OpenSIM (Open Simulation engine for Interoperable Models) for Weapons Effectiveness Analysis

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Abstract *– As modern weapon systems become complex in dynamics and operational environments, evaluating their effectiveness becomes a hard task, accordingly. In order to analyze the effectiveness of a weapon system realistically, we have to consider not only dynamics of the weapon system, but also natural environments under which the weapons are operated, and operational strategies with which the weapons are utilized, as well. These factors are hard to control in real world, and thus, simulation technology has been massively used as an alternative for the effectiveness analysis. OpenSIM(Open Simulation Engine for Interoperable Models) is a simulation environment for weapons effectiveness analysis. OpenSIM provides 1) a modeling framework to represent weapon systems, environments and operational strategies, 2) various simulation services including scheduling, journaling, and logging, 3) linkage to other simulation systems, such as live and virtual simulators, and commercial engineering tools,. In this work, we present tools and services of OpenSIM and illustrate how OpenSIM can aid weapon engineers to perform complex modeling and simulation tasks for weapons effectiveness analysis.*

Keywords: Weapons Effectiveness Analysis, Simulation Engine, Integrated Simulation Environment, Hybrid Simulation

1 Introduction

Modern weapon systems are very complex in their structure and dynamics. They operate with sensors, commands and shooters distributed over the network, and cooperate based on complex engagement strategies [1]. Effectiveness of weapon systems can vary according to various factors on natural environments (i.e. sea, ground, air) and operational environments (i.e. engagement strategies). These factors are hard to control in real world, and thus, simulation technology has been massively used to measure/predict the effectiveness of a weapon system. In order to simulate a weapon system and assess its effectiveness in various war conditions, we need a set of models to represent weapons dynamics, natural environment, and operational environments. These models require us to employ different modeling methods. For example, dynamics of the weapon system are usually represented with a set of mathematical equations. Natural environments and operational environments are represented as a set of states and state transition rules. Simulating different types of models together challenges us to coordinate the advancement of simulation time and data flow. M&S (Modeling and simulation) tasks can be more complicated when the weapon systems interoperate with existing Live, Virtual and Constructive simulators [2].

A simulation environment can be defined as a suite of tools and services that assist developers and analysts to perform modeling and simulation activities [3]. An integrated simulation environment for weapons effectiveness analysis can greatly help weapon engineers and analysts to perform complex M&S tasks. However, there have been insufficient research works on *what constitutes a simulation environment for weapons effectiveness analysis*. In this paper, we identify requirements for the M&S environment of weapons effectiveness analysis, and present OpenSIM (Open Simulation engine for Interoperable Models) as a solution.

This paper is organized as follows. Section 2 reviews related works and identifies M&S requirements for the weapons effectiveness analysis. Section 3 presents OpenSIM and explains how the OpenSIM can help weapon engineers and analysts to measure/predict the effectiveness of a weapon system. Tools and services in OpenSIM will be presented with a simple example. Section 4 concludes this paper with future works to achieve.

2 Related Works

Modeling and simulating weapon systems are very complex tasks. Several simulation environments have been developed to ease the complexity involved in theM&S tasks.

JMASS (Joint Modeling and Simulation System) [4] is a modeling and simulation system that provides capabilities for defining models, combining models into simulations, executing simulations, and post-processing the results. JMASS provides several tools and predefined C++ components that simplify the configuration of models and provide access to common simulation services, such as timing, event queuing, and inter-component communication.

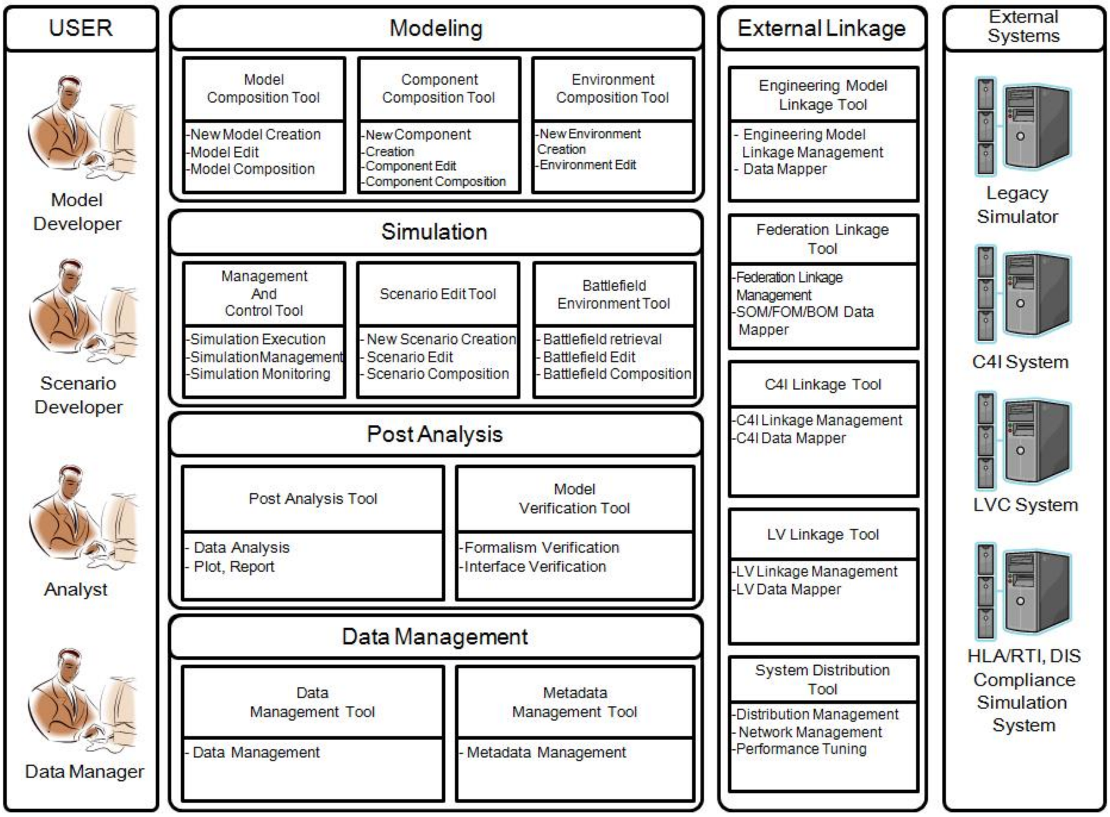


Figure 1. OpenSIM : Overview

JMASS is used to build digital system models for engineering and engagement-level simulations.

In OneSAF, simulation behaviors and models are data driven, to support customization and “what-if” analysis. System capabilities are exposed by powerful visual tools. High degree of interoperability through DIS (Distributed Interactive Simulation) and HLA (High Level Architecture) [6] is provided in OneSAF.

Based on the existing M&S environments in the military community, we can identify services that could be used for leveraging M&S activities for weapons effectiveness analysis:

- A standard modeling framework + formalism: Weapons effectiveness analysis involves many models of different types. A standard modeling framework can provide useful constructs to build different types of models. Adding formalism to the modeling constructs can make the structure, behaviors and interfaces of the model “seeable”. Weapon engineers can utilize these information to locate reusable M&S assets.
- Simulation services: Besides the basic simulation services such as scheduling, journaling, and logging, weapon engineers need explicit supports for hybrid simulations in order to coordinate time advancement between engineering-level simulations (i.e. simulation of weapon models) and engagement-level simulations (i.e. simulation of natural and operational models), transparently.
- Linkage to Legacy simulation systems and Commercial engineering tools: Simulating weapons effectiveness often requires interoperation with various legacy simulators, such as Live, Virtual and Constructive simulators and Command/Control systems. Many existing weapon models have been constructed with commercial engineering tools, such as MATLAB®/SIMULINK®. Linkage to the commercial tools is also desirable to improve reusability of the existing weapon models.

OpenSIM realizes these features with a set of tools, services, standard interfaces. Details can be found in Section 3.

3 OpenSIM(Open Simulation engine for Interoprable Models)

OpenSIM (Open Simulation engine for Interoperable Models) is an integrated simulation environment for weapons effectiveness analysis. OpenSIM provides a suite of tools and services for developing, executing and analyzing simulations of weapon systems, as shown in Figure 1. OpenSIM is *open* to different types of models, different levels of simulations, and different types of legacy systems. We introduce the modeling framework, simulation services, and linkage capability of OpenSIM in Section 3.1 – 3.3.

3.1 Modeling Framework

A modeling framework guides modelers to organize a system into a set of small components that can be separately executable on different computers. The modeling framework of OpenSIM has been devised based on DEVS(Discrete Event System Specifications) formalism [7]. DEVS is a formal modeling method to hierarchically describe entities and behaviors of a system. DEVS provides two types of models for hierarchical composition. An *atomic model* depicts a system as 3 sets (a set of inputs, a set of outputs, a set of states) and 4 functions (external transition function, internal transition function, output function and time advance function). A *coupled model* consists of a set of atomic models, coupling information among the atomic models, and input/output ports. DEVS has been successfully used in defense modeling and simulation developers and resulted many applications with various computer languages, such as, C++ and Java [8,9].

Figure 2 shows our modeling framework based on DEVS. In order to assess the effectiveness of a weapon system, we have to consider 1) dynamics of the weapon system, 2) environments where the weapon system are deployed, 3) engagement strategies where the weapon system are operated. As illustrated in Figure 2, our framework organizes a weapon simulator with three models: weapon model(s), environment model(s) and engagement model(s). A model can be further composed of components and subcomponents, which are described with 3 states and 4 transition functions. The proposed modeling framework helps developers to chop the whole simulator into small-sized components which can be independently executable on different computers. [10]

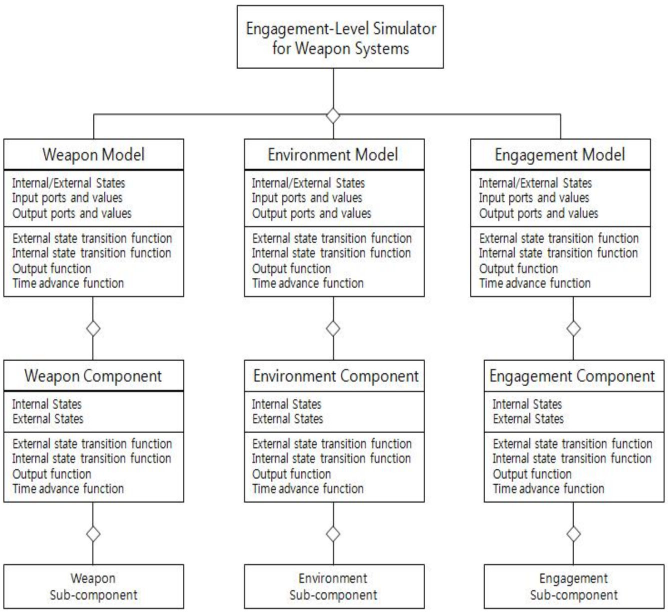


Figure 2. OpenSIM Modeling Framework

The modeling framework can also facilitate reuse of weapon simulators. For example, the environment model of a torpedo can be reused in a missile simulator, even though we can't reuse the torpedo simulator as a whole. Users can see all semantic information on the models in terms of the structures and behaviors (i.e. states and state transitions) and utilize the information to locate reusable model candidates.

OpenSIM provides a set of tools and services to enable the proposed modeling framework. Modelers specify weapon models, environment models and engagement models on easy-to-use GUIs on OpenSIM. An example is shown in Figure 3. An aircraft is composed of *Navigator, Radar* and *Missile*. *Navigator*, *Radar* and *Missile* are modeled with Atomic Components of OpenSIM with 3 states and 4 transition functions. An aircraft couples *Navigator*, *Radar* and *Missile* as shown in Figure 3.

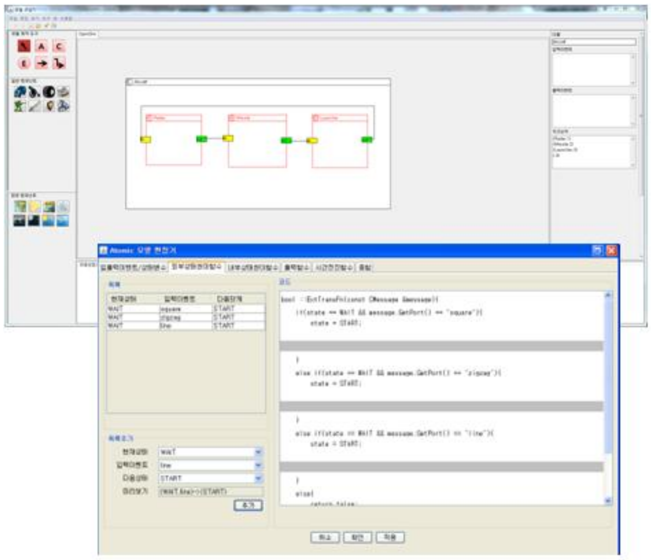


Figure 3. Modeling Tools in OpenSIM

All these information are fed to *Translator* of OpenSIM, which automatically generates the correponding C++ codes, as shown in Fugure 4. OpenSIM also offers services to build environement models. For example, *Atmosphere services* allow environment models to reference atmospheric data at a given altitude and location. Various utility services are provided to help developers build models. Data structures and algorithms, mathematical solvers, and random number generators are the examples.

3.2 Simulation Services and Tools

OpenSIM provides a set of services to simulate weapon systems in natural and operational environments. Followings are parts of OpenSIM simulation services.

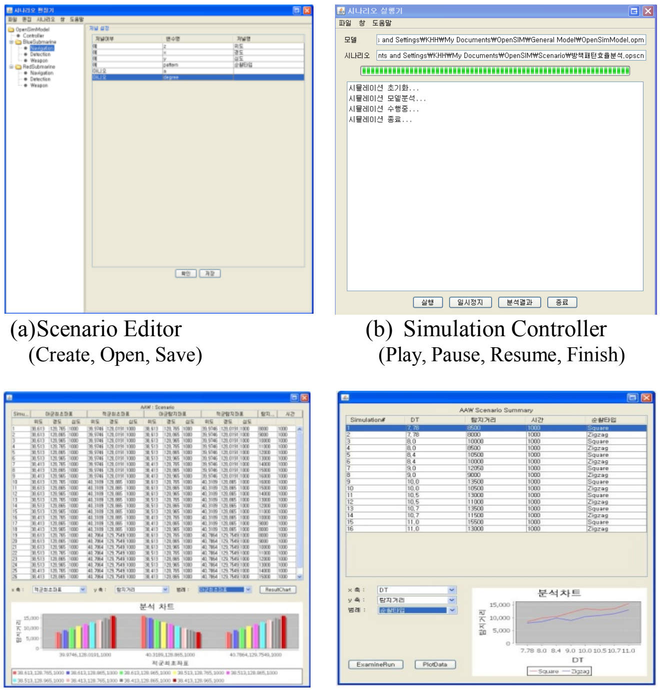
- Scheduling services: OpenSIM manages time to support hybrid simulation. Weapons change behaviors continuously, while their operational strategy changes with discrete amount of time.

```
class Radar: public Op_ModelA {// Radar ModelA
public:
    Radar();
    Radar(std::string name);
    virtual ~Radar();

   //External, Internal function
   virtual bool ExTransFn(const Message);
   virtual bool InTransFn();
   // Output, Time advance function
   virtual bool OutputFn(Message &);
   virtual TimeType TimeAdvanceFn();
};

class Missile: Public Op_ModelA { // Missile ModelA
……
};

//Navigator ModelA
class Navigator: Public Op_ModelA {
……
};

//AirCraft ModelC = Navigator+Radar+Missile
class AirCraft: public Op_ModelC {
 public:
   AirCraft();
  virtual ~AirCraft();
}

AirCraft::AirCraft() {
  Navigator* navigator;
  Radar* radar;
  Missile* missile;

  navigator = new Navigator("Navigator");
  radar = new Radar("Radar");
  missile = new Missile("Missile");

  //Register components and Set ports
  AddComponent(3, navigator, radar, missile);
  AddInPort(1, "in");
  AddOutPort(1, "out");

  // Coupling Information
  AddCoupling(this, "in", navigator, "in");
  Addcoupling(navigation, "done", radar, "in");
  AddCoupling(radar, "detected", missile, "in");
AddCoupling(missile, "shot", this, "out);
```

Figure 4. Automatic Code Generation (in part)

Scheduling services process events in time order and allow continuous and discrete-event simulations to occur together.

- Internal high-speed communication services: OpenSIM provides services to run models in either single- or multi-threaded modes to speed up simulation.
- Resolution Services: Weapons effectiveness analysis involves various models with different levels of detail. Model developers can specify the level of detail for their models. Analysts can switch simulation levels of detail, on the fly, by using the resolution services.
- Journaling Services: Attributes can be selected for periodic output during a simulation. Journaling services sample the values of selected attributes during a simulation and save the sampled values to a specified file format in OpenSIM.
- Message Logging Services: Message Logging services write messages logged during a simulation to the corresponding output medium.



(a)Scenario Editor (Create, Open, Save)

(b) Simulation Controller (Play, Pause, Resume, Finish)

(c) Analysis Tools (Plots, Reports)

Figure 5. Simulation and Analysis Tools in OpenSIM

OpenSIM provides a set of tools to help analysts define simulation scenarios, manage and monitor simulations, as shown in Figure 5. A set of analysis tools are also provided to help analysts view simulation results.

3.3 Linkage Services

In this section, we briefly introduce OpenSIM linkage services.

- Linkage to existing HLA Federations: Weapon models may interoperate with existing HLA Federations. OpenSIM provides gateway services to connect existing HLA federations. Gateway services should coordinate the advancement of logical and/or real time, and provide translation between different data models.
- Linkage to Web: Weapons effectiveness analysis may involve various devices, platforms, and even organizations dispersed over the network. Web services are expected to provide an ideal solution for integrating various simulation artifacts disparate platforms, systems, and organizations [11]. A SOAP interface and its services enable various web applications to communicate with the models within OpenSIM.
- Linkage to LVC Simulators: OpenSIM LVC gateway services automate integration with LVC standards, such as HLA, DIS (Distributed Interactive Simulation), and TENA (Test and Training Enabling Architecture) [12].

- Linkage to Engineering Tools: Dynamics of weapon systems are usually described with complex mathematical equations. Commercial tools, such as MATLAB®/SIMULINK® [13] are very popular to many engineers in M&S community to represent dynamics of weapon systems with mathematical equations. OpenSIM allows engineers to develop and test weapon models using MATLAB/SIMULINK. By using linkage services, the weapon mathematical models are connected to engagement and environment models within OpenSIM [14].

Most of the linkage services are under development. Common basic services, such as SOM/FOM translation services, are being identified. The SOM/FOM translation services provide data translation between various systems (i.e. Engineering Tools, LVC simulators, etc) in a uniform manner.

4 Conclusion

Measuring the effectiveness of weapon systems involves complex M&S tasks – Different types of models should be simulated with engineering-level, engagement-level, and their combined levels. Linkage to the legacy systems, such as LVC simulators, and commercial engineering tools make the M&S tasks even more intractable. An integrated simulation environment can help weapon engineers/analysts to semi-automate subsets of the required M&S tasks. OpenSIM provides a suite of tools and services for developing, executing and analyzing simulations, and linking the legacy systems and engineering tools for weapons effectiveness analysis. OpenSIM is under development, and we would like to test out OpenSIM with various weapons for continuous improvement. Some of the important research issues have not been addressed in this work – How to manage a model repository? How to compose complex weapon systems of systems by taking ontology into consideration? We would like to study these issues in the future.

Acknowledgement

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