ICAS 2020 SHANGHAI
International Council of the Aeronautical Sciences
32nd Congress of the International Council of the Aeronautical Sciences
September 6-10, 2021
Pudong Shangri-La, Shanghai, China

SoS Behavior Model Transformation for Aircraft Top-level Demonstration

Zang Jing[1], Zhu JiaQiang[1]

[1]Chinese Aeronautical Establishment, Xiaoguandongli No.14, Beijing 100029, PR China

Abstract

The model continuum is necessary in aircraft top-level demonstration for continuous virtual verification and validation. The architecture models may not be directly executed in the SoS simulation system with the misunderstanding risks and longer iteration cycle of verification and validation. To partly achieve the single truth source required in MBSE, a SoS behavior model transformation method is proposed. The sequence diagrams can be mapped to partly fulfill the scenario for SoS simulation. The state diagrams can transformed to the behavior models in SoS simulation system though format conversion of the SoS architecture outputs. A sample case is provided to illustrate a specific scenario of air-surface attack with behavior models transformation.

Keywords: system of systems, behavior model, aircraft, top-level demonstration

1. Introduction

In Model-Based System Engineering(MBSE)[1-3], the model continuum is necessary in aircraft top-level demonstration for continuous virtual verification and validation[4]. The purpose of SoS (system of systems) design in aircraft top-level demonstration is proposing the aircraft stakeholder requirements including functional requirements and performance requirements basing on operational concept analysis[5]. The architecture modeling method is used in SoS design and the SoS simulation is used in virtual verification and validation for the SoS architecture. However, there are clearly gaps between architecture models and SoS simulation models. Because of different modeling tools, these two kinds of models should be mapped manually nowadays result in longer iteration cycle of verification and validation with misunderstanding risks.Therefore, the method of SoS behavior model transformation should be proposed to partly maintain continuity.

2. Gaps between Models of Architecture and SoS Simulation

In this article, the SoS simulation levels include campaign, mission, and engagement correspond to the top three layers of the traditional modeling and simulation(M&S) pyramid[6]. In the same aircraft development project, the object of the SoS architecture and SoS simulation should be the same SoS, so the SoS simulation can be used for verification of the architecture models. Shown in Figure 1, the models of SoS architecture and SoS simulation have different patterns. SoS architecture models are concept models described by formal language such as SysML(Systems Modeling Language). Moreover, the models in the SoS simulation include the physical models and behavior models. In SoS simulations, most objects have behavior, which define their actions and activities over time.Behavior can include the reactions and interactions of components of physical systems to environmental conditions or the reactions and interactions of individuals, organizations, and societies[6].

The following issues need to be noticed in aircraft top-level demonstration:

a) Because the physical properties of systems are not focused on in typical architecture modelling, the physical models in SoS simulation can not be mapped from the SoS architectureeffectively. The physical models can be achieved basing on cross-domain integration of legacy models[4] and the aircraft conceptual scheme(physical)[7] which may not be completed in top-level demonstration.

b) Verification of all SoS architecture models through SoS simulation is not feasible or necessary. Logical verification is adequate for quite a number of architecture models.

c) The formal SoS architecture models are completed following an architecture framework such as DoDAF(Department of Defense Architecture Framework), MODAF(British Ministry of Defence Architecture Framework), or UAF(Unified Architecture Framework) for different specialist areas. On the other hand, the models of SoS simulation are personalized because of different software vendors.

d) The description of organizations is existed in most SoS simulation software while the operation of SoS simulation needs to be implemented through specific systems. Therefore, models of SoS simulation may have finer granularity than typical SoS architecture models. The SoS architecture models can be abstract and macroscopic without detailed physical properties.

Overall, the SoS architecture models may not be directly executed in the SoS simulation system with the misunderstanding risks and longer iteration cycle of verification and validation. To partly achieve the single truth source required in MBSE, the behavior models of SoS architecture need to be transformed for being executed in SoS simulation system. The behavior model transformation can be realized by three steps such as manual modeling, directly drive, and smooth transformation[4]. The manual modeling method which can be regarded as the discontinuous modeling has a lot of shortages. Regarded as the low-level continuous modeling, the entities in the simulation system are directly driven by the architecture models instead of the behavior models in the same range. Based on the interface definition, the directly drive method which is still developing can support different software. To achieve the smooth transformation as the high-level continuous modeling, the unified meta-model should be defined. However, there are some difficulties caused by the undisclosed meta-models (actual existed) of the behavior models from most simulation systems. Therefore, a SoS behavior model transformation method is proposed in this article for aircraft top-level demonstration.

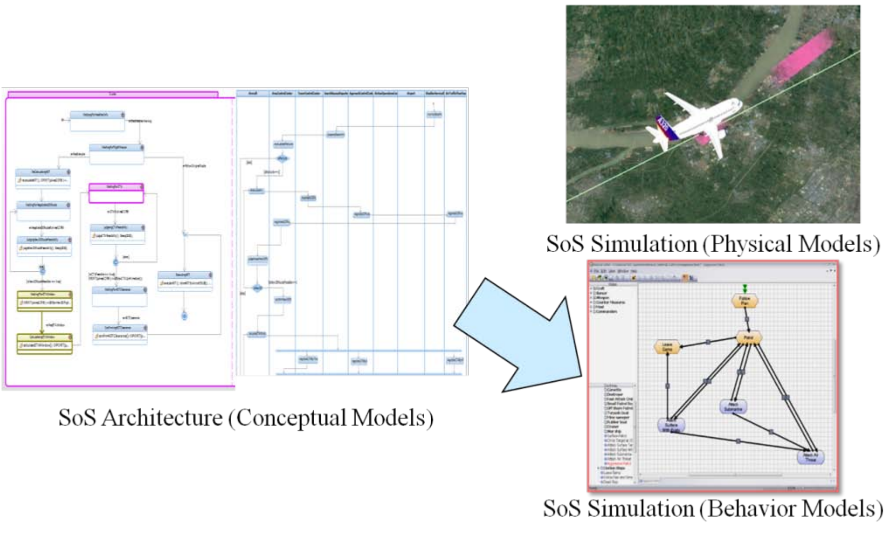


Figure 1 –Different model patterns of SoS architecture and SoS simulation.

3. Model Transformation Method

SoS architecture is modeled from different viewpoint while the SoS simulation also includes multiple granularity models. To keep the consistence in model transforming, the architecture models from operational viewpoint can be transformed to the behavior models of coarse-grained aggregation simulation models with simplified physical models frequently used in campaign simulations to achieve the spatiotemporal verification and effectiveness evaluation for performers (Fig. 2). On the other hand, the architecture models from system viewpoint can be transformed to the behavior models of fine-grained simulation entities frequently used in campaign and mission simulations to achieve the spatiotemporal verification and effectiveness evaluation for systems (especially aviation equipment in aircraft top-level demonstration).

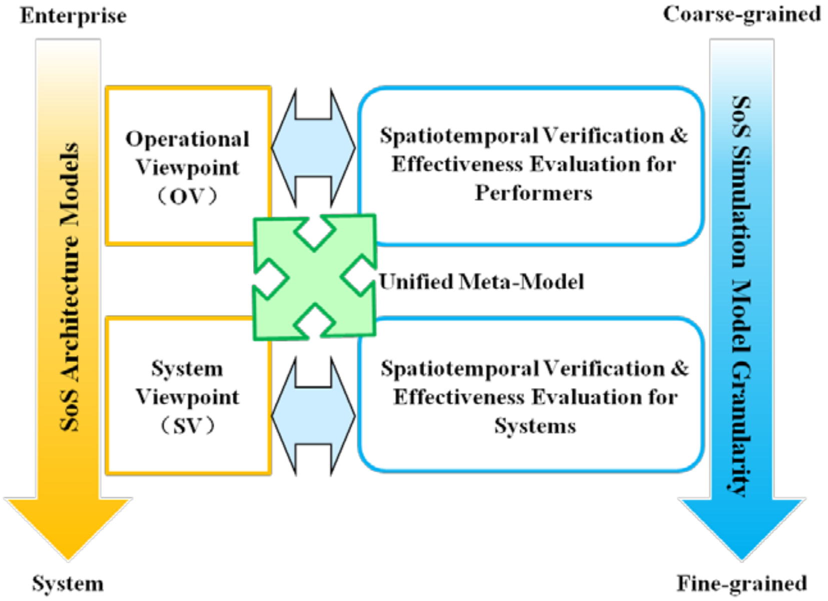


Figure 2 –Multi-granularity behavior model transforming.

The SoS architecture is composed of view models with a graphical representation to describe the whole SoS from different viewpoint. Several view models which can describe the dynamic characteristics of SoS will be selected for the exploration of model transformation. The sequence diagrams can be mapped to partly fulfill the scenario for SoS simulation. The state diagrams can transformed to the behavior models in SoS simulation system though format conversion of the SoS architecture outputs (Fig. 3).

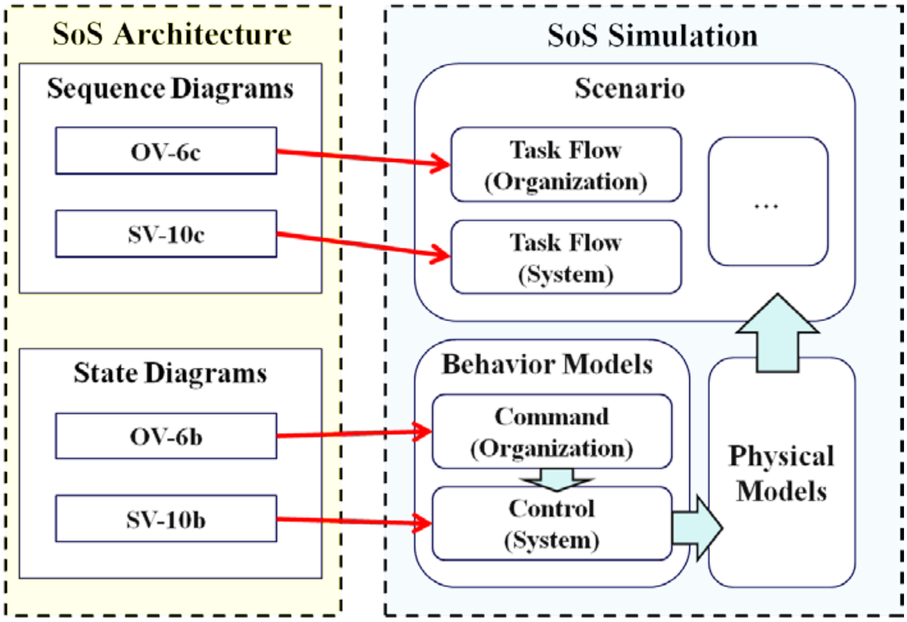


Figure 3 –Model mapping from architecture to SoS simulation.

3.1 Simulation Scenario

Simulation scenario is simulation data of scenario description loaded to simulation system as a script. To achieve the simulation with human not in the loop, modern simulation software provides the partly mission planning capability. The scenario descriptions of different simulation system are not exactly the same, but environment (including natural and non natural environment), forces (including craft, commanders, and even ammunition such as missiles), organizations, and tactics (including task flows) are involved usually in military area (Fig. 4). A complete scenario should follow the W5 principle as Who, When, Where, What, and Why[8]. Who defines the combat units including systems with different functions in SoS as the basic objects in SoS simulation. When and Where describe the space-time motion planning of combat units. What and Why illustrate the goal and reason of the mission.

Obviously, the data requirement of simulation scenario will not be totally covered by SoS architecture. Therefore, the sequence diagrams of SoS architecture are selected to be transformed to parts of the task flows of scenario in this article. Operational/ System Activity Sequences (OV-6c/ SV-10c in DoDAF) view model identifies and describes a sequence of activities using before-after relationships within a described architecture[9][10]. OV-6c focuses on the organizational activities while SV-10c pays attention on the activities performed by systems. Therefore, with transformation, OV-6c can be used to generate the command flows of organization level while SV-10c can be used to generate the control flows of system level.

However, the SoS simulation includes not only logical simulation but also the calculation of physical models with existence of contingency. As a result of that, the task process happened in SoS simulation experiment will be hard to be exactly the same with the design in sequence diagrams. The granularities of simulation scenario and SoS architecture are not always the same. Sometimes, the descriptions of the activities of specific systems in SV-10c are not required for simulation scenario. As the scenario maker, a commander does not have to control the activities of each system. To bridge the cap between these models, generating the scenario by standardized description based on the definition of Military Scenario Definition Language (MSDL) or Coalition Battle Management Language(C-BML)[8] may be a feasible method.

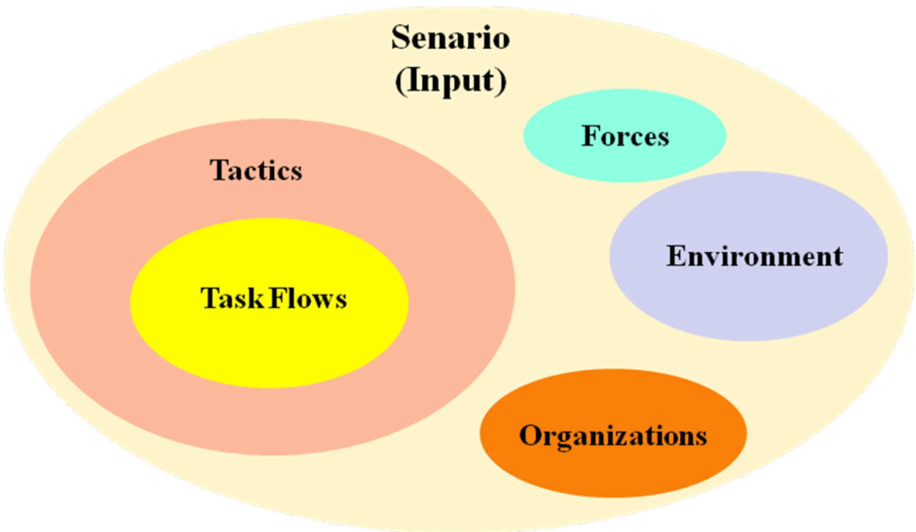


Figure 4 –Elements of typical simulation scenario.

3.2 Behavior Model Transformation

The tactics in scenario are realized by behavior models of every simulation units. In a typical SoS simulation, each unit can execute the action basing on the confronted condition and pre-set rules. The behavior models can be expressed by state machine which can be mapped from state diagrams of SoS architecture. Just as the state diagrams and sequence diagram in the SoS architecture need to be consistent, the behavior models have to realize the task flows designed in scenario. In SoS simulation systems, a typical behavior model consists of states and conversion rules. Meanwhile, Operational/ System State Transitions (OV-6b/ SV-10b in DoDAF) view model focuses on some selected resource whose properties may change in interesting ways within a described architecture. Nowadays, the architecture state machine models can already drive the simulation entities directly [6] through DDS(Data Distribution Service) flexible bus [11][12](Fig. 5).

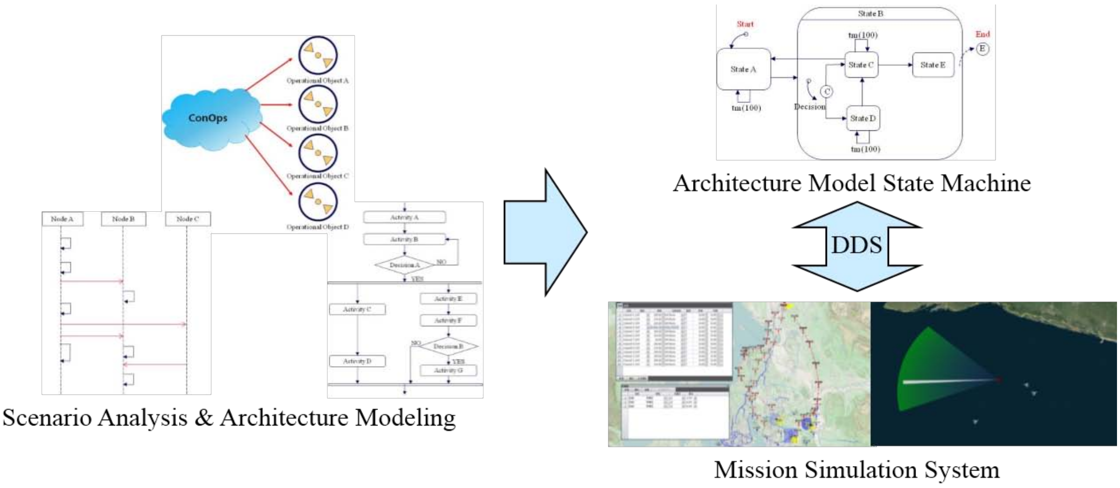


Figure 5 –State machine model transforming through DDS.

In this article, to take advantage of the logically proven architecture models, basing on the interface definition, the format conversion method is used for transforming the state machine models from SoS architecture such as OV-6b and SV-10b to the state machine models of corresponding organizations/ systems in the SoS simulation system instead of once more behavior modeling (Fig. 6). Furthermore, the developing meta-model definition basing on the aircraft operational ontology [13-16] will realize the smooth transformation.

Without physical properties, the organizational units attach to the other physical entities in the simulation system used in the sample case. However, these organizational units have behaviors as same as the physical systems. Similar to the scenario models transformation, OV-6b will be used for generating the command behavior of organization level while SV-10b will be used for generating the control behavior of system level. The state machines of organization level drive the state machines of system level which drive the physical models of specific systems (Fig. 3).

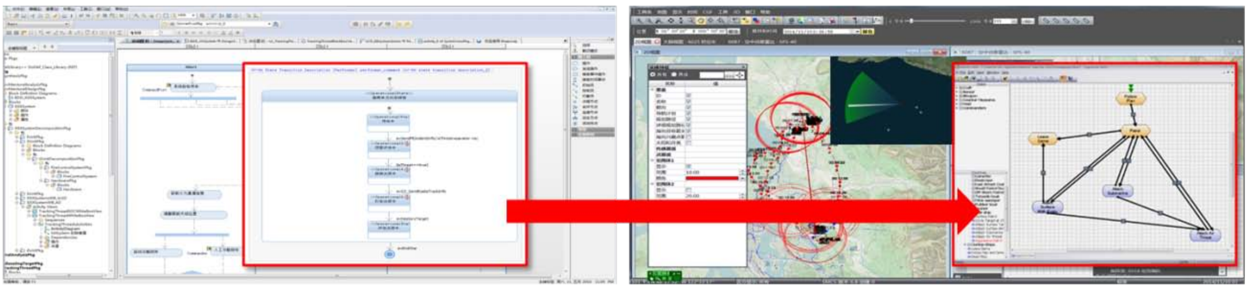


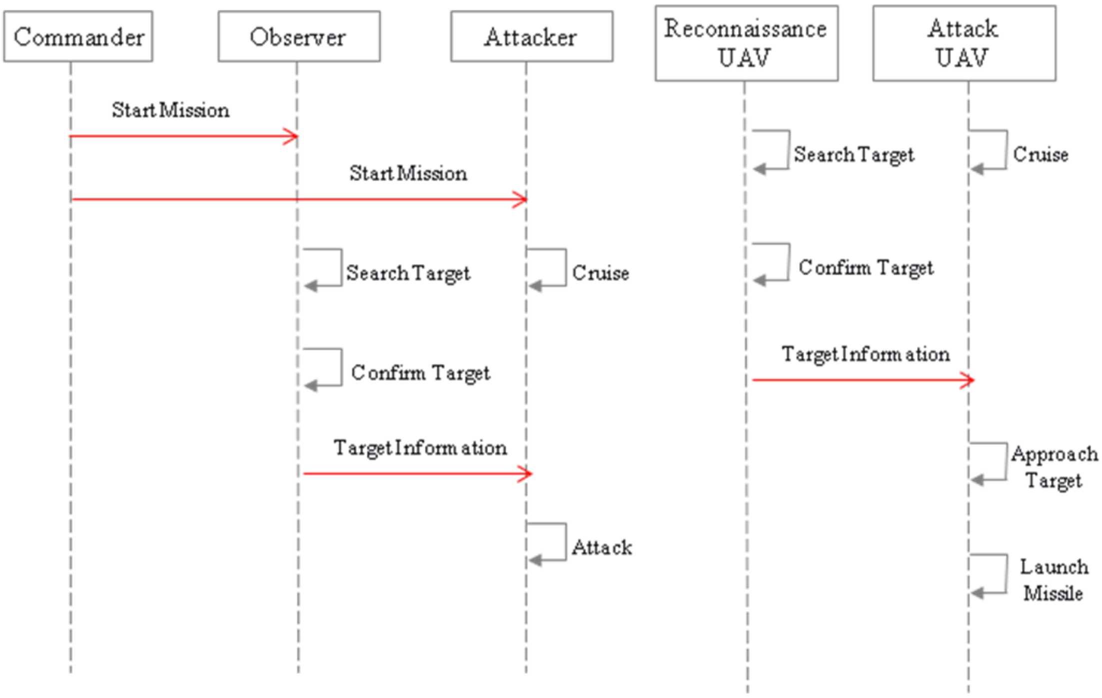
Figure 6 –Behavior model transforming as state machine.

4. Sample Case

The sample case is provided to illustrate the model transformation for an aircraft SoS simulation through the consistency verification of models. Shown in Figure 7, the scene includes two different unmanned aerial vehicles (UAVs). The goal of the task is to find and destroy a surface ship.

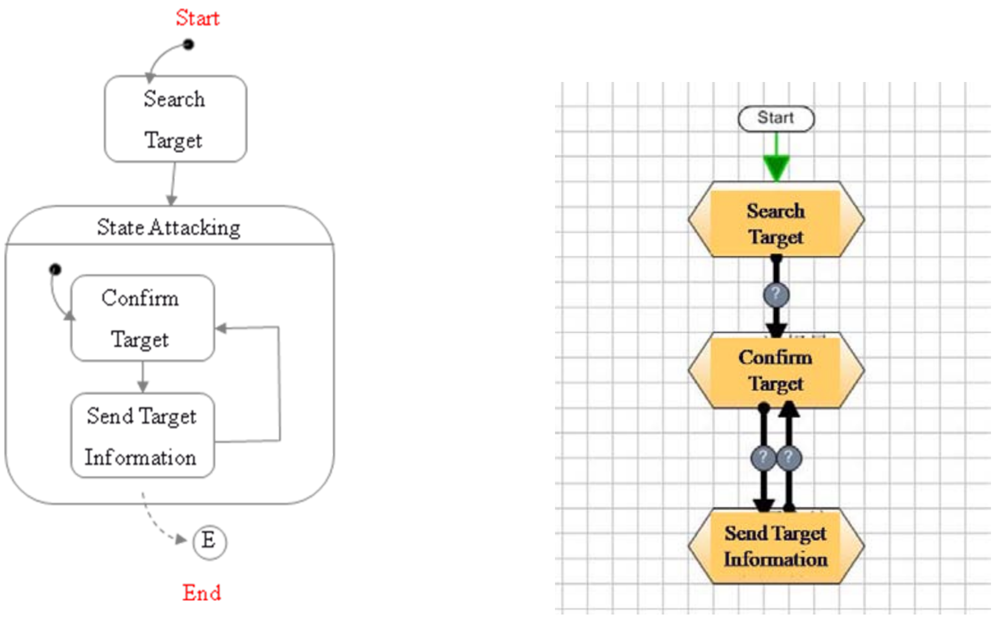
Figure 7 –Scene of sample case.

As a simple episode of the mission, the reconnaissance UAV searches the target and sends the target information to attack UAV which is responsible for attacking by missiles. Shown in Figure 8, OV-6c and SV-10c describe the event trace of organization level and system level. Shown in Figure 9 and Figure 10, the behavior models of organization level and system level are achieved to realize the corresponding task flows.



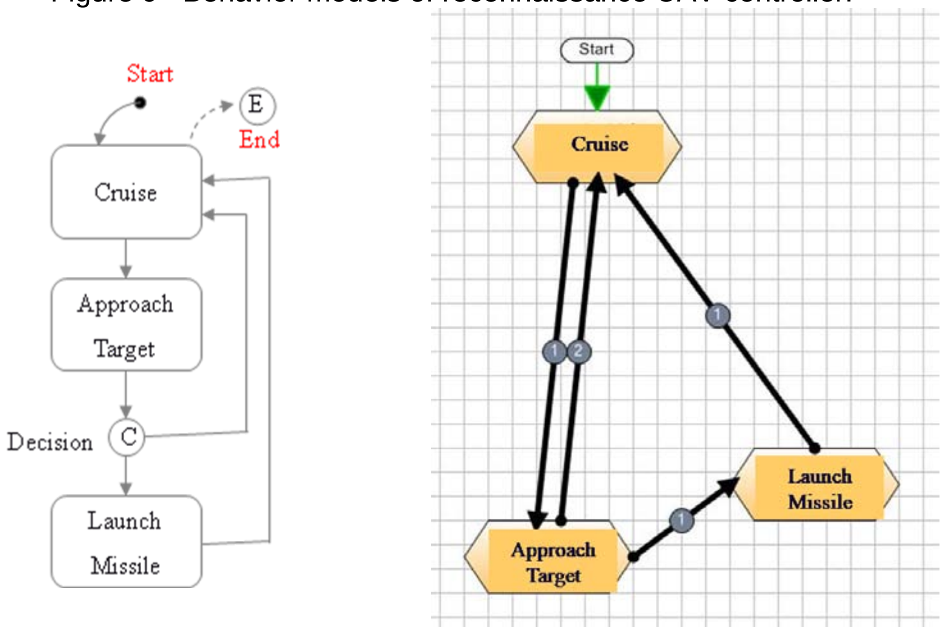
(a)OV-6c (b)SV-10c

Figure 8 –Event trace description.



(a)OV-6b of Observer (b)State machine of reconnaissance UAV controller

Figure 9 –Behavior models of reconnaissance UAV controller.



(a)SV-10b of attack UAV (b)State machine of attack UAV

Figure 10 –Behavior models of attack UAV.

Shown in Figure 11, the event record after the SoS simulation experiment keeps the same as the process design in OV-6c and SV-10c. It is worthwhile to note that the result of this sample case preliminary verifies the consistency of model transformation from SoS architecture to SoS simulation but does not verify the logic of architecture model through SoS simulation. There are already some modeling tools can support logical verification by generating state machine codes from concept models.

Text
Commander UAV-Reconnaissance Controller of type Foursome Leader sent command Target Information to subordinate UAV-Attack Controller of type Pair Leader,
Commander UAV-Attack Controller of type Pair Leader sent command Attack Surface Target to subordinate UAV-Attack of type Attack, Result: Success
Commander UAV-Reconnaissance Controller of type Foursome Leader sent command Target Information to subordinate UAV-Attack Controller of type Pair Leader,
Commander UAV-Attack Controller of type Pair Leader sent command Attack Surface Target to subordinate UAV-Attack of type Attack, Result: Success
Air Surface Missile created with ID 195
Attack UAV fired Air Surface Missile at Destroyer A, 2 unit(s)
Air Surface Missile created with ID 192

Figure 11 –Events record in SoS simulation.

5. Conclusion

The proposed SoS behavior model transformation method can satisfy the requirement of the continuous virtual verification and validation in aircraft top-level demonstration. Because the purposes and granularities of the models for SoS architecture and mission simulation are quite different, it is difficult to achieve the model transformation ideally. SoS architecture models from different viewpoints and multiple granularity simulation models can be transformed basing on the unified meta-model for spatiotemporal verification and effectiveness evaluation. Only several limited architecture models such as Operational/ System Activity Sequences view models and Operational/ System State Transitions view models are selected to transform to scenario models and behavior models in mission simulation. If the meta-model definition covering the SoS architecture and mission simulation is completed, the fast automatic/ semi-automatic model transforming will come true with artificial intelligence (AI) technology.

6. Contact Author EmailAddress

mailto: zangjing2006@163.com

7. CopyrightStatement

References

[1] MacCalman A, Lesinski G and Goerger S. Integrating external simulations within the model-based systems engineering approach using statistical metamodels. *Procedia Computer Science*, Vol. 95, pp 436-441, 2016.

[2] Acheson P, Dagli C and Kilicay-Ergin N. Model based systems engineering for system of systems using agent-based modeling. *Procedia Computer Science*, Vol.16, pp 11-19, 2013.

[3] Ruijven L C. Ontology and model-based systems engineering. *Procedia Computer Science*, Vol. 8, pp 194-200, 2012.

[4] ZangJ, WangQ, ZhuJ Q. Continuous Modeling in Aircraft Top-level Demonstration. *31st Congress of the International Council of the Aeronautical Sciences(ICAS 2018)*, 2018.

[5] LiQ, YanJ, ZhuJ Q, HuangT, and ZangJ. State of art and development trends of top-level demonstration technology for aviation weapon equipment. *ActaAeronauticaetAstronauticaSinica*, Vol. 37, No. 1, pp 1-16, 2016.

[6] Loper M L.*Modeling and simulation in the systems engineering life cycle*. Springer. 2015.

[7] Luo M Q, Liu H, and Wu Z. Prototype system research on open conceptual aircraft design. *ActaAeronauticaetAstronauticaSinica*. Vol. 29, No. 4, pp954-959, 2008.

[8] SHEN L L, WANG M. Study on Definition of Complicated Electromagnetic Environment Scenario by Combining MSDL with C-BML. *Communication Countermeasures*. Vol. 36, No. 2, pp 41–44, 2017.

[9] Guo, J., Lin, Q. The research on requirement analysis of electronic information equipment SoS based on DoDAF. *2011 International Conference on Electronic & Mechanical Engineering and Information Technology*. 2011.

[10]Wang J X, Zou J, Yang F, and Pan Q. Research on architecture modeling of the strategic early-warning system based on DoDAF. *32nd Chinese Control Conference*. pp 8681-8686, 2013.

[11]Kim D, Oh H, and Hwang S W. A DDS-based distributed simulation for anti-air missile systems. *2016 6th International Conference on Simulation and Modeling Methodologies, Technologies and Applications (SIMULTECH)*. pp 1-7, 2016.

[12]Park Y, and Min D. Distributed traffic simulation using DDS-communication based HLA for V2X. *2015 Seventh International Conference on Ubiquitous and Future Networks*. .zip,zip.zip.zip.zippp 450-455, 2015.

[13]Zomer L, Moustaid E, and Meijer S. A meta-model for including social behavior and data into smart city management simulations. *2015 Winter Simulation Conference (WSC)*. pp 1705-1716, 2015.

[14]Xu J, Ye D, and Ma Y. The design of a domain-specified visualization modeling language for warfare simulation based on meta-model. *2013 IEEE 4th International Conference on Software Engineering and Service Science*. pp 179-183, 2013.

[15]Vo D, Drogoul A, and Zucker J. An Operational Meta-Model for Handling Multiple Scales in Agent-Based Simulations. *2012 IEEE RIVF International Conference on Computing and Communication Technologies, Research, Innovation, and Vision for the Future (RIVF)*. pp 1-6, 2012.

[16]Ruijven L C. Ontology for systems engineering. *Procedia Computer Science*. Vol. 16, pp 383-392, 2013.