<u>Combat Vehicle Electronics Component Integration with SES Process</u>
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Kevin Chang, PhD   Sung Kwon   Kasra Naghshineh

BAE Systems
Land & Armaments – Ground Systems
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<u>Abstract</u>

Modern military ground vehicles have to perform missions in very demanding environments. To meet operational and mission objectives, the development of military vehicles requires the integration of complex electronic components and sophisticated tactical messages. The integration, testing and schedule/cost challenges require a flexible build environment capable of supporting comprehensive testing and complex troubleshooting.

This paper describes an integrated engineering environment developed by BAE Systems that combines an integration and test process called Simulation-Emulation-Stimulation (SES) using physics-based high-fidelity simulation models. This environment creates real-time vehicle simulations of system and electrical control behavior that enable the visibility of electronic component messages and signals. It is used to integrate tactical software and electronic components as well as to test and verify vehicle subsystem and system level requirements and performance. With this integrated environment, vehicle electronic and software integration issues can be identified and resolved in the lab before on-vehicle integration occurs, significantly reducing overall project risk to both schedule and cost.

<u>Introduction</u>

BAE Systems is a global defense and aerospace company delivering a full range of products and services for air, land and naval forces, as well as advanced electronics, information technology solutions and customer support services.

BAE Systems Inc. is the US subsidiary of BAE Systems PLC. It provides support and service solutions for current and future defense, intelligence, and civilian systems. Land and Armaments (L&A) is one of the BAE Systems Inc. operating groups which is a global leader in the design, development, production, and service support of armored combat vehicles, major and minor caliber naval guns and missile launchers, canisters, artillery systems, and intelligent munitions.

Within BAE Systems' L&A operating group, the Ground Systems (GS) business unit develops and manufactures major ground combat systems, including Bradley, Paladin, M113, and MRAP, for the U.S. Army and Marine Corps and allied nations.

Bradley

Paladin

The development of military vehicles requires the integration of complex electronic components and sophisticated software. In order to successfully build and test entire vehicles, an integration and test methodology that includes processes, technologies and facilities is needed to deliver on time and on budget.

Modern ground combat vehicles need to perform complex missions with speed, accuracy and survivability. Since vehicle electronics in modern combat vehicles control major systems such as navigation, communications, and weapons, effective electronics integration and testing is paramount.

One approach to electronic component integration would be to actually install the equipment and then test it on the vehicle. The disadvantage of this method is the absence of any interface, power or unit testing before installation. This causes greater difficulty debugging integration issues resulting in significant increases to schedule risk and cost.

An alternative approach to electronic component integration is to perform lab integration and testing prior to on-vehicle integration.

Components will undergo interface testing for hardware and software:
- Hardware connector fit checks
- Signal breakouts
- Message communication protocol verification (1553, RS-232, CAN, Ethernet)
- Message timing verification

Components will undergo functional unit testing:
- Initialization and power up
- Command and response
- Electrical testing to boundary conditions (min, max)
- Electrical testing exceeding operating conditions

Performing these vehicle build tasks in a flexible lab environment reduces risks to schedule and cost by simplifying integration and troubleshooting. Integration issues such as hardware availability and software compatibility can be fixed early in the build process preventing excess delays and cost.

BAE GS has developed an end-to-end electronic component and platform integration solution. This paper describes this process which supports system level through component level build and test and while minimizing integration and test risks.

Simulation-Emulation-Stimulation (SES) Process

To increase vehicle integration efficiency, reduce cost and schedule risk, BAE GS has developed the Simulation-Emulation-Stimulation (SES) process for vehicle integration and test. Originally developed for the Bradley A2 vehicle electronics upgrade, it has since been evaluated and certified for CMMI[1] Level 5. The SES process has become an integral part of Bradley product development and lifecycle support (see figure 1) and has been successfully deployed to shorten cycle times and improve quality and reliability. The process is used to provide early interface support and proof of principal concepts for Preliminary Design Reviews (PDR) and design validation and verification for Critical Design Reviews (CDR).

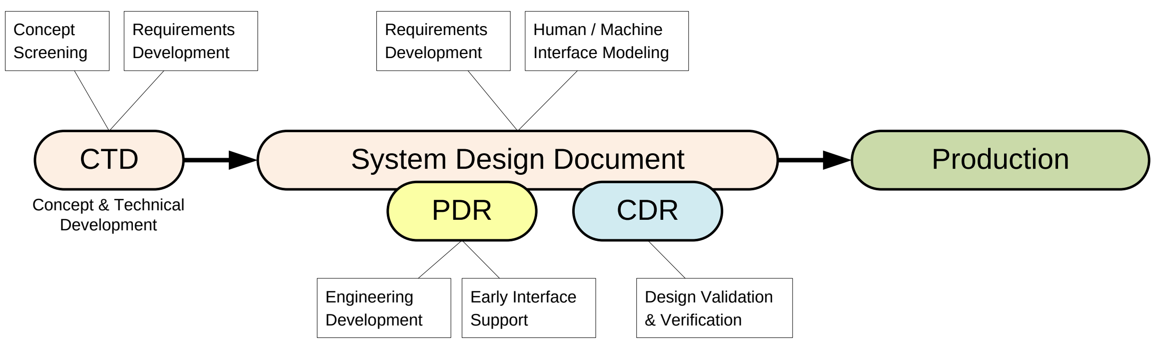

Fig 1: Product Life-Cycle Support

The SES process is used for the integration and test of vehicle systems, subsystems and components using simulators, emulators and hardware. Using this process, a vehicle environment is developed which has the capability to perform most testing, integration and troubleshooting tasks before any real software or hardware is available.

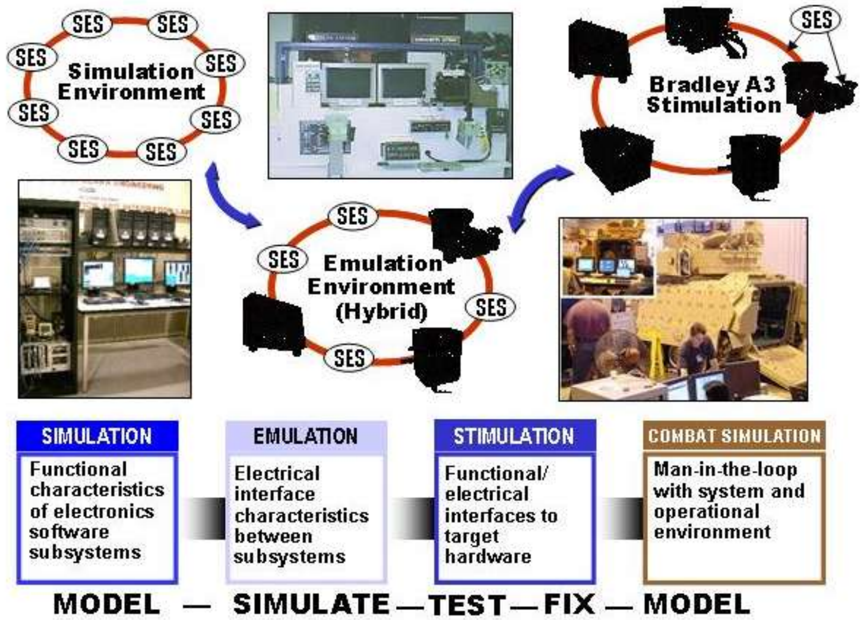

Fig 2: SES Process Description

The **Simulation** phase of the SES process consists of initial architecture and tactical message verification using only software models of vehicle systems. Although vehicle hardware will likely be unavailable at this stage build, functional characteristics of electronics are simulated to develop the environment used for the initial integration of hardware interfaces. This allows for early integration tasks to proceed without fully developed software or hardware.

As hardware designs mature, the **Emulation** phase of the SES process is able to utilize models that execute on platforms (emulators), which contain vehicle interfaces. These interfaces include actual connectors, protocols and tactical messages. Using emulators, integration and testing will expand to hardware interfaces, tactical message timing, logical behavior, and fault handling and response. Using emulators and tactical software, many integration and troubleshooting issues can be resolved without vehicle hardware.

As hardware become available, the **Stimulation** phase of the SES process will seamlessly replace emulators with vehicle hardware. This enables the validation of vehicle hardware behavior, interfaces and requirements. In addition, vehicle troubleshooting tasks can be accomplished in a lab environment with greater ease then on an actual vehicle. With the majority of hardware issues resolved, the transition to the vehicle platform can be accomplished smoothly.

SES Integration Environment

Based on the SES process, GS has developed the SES integration environment. This environment was designed to simulate vehicle systems and to be used in conjunction with tactical software in order to create a virtual vehicle in a lab setting. The components of this environment consist of a real-time target machine, host computer, bus message monitoring system, automated testing [2], and the vehicle hardware. In addition, power, signal conditioning, and vehicle buses are implemented in order to support hardware components in the lab (see figure 3).

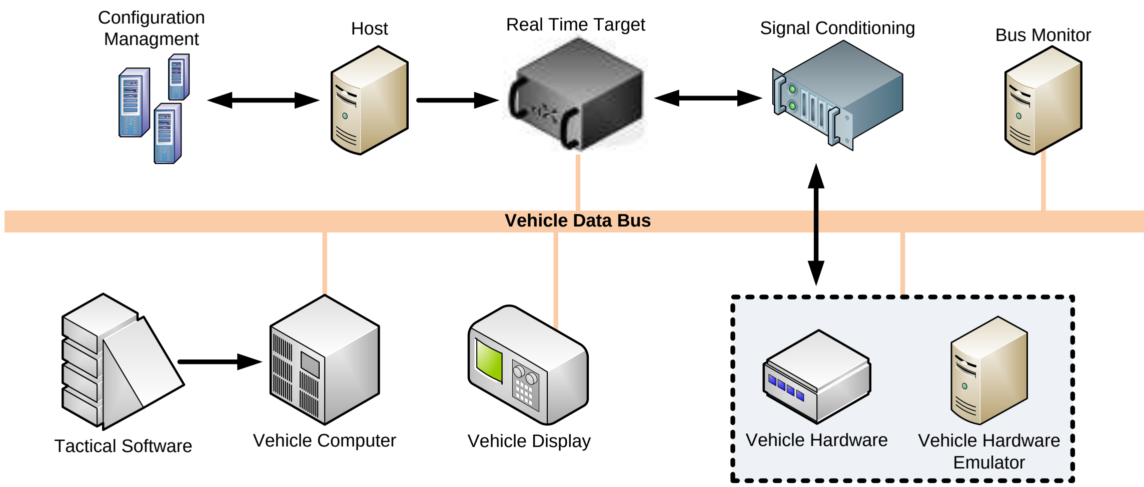

Fig 3: SES Integration Environment Architecture

The **Host PC** is a non-real-time platform used to develop models, execute simulations, and provide a graphical user interface. Vehicle system models are developed using MATRIXx/SystemBuild[3]. Back-end simulation components such as system interfaces, behavioral characteristics and architecture are modeled according to released system requirements documentation. The front-end user interface (including switches, knobs, meters, etc.) is developed using LabVIEW[3] from National Instruments and represents vehicle control panels.

The **Real-Time Target** is an ADI[4] rtX simulation platform running the QNX real-time operating system powered by Intel processors. The rtX and the ADI[4] simulation frameworks provide critical software and hardware interfaces used by MATRIXx/SystemBuild[3] models to communicate with I/O devices and LabVIEW[3] user interface panels. The rtX is an integrated environment for closed-loop simulation and, when combined with signal conditioning, provide for hardware-in-the-loop (HIL) tests as well.

Vehicle models are downloaded from the Host PC to the Real Time Target for execution. The simulation includes all required vehicle components, except for the items present as hardware, and acts as remote terminals to the bus controller (see vehicle computer below). The target platform is equipped with the I/O interfaces needed to support the simulation, including MIL-STD-1553, Ethernet, CAN, and RS-232. LabVIEW[3] panels are used to control the simulation and manipulate inputs.

To perform hardware-in-the-loop (HIL) testing, vehicle hardware will interface with the Real-Time Target I/O devices for command and response stimulation as well as electrical testing. **Signal Conditioning** (see figure 4) is used to scale signal voltages, and will allow for the normal operating voltage range of the vehicle electronic components to be compatible with the Real-Time Target I/O devices. Signal conditioning will also be used to validate component operation under boundary condition electrical testing where minimum and maximum rated voltages are applied.

The **Bus Monitor** provides data monitoring and logging tools which are used for hardware component integration, testing and troubleshooting. As simulations are executed, vehicle bus data (MIL-STD-1553), which includes component command and response, is available in real time and can be captured for analysis as needed.

Electronics/LRU Integration

Vehicle hardware is used in the SES integration environment to provide functionality not present in the vehicle simulation. The **Vehicle Computer** with **Tactical Software** provides central processing functionality for interfacing with, and controlling all of the tactical and weapon systems. It also acts at the MIL-STD-1553 primary bus controller. The **Vehicle Display** (Color Flat Panel Display) provides the capability for viewing tactical alpha-numeric and graphics used to represent vehicle status and fault conditions.

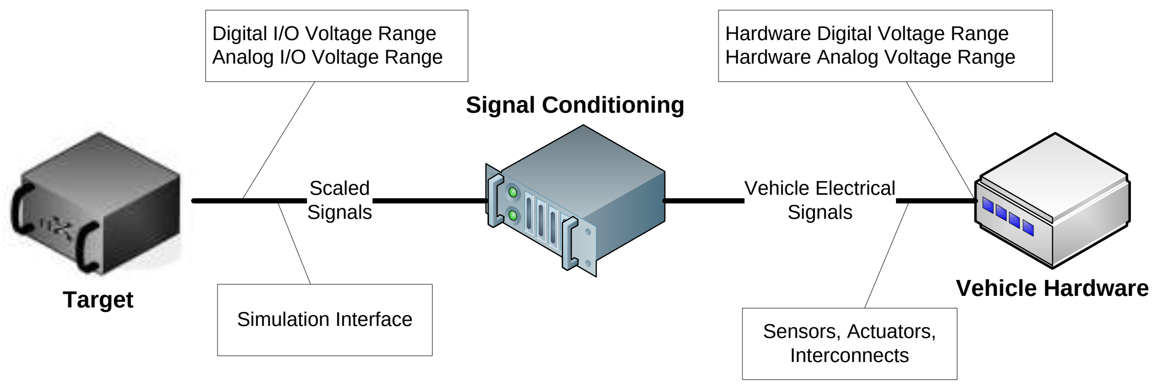

Fig 4: Hardware-in-the-Loop Signal Conditioning

The actual **Vehicle Hardware** and the hardware **Emulators** are interchangeable and provide the functionality and interfaces of the components needed for integration. Emulators are representations of such vehicle hardware as prototypes, brass-boards and stand-alone component simulations used for hardware interfaces.

Utilizing this environment, components are integrated to the vehicle using the SES process. Initial component tactical messages are modeled and tested as part of a system architecture simulation.

As the component design matures, the model is migrated to an emulation platform where tactical behavior, data protocols and hardware interfaces (ports and connectors) are added to the initial simulation. The original component model is disabled in the system simulation in order to utilize the stand-alone emulator which communicates directly on the vehicle data bus. The emulator allows for further component integration and testing of hardware interfaces, tactical message timing, logical behavior and fault handling.

Leveraging previous integration efforts, the vehicle hardware is able to seamlessly replace emulators. The validation of vehicle hardware behavior and its interfaces is then accomplished by stimulating components and analyzing their response. Final component checkout and troubleshooting is then performed in preparation for vehicle installation.

SES Implementation:

The Digital Vehicle Distribution Box (DVDB) distributes power and provides MIL-STD-1553, RS232, Ethernet, USB and CAN interfaces to a vehicle's hull electrical subsystems. In this section, an electronics component of the DVDB is used to show how the SES environment is utilized to integrate this component for vehicle development.

First, vehicle system and tactical software requirements are used to create a model of the DVDB on the host computer for **Simulation**. Figure 5 shows an example of how a new proposed vehicle component would be modeled using the SES process. As the diagram shows, it starts by obtaining all requirements and interface design documents pertinent to the component being modeled. This information is used to generate a model of the component using a commercial modeling tool such as MATRIXx/Systembuild[3] or Matlab/Simulink[5].

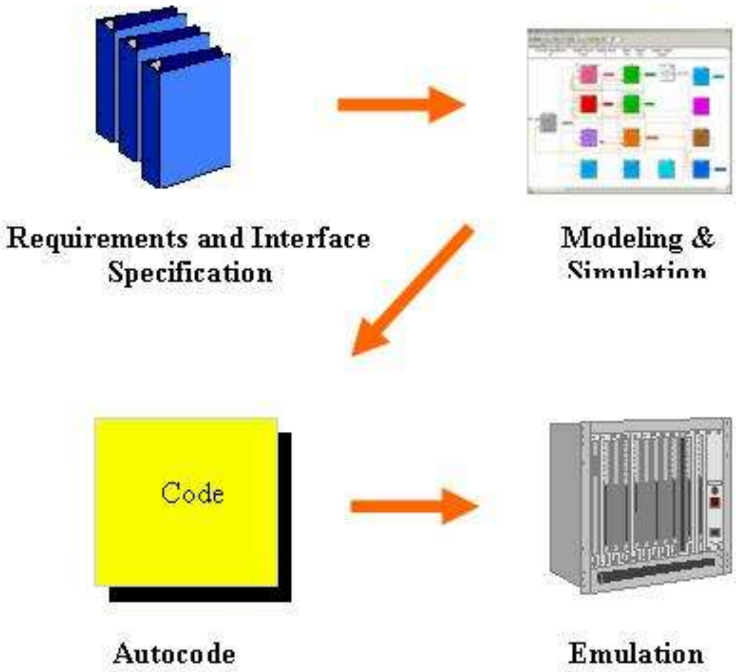

Fig. 5: Example of simulated LRU GUI front end

The developed model will run on the host computer and interact with Graphical User Interface (GUI) panels also running on the host computer. Figure 6 shows a typical GUI panel as derived from the actual component. The GUI panel is implemented as a user control device to inject commands to the DVDB model. Although it will not be running in real-time, nor will it be using the vehicle bus, it is useful to validate the defined interface of the DVDB with other vehicle components and subsystems for integration and to test tactical software logic before running the model in real-time for Emulation.

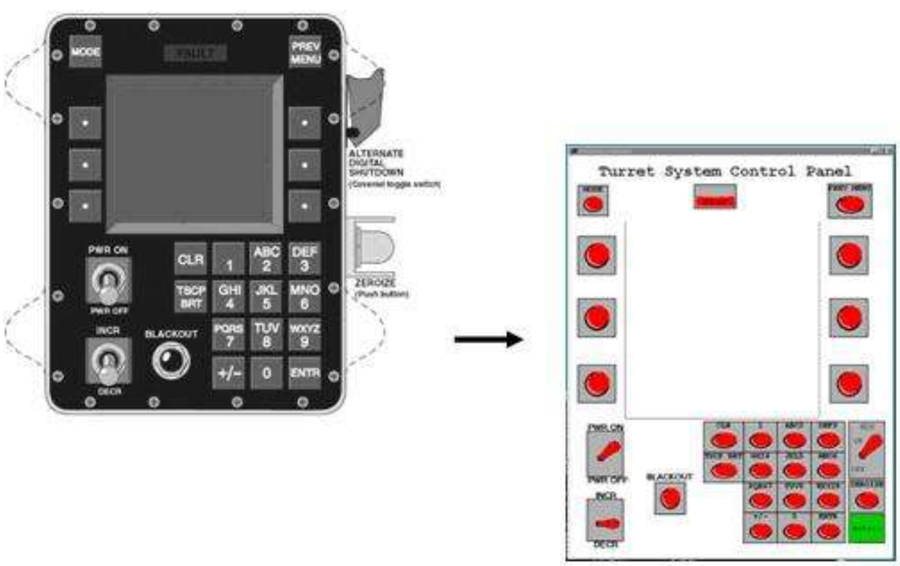

Fig. 6: Simulated GUI front end of electronics hardware

Once this model has been proven on the host through interactive simulation using the graphical panel, it will be converted to source code using Auto-coder from MATRIXx[3] or Matlab[5] to port to the real-time target. During **Emulation**, the real-time DVDB model will interface with the tactical software and electronics components using actual vehicle bus communication. To control the model, the GUI panels on the host computer will also be connected to the target through network communication. During the Emulation phase, both message and signal will be running in a real-time environment to test frequency and timing and to resolve any deadlock problem of communication from multiple hardware components and vehicle subsystems.

The DVDB real-time model needs to be replaced by hardware to perform **Stimulation**. First, the emulated DVDB model needs to be disabled from the target. All the messages and signals for the DVDB model need to be rerouted to the DVDB hardware. To connect to the hardware, all the signals need to be conditioned to have proper voltage and current for the hardware. Figure 7 demonstrates a case where tactical software running on the vehicle processing unit is replaced by an external Stimulator. Note that this Stimulator can be a commercial bus controller with simple interface compatible messages or it can mimic the tactical software using more advanced modeling tools.

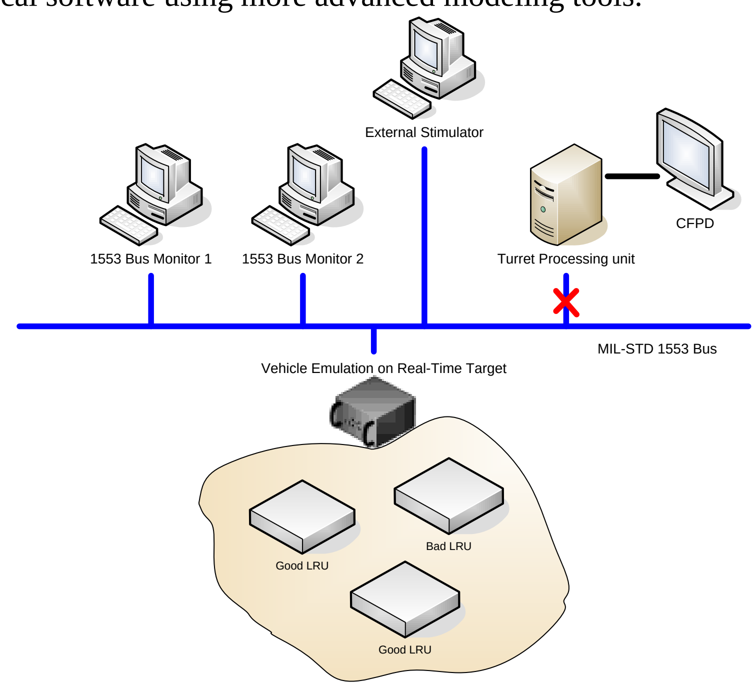

Fig. 7: Stimulation Mode

In the Simulation phase, the DVDB hardware unit will be first tested to ensure the unit itself is operating properly. Then, the unit will be integrated with the target machine to perform integration and test with the rest of the system and tactical software. If the integrated system is not performing correctly, the real-time DVDB emulation model will be used to validate the DVDB hardware unit. Once the hardware unit is tested, it will be installed in the vehicle for platform level integration and test. The SES environment will re-enable the emulated DVDB model so other tests including automated stress tests and further target integration tests can be performed in the SES environment.

Another imperative feature of SES Emulation is fault injection to simulate electronics component rainy day behavior to test tactical software logic. Figure 8 illustrates a typical fault scenario. In this case, an emulated component is prevented from communicating on the vehicle bus. The tactical software which is controlling the bus in this scenario will see the failure and should take the proper precautions.

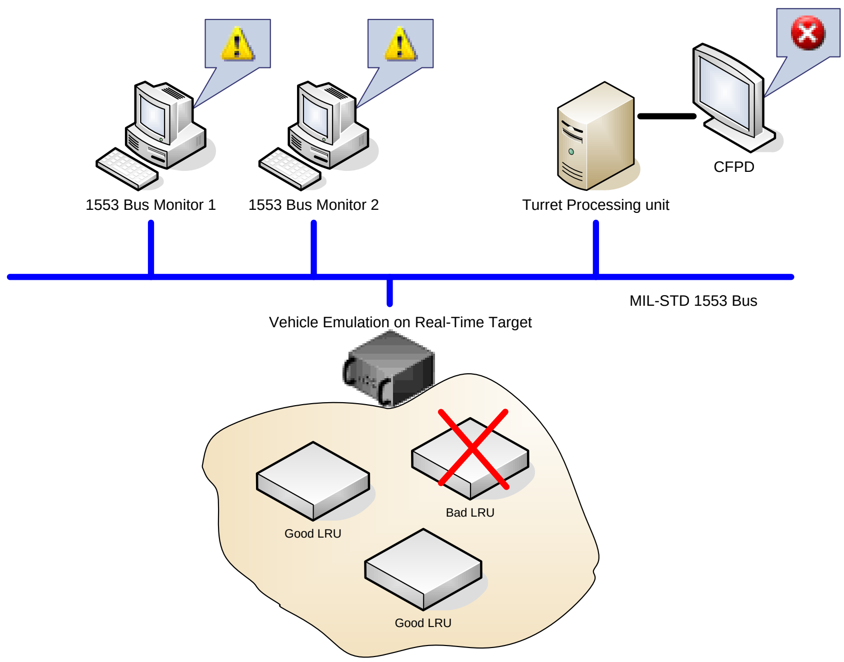

Fig. 8: Fault Injection Scenario

As the fault scenario above demonstrates, the tactical software can be thoroughly checked on the SES bench using all of the tools available to the software development and test teams. It is only after this stage that one may opt to utilize the vehicle with a high degree of confidence that basic issues have been addressed on the bench. SES also supports life cycle development. Figure 9 shows a typical example of a component going through the SES process and then on to the vehicle.

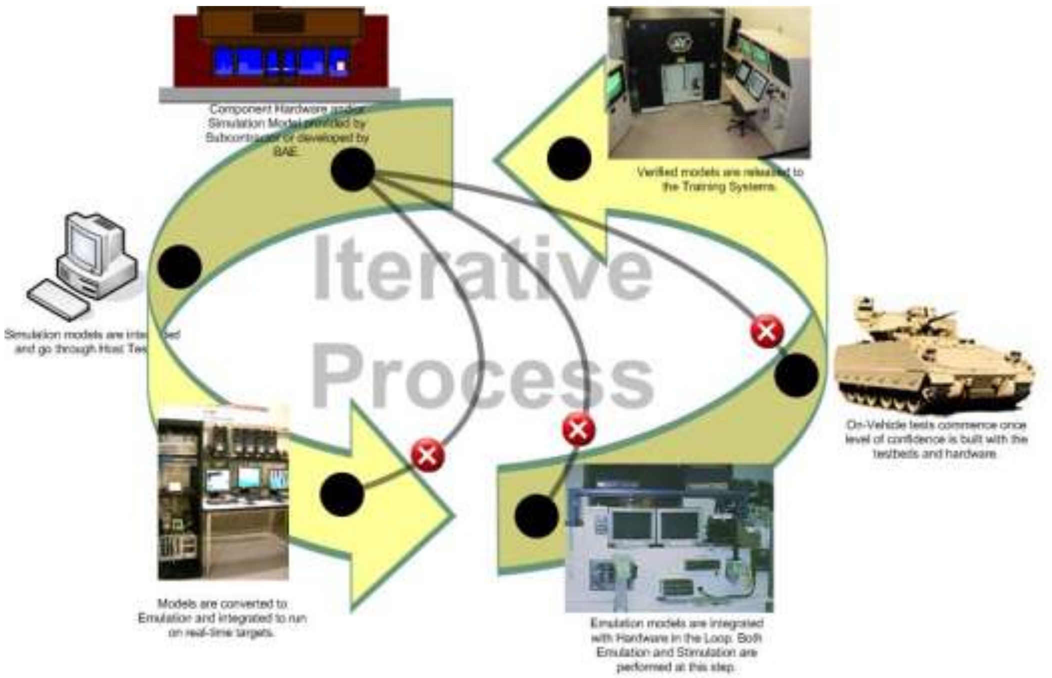

Fig. 9 SES iterative process lifecycle

Note that as the diagram shows, the component in question may undergo further iterations within the lab if vehicle tests indicate integration issues. Examples of the benefits of using high fidelity models in the SES environment can be found in the integration and test of any electronics component. Using the high fidelity electronics models and the SES environment will enable the tasks such as message protocols verification, hardware signal interface verification, tactical behavior validation and tactical message timing verification. Internal visibility of high fidelity models allow for quick troubleshooting and resolution. Once integration and troubleshooting have been completed, vehicle hardware is used to validate the system requirements of the component.

Conclusion

The BAE Ground Systems SES environment reduces cost and schedule risk to vehicle integration. By employing a lab integration approach to electronic components, time consuming and complicated vehicle installation tasks can be avoided while providing bus monitoring and fault injection capabilities essential for troubleshooting. This improved integration and test process increases overall vehicle build efficiency and reduces the deployment time to theatre.

Benefits from using the SES process include:

- Reducing cost and schedule risk to vehicle development and integration
- Increasing troubleshooting efficiency
- Reproducible problems from the field

- Mitigation of hardware availability risk during integration
- Reducing hardware and software upgrade cycle time

By applying the SES process, BAE GS has successfully developed ground combat vehicle in support of various Government programs.

Driver Training System

Crew Trainer

Another benefit of applying the SES process for vehicle integration and test is to develop training systems. Since the SES models simulate vehicle behavior and proper message interfaces, GS developed training systems are based on the developed SES models. The above pictures show two trainings systems developed for combat vehicles. One has been used for driver training and the other one has been developed for crew training.

<u>References</u>

1. CMMI**,** Capability Maturity Model Integration by Software Engineering Institute

2. Kato, H., Naghshineh, K., Hamamoto, B., "Automated Test Environment with the Simulation-Emulation-Stimulation Process", Virtual Concept 2005, Biarritz, France, November 2005.

3. MATRIXx™, SystemBuild™, AutoCode™, RealSim™, Xmath™ and LabView™ are trademarks of National Instruments Corporation.

4. ADI, Applied Dynamics International

5. Matlab™ and Simulink™ are trademarks of The Mathworks, Inc.