a prototype in a safe environment before going on the road. They constructed a HWIL (called "HIL" in this video) environment in which a prototype dashboard can be tested by being connected to a computer that can simulate all the real-time car dynamics and vehicle control signals that will interact with the dashboard displays.

What Is a Systems Integration Laboratory?

As was explained in the lesson "What Is Test and Evaluation?," many commercial companies think in terms of using T&E to ensure that a product works as intended and is maturing in accordance with an expected schedule. Those companies conduct integrated testing early to expose weaknesses in a product’s design. The intent is to find out about problems early in the design and production of prototype systems, when they are easier and cheaper to fix. The communications company AT&T, for instance, refers to this as a "break it big early" philosophy. To reduce the risk of problems later in production, a concept they call "late-cycle churn," Boeing used a new technique to validate the 777-200 airliner’s maturity in a controlled setting — a Systems Integration Laboratory (SIL).
Think of a Systems Integration Laboratory (SIL) as Hardware-in-the-Loop (HWIL) on steroids. A SIL is a risk-reduction facility where the complete product or system, including software and hardware, can be integrated and tested prior to building the first production prototype. The SIL will often start out with constructive models, which are replaced by HWIL and actual subsystem hardware as the system matures over time. The SIL provides a test facility that is a cross between a pure simulation and the final system. The SIL uses as many actual operating sub-systems, such as hydraulic sub-system, engine and power train, flight controls, and computer resources, as is technically and economically feasible.

The SIL enables the system to be tested around the clock, through a range of normal and extreme operating conditions in a very cost-effective manner. Boeing made extensive investments in their SIL so that they could test all of the 777-200’s main components in simulated flight conditions(Figure 1.6).

Boeing linked over 60 geographically separated laboratories into the SIL. The laboratory combined actual 777-200 HWIL sub-systems, such as avionics, electrical system, and cockpit flight controls, with simulated flight conditions. Each simulated test flight recorded measurements from all systems, giving engineers the accurate data needed to investigate system operation and interaction. Test problems were recorded for each flight, entered into a tracking system, and processed as a “real” airplane flight discrepancy report. In this way, Boeing used the problems discovered during these simulated test flights to improve the aircraft, saving time and money. Boeing officials claim that the accuracy of the computer-generated information is critical to the credibility of such a laboratory and that Boeing’s large base of real-world, credible data was vital to the laboratory’s success. Ultimately, the laboratory “flew” about 2,000 test hours on the 777-200 and greatly enhanced the efficiency of subsequent actual flight tests. Flight testing still revealed problems, but the number of new problems was low, not significant enough to cause "late-cycle churn" or other problems in later development. Boeing was able to analyze early problems and identify potential solutions that were validated in the Systems Integration Laboratory before being incorporated on the aircraft. The monthly test-flying hour rates of the 777-200 airplane exceeded all previous programs, yet the number of new problems found on the airplane was low. Using a well-engineered SIL enabled the developer, Boeing, to reduce "late-cycle churn" and the risk to their product, saving time and money and ultimately allowing them to build a better airliner. 

FIGURE 1.6
A Boeing 777-200 cockpit mockup included HWIL as part of a broader SIL. Using a SIL, Boeing included aggressive integrated TE from the very beginning of the aircraft’s design and development. This approach was so effective that the Federal Aviation Administration certified the initial aircraft for overseas flight on the basis of Boeing’s TE results. The certification normally requires two years of flight service. (Courtesy of Boeing)

http://www.youtube.com/watch?v=4KWEjWV2W90 Go to this link to see a System Integration Laboratory application used in developing new aircraft.
**What Is Distributed Testing?**

All the categories of live, virtual, and constructive models and simulations, including HWIL and SILs, can be connected or linked. In many cases, this is done with systems and capabilities, such as a SIL, that are not co-located. By sharing information through a **Wide-Area Network (WAN)**, LVC capabilities can be linked around a campus, around a city, or around the world to form a distributed environment. When this is done to support TE, it is referred to as distributed testing.

**Distributed testing** can be used to link sub-systems, systems, or system-of-systems to provide a distributed environment. Distributed testing can be used to integrate subsystems that are being developed or already exist at geographically separated facilities. It can also be used in lieu of some large-scale "open air" tests using actual, live, operational hardware for the systems involved. Conducting distributed LVC testing compliments live-only testing and provides the means for rapid integration of components and systems early in a product’s developmental life cycle. It also provides an efficient means of adding realism to TE by providing systems and capabilities not otherwise available, or by including separate but interrelated systems.

Distributed testing is particularly suited to some T&E, such as assessing a data exchange requirement between components, sub-systems, or systems, or within a system-of-systems. However, distributed testing will not be appropriate for all T&E. For example, system performance testing, product reliability testing, and other testing that does not include other systems or sub-systems will not likely use distributed methodologies.

**How to Plan for Distributed Live, Virtual, and Constructive Simulations in T&E**

Product developers should plan for T&E across the product’s entire developmental cycle to ensure that the product, its components, and its systems meet the appropriate maturity levels. M&S should be part of that planning to identify high-payoff areas in which to apply M&S and distributed LVC testing to conserve scarce resources. From early distributed tests using HWIL and SILs to test rehearsals using distributed LVC simulations, distributed testing can help early identification of problems and provide a cost-effective means to check out "live" test scenarios and thus reduce risk of failure for live-only testing. Distributed LVC simulations can provide a realistic environment for the system under test when it is impractical or too costly to use real-world assets. This is especially true for testing a system that is part of a system-of-systems, which will be discussed further in the next lesson.

Computer-generated test scenarios and capabilities, as well as LVC simulations of the system, can support distributed T&E by creating and enhancing realistic test environments. HWIL simulations enable testers and product developers to interact early with components and systems. Distributed LVC T&E can be used to identify and resolve issues of technical risk that require more focused testing. LVC simulations provide mechanisms for planning, rehearsing,
optimizing, and executing complex tests. Integrated, distributed testing might also provide a means for examining why results of a physical test might deviate from pre-test predictions.

Lesson Summary

- A model is a representation of an actual or conceptual system.
- A simulation is an implementation of a model over time.
- The categories of simulations include:
  - Live: real people, real systems.
  - Virtual: real people, simulated systems.
  - Constructive: simulated people, simulated systems.
- Verification and validation (VV) provides confidence that the model or simulation used in TE works the way it was designed and is an adequate representation of the "real world" for its intended use in a particular test.
- Hardware-in-the-Loop (HWIL) is a hybrid simulation that includes actual system or component hardware in conjunction with other LVC applications. It is not limited to a specific system or laboratory.
- A Systems Integration Laboratory (SIL) is a risk-reduction facility where the complete product or system, including software and hardware, can be integrated and tested prior to building the first production prototype.
- Distributed testing is a process for linking various geographically separated live, virtual, and constructive sites and capabilities together in a distributed environment.

Review Questions

1. What is the difference between a model and a simulation?
2. What are live simulations?
3. What are virtual simulations?
4. What are constructive simulations?
5. Briefly compare verification and validation.
7. Describe a Systems Integration Laboratory (SIL).

Further Reading/Supplemental Links

http://www.youtube.com/watch?v=ISiia1syhTM Not all HWIL testing is done by major companies on million dollar products.

http://www.youtube.com/watch?v=riBSh-4fxoc An example of a simulator, a virtual driving simulator. It includes selectable driving conditions, such as weather, traffic, urban buildings, and even a seat belt warning alarm, and uses a modified computer flat screen.

http://www.youtube.com/watch?v=HNC2SKzYZTM Another example of a virtual driving simulator. This is an emergency vehicle simulator that includes a more realistic "wrap around" screen configuration that is able to replicate accidents.
1.2. Live, Virtual, and Constructive Simulations in Test and Evaluation

http://www.youtube.com/watch?v=KxpjiVDVo8Y This link will show you a virtual sinus surgery simulator. The operator manipulates the simulated operating probe and then sees what a doctor would see with a real probe and a real patient. How would you validate and verify this virtual simulation?

**Points to Consider**

For this lesson, points to consider are provided as an aid to the instructor to stimulate critical thinking among the students. These questions have no right or wrong answers, but may help further the student’s understanding of the material. Suggested responses are provided to help the instructor guide the discussion.

- In Test and Evaluation, why is the verification and validation (VV) process for Models and Simulations so important? (Suggested response: Verification and validation provides a structured approach to develop MS tools for the test process. It ensures that the MS used will represent real world and that they don’t introduce errors or misrepresentations of the systems or the environments. This addresses the very basic questions all testers must ask themselves at some point in the TE process, “How good is my data?”)
- When are distributed LVC methodologies not appropriate in TE? (Suggested response: The most obvious conditions include system performance testing and reliability testing. You may be able to use MS to help plan for a test of a new light bulb (i.e. how many bulbs you will need, how many times you should turn them on/off, and how long you should plan to leave them on). But to actually test the performance and reliability of a light bulb, you will need to use actual hardware. And, of course, a pizza taster’s job would be very difficult to model or simulate.)
- What are some ramifications of developing a LVC distributed environment? (Suggested response: Developing a live, virtual, and constructive environment can be expensive, especially the initial development. But if it is an accurate representation, it will rapidly pay back those costs by reducing the expense in future testing. As the test planners become familiar with the LVC environment, they can use it for concept development for a whole new system to see how it operates in that environment. Developers can do that even before they have the hardware needed for the new concept.)
- Do LVC simulations have to be co-located to be effectively used in TE? (Suggested response: It may seem counterintuitive, but no, models and simulations do not have to be co-located with the system under test. In fact, one of the primary advantages of using LVC simulations is the fact that they can be geographically separated, or distributed, and still provide the capabilities and environments needed for testing. This distributed LVC concept will be examined in the lesson "Introduction to TE of System-of-Systems and Interoperability.")

**References**

1. DoD 5000.59-M “DoD Modeling and Simulation Glossary”
2. DoD 5000.59-M “DoD Modeling and Simulation Glossary”
3. DoD 5000.59-M “DoD Modeling and Simulation Glossary”
5. DoD 5000.59-M “DoD Modeling and Simulation Glossary”
A flight discrepancy report is a form used by pilots to describe malfunctions and problems an aircraft encounters during a flight. Maintenance personnel then use this report to identify what repairs must be made to the aircraft before it flies again. Not all discrepancy reports are serious, as they can identify that a minor light bulb has burned out and needs replacing. Or they can be very serious and cause the grounding of the aircraft, such as an engine failure during flight.
Lesson Objectives

- Describe a system-of-systems
- Explain the differences between a system and a system-of-systems
- Describe network-centric
- Describe interoperability

Vocabulary

**system**
A collection of interacting or interdependent components organized to form an integrated whole and accomplish a specific function or set of functions. Their parts must be related. They must be designed to work as a coherent entity, otherwise they would be two or more distinct systems. Generally, a system will produce a single function or result. Your MP3 player is a system in that it consists of various components that are combined with the purpose of working together to perform a specific function.\(^1\)

**system-of-systems (SoS)**
A set or arrangement that results when independent and useful systems are integrated into a larger system that delivers unique capabilities. A system-of-systems can result in unexpected interactions and unintended consequences. Test and evaluation (TE) of a system-of-systems must not only assess performance to desired capability objectives, but must also characterize the additional capabilities or limitations due to unexpected interactions. Systems-of-systems is a new and evolving area for development, acquisition, and TE.\(^2\)

Check Your Understanding

In previous lessons, you gained insight into how live, virtual, and constructive (LVC) simulations can be applied to test and evaluation (T&E). More specifically, you learned how a distributed LVC environment can be built by connecting various geographically distinct capabilities needed for testing. The interaction of these capabilities, or systems, must now be understood before we can examine the direct applications of using distributed LVC simulation in T&E.

Introduction

This lesson will address the concepts of the interaction needed of systems to form a system-of-systems in a network-centric environment, and then introduce the very important concept of interoperability. Interoperability between systems is a fundamental requirement for what makes a system-of-systems actually work, so it is a natural focus for testing a system-of-systems.
Lesson Content

What Is a System-of-Systems?

A system can be defined as a functionally, physically, or behaviorally related group of regularly interacting or interdependent elements that form a unified whole. Test and Evaluation (TE) is used to assess a system for its ability to achieve a desired effect or to perform a set of tasks under specified standards and conditions. TE on a system can be either technical TE or user TE.

When independent systems are integrated into a larger system, it is known as a system-of-systems, or SoS. A SoS delivers unique capabilities and interactions that are not found in individual systems. Both individual systems and SoS conform to the accepted definition of a system, in that each consists of parts, relationships, and a whole that is greater than the sum of the parts; however, although a SoS is a system, not all systems are SoS. For instance, a Nintendo Wii is a system (Figure 1.7). The individual parts of a Nintendo Wii include the console, wireless controller, a separate display screen, and the Wii remote, which can be used as a handheld pointing device and detects movement in three dimensions. But all these parts are components that are integrated into a larger system. Complex, yes, but these components cannot stand alone. Each component needs the rest of the components to be able to function properly.

SoS is a rapidly changing area for product development and T&E. The SoS concept should include the system in the broadest sense, from performance of specific components to the network-centric interaction of an entire SoS. The exchange of data in a SoS can result in unexpected interactions and unintended consequences. T&E of a SoS will have unique requirements due to the complexity of the communication and data exchange within the individual systems. T&E of SoS must not only assess the desired performance capability of individual systems, but
must also assess the additional capabilities or limitations due to these unexpected interactions. Early testing, both technical and user testing, is especially important in a SoS to help mitigate the risk of "late-cycle churn" (defined in the lesson "What Is Test and Evaluation?"). Testing in a distributed LVC environment can more easily, and with fewer resources, replicate the intended SoS and its operating environment. LVC simulations, Hardware-in-the-Loop (HWIL), or a Systems Integration Laboratory (SIL) provide a unique capability to conduct testing of SoS and is a practical and efficient way to build a test environment for complex SoS. In fact, using distributed LVC simulations may be the only practical way to discover the unexpected interactions and untended consequences common to a SoS.

What Is Network-Centric?

Network-centric, or "net-centric," refers to participating as a part of a continuously evolving, complex community of people, devices, information, and services interconnected by a communications network to achieve optimization of resources and better synchronization of events and their consequences. Many experts believe the terms "information-centric" or "knowledge-centric" would capture the concepts more aptly because the objective is to find and exploit information. The network itself is only one of several enabling factors along with sensors, data processing and storage, expert analysis systems and intelligent agents, and information distribution. The shift away from point-to-point system interfaces to network-centric interfaces brings significant implications for the T&E community.⁴
The net-centric environment is a framework for full human and technical connectivity. It allows product users to share the information they need, when they need it, and in a form they can understand and act on with confidence.\(^5\) It should also protect information from those who should not have it. Net-centric systems for TE enable users to handle information only once, post data before processing it, access data when it is needed, collaborate to make sense of data, and diversify network paths to provide reliable and secure network capabilities. This allows for improved resource management and provides better information on events and conditions needed by the developer and test planners.

The challenge to the T&E community is to represent the integrated architecture in the intended operating environment for the product, systems, and system-of-systems — that is, in a net-centric environment. It is imperative that the T&E community develop net-centric test planning that reflects the intended operational environment and interfaces within which the intended products and capabilities must be tested. This would include characteristics of individual systems and network characteristics and factors such as network loading, bandwidth, throughput, packet loss, latency, and jitter.\(^6\) While these terms of network performance are beyond the scope of this lesson, the student should understand that each of these characteristics form only a part of a very complicated process that will need to be addressed when conducting TE in a network-centric environment.

**What Is Interoperability?**

Interoperability is defined as the ability of systems or components to provide data, information, and services to, and accept the same from, other systems or components and then to use the data, information, and services to enable them to operate effectively together. Interoperability is absolutely required of systems and SoS operating in a net-centric environment. It is this interoperability that enables systems that have been connected to act as a system-of-systems.

Assessing interoperability performance in a net-centric environment for system-of-systems is a key element of using distributed LVC simulations for T&E.

The complexity and expense of today’s net-centric systems clearly demonstrate the need to test early and often throughout the development and fielding process of a product. Early testing of a system’s capability to operate in its intended environment will allow designers and system engineers to identify and correct fundamental issues with performance and interoperability before they become operational specifications. As the transition to net-centric SoS is accelerated, the requirement to successfully demonstrate systems interoperability will increase. Thus, the need to use distributed testing with LVC simulations becomes the only feasible method to efficiently confirm system maturity, effectiveness, and performance.
FIGURE 1.9
The continental U.S. power transmission grid is a good example of a net-centric system-of-systems. It consists of about 300,000 km of lines operated by approximately 500 companies. Transmission networks are complex, with redundant pathways and a wide-area synchronous grid, or "interconnection." This allows transmission of power throughout the area, connecting a large number of electricity generators and consumers and potentially enabling more efficient electricity markets and redundant generation. Electricity generation and consumption must be balanced across the entire grid because energy is consumed almost immediately after it is produced. Remember that the exchange of data in a system-of-systems can result in unexpected interactions and unintended consequences. Likewise, a large failure in one part of the power grid — unless quickly compensated for — can cause current to re-route itself to flow from the remaining generators to consumers over transmission lines of insufficient capacity, causing further failures. One downside of a net-centric system-of-systems, such as a widely connected power grid, is the potential of cascading failure and widespread power outage if the grid is not managed properly. The challenge for TE planners is developing the capability to test products in this type of distributed net-centric environment.

Lesson Summary

- A system-of-systems can be defined as the configuration or arrangement that results when independent and specific systems are integrated into a larger system, thus delivering unique capabilities and interactions.
- Network-centric, or "net-centric," refers to participating as a part of a continuously evolving, complex community of people, devices, information, and services interconnected by a communications network.
Interoperability is the ability of systems or components to provide and accept data, information, and services that enable them to operate effectively together.

Review Questions

1. Describe the differences between a system and a system-of-systems.
2. List the two significant features of a system-of-systems.
3. How does a network-centric capability affect distributed T&E?
4. Why is interoperability between systems important?

Further Reading/Supplemental Links

http://www.youtube.com/watch?v=ZMDROyNXrvo Go to this link to view how a car company used distributed capabilities to design a new car. Note the globalization where design team is one place and engineering team is another place.

Points to Consider

For this lesson, points to consider are provided as an aid to the instructor to stimulate critical thinking among the students. These questions have no right or wrong answers, but may help further the student’s understanding of the material. Suggested responses are provided to help the instructor guide the discussion.

- We now have all the "parts" necessary to understand TE using distributed live, virtual, and constructive simulations.
  - What practical applications do you see? (Suggested response: When properly understood and planned for, distributed LVC methodologies will apply to the TE of most products and systems that must interact or exchange data with other products or systems. The most dramatic applications will be in large system-of-systems testing, due in part to the difficulty and expense in developing live-only testing scenarios.
  - What benefits do you envision? (Suggested response: When live systems do not need to be co-located to complete a test event, there will be immediate cost and time savings to the TE program, simply because of the expensive and time-consuming nature of collecting these systems in one place. That in turn will have multiple affects in how realistic that testing can be, how early the product or system can be tested, and eventually reduce the cost of making corrections to the design and development of the product. That will ultimately result in a better, quicker, and cheaper product to the customer.
  - What are some potential drawbacks? (Suggested response: Distributed LVC testing will not be cost-free. There will be a lot of "up front" costs, and it can be difficult to provide the network and environment needed. Distributed testing will not be appropriate for every TE situation. Also, it is a relatively new concept, and in some cases it can appear to be "too hard" to do. These drawbacks will be discussed in the next lesson, but it should be stressed that, for many if not most cases, distributed LVC testing will save the developer time and money.
- How does network-centric affect TE planners? (Suggested response: Net-centric systems-of-systems will present TE planners a very complicated problem in designing accurate environments for test events that will replicate the "real world" in which the product or products will operate. They will have to anticipate and
account for unexpected and unintended interactions of the various systems. This is important, as the developer will need to know what deficiencies belong to his product(s) and what problems are due to other system(s) or even the environment.

References

1 DoD 5000.59-M “DoD Modeling and Simulation Glossary”
2 Defense Acquisition Guidebook, July 29, 2010, Chapter 9, *Test and Evaluation*
4 Webster’s Dictionary (online), [http://www.websters-online-dictionary.org/definitions/Net-Centric](http://www.websters-online-dictionary.org/definitions/Net-Centric)
1.4 Considerations for Distributed Live, Virtual and Constructive Simulations in Test and Evaluation

Lesson Objectives

• Explain the limitations and advantages of Test and Evaluation (TE) in a distributed environment
• Describe how distributed live, virtual, and constructive (LVC) TE can:
  – Mitigate risk in product development
  – Improve TE capabilities
• Explain why distributed LVC TE is not meant to replace live testing
• Describe the importance of "test-fix-test"
• Explain the advantages of scalable distributed TE events

Vocabulary

scalable: In electronics (including hardware, communication, and software), scalability is the ability of a system, network, or process to handle growing amounts of work in a graceful manner, or its ability to be enlarged to accommodate that growth. In the context of distributed TE, we will refer to scalability as the ability to control the size and complexity of a distributed LVC event. It can be very small, to accommodate only two connected systems, or very large and complex, encompassing many systems and even multiple systems-of-systems.¹

Check Your Understanding

In the three previous lessons, the student has been exposed to all the various "parts" needed to plan for and conduct distributed testing using LVC simulations. They should now have a basic understanding of the complexities and advantages of using such a T&E methodology. The concepts and details we have provided were not intended to make the student an expert on either T&E or distributed testing. But there should be a good enough foundation to understand when distributed LVC should be considered in T&E planning.

Introduction

Testing using distributed LVC simulations is not meant as a solution to all T&E requirements. Nor will it correct all the "late-cycle churn" problems in developing a new product. However, there are distinct advantages and practical applications that can provide tremendous benefits. In this final lesson, we will introduce you to various considerations and specific advantages to the test planners, the developer, and ultimately the customer.
Lesson Content

Limitations to Conventional Live Test and Evaluation Methodologies

Conventional Test and Evaluation (T&E) with actual and complete systems can provide for testing in representative and realistic real-world environments. However, this usually requires building a large and expensive T&E event. In many cases, testing in such a live scenario will be subject to limiting factors, such as:

- Systems that are interdependent with a system-of-systems might not be readily available because they are in high demand elsewhere, do not exist in adequate numbers yet, or do not exist at all.
- There may be limited availability of related systems needed to complement a system’s realistic environment.
- Systems may not be co-located at the test site.
- Fully complete, actual systems are not built yet.

In fact, in most cases, needed systems and capabilities are not co-located at the desired T&E venue. Relying solely on live systems for T&E is often impractical, usually very expensive, and sometimes simply impossible.

What Are the Advantages of Distributed Testing with Live, Virtual, and Constructive Models and Simulations?

A distributed T&E environment can be built using a mixture of live, Hardware-in-the-Loop (HWIL), virtual, and constructive capabilities, all connected together. That is, the various testing components can be connected on a network to form a distributed operating environment for the system under test (SUT) linking all its enabling systems. In this distributed environment using LVC representations, the testing components and systems need not be co-located. This distributed test approach will allow the product’s developer to customize the T&E methodology to capitalize on the particular advantages of each capability as it is needed. Also, components and systems not previously available can be fully integrated into the T&E process.

Distributed LVC Testing allows the developer to customize the T&E methodology to capitalize on particular advantages and integrate each capability as it is needed, with less time, cost and risk than conventional live testing.

Distributed test events need not be solely large scenario-driven events, nor incorporate the LVC assets available all at once. One event may include live and virtual capabilities, another may include virtual and constructive, while a third may link multiple HWIL or Systems Integration Laboratory (SIL) facilities with a live operator. Smaller-scale testing can be done using a distributed infrastructure to provide technical risk reduction prior to linking the environment of all interrelated systems in a larger test. Linking the various systems and components of a large system or system-of-systems using distributed test capabilities may prove to be the simplest, quickest, and cheapest way to avoid the pitfall of conducting T&E assessments based solely on individual, system-particular performance parameters.

How Does Distributed Live, Virtual, and Constructive T&E Mitigate Risk?

In previous lessons, we have shown how various companies and developers consider reducing what has been called "late-cycle churn" in the design and manufacturing process for new products. As we discussed in the lesson "What Is
Test and Evaluation?," the Pentium® Pro and Pentium® III are much more complex and have significantly improved capabilities over their predecessors, yet due to improved T&E capabilities they were developed in the same amount of time as the original Pentium® microprocessor. Some consider the concept of "break it early" to be important in finding problems with a product or system so they can be corrected before the design is finalized. The problem with the concept of "breaking it early" is how to best do that. Testing using only actual, live systems may be logistically impossible, and can intrude on production schedules. In some cases, it may be impossible if the system under test has not yet been completely built. A distributed LVC environment can be developed at a fraction of the cost of testing with live systems. This in turn offers two distinct advantages for both test planners and the developer in mitigating risk for a new product:

- Distributed testing allows for early and continuous TE to be integrated into the product’s developmental process. This idea is called "test early, test often" and allows developers to embed testing into all phases of a product’s design, development, and production. As we have shown in previous lessons, conducting TE very early in a product’s maturity cycle by linking distributed components or using HWIL and SILs allows developers to correct problems early, when they are cheaper and easier to fix.
- Distributed LVC simulations can be built to provide a realistic environment for the product or system under test, including all the necessary and interrelated systems. That is, the system under test’s planned or expected real-world operating conditions can be replicated in a distributed testing environment that can provide the characteristics, components, systems, and other capabilities needed to test technical and user performance. Providing this realistic environment early and often allows the developer to learn how their product may behave in actual operating conditions well before the product’s design is finalized, when problems are easier and cheaper to fix.

These two advantages become even more apparent when one considers not just individual systems, but the rapidly expanding network-centric environment and the need to conduct T&E in ever more complex systems-of-systems. The ability to "test early, test often" in realistic environments will become a driving force behind distributed testing.

**How Does Distributed Live, Virtual, and Constructive T&E Improve Testing?**

There are many aspects to using distributed LVC simulations to improve T&E.

- Representations of the system under test (e.g., HWIL, SILs) can be integrated into the testing process before the actual system under test (SUT) is built.
- Representations of other systems with which the SUT must interact can be integrated to test for interoperability.
- Systems and components can be integrated into the test of a live system without having to move the additional systems and components to the test site.
- Environmental models can be linked into the test to provide a realistic real-world environment. This can include bringing weather, challenging terrain, safety hazards, and other challenges into the test.
- In many cases, distributed test events are easy and relatively cheap to repeat. This allows the developer to collect much more data on the technical specifications and performance of a product.
- Due to the more controlled LVC environment, there is a significantly reduced risk of damaging the system under test, test equipment, or people.
- The test can proceed without damaging the environment, thus mitigating environmental restrictions on testing.
- Distributed test events allow for enhanced cross-flow of test data between distributed LVC TE systems and facilities.

Conducting a technical or user test on a pizza, as described in the lesson "What Is Test and Evaluation?" may be time-consuming, but it is a relatively simple process. Testing today’s complicated systems and systems-of-systems, such as a new airliner flying in the national airspace system, presents much more of a challenge to developers and test planners. Ultimately, LVC representations can be used to evaluate the capabilities of a system or system-of-systems.
1.4. Considerations for Distributed Live, Virtual and Constructive Simulations in Test and Evaluation

in a realistic distributed environment. This distributed environment can be developed at a fraction of the cost of testing with all live components and provides the capability to evaluate technical and operational performance for individual systems and systems-of-systems. This way, technical T&E can incorporate realistic environments much earlier in the product’s design phase. User T&E planners can also use distributed LVC T&E methodologies to verify early that the system under test works both "stand alone" and in the expected system-of-systems environment. Early integrated testing will allow the developers to find problems early in a product’s development, while they are still relatively easy and inexpensive to correct. Testing can then continue across the entire developmental cycle of a new product.

Why Is the "Live" So Important to T&E?

In order to convince him or herself, the agencies that oversee the industry (e.g., the Federal Aviation Administration or the Environmental Protection Agency), and the customer that the system performs as intended in the expected environment, the developer will be compelled to test the system in the "real world" using the actual system with other, related actual systems. Some T&E planners may want to consider using a Modeling and Simulation (M&S) methodology only, with no live systems. Regardless of how well a model or LVC simulation is constructed, it is still a representation. It will be very difficult to convince the decision maker that the system under test will function as intended in the real world using only M&S. For credible T&E, there must be some level of testing with a real system, a real user, and the expected, actual environment. In short, T&E planners must do "live" testing using real people and real systems to ensure the product has no serious faults or safety issues before it is released for use by the customers. Because of the ability to inject the "live" into testing, distributed LVC testing can provide for earlier identification of problems and reduce the amount of live testing, thus reducing cost and risk.

Distributed LVC testing cannot eliminate the risk of a major fault in the product, but can be used to build up to a live test and greatly reduce the risk before the live test occurs. A good example of this occurred recently, when the U.S. Air Force was adding a new digital communication capability to portions of their bomber fleet. Prior to conducting an actual flight test, the Air Force tested the interoperability of the new communication system by linking an actual bomber aircraft that was on the ground but manned with real pilots to a virtual simulator of an airborne communications aircraft at a separate base, also manned with real operators. A data collection facility at yet another base was also linked to complete the test. The Air Force testers discovered problems in the communications software, which the developers fixed within hours. The testers then ran the test again to verify that the communication system performed as intended with the fixes applied. All this was done with a combination of live and virtual systems separated by hundreds of miles without requiring a single flight. Conducting the live and virtual distributed testing provided for a significant reduction in risk to follow-on live flight tests of the new communications system, and saved the expense of multiple flight tests.
What Is "Test-Fix-Test?"

The above Air Force example leads us right into the concept of test-fix-test. The complexity and expense of today’s net-centric systems clearly demonstrate the need to test early and often throughout the development process and the life of the system. Test-fix-test refers to an iterative process in which the new system is subjected to a test, deficiencies are immediately corrected, the corrections are tested, and then the system continues on to another development and test cycle.

Table 1.1 shows the cost of fixing a defect depending on the stage during development it was found. For example, if a problem in the design is found only post-release, then it would cost 25 to 100 times more to fix than if it had already been found by the design phase review. In addition to the safety aspect, think of the expense of a nation-wide recall of automobiles due to a faulty design of the brakes or an accelerator switch when thousands and thousands have been sold to customers. Successful test-fix-test generally involves early and continuous testing of the new system from the early developmental stage through fielding to customers, to dramatically reduce a product’s "late-cycle churn." This is exactly the impact a distributed SIL can have on developing new products like the Boeing 777-200.

Early testing of a system’s capability to operate in its intended environment will allow designers and system engineers to identify and correct fundamental issues with performance and interoperability before they are built into the system. That will obviously reduce development time and cost and help designers build a better product, faster, and at a lower cost!

### Table 1.1: Cost to Fix Defect versus Time Detected

<table>
<thead>
<tr>
<th>Cost to fix a defect</th>
<th>Time detected Design</th>
<th>Time detected Construction</th>
<th>Time detected System test</th>
<th>Time detected Post-release</th>
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<tbody>
<tr>
<td>Design</td>
<td>1×</td>
<td>10×</td>
<td>15×</td>
<td>25-100×</td>
</tr>
<tr>
<td>Construction</td>
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<td>1×</td>
<td>10×</td>
<td>10-25×</td>
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**Test-Fix-Test**

- Continuous testing across the product’s developmental life cycle
- Reduces acquisition time and cost
- Helps find and correct problems early in a system’s development – when they are less costly to fix

Advantages of Scalable Distributed Live, Virtual, and Constructive T&E Events

Distributed LVC methodologies offer T&E planners the opportunity to participate in scalable LVC events tailored to the test requirements. Distributed test events can be planned to support varying degrees of complexity, capabilities, requirements, funding, system maturity, and scheduling limitations. This includes experiments, early technical testing, and even follow-on user testing that might consist of:

- A **distributed system-to-system event** consists of connecting two systems or sub-systems together to test their interaction. In a distributed system-to-system event, test planners have the maximum ability to inject their test requirements into the event and to control test conditions and execution. These generally small, inexpensive events can be an excellent venue for "test-fix-test" and early risk reduction for the system/product, in order to assess the interaction and data exchange between systems or components. It allows the test planners to
schedule and execute the event as often as needed, with minimal costs and without having to move the systems or sub-systems to the same place. This can be done using HWIL or a SIL to represent the system under test.

- A distributed network-centric event is a TE event that uses an environment of LVC models and simulations. The size and complexity of the TE event and the capabilities provided will naturally depend on the TE requirements. Test planners could use a relatively small event to provide the most realistic environment possible, from concept exploration through follow-on TE when it is too costly to bring all the player systems together at a single place. This would inject a real-world influence early in the product’s design and development stage. A larger distributed LVC event could be an excellent venue to provide an assessment of system-of-systems interoperability issues early in the acquisition process. That is especially true when there are not adequate numbers of systems under test or support assets required for live testing. An even more complex network-centric distributed TE environment would provide interactions between systems in a realistic system-of-systems environment. An important advantage of such an event is the ability to provide a realistic operating environment. This could include such factors as weather, rough terrain, heat, cold, adverse air quality (such as smoke and haze), and poor lighting conditions. In this case, virtual and constructive capabilities could supplement live systems to assess interoperability and reduce risk at a fraction of the time and cost of a live on-site test event. These larger events could naturally include various HWIL facilities and even multiple SILs.

Are There Disadvantages to Distributed Live, Virtual, and Constructive T&E?

As with every aspect of T&E, not all solutions will be appropriate for every situation. Distributed LVC simulation would certainly not be appropriate for testing the pizzas or permanent wave machines that were discussed in the lesson "What Is Test and Evaluation?" Using distributed LVC T&E is certainly not free. The various systems and components must be brought on line, which may be difficult with differing communication systems. Distributed testing requires detailed test planning, so all the factors affecting the test must be understood and addressed before the test execution. For many distributed LVC T&E events, there may not be a completed product or real system, and in some cases no actual users. This may complicate the problems the developer may have testing the product or system in use by actual customers. But these same limitations apply to conventional testing. While not a panacea, and not appropriate for all situations, distributed LVC T&E has proven in many situations to help developers build a better product quicker and cheaper.

What Is the Bottom Line?

Conducting T&E using distributed LVC simulations can save the product developers time and money, reduce risk, and ultimately produce a better product! It is not appropriate for every situation, but given that a product developer does not want to sell the customer a product that does not work, they will need to test the product to ensure that the product works as intended in the conditions the customer will actually use it. Conducting T&E with live-only systems will become increasingly more difficult in the ever-changing network-centric, system-of-systems world we live in. Using LVC simulations in a distributed test environment can enable developers to test early and often in a product’s development cycle and so identify and fix problems when they are much easier and cheaper to correct. A distributed LVC test environment presents a unique capability for testing net-centric systems-of-systems.
Lesson Summary

- There are limitations to testing with actual live, complete systems.
- Advantages of using distributed live, virtual, and constructive simulations in test and evaluation include being able to more easily customize individual events based on requirements and capabilities.
- Risk in developing a new product can be mitigated by:
  - Testing much earlier and more often in a product’s development. This idea is called "test early–test often."
  - Providing a realistic environment for the product or system under test and all interrelated systems.
- TE using distributed live, virtual, and constructive simulations improves the TE process and enables early and continuous testing across the developmental life cycle.
- "Test-fix-test" refers to an iterative process in which the new system is subjected to a test, deficiencies are immediately corrected, and then the system continues on to another test cycle.
- Distributed test events can be scalable and planned to support varying degrees of complexity, capabilities, requirements, funding, system maturity, and scheduling limitations.
- The bottom line is that TE using distributed LVC simulations can save the product developer time and money, reduce risk, and ultimately produce a better product!

Review Questions

1. List two limitations in conducting T&E with actual live systems.
2. How does distributed LVC T&E mitigate risk?
3. How does distributed LVC T&E improve testing capabilities?
4. What is "test-fix-test"?
5. Why is scalability important in distributed LVC T&E?
6. What is the bottom line in using distributed LVC simulations in T&E?

Further Reading/Supplemental Links

http://www.benmeadowcroft.com/reports/systemfailure/ Go to this link to view a report on the major causes of system failure. The continued testing of systems already in use by the customer is also important in being prepared for potential system failures.

Points to Consider

For this lesson, points to consider are provided as an aid to the instructor to stimulate critical thinking among the students. These questions have no right or wrong answers, but may help further the student’s understanding of the material. Suggested responses are provided to help the instructor guide the discussion.

- A study conducted by the National Institute of Standards and Technology in 2002 reported that software bugs cost the U.S. economy $59.5 billion annually. More than a third of this cost could be avoided if
better software testing was performed. Why is it that some companies don’t embed TE early into their product’s development? (Suggested response: An aggressive TE program can appear to be expensive and time-consuming. There is no doubt that some test events, even distributed LVC events, can have a large "up-front" cost. While developers will ultimately reap time and cost savings, the "up-front" cost of TE can be intimidating. Also, there can be an attitude with some developers that TE only brings bad news. While that may be true in the short term, as TE discovers faults and problems in a product, TE should actually be considered a money maker. Discovering those faults and problems early in a product’s development can only reduce the cost to the developer and customer. TE doesn’t cost, TE pays!

• We have shown how early distributed testing provides for a testing capability without having to bring all the required test assets to one place. This will save developers time and money and reduce risk, especially for a system-of-systems in a net-centric environment. However, can a distributed LVC test capability provide for a more thorough evaluation? That is, can distributed methodologies improve the evaluation part of the test and evaluation process? (Suggested response: Most test planners will focus on the distributed aspect of data collection during a test. That is, distributed LVC methodologies allow for the tester to move data and not necessarily the people needed to collect and analyze the data. While not immediately obvious, the same potential holds true for the evaluation of the test data. When the data is available on a distributed network, the evaluators are able to access the data while not having to be co-located. This ability for distributed evaluation and even reporting is yet another advantage of using distributed LVC simulations for TE.

• Distributed testing is gaining recognition and acceptance from developers and testers. However, while the concept has proven its worth, work remains to improve distributed test capabilities and to educate product developers and testers to use it appropriately. This chapter in the Modeling Simulation Flexbook® digital resource is intended to address this very subject. In completing these four lessons, you now have a very good foundation in TE and how distributed LVC simulations can be used.

References


3 Ferguson, Chip, Making the Case for Distributed Testing, ITEA Journal, Sept 2010

4 NIST. Economic Impacts of Inadequate Infrastructure for Software Testing, May 2002