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GROUND VEHICLE BRIGADE LEVEL INTEGRATION LABORATORY (GVBLIL) DIGITAL & PHYSICAL TWINS PLUG-IN ADAPTORS

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ABSTRACT

Digital Engineering practices and ecosystem capabilities [1] optimize designs by providing digital solutions with end-to-end information flows that are consistent from concept development, through test and experimentation, all the way to fully defined capabilities influencing systems across Ground Vehicle Brigade Combat Teams (GVBCT). This approach delivers: 1) improved development, demonstration, and assessment of autonomous vehicle capabilities, technologies, software, algorithms, controls, and performance; 2) a plug and play (PnP) interface for system-of-system and vehicle platform mission thread analysis and interoperability; and 3) 3D gaming technology to support advanced virtual scene generation and world model. The modernization of laboratory facilities to meet research and development (R&D) needs, support advanced technology development, and improved vehicle prototypes. The Brigade Level Integration Laboratory (BLIL) architecture provides a set of views composed using Systems Modeling Language (SysML) and governed by agreed-upon Architecture Viewpoints in accordance with IEEE 42010-2011[3]. This model-based architecture elaborates on the problem and solutions domains for the BLIL encompassing its requirements, structure, behavior, and constraints with full relational tracing between system elements in SysML to demonstrate that the architecture satisfies all BLIL requirements.

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1. INTRODUCTION

SAIC has contributed to the design, build, and operation of more than thirty-five laboratories that have provided Software in-the Loop (SWIL) and Hardware in-the Loop (HWIL) for the Army, Navy, Marines, Air Force, and National Aeronautics and Space Administration (NASA). There are three types of laboratory instantiations: 1) Use an existing laboratory if it meets requirements; 2) Modify an existing laboratory to meet requirements; and 3) Construct a new laboratory to meet requirements. SAIC has successfully instantiated laboratories in all three categories and helped to develop the only Army Brigade-level laboratory currently existing at AvMC/PEO Aviation. The following technical approach improves capabilities, resulting in detailed end-to-end vehicle systems and software evaluations in a controlled environment that uses software, hardware, and operator in-the- loop demonstrations.

2. OVERVIEW

The existing GVSC Laboratories with modifications will support the Ground Vehicle Brigade Level Integration Laboratory (GVBLIL) capabilities and functionality in order to enhance the current technical capabilities with hardware, software, and human in the loop product development. Figure 1, GVBLIL depicts the integration and capabilities extended to support system-of-system & platform interoperability, testing, and evaluation. The GVBLIL supports a cloud-based infrastructure with virtualization technology coupled with Modeling and Simulation (M&S) software and hardware for Digital Engineering (DE) [1]. The Model Based Systems Engineering (MBSE) analysis serves to develop, analyze, curate, and manage engineering models and other digital artifacts. DE MBSE and supporting Ecosystems supports the disciplined management of the lifecycle from mission-driven system requirements to system decommissioning. Software development may be required to act as middleware between systems to enable interoperability between architectures and stove piped systems. The GVBLIL configuration provides the ability to design and transform current solution enterprise tools and processes enabling a more efficient and effective usage, integration, organization and management, and curation throughout the system lifecycle. This transformation will be the foundation for the successful integration of current and future Modeling and Simulation (M&S) tools and processes and will facilitate low risk interoperability between legacy and fielded systems, as well as emerging vehicle platforms, and technologies associated with Project Convergence and other Army modernization initiatives. This GVBLIL will have the capability to conduct experiments employing both live and virtual resources and be able to integrate with other Army laboratories and simulation tools.

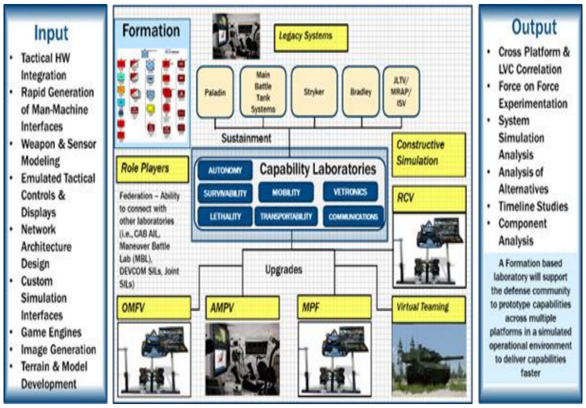

Figure 1: Ground Vehicle Brigade Level

2.1. Factors for Consideration

The current environment for ground vehicle product development and integration laboratories provides the means to perform analysis, integration, testing, evaluation, and data collections primarily supporting individual platforms including hardware, software, and control functionality. While this is adequate for individual platforms, an integrated environment for the GVBLIL will better align with the Army Modernization Enterprise (AME) goals to increase survivability, mobility, and lethality of platforms through modular open systems architecture, advanced manned-unmanned teaming and cybersecurity. The implementation of an integrated BLIL will enable vehicle platform developers and product integrators to comprehensively examine and evolve vehicle systems holistically as a force and provide a risk reduction environment. This will provide the ability to explore operational applications for development of innovative technologies in the ground vehicle domain and support organizational objectives and capabilities. Additional considerations include but are not limited to holistically developing and equipping GVBCTs as a Lethal Maneuver Force when conducting All-Domain Operations (ADO). This promotes the continual influence of warfighters in the design and implementation of relevant technical solutions related to the Next Generation Combat Vehicle (NGCV), Robotics, and other recent platforms (i.e., requirements, architectures, designs, integration, testing, evaluation, etc.)

These considerations require significant effort to re-categorize, compare data and attributes across domains. To alleviate this, we recommend an Integrated Cloud Environment that will be a government-owned Live, Virtual, & Constructive Simulation capability that provides a relevant end-to-end holistic system environment for rapid integration, testing, experimentation, training, verification, certification, and assessments of architecture, interfaces, performance, and standards compliance for current and emerging systems. The desired outcome would be linking laboratories to combine into a single BLIL. The interconnections of the Closed Restricted Network (CRN) boundary can be accredited with an Army Authority to Operate (ATO) on the Non-Classified Internet Protocol Router Network (NIPR) / Secret Internet Protocol Router Network (SIPR) by following all Federal Information Security Management Act (FISMA) requirements and adhering to the National Institute of Standards and Technology (NIST) Risk Management Framework (RMF) guidance. This allows current GVSC and remote laboratories to retain their autonomy while providing resources to the BLIL.

3. OPEN ARCHITECTURES

The following Government owned architectures and environments are supported in the GVBLIL framework by implementing common services and software middleware providing open interfaces and plug-ins for the Digital Engineering ecosystem, application software, hardware, simulation, simulators, etc. (Reference Figure 2).

- Vehicle Integration for C4ISR/EW Interoperability (VICTORY)
- Sensor Open Systems Architecture (SOSA)
- Future Airborne Capability Environment (FACE)
- Modular Open Systems Architecture (MOSA)
- Modular Open Radio Frequency Architecture (MORA)
- C5ISR/EW Modular Open Suite of Standards (CMOSS)
- Ground Combat Systems Common Infrastructure Architecture (GCIA)

The Digital Engineering (DE) Modeling and Simulation (M&S) ecosystem supports SysML and Unified Modeling Language (UML) methods to create automations to integrate software applications and controls combined with enabling technologies such as Rhapsody, Cameo Enterprise Architecture (CEA) and Rational "Dynamic Object Oriented Requirements System" (DOORS)

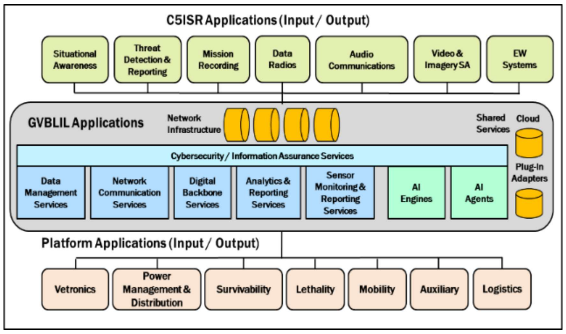

Figure 2: GVBLIL Framework

Next Generation. The M&S ecosystem provides integrations for the systems and subsystem architectures providing interoperability between various variant configurations. The models define interfaces (e.g., plugins) that support integrations with various views and viewpoints (e.g., commonality, Warfighter functions, workload, legacy applications, autonomy) supporting the respective domains and missions.

The framework supports agile practices to expedite both systems and software engineering, greatly reducing development time and providing visibility throughout the product life cycle. SAIC has made significant investments in the development and integration with modeling and product life-cycle tools including automations that integrate with the commercial software tools to provide the Digital Twin capabilities. Specifically, tool integrations are available to support DE MBSE, IBM Rhapsody, CEA, Matlab Simulink, etc. We apply these capabilities to conduct analysis and develop models to enhance system architecture integration. The BLIL environment will include vehicle power configurations (e.g., 12vdc, 24vdc, 48vdc, 600vdc) or combination to support interoperability, facility, and system requirements. The BLIL support variant product configurations. The BLIL configuration supports software and data exchange between Government and industry architectures and internal elements as represented in Figure 2. The BLIL also supports the Robot Operating System-Military (ROS-M), Joint Architecture for Unmanned Systems (JAUS) and the Pentagon-defined Inter-Operability Profile (IOP) for ground vehicle robotic assets.

4. INTEROPERABILIY

Interoperability enables different systems and platforms comprised of software, hardware, and components to cooperate as a holistic application, communicate and exchange data. There is a need to integrate vehicle applications, functionality, behavior, etc. across various disparate laboratories to create a BLIL. In order to achieve this, a system framework and GVBLIL Plug-in technology comprised of software middleware and interface adaptors are required. Figure 2 depicts the software middleware, services, and applications necessary to support integration and interoperability. While both integration and technological interoperability involve connecting applications and facilitating data transmission, the main difference is in how the different systems communicate. Interoperability is the real-time data exchange between different systems that speak directly to one another in the same language, instantly interpreting incoming data while preserving its original context. Integration refers to the process of combining multiple applications to function together as one uninterrupted system, often involving the use of middleware. Integration provides an environment in which a series of products can talk to each other in their current state while also maintaining compatibility with future versions of each product. For two or more systems to be interoperable, they must be able to exchange, interpret, and present shared data in a way that is understood by the other. This is accomplished with the establishment of syntactic interoperability, which involves adopting a common data format with common data structure protocols, followed by semantic interoperability, which involves the addition of metadata that links each data element to a controlled, shared vocabulary. Within this shared vocabulary are associated links to an ontology, which is a data model that represents a set of concepts within a domain and the relationships among those concepts. The adoption of these common standards enables the transmission of meaningful information that is independent of any information system. The benefits of interoperability include increased productivity, reduced costs, and reduced errors.

5. DIGITAL ECOSYSTEM

SAIC has developed and integrated digital ecosystems to create BLIL for various DoD applications similar to Figure 1. The BLIL will be a reconfigurable, extensible, platform based on government off-the-shelf (GOTS) and commercial off-the-shelf (COTS) products. The BLIL infrastructure allows for evaluation of third-party products in an operationally relevant common environment using appropriate mission scenarios and common metrics. Examples include integration with GOTS/COTS, such as relevant tactical systems/software (e.g. VHF/UHF Voice, Blue Force Tracking (BFT), Joint Battle Command Platform (JBC-P), Tactical Ground Reporting System (TiGR), and Command Post of the Future (CPOF). The BLIL utilizes the NIPR/SIPR network. The environment is monitored and maintained following the Defense Information Systems Agency (DISA) Security Technical Implementation Guides (STIGs), while leveraging technologies such as Host-Based System Security (HBSS) and Assured Compliance Assessment Solution (ACAS) solutions and internal network performance and monitoring (SolarWinds and Wireshark). Additionally, cyber best practices are applied to ensure compliance to various Department of Defense (DoD) policies. This approach allows the laboratories the ability to maintain their independence while still providing resources to the BLIL while reducing risk.

6. DIGITAL TWIN

The foundation for the digital twin architecture as represented in Figure 3 supports the analysis of alternatives and requirement design for product development categories. The architecture provides standards for sensor integration, secure processing, and data management by modeling the complex systems in GVBCTs over the performance measures. We start at the bottom with the development of the digital architecture and continue to add layers as we interface with other solution categories. This becomes the digital environment as designed and as-delivered model that is used to do integrations, upgrades and redesigns ultimately reducing risk, time, effort, and cost. The digital twin practice as represented in Figure 3 optimizes complex system decisions (designs and analysis of alternatives) by calculating performance measures and constraints at the speed of digital processing. The digital twin modeling and simulation (M&S) process can be driven with Artificial Intelligence (AI) and Machine Learning (ML) applications and services to dynamically and intelligently run real-time applications. This allows for digital modeling of an unknown environment to optimize and reconfigure in real-time. Doing so optimizes battle management command and control ensuring weapons employment applies all appropriate factors (weapons, targets, needed effects, timing, location, physics, etc.). Through the digital architecture these aspects are tied together to enable decisions at

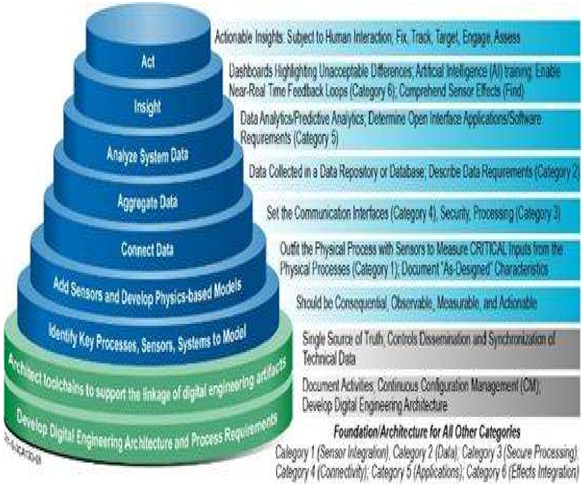

Figure 3: Digital Twin Methods

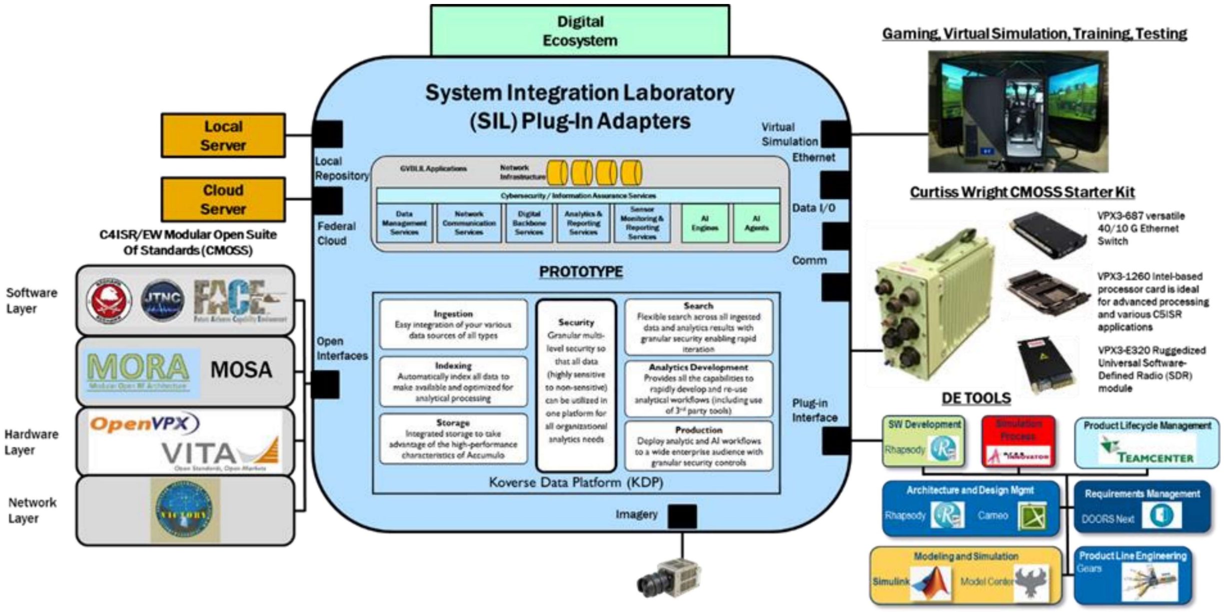

Figure 4: BLIL Plug-In Adapter

computer time using the cloud. The digital twin can be used for hardware in the loop and human in the loop integration and test. It would reside in the GVSC-owned Integrated Cloud Environment, use the resources of the federated laboratories, and be under strict configuration management processes. The digital twin practice includes MBSE as the core element of the life-cycle modeling practice that integrates with virtual simulation, hardware-in-the-loop (HWIL), and software-in-the-loop (SWIL) to support rapid product development.

The DE capabilities enable organizations to optimize design by providing digital solutions with end-to-end information flows that are consistent from concept development, through test and experimentation, all the way to fully defined capabilities improving systems across GVBCTs.

A Plug-in Adaptor represents the BLIL architecture in Figure 4. This model-based architecture elaborates on the problem and solutions domains for the BLIL encompassing its requirements, structure, behavior, and constraints with full relational tracing between system elements in SysML to demonstrate that the architecture satisfies all BLIL requirements. This approach establishes baselines for configurations and identifies performance parameters and metrics for the applications (e.g., computing hardware, computing software, memory, throughput for SW applications, control software, supporting test equipment, stakeholder needs and requirements, operational scenarios, and much more). This approach allows for full system, subsystem, component and software to be integrated and tested/certified. SAIC provides a DE solution that integrates Reference Architecture Framework (RAF) and partial prototype BLIL plug-in adapter (Figure 4), which reside in the NIPR/SIPR computing environment consisting of blade computers. The BLIL plug-in adapters provides an integration bridge supporting interoperability protocols to connect legacy system, hardware, and software components. The BLIL plug-in adapter provides open and scalable interfaces to the C4ISR/EW Modular Open Suite of Standards (CMOSS) layers and the MOSA initiative, cloud computing services, local network services and storage repositories, and interfaces with various local hardware, network, and software development applications. The plug-in provides the means to establish a standard set of protocols and interfaces that can be reconfigured or adapted to meet specific configurations based on the product development needs.

6.1. Software Factory

The Software Factory consists of many software elements, configurations, tools, compilers, processes, schemas, etc. to support the development and deployment of software applications and services to support the product lifecycle phases and models. This factory implementation supports open standards and interfaces for FACE, CMOSS, MOSA, VICTORY, MORA, and OpenVPX for hardware form factor.

The software factory begins at the earliest stage of systems engineering with respect to Systems Engineering MBSE analysis and behavior models representing the systems, platform, and component functionality. Without the proper systems engineering and analysis, developing software independent from SE MBSE best practices (i.e., authoritative source of truth) creates risk associated with product defects and rework. The feature models are developed early in the product lifecycle (e.g., black-boxes) to reduce downstream product defects. Figure 5 depicts a feature model, which incorporates systems functional analysis, functional behavior, signal interfaces, user interface, and associated failure mode, effects and criticality analysis in accordance with ISO 26262[2], Functional Safety Standard. The feature model is designed as a façade pattern, which hides the complexities of the system or feature behavior and provides interfaces to the system or subsystem of interest. This is a structural pattern which supports plug-and-play, plug-in behavior, etc. which is hidden to facilitate interoperability and ease integration. The interfaces are modeled using SE MBSE best practices and the Systems Modeling Language (SysML) tools like IBM Rational Rhapsody and Dassault Systemes Cameo Enterprise Architecture. The feature model interfaces are localized to the top-level system block (represented in color blue). The signal interfaces are encapsulated in the lower derived behavior, with the corresponding feature behavior, and user interfaces. These interfaces are plugged into the software factory implementation, utilizing the Unified Modeling Language (UML) and executed on general computing or real-time embedded software and hardware. The IBM Rational Rhapsody tool supports numerous software languages (e.g., C, C++, JAVA, Ada, etc.) and real-time operating systems (e.g., VxWorks, RTLinux, etc.). The SysML provides the ability to develop executable simulation representing the system behavior and interactions. The external interfaces are stimulated and exercised via a test panel. This provides the means to conduct verification and ensure the failure modes and hazards represented by the system to prevent mishap or errors from occurring. The test panel can be created using test equipment and hardware and the feature model verification can be retested with hardware-in-the-loop. This feature model is easily transferred from the systems model to the software model environment in the software factory. The scaled Agile Framework and DevSecOps best practices are applied to produce feature models. This allows rapid product development utilizing the BLIL Plug-in Adapter represented in Figure 5.

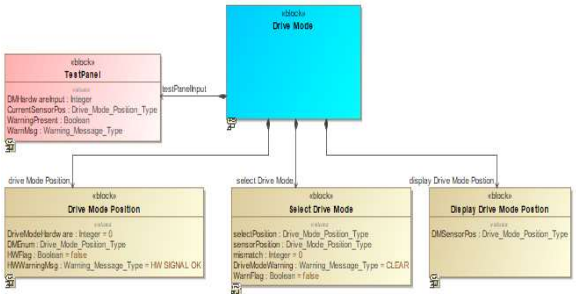

Figure 5: Feature Models

7. PHYSICAL TWIN

The physical twin is a relative term that describes the real-world physical system-of-systems or platform vehicle products associated with design, software, hardware, component elements. The current physical assets in laboratories which contain cables, connectors, test equipment, hardware, application software, embedded real-time software, power, electronics, etc. represent the physical twin. The digital twin is replicating the physical elements in digital formats containing data, behavior, functionality, logical entities for communication, data transports, serial connections, etc. The physical twin is the combination of the laboratories connected via the federal cloud, GVBLIL Plug-in Adaptor providing physical interfaces for various hardware-in-the loop product development, integration, and connections.

8. CONCLUSIONS

The Ground Vehicle Brigade Combat Teams (GVBCT) require additional resources and capabilities to support mission and operational analysis and support evaluation of system-of-system, vehicle systems, and platforms across the BCT. The Ground Vehicle community can integrate laboratories by implementing the BLIL plug-in. The BLIL plug-in can be developed incrementally to demonstrate functionality and technologies supporting interoperability, open system architectures, hardware-in-the-loop, behavior simulation, virtual simulation, and much more. The above technical approach provides the DE ecosystem, tools, software middleware and services necessary to evolve the Ground Vehicle domain and meet the BCT needs. These practices, methodologies, and tools manage risk and improve products to support the BCT and product developers.

9. REFERENCES

[1]Department of Defense, “Digital Engineering Strategy,” Office of the Deputy Assistant Secretary of Defense for Systems Engineering, Washington, D.C., June 2018.

[2]ISO 26262, “Road Vehicles – Functional Safety,” International Standard, second edition, December 2018.

[3]ISO/IEC/IEEE 42010:2011, Systems and Software Engineering - Architecture Description, International Standard, first edition, December 2011