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CAPABILITIES BASED TESTING OF DEFENSE MULTI-INTELLIGENCE SYSTEMS

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ABSTRACT

Today's weapon systems are becoming increasingly complex and usually involve other assets to accomplish their missions. Interdependencies among the weapon system components such as its sensor, sensor subsystems, communications, navigation, etc., are crucial to the System Engineering (SE) design and test process. Inserting the individual weapon system into a larger context of a System-of-Systems (SoS) and Family of Systems (FoS) increases the Test and Evaluation (T&E) complexity exponentially. The ability to readily orchestrate myriad of test conditions and scenario alterations in a SoS/FoS context must be devised to enable the evaluation of alternative designs in order to adapt to future missions, threats, and technologies. This paper will address the coupling of Modeling and Simulation (M&S) and systems engineering to support cost-effective decisions on concept development, technology evaluation, material, doctrine, tactics, combat techniques and force structure. Current information technology (IT) trends, e.g., virtualization, cloud computing, micro-services, containerization, etc., helps manage the orchestration of tests on the M&S testbed.

1. INTRODUCTION

This paper addresses a tightly integrated approach in using Modeling and Simulation (M&S) in the weapon integration and test support process to help avoid or reduce costs. The activities and products described herein leverages Live, Virtual, and Constructive (LVC) simulation environments to evaluate and assess Department of Defense (DoD) multi-intelligence (multi-INT) Electronic Warfare Support (EWS) systems [1]. The intent of the M&S testbed is to determine how well the equipment works within an operational situation. With the advancement of Information Technology (IT) solutions, interdependencies among the systems can be realized and capitalized on simulation testbeds to support concept development, technology evaluation, material, doctrine, tactics, combat techniques, and force structure. Our M&S strategy is to develop virtual representation of a system through iterative improvement of its digital representations, beginning with the identification of system concepts, and continuing with the selection of best concepts and evaluation of those concepts against user life-cycle requirements.

In order to support this strategy, M&S software is developed in a Modular Open Systems Approach (MOSA), employing modular design tenets, and using well defined, mature, readily available interface standards. The benefits of MOSA are to ensure an architecture with software modules with minimal dependencies (loosely coupled) on one another with minimal dependencies, therefore changes made to one module does not proliferate throughout the system. Also, the MOSA design characterizes modules by single assignment of functionality (high cohesion) such that changing a particular system behavior does not cause any major significant changes in other areas.

The expanding complexity of today's defense systems has caused M&S to become increasingly important in supporting T&E goals [2]. Methods are discussed to aid in the evaluation and decision making process when integrating new systems, concepts, or early state technologies into a EWS system. Our approach is to build an M&S operational model that represents the Intelligence, Surveillance, and Reconnaissance (ISR) functions of the weapon system of Tasking, Collection, Processing, Exploitation, and Dissemination (TCPED) thread. The models are parametrically driven to enable the evaluation of alternative designs to adapt to future missions, threats, and technologies.

2. BALANCED APPROACH

Risks are reduced by closely integrating both M&S and Total Ownership Cost (TOC) throughout the Systems Engineering (SE) process. Information is assessed using an iterative modeling process to continually identify and support TOC reduction initiatives from very early on and throughout the acquisition decision process. The results of this process are used as inputs to guide the overall acquisition strategy, discern between system performance goals and objectives, identify cost and schedule risks, minimize shortfalls in system level performance, and perform cost, schedule, and performance trade-offs.

The activities of a SE process starts with a thorough understanding of mission needs and requirements analysis, then progresses into a functional analysis, system design and synthesis and system validation. The M&S design and development begins at the initial stages of the systems acquisition life-cycle. *Figure 1* illustrates our balanced approach to the advancement of a weapon system.

During the system acquisition pre-milestone A phase, the T&E strategy addresses M&S as a tool to evaluate system concepts against mission

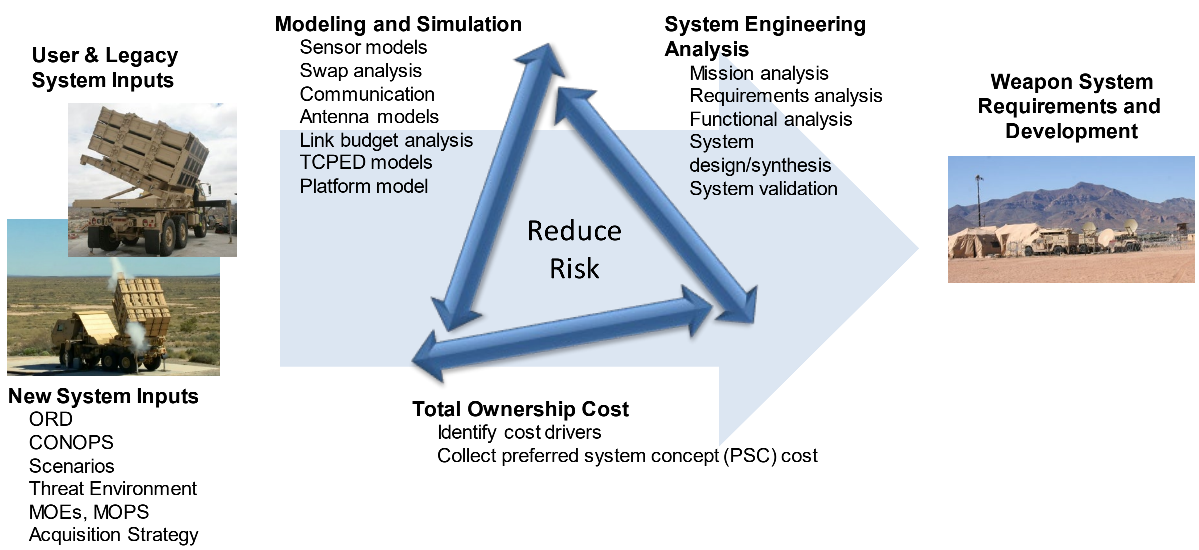

Figure 1 A Balanced Approach to System Development

requirements. M&S can provide analytical studies and results to aid in the decision making process, identifying and managing associated risks. An M&S operational modeling capability, when built correctly, can greatly augment T&E procedures; looking into optimizing systems specifications and error tolerances based on the simulation results.

3. ITERATIVE M&S REFINEMENT

An iterative modeling process is used to deliver an M&S testbed that accurately represent the operational aspects and throughput performance of the actual EWS system. The refinement and verification process involves iterating the sequence of test planning, test execution, test analysis, and discrepancy identification. The refined and verified M&S suite is then be used to perform analysis verification of the System Under Test (SUT). *Figure 2* below illustrates the iterative refinement and how to support integration and testing of the SUT.

Our process involves using M&S capabilities to simulate the as-built EWS system configuration at different stages of integration. Predicted performance information obtained from earlier level of integration testing is used in configuring the current level of integration. After the testing is performed, predicted results obtained from the M&S testbed are compared with the test measurement results and the acceptance criteria to determine if any anomalies occurred. If the predicted results and measured results are within the bounds set by the acceptance criteria, then the test article proceeds to the next level tests.

3.1. M&S Testbed

M&S can be used in supporting the following areas:

- The functional and performance definition of the EWS system mission,
- Alternative sensor package performance studies,

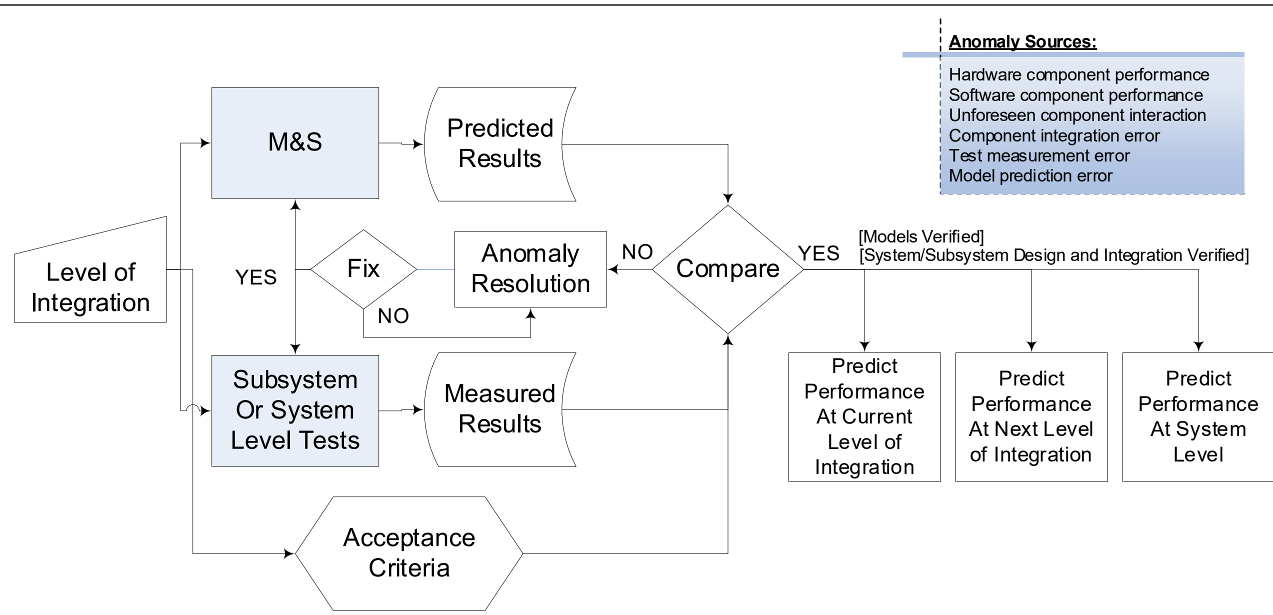

Figure 2M&S Validation for Use in T&E

- Pre-developmental test performance evaluations and post-developmental test analyses, and
- Provide feedback to various cost and performance tradeoffs.

The testbed provides a simulation capability of individual subsystems to aggregations of subsystems up the hierarchy of segments to the EWS system, of multi-INT mission planning, collection, processing, exploitation, and information dissemination. A building block approach is used to compose subsystems into systems that is used as payload in a weapon vehicle, then inserted into a larger LVC warfighting scenario comprised of thousands of simulated interactions.

Performance data for the SUT is provided by the SE team. These subsystems when modeled represent the individual components, communication links, throughput estimates, as well as threats, and environment propagation losses. A properly designed M&S testbed can allow "real" hardware or communication network (*i.e.,* Link-16 system) be inserted in the loop. *Figure 3* illustrates the M&S architecture representing a SoS/FoS application.

Because the M&S testbed is used to evaluate alternative response strategies as part of the multi-INT mission planning functionality, the architecture is extensively designed using MOSA principles to allow segregation of models and algorithms, thus allowing an easier path for the revisions or maintenance of software. Key to the design is a simulation harness used as a transparent proxy that runs on the periphery of the host(s) where the simulation or Command and Control (C2) application are being run. The purpose of this component is twofold: (i) to provide an additional layer of abstraction and control, and (ii) to provide applications an entry point into the simulation framework through existing application interfaces.

3.2. An Example – RF Aperture Model

The following example is presented to illustrate a building block approach to modeling key system subcomponents that makes up a total system. In this example, a Radio Frequency (RF) receiving antenna is modeled. When developed, the antenna

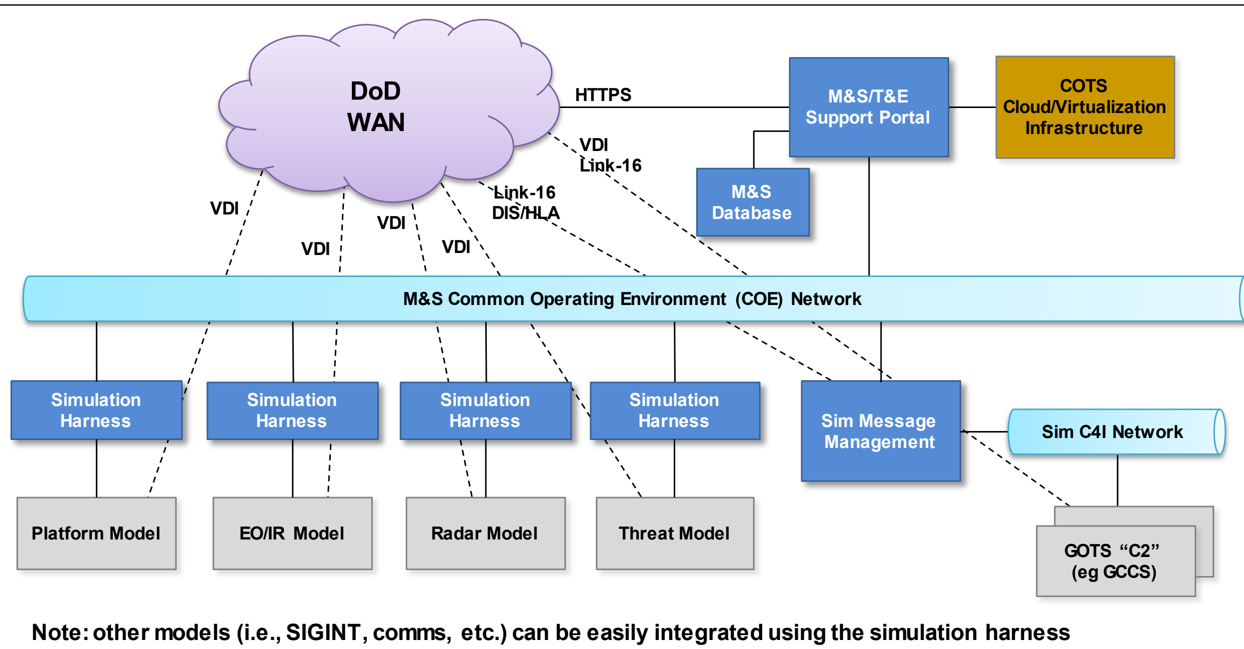

Figure 3 Architecture Employing MOSA Concepts

model is then combined with other subsystems, *i.e.,* receiver model, processor model, operator interfaces, *etc*. Key system requirements to the aperture modeling design are as follows:

- Frequency and Field-of-View (FOV) coverage compliant with the sensor system,
- Antenna gain patterns, and
- Electro-magnetic Interference (EMI) compatibility for interoperability with other transmitters and receivers.

There are numerous antenna modeling tools for the modeler. In order to represent the antenna pattern, a series of antenna gain tables is provided to the model. One approach is to provide two-dimensional array Azimuth/Elevation (Az/El) tables, representing antenna gain for discrete frequencies across the maximum operating band of the receiver. These tables are used as initial assessment of the design, but will be augmented by real data from T&E instrumentation data as the system matures and undergoes live testing in an anechoic chamber where a record of the signal strength from a calibrated signal on a full rotation of the antenna is performed. The models are used to simulate the planned tests, using to establish the predicted outcome of the test, and possible refinement of the plan based upon predicted results. Also, a propagation loss server is provided in the M&S testbed using service based requests to account for spreading losses, atmospheric losses, and rain or fog condition losses.

To "look-up" a particular antenna gain, the model determines the incident Az/El angles of the received signal (*i.e.,* target signal) relative to the current position and orientation of the vehicle carrying the antenna. Secondly, the model transforms the incident angles of the received signal to a relative pointing angle of the antenna. Then, a table "look-up" is performed to the appropriate azimuth and elevation antenna gain value based on the frequency of the received signal. For Az/El angles that are shadowed or out of the FOV of the antenna, large antenna loss values are placed at those entries in order to represent full spherical coverage around the vehicle. As the system matures and results are obtained from live-T&E anechoic chamber recordings, the data is further refined in the M&S dataset to account for other real-world effects stemming from the vehicle structure and side-lobe levels.

3.3. LVC Environment for T&E

The nature of the synthetic LVC environment can be integrated with existing systems, networks and new tools/services to create a more advanced T&E environment that can be centrally managed. Testers simply open their browsers, sign in, configure, and execute T&E scenarios. Various T&E environments can be instantiated as needed, customized with modular scenarios and provide omnipresent services and tools to enable performance control and management.

The M&S framework provides a suite of message management services that are standalone, stateless, and as atomic as possible in terms of function and responsibility. By default, each T&E session shall include, at a minimum, one message management instance that is provisioned as part of the T&E session infrastructure. The following individual services are available to simulation applications within a T&E session: track aggregation, Distributed Interactive Simulation (DIS) or High-Level Architecture (HLA) or Test and Training Enabling Architecture (TENA) exchange services, and C2 (JREAP/Link-16) exchange.

LVC environments allow for the prediction of system performance over a wider range of conditions than tested, or to predict performance for conditions not achievable in the laboratory. Inserting the SUT (virtual representation) into a larger LVC operational environment helps to convey the effectiveness of the system under stressing target dense environments.

4. IT RESOURCES

The M&S testbed is executed in a localized cloud architecture utilizing virtualization infrastructure

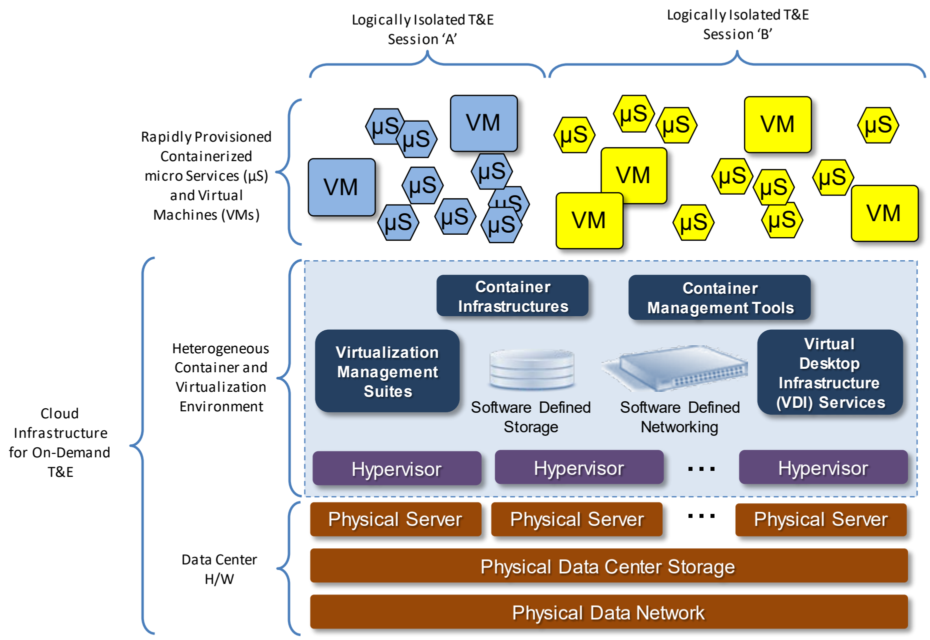

Figure 4 On-Demand, Cloud Provisioned VMs for T&E Sessions

running containerized test components. Current technology trends, *e.g.,* microservices, cloud computing, containers, virtualization, *etc.,* supports open systems architectural approach [3]. The orchestration of components is managed by the M&S framework abstraction layer to unburden the user from the complexities of the underlying legacy systems, and provides an open framework for incorporating a variety of diverse simulation models (*i.e.,* imaging sensor models, RF models, enemy threats, propagation loss models, *etc.*). *Figure 4* illustrates cloud computing components.

T&E sessions are provisioned, recycled and removed without the need to configure physical workstations, servers, and networks. Another compelling reason to do so is to keep the workstation in very close proximity to increasingly large, configuration managed data sets. It is common where data sets are in the terabyte scale, and having the workstations close in proximity greatly reduces the time in accessing the data for analysis.

Instances of Virtual Machines (VMs) and containerized microservices, complete with preinstalled and preconfigured constituent T&E system software modules, can be readily and rapidly provisioned on very short notice in data center virtualization or cloud computing hardware. Similarly, the resources (VM instances) are easily and rapidly returned to the data center resource pool, ready to support another T&E event. Virtualization technologies has advantages in providing short notice multi-domain T&E and "hardening" of the system to avoid network intrusion due to a smaller cyber-attack footprint.

5. T&E PHASE

Prior to the T&E phase, M&S efforts focus mostly on mission analysis. The M&S testbed continues to progress in development and fidelity during the material solution analysis and technology development phases and well into the engineering and manufacturing development phase. When the system reaches the initial operational T&E phase, major system objectives and prioritization of key objectives would be realized. The T&E objectives such as measures of effectiveness/performance (MOE/MOPs), measure of suitability (MOS), and

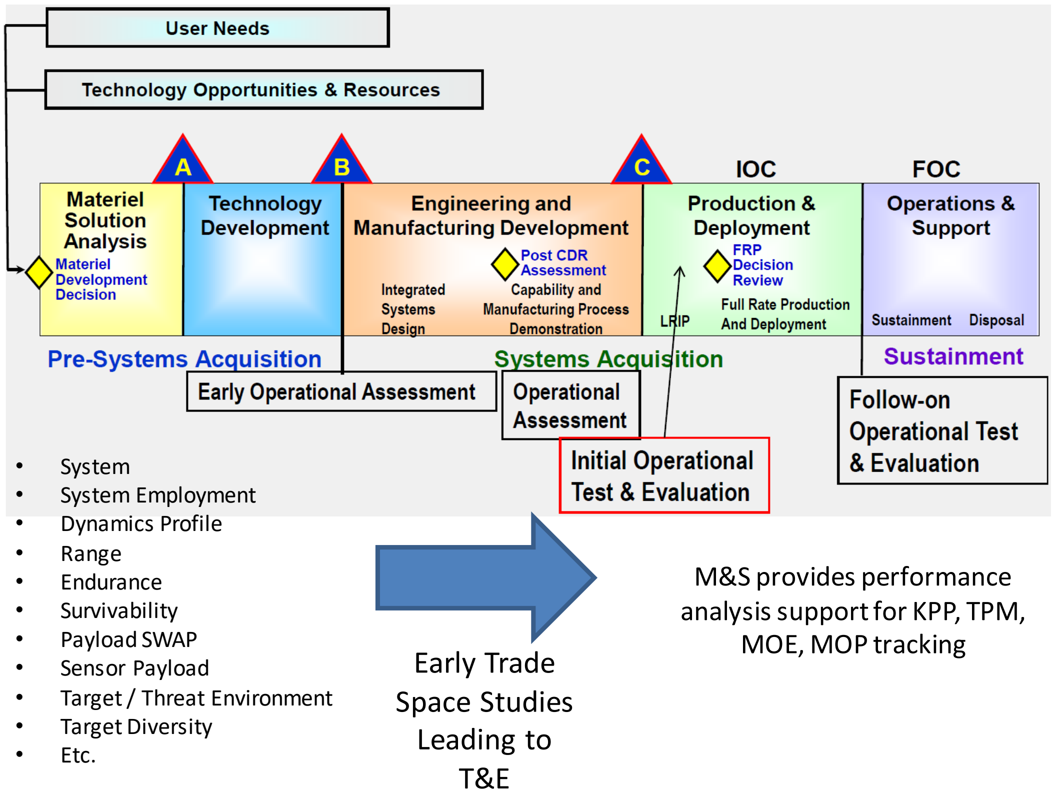

Figure 5 Acquisition Lifecycle DoDI 5000.02

the prioritization of requirements Key Performance Parameters (KPPs) of threshold vs. objectives are understood. A robust M&S that is rigorously developed and refined based on real-world testing can often be used to focus live testing on gaps or difficult to simulate environments. At this time, a prioritized roadmap of system tests to conduct and T&E strategy using the M&S testbed is developed. *Figure 5* illustrates the acquisition lifecycle following Department of Defense Instructions (DoDI) 5000.02 [4].

Elements of M&S are beneficial to model the upstream components prior to the generation of real signals (emulation) for the SUT or part of a system component. As an example, the M&S is used to understand the characteristics of the threat signals such as angle of arrival, signal density, engagement characteristics, types of signals, *etc*. Having already developed the M&S testbed early in the system lifecycle, allows for reuse of the threat, engagement, aperture and propagation loss models as a starting point for the generation of an emulated signal for T&E. The signal is generated at the specific stage and injected into appropriate points of the SUT as though it is seeing the real signal in an operational situation.

6. CONCLUSION

This paper addresses new methods and technical assets in LVC simulation environments to evaluate, assess and test advanced DoD multi-INT systems. The balanced approach methodology described how M&S can augment live testing throughout the different stages of systems engineering. With the maturing of cloud computing resources, this is an opportunity to leverage IT for capabilities based T&E. The expanding complexity of today's defense systems makes it imperative that M&S be used in conjunction with T&E in ways that live testing alone is not possible or cost prohibitive. It also provides a larger perspective from the tester's viewpoint by considering the weapon system in a SoS/FoS operational context. A combination of M&S and T&E expands the conditions to be tested, and also augment live testing for conditions that are not achievable in the laboratory [5].

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