A Comparison of Guided Missile Simulations Between EADSIM and SADM in Composite Combat Mission Planning Simulation Environments

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ABSTRACT

High Level Architecture/Run-Time Infrastructure (HLA/RTI) is used to connect individual simulators on networks in order to interoperate heterogeneous simulators. In defense domain, Ship Air Defense Model (SADM) and Extended Air Defense Simulation (EADSIM) are two of most advanced simulation tools. To interoperate these SADM and EADSIM, this paper attempts to use HLA/RTI that helps to support a Composite Combat Mission Planning Simulation Environment (CCMPSE). The CCMPSE allows us to analyze a group of simulations for comprehensive and accurate experiments. For the first time, this paper analyzes guided missile simulations in EADSIM and SADM by comparing related simulation models in their parameters and considerations. It presents characteristics of these models in view of guided missile simulation perspectives. For the contributions of this paper, it provides insights to select guided missiles between SADM and EADSIM on the CCMPSE according to specific simulation purposes.

Key words: EADSIM, SADM, Composite Combat Mission Planning Simulation Environment, Guided Missile Simulation

1. INTRODUCTION

HLA stands for High Level Architecture and links a standard for individual simulators. Department of Defense (DoD) firstly suggests HLA, and HLA became a standard as IEEE 1516 in 2000. HLA also provides interoperability through networks among heterogeneous simulators[2-4]. HLA creates one federation, and the federation assigns a single federate to the simulators that are implemented in different programming languages and have different operating environments. RTI stands for Run-Time Infrastructure and are developed by Defense Modeling Simulation Office (DMSO)[5]. RTI is a software module that implements interface specification between federates in HLA network environment. It services time and data synchronization between federates in a single federation.

EADSIM(Extended Air Defense Simulation) and SADM(Ship Air Defense Model) are M&S tools that widely used in defense domain. EADSIM is developed by Teledyne Brown Engineering In USA [7]. EADSIM is a software tool that offers a variety of weapon models such as aircrafts and missiles. EADSIM is currently used for operational analyses. SADM is developed by BAE SYSTEMS in Australia and is a simulation tool for ships and their air threat[6].

In the previous study[1], I had developed the Network-based Composite Combat Mission Planning Simulation Environment (CCMPSE). The CCMPSE provides more sophisticated effects analyses using weapon models provided from both EADSIM and SADM. this paper compares and an-
analyzes missile models between EADSIM and SADM. Fig. 1 shows the configuration of CCMPSE in HLA/RTI. The CCMPSE consists of Composite Combat Mission Planning Control System (CCMPSCS), 2D/3D visualization system, and platform models from EADSIM and SADM. They are interfaced with HLA/RTI as a member of individual networked systems. Under these environments, new simulators, which have HLA/RTI interfaces, can participate in the network.

The CCMPSCS manages simulation time[11] and status of simulation objects in simulation scenarios in operating in the CCMPSE. The simulation objects indicate weapon systems in platform level. The 2D/3D visualization system provides behaviors and status of weapon systems on screens with assigned 2D/3D objects. EADSIM and SADM individually operate simulation scenarios which are the same scenarios in the CCMPSE. Except for their own weapon systems, each simulator virtualizes the simulation objects and obtains/update status of them from the HLA/RTI network. The CCMPSCS step by step simulate the scenario with synchronization of simulation time. Fig. 2 illustrates the configuration of the CCMPSCS.

In this paper, it firstly discusses the simulation characteristics of EADSIM and SADM. After that, this paper establishes comparison perspectives of missile models for mission simulations. Under the perspectives, I analyze each missile model in EADSIM and SADM. As a contribution point of this paper, it provides insight to select the right guided weapon for simulation purposes when guide missile simulation operated through interconnected EADSIM-SADM. (This paper is an extended version of “Analysis of Missile Models between SADM and EADSIM” in 2013 symposium of the KIMST).

2. EADSIM AND SADM SIMULATION

This section discusses the characteristics of EADSIM and SADM simulation with their analyses. Academically, M&S in defense domain is classified into theater, mission, engagement, and engineering levels[8]. Simulation models in theater level are used for Measure Of Outcome(MOO) such as abilities of whole friendly(or whole enemy) forces. Simulation models in mission level are used for Measure Of Effectiveness(MOE) such as survivability and lethality between weapon systems. Simulation models in engagement level are used for performance analyses in groups of weapon sys-
tems: namely, Measure Of Performance(MOP). Finally, simulation models in engineering level are used for depth in MOP of individual weapon systems. With these classifications, models in EADSIM is categorized in mission level's simulation, and models in SADM is categorized in engagement level's simulation. However, models in EADSIM technologically support MOP analyses as to engagement level's simulation. Likewise, models in SADM also support MOE analyses such as survivability in limitedly implemented functions.

The EADSIM simulation engine is structured in multiple layers as laydown, platform, system model, jammer, sensor, communication device, and weapon. a single object in each layer stands for an element; therefore, EADSIM allow us a variety weapons to compose and build weapon systems(or models) like LEGO blocks[1]. SADM simulates air defenses in self/group defenses to air threats in marine environments. However, SADM does not provide functionality to create new weapon systems as EADSIM does. Based on detailed attributes and fidelity, SADM focuses on practical simulation and analyses in engagement level. Moreover, it provides interfaces with SIMDIS(SIMulation DISplay)[9]; therefore, the results of simulations can visually be verified.[1]

EADSIM and SADM have their own different advantages in simulation models and engines. Theoretically, the simulation environments[1] including all of these advantages through simulation interlocking between EADSIM and SADM can be built. For example, interlocked simulation scenarios on HLA/RTI network environments can be used for analyses on both aspects of engagement and mission level by interoperating EADSIM and SADM engines. Under these environments, results of interlocked simulation scenarios are derived from only each weapon system that is affiliated to own simulation engines. Therefore, in these circumstance, it became important to select wisely simulation models that commonly provided from EADSIM and SADM when interlocked simulation scenarios are made on HLA/RTI networks.

3. COMPARISON OF GUIDED MISSILE SIMULATIONS

In this section, it firstly establishes four comparison aspects for guided missiles in EADSIM and SADM. According to the established aspects, it relatively compares and analyzes parameters in models in EADSIM and SADM which are related to guided missiles. First aspect is body models of guided missiles. Body models related to guided missiles are closely related to material and weight in guided missiles of physical design and its design evaluations. Moreover, the body models are mainly used for simulation of relations to the exposure to radar models. Second aspect is kinematics models of them. In guided missile design, kinematics is a close relationship between propulsion and aerodynamics, and it is mainly used for simulation analyses such as maneuverability performance of guided missiles. Third aspect is seeker models of guide missiles. It is mainly used for simulation of the operation and the response capability of target recognition capability and soft-kill of seeker. Final aspect is operation models of weapon systems. It analyzes whether the weapon system can achieve its original purposes when combining newly developed guided missiles with existing platforms.

3.1 Body Models

The body models are used in various perspectives of simulations on guided missiles such as visualizations or RCS(Radar Cross Section) computations. the body models of guided missiles can be simply classified into length, diameter, wings, and RCS. Both EADSIM and SADM models do not consider length and diameter of missiles. The length and diameter are important factors in determining the size and internal volume of the contour. When a missile is newly designed, the in-
ternal volume crucially determines space assignments of each element inside missile such as payload, seeker, and fuel for impellent forces. Also, it affects time of flight (TOF) and explosive diameter. Moreover, length and diameter, together with material, have a decisive influence on weight of missiles; therefore, these should be considered in simulation of flight distance and flight time by assigned thrust.

In terms of wings of missiles, form of wings, their locations, numbers of them, and their size should be considered in order to compute lift forces as an input parameter to kinematics models. In other words, the lift forces are closely related to boost, sustain, and coast flight; therefore, these affect flight time of the missile[10]. However, both EADSIM and SADM completely ignore factors in wings of missiles. Especially, the size of wings is a critical factor to maneuverability performance and maximum turn performance[10].

In terms of RCS of missiles, both EADSIM and SADM completely depend on external input parameters such as RCS scalar or RCS table data. In cases of RCS scalar, missile models in the simulation tool are recognized as appearance of missiles in body models is simply a sphere. In cases of RCS table data, these models recognize as a missile is composed of small parts, and RCS is changed depending on a view point of the radar (including azimuth and elevation) to the missile.

In EADSIM simulations, both RCS scalar and RCS table data model are provided. The number of frequencies, the frequency value, the search range of the radar, and the sampling angle set of the azimuth/elevation angle are tabulated in unified degree of m°. SADM simulations fully support functionality of RCS computations that EADSIM provides. SADM additionally considers RCS In-phase and Quadrature (IQ) matrix, RCS multi-scattering matrix, and fluctuating RCS options. Moreover, SADM uses both m° and dBsm as degrees of RCS. The RCS IQ matrix does indicate that data in table is not scalar but is defined in vector values considering phase differences. The RCS multi-scattering matrix does indicate that a target is not a single object but a complex component; therefore, RCS of the target is computed as sum of the vectors of the reflected signals for each component.

The fluctuating RCS indicates RCS Probability Distribution Function (RPDF) of Radar model, and the RPDF is calculated by swelling models. In EADSIM, there is no clear explanation on uses of fluctuating RCS; however, SADM mandatorily selects one of five RPDFs and its related swelling model when RCS is computed. In summary of body models in EADSIM and SADM, both of them minimize associativity between body models and kinematics models, and on the separated standpoint, only externally calculated RCS is considered as inputs of kinematics models.

3.2 Kinematics Models

Kinematics models of missiles are simulated and analyzed in aspects of maneuverability and tactical operation suitability. I have compared the kinematics models from EADSIM and SADM in views of velocity, location (latitude/longitude), altitude, approaching angle, thrust, and aerodynamics. Both EADSIM and SADM have the same paradigm in that parameters in velocity, location, and altitude are combined and managed with a waypoint. Through a set of waypoints, additional information, such as acceleration, is internally calculated and made.

In view of approaching angles, SADM allows heading angles with simple parameter inputs or random setting without adjusting waypoints themselves. However, adjusting moving directions between waypoints is an only way to set approaching angles in EADSIM. In view of thrust, EADSIM uses a thrust table that presents axial thrust data over time, and it simulates flying power based on initial weight of a missile and weight with con-
sured thrust fuel over time. However, SADM provides the same functionality only for air defense missiles. In view of aerodynamics, both EADSIM and SADM consider parameters on G-limitation such as max lateral/axial acceleration; therefore, these are considering air density at different altitudes of global environments between waypoints. In other words, aerodynamics within the permissible ranges are replicated in simulations. In EADSIM, lift force and drag force table data are additionally applied to aerodynamics computations. However, SADM provides these force table data only for air defense missiles.

3.3 Seeker Models

In terms of seeker models, EADSIM considers seeker models as another kind in radar models; therefore, it does not take into account of the unique characteristics of seeker models. However, SADM takes care of the unique characteristics of seekers; therefore, more sophisticated seekers can be described through seeker models in SADM. I establish six comparison points in seeker models such as types of seeker, dual-mode, turn-on schedule, antenna properties, ECCM (Electronic counter-countermeasure), Doppler.

In types of seeker, EADSIM and SADM supports various types of seekers: namely, active, passive, EO, and IR models. SADM provides two interfaces to set up multiple combinations of seeker types as a dual-mode; however, EADSIM does not support the dual-mode, and it selects and operates only one seeker type independently. In EADSIM, there are a GUI to model multiple seeker models into one weapon system, but this is for a priority of seeker models, not dual-model seeker controls. In EADSIM scenario, only one seeker model is applied to simulations. In view of turn-on schedule, EADSIM does not take into account of turn-on schedule completely. However, seeker models in SADM consider detailed properties of turn-on range, turn-off range, and searching process; namely, (1) Turn-on, (2) Search, (3) Secondary search, (4) Acquisition, (5) Track, (6) Re-acquisition, (7) HOJ mode, and (8) Turn-off. In a point of antenna properties, both EADSIM and SADM consider detailed properties of antennas. In an aspect of ECCM, SADM provides a variety of electronic warfare models such as jammer, chaff, decoy, etc. However, EADSIM offers only parameters related to jammer such as sidelobe cancellation, burnthrough sector, and ECCM frequency agility. Finally, in terms of Doppler in which seekers can measure speeds of a target, seeker models in EADSIM only provide a number of poles and mainlobe to sidelobe ratio. However, seeker models in SADM Doppler provides weighting function as combinations of parameters, and these parameters are interlocked to Countermeasures of ECCM. Therefore, SADM supports more elaborate seeker models compared to EADSIM’s seeker models.

3.4 Operation Models

In views of operation models in EADSIM and SADM, each has different strengths and weaknesses. It has compared the operation models in views of attack tactic, defense fire policy, launcher model, operational process, communication, and cost.

Firstly, in an aspect of attack tactic, SADM provides GUIs to set parameters related to terminal dive, dive angle, terminal popup, weave, etc. But, EADSIM reproduces these attack tactics, which SADM provides, only with adjustments of waypoints; however, these are not suitable for operation simulation analyses like [12]. In a view of policy of defense, both EADSIM and SADM many of defensive shooting policies: namely, S-L-S (Shoot-Look-Shoot), SS-L-SS (Shoot Shoot-Look-Shoot Shoot), etc. In terms of launcher models, EADSIM provides a lot of launcher platforms and analyses of operational simulations using a variety of launching conditions on platforms. However, SADM does not have such platform options and
take into account of only VLS (Vertical Launching System) and trainable parameters.

In considerations of operational processes, SADM does completely not consider simulation analyses in accordance with designs of the process. However, EADSIM can make a ruleset with combinations of user-define phases and pre-defined phases such as target-select, intercept, fly-out, and kill-assessment. In order to prove the generated rulesets, EADSIM simulates the pre-processing on EADSIM engine before operating actual scenarios. In terms of communications in EADSIM and SADM, both establish C2 communication models between platforms. In EADSIM, there are communication elements to be embedded into a platform; therefore, communication networks could be built between weapon systems. EADSIM communication models support communication protocols (such as Link-11, Link-16, VMF, etc.), types of communication (such as unicast, multicast, broadcast, etc.), and update cycles of target information in order to simulate a variety of communication environments. Moreover, there are network simulation functions: namely, C2 traffic analyses on sizes of communication message queue that is interoperated with phases in a ruleset. However, SADM communication models take into account of C2 communication systems only for air defenses. SADM considers only wireless communications, and there are only On/Off parameters in a GUI. In other words, each platform is independently operated in cases that the 'Off' parameter is applied to the scenario. There is no command and control system in these cases. In cases of 'On', Link-11 communication networks are established among friendly forces. However, there is no user’s GUIs to set up detailed communication environments, and the pre-defined communication delay of link-11 in SADM simulation engine is applied and simulated. In terms of cost, EADSIM does not consider operational costs including costs of guided missiles. SADM partially supports cost analyses for air defenses as prices are assigned by types of guided missiles. Table 1 summarizes the comparison results.

4. A CASE STUDY

In this section, a case study with a scenario for CCMPSE, which I have taken from the previous study[1], is conducted. Table 2 summarizes simu-

<table>
<thead>
<tr>
<th>Perspective</th>
<th>EADSIM</th>
<th>SADM</th>
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<tbody>
<tr>
<td><strong>Body</strong></td>
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<tr>
<td>Length</td>
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<td>Diameter</td>
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<td>Wing</td>
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<td>Latitude/Longitude</td>
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<td>Altitude</td>
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<td>Approaching Angle</td>
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<td>Thrust</td>
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<td>Aerodynamics</td>
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<td><strong>Seeker</strong></td>
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<td>Turn-on Schedule</td>
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<td>Doppler</td>
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<tr>
<td><strong>Operation</strong></td>
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<tr>
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<tr>
<td>Launcher</td>
<td>S</td>
<td>P</td>
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<tr>
<td>Cost</td>
<td>N</td>
<td>P</td>
</tr>
</tbody>
</table>

*S: Support, P: Partially Support, N: Not Support

Table 2, Simulation objects in the common scenario[1]

<table>
<thead>
<tr>
<th>Perspective</th>
<th>Red Team</th>
<th>Blue Team</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EADSIM</strong></td>
<td>MIG-21(4), BM(1)</td>
<td>F-15K(1), Satellite(2), ATGM(2)</td>
</tr>
<tr>
<td><strong>SADM</strong></td>
<td>Bunker(1), SAM(7)</td>
<td>SAM(1), Destroyer(1), Aegis(2), Convey(2)</td>
</tr>
</tbody>
</table>

*BM: Ballistic Missile, ATGM: Air To Ground Missile, SAM: Surface To Air Missile.
lation objects in the scenario.

In CCMPSE, there are three scenarios: one is for EADSIM simulation engine, second is for SADM simulation engine, the other is for CCMPSCS. These scenarios are shared via HLA/RTI, and the three scenarios are completely same scenarios. However, CCMPSCS has a scenario which is composed of all ghost objects from both EADSIM and SADM. The EADSIM engine has a scenario which consists of its own simulation objects and ghost objects from SADM. In the same way, the SADM has a scenario which consists of its own simulation objects and ghost objects from EADSIM.

The ghost objects generate no events, and these are just projected from their original simulation objects and updated status of them in real time. Events between a ghost objects and a real simulation object are transferred to the target engine of the simulation object through CCMPSCS. The response and status of the simulation object are firstly applied to ghost objects in the scenario in CCMPSCS. Through CCMPSCS, the results are finally transferred in the original engine and applied to the simulation object in the scenario that have firstly generated the events. Fig. 3 illustrates the concept of simulation compositions in the case study.

I had established the Korean peninsula as a simulation space in CCMPSE. Firstly, a F-15K aircraft of the blue team launches two ATGMs in the Yellow sea area, and the two ATGMs target a bunker of the red team. The bunker is an asset that is protected by a system of seven SAMs. In East sea area, four MIG-21s of the red fly and attack two convoys and a destroyer. The two convoys escort the destroyer as a group of air defense systems. A ballistic missile of the red is launched to target an aegis; however, the SAM system of the blue finally intercepts the ballistic missile. In roles of CCMPSCS in CCMPSE, CCMPSCS manages simulation time and status of simulation objects. In other words, it obtains status of simulation objects and applies their ghost objects in real time. Therefore, CCMPSCS can analyze life time of each simulation object and determine mission successes or not in each object.

From EADSIM simulation engine, it can have obtained the following simulation results of missiles:
- TOT(Time on Target) analyses and timeline analyses on thrust/aerodynamics with velocity and LLA(Latitude, Longitude and altitude) of the two ATGMs of the blue.
- Analyses on performances in operational processes and communications with two satellites of F-15K’s weapon system of the blue.

From SADM simulation engine, it can have obtained the following simulation results of missiles:
- Timeline analyses on RCS of the red’s ballistic missile in a perspective of a radar model in the SAM systems of the blue. Fig. 4 shows SIMDIS visualization of these timeline analyses since SADM simulation engine has an interface and display with SIMDIS.
- Analyses on a performance of a seeker model of the SAM of the blue such as antenna and turn-on schedule.
- Timeline analyses on the SAM of the blue; namely, velocity, approaching angle, and LLA.

![Fig. 3. The concept of simulation compositions[1].](image-url)
Defense fire policy and cost analyses on the SAM system of the blue.

In the case study, the detailed data was not discussed because of confidentiality reasons.

5. CONCLUSION

This paper has analyzed the guided missiles from EADSIM and SADM in order to correctly make simulation scenarios in CCMPSE for specific simulation purposes. The CCMPSE is a networked simulation experiment that interconnects heterogeneous simulation tools in order to make interoperable simulations. The objectives of this paper is to wisely select guided missiles models to make a suitable scenario for the simulation purpose, and I have analyzed simulation models related to guided missiles in EADSIM and SADM in terms of missile body, kinematics, seeker, and operation. In the following, we summarize the comparison results.

First, it has confirmed that both EADSIM and SADM were inappropriate for simulating external and internal designs of missiles, and they are taking into account of simulations of perspectives of only performances in weapon systems. Especially, they do not consider structural parameters of missiles: moreover, both are not internally computed on the structural external models but simulated by inputting a fixed value with external parameters such as RCS. Therefore, in cases of simulation of physical design, it will be a reasonable choice to develop an independent external simulator and participate in a form of an independent network system in CCMPSE.

Second, in an aspect of kinematics, both model a set of waypoints in order to compute location, velocity, acceleration, altitude, etc. In cases of simulating a sophisticated target attack, such as a transit angle, missiles models from SADM are useful. However, simulation analyses using engineering calculations such as flight distance, altitude, average acceleration based on thrust or aerodynamics, it must select missile models or platforms from EADSIM.

Third, it should select SADM models in a perspective of seeker simulations. The seeker simulations in SADM models take into account of unique characteristics of seekers, such as dual-mode and ECCM, rather than EADSIM seekers. In order to conduct a sophisticated simulation of seekers, SADM seeker models are more effective.

Finally, in discussion of operational models of missiles, it should select SADM missile models in order to conduct attack tactics or cost based simulations. However, it must make a choice of EADSIM missile models or platforms for modeling or defining launchers, data communications, and operational processes of users’ own in order to simulate operational simulation analyses.

For the future works, I plan to conduct a study to formalize the simulation and analyses methods of missiles in CCMPSE based on simulation characteristics of missiles models from EADSIM and SADM. With the formalized methods in CCMPSE, it is enable for simulations of an effective and reliable guided missiles through efficient usages of EADSIM and SADM tools.

REFERENCE

[1] Jingyu Kim, "HLA/RTI Based on the Simula-


Jingyu Kim received the PhD in Computer Science from Korea Advanced Institute of Science and Technology (KAIST) in 2013. He currently works in the Agency of Defense Development (ADD) in Republic of Korea. His research interests include software architecture, analysis of system operations, and system interoperability.