When Tradespace Analysis Met Combat Modeling and Simulation

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ABSTRACT

The Department of Defense (DoD)'s Science & Technology (S&T) priority for Engineered Resilient Systems (ERS) calls for adaptable designs with diverse system models that can easily be modified and re-used, the ability to iterate designs quickly and a clear linkage to mission needs. Towards this end, tradespace analysis is of great importance. The Georgia Tech Research Institute (GTRI) has been developing web-based, collaborative modeling and simulation tools that use a Model-Based Systems Engineering approach to address the analysis of alternatives for acquisition programs to assess cost, schedule and performance risk; of particular note is the United States Marines Corps (USMC) funded Framework for Assessing Cost and Technology (FACT). In parallel, the United States (U.S.) Army Research Laboratory (ARL) has been pursuing the Executable Architecture Systems Engineering (EASE) research project, which links analytical, experimental and training objectives with the technical complexity of modeling and simulation in an easy to use, scalable tool. This paper details an effort to develop a formal Application Programming Interface (API) between FACT and EASE, which creates the ability to develop system concepts and assess Measures of Performance (in FACT), and then send those system concepts to a combat simulation to assess Measures of Effectiveness (through EASE), and finally back to FACT for a high-level trade study. It further describes a proof-of-concept demonstration using a Force Protection use case that allows a user to tune parameters of detection on an unmanned platform that is then simulated in an operational scenario to collect performance data. This effort effectively lays the framework for future simulation-enabled tradespace analysis that will be a pillar of ERS and can be adapted by other simulation efforts.

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BACKGROUND

Engineered Resilient Systems

Engineered Resilient Systems (ERS) is a Department of Defense (DoD) Science and Technology (S&T) effort to provide new computational technologies and processes to address one of DoD's most pressing needs – transformation of its acquisition process. ERS is working to provide new S&T through which better-informed decisions can be made "efficiently, effectively, and rapidly" in the acquisition process (Holland, 2012). The effort seeks to empower better acquisition decisions within the DoD by providing: a rigorous, science and engineering-based process for requirements generation; a more complete analysis of alternatives; and, a better prediction and incorporation of lifecycle performance and cost. ERS aims to meet these objectives by developing new tools and techniques for the analysis of alternatives, design, development, manufacturing, and operation of defense systems, hosted within an open framework.

Spero et al. (2014) sought to assemble a "best common practice" process for the identifying and/or creating a tradespace exploration tool for ERS. They examined 81 candidate tradespace exploration tools and showed that although a specified formal tradespace process is not used for DoD programs, one could be developed to enable the ERS tradespace vision on a particular project. They emphasized, however, a shift towards common tradespace methods and tools with a primary recommendation for further work being a validation of their effort with an application use case. Therefore, this paper aims to address the application of a tradespace exploration methodology within the Model-Based Systems Engineering (MBSE) construct.

The work represented in this document supports the goals of ERS through an investigation of using tradespace tools developed at the Georgia Tech Research Institute (GTRI) in tandem with Army Research Laboratories (ARL) simulation technologies in order to characterize the impact of design changes on the mission. This required modifying both tools as needed to support the research objectives. The intent is for these combined tools to eventually serve as a proving ground for an apples-to-apples comparison of trades during concept development, analysis of alternatives and materiel solutions analysis.

Framework for Assessing Cost and Technology

In support of the United States Marine Corps Systems Command (MARCORSYSCOM), GTRI developed the Framework for Assessment of Cost and Technology (FACT), which is a Modeling and Simulation (M&S) tradespace tool that executes MBSE to address the analysis of alternatives for the acquisition programs capable of assessing cost, schedule and performance risk. FACT was developed with the recognition of dependency relationships between technology, resources and time, leveraging M&S to determine how changes in any of these independent variables will impact the other variables. FACT establishes the required workflow/dataflow dependencies from a standards-based architectural framework to gain a better understanding of the design trade space. (O'Neal et al., 2011) (Ender et al., 2012) (Browne et al., 2013)

Executable Architecting Systems Engineering

ARL Human Research and Engineering Directorate's Simulation and Training Technology Center (HRED STTC) has been pursuing linking analytical, experimental and training objectives with the technical complexity of M&S in an easy to use, scalable tool through the Executable Architecture Systems Engineering (EASE) research project (Gaughan et al. 2013). The goal of EASE is to lower the barrier of entry to the use of M&S by providing a single interface for systems engineers, software developers, information technology professionals and analysts to work together to define the simulation systems engineering data and execute the appropriate applications in order to support the M&S user's goals. EASE provides an interface to M&S users to select the capabilities they require and the scenario necessary to stimulate the appropriate warfare circumstances. The selection criteria filters and displays the most appropriate executions for the user to choose from. The user can then adjust configuration elements that have been exposed by the developers, select the number of runs they need to execute, schedule runs and hit the "Go" button to execute. The web-based interface provides a mechanism to launch potentially complex M&S in the cloud or on specific computing hardware. The systems engineers, developers and integrators can centrally manage all aspects of EASE and how to execute the proper M&S systems to achieve the M&S users' requirements. Having a data-driven and easy to use interface keeps information current. In turn, each user can be assured that they're referencing and updating the latest information.

INTEGRATION PHILOSOPHY

The interface between the GTRI tradespace analysis tools (primarily FACT) and EASE has been formalized. FACT provides a User Interface (UI) for analysts to quickly and accurately assess and compare alternatives to execute materiel solutions analysis. EASE allows for the orchestration of simulation execution based on systems engineering details of system interoperability. Combining these two projects allows for execution of simulations in support of tradespace analysis in addition to the existing model. This section represents the results of the definition of an Application Programming Interface (API) developed by ARL and GTRI.

This interface was designed and implemented with the long-term vision of ERS as the primary motivation. It was additionally designed for application across the spectrum of warfare, simulation software and possible results. Integrating FACT and EASE allows for the use of simulation in numerous aspects of tradespace analysis. Typically execution of a simulation is complex, which introduces errors, long timelines and executions difficult to reproduce given an element of noise (or randomness) in environmental or scenario attributes. The EASE project provides a management mechanism for simulation environments including both standalone simulation applications as well as complex distributed simulation environments. The knowledge of developers, integrators and systems engineers is captured to provide automated management and execution of simulations. The goal is to have EASE abstract the complexity of simulation and provide data/information for use in the tradespace process, specifically to provide the operational context of a tradespace decision. By integrating a diverse set of simulation capabilities into EASE, such as One Semi-Automated Forces (OneSAF, 2014) and the Infantry Warrior Simulation (IWARS) (Technology Solution Experts, 2013), materiel under exploration in FACT can be represented through the systems engineering understanding of how these tools work.

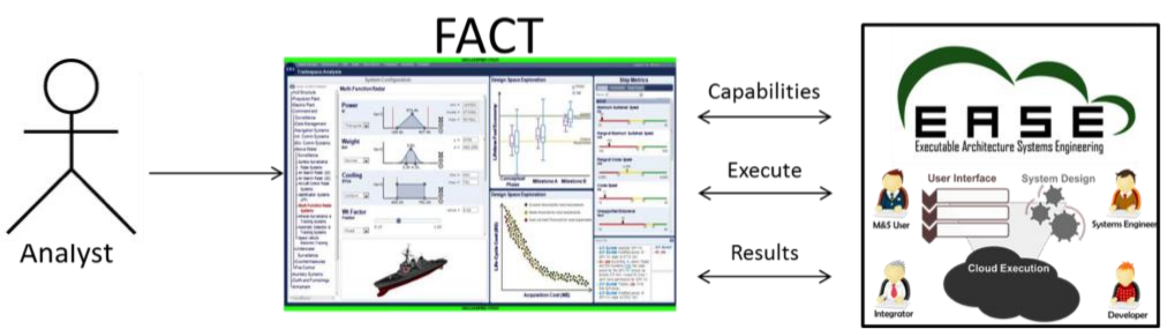

Figure 1. Concept of Operations

By capturing what simulations are capable of modeling along with the interfaces to modify model representations within them, the interchange of capabilities and results between the tradespace and operational worlds is possible. This capture goes down to the application level and occurs by working with developers, integrators and systems engineers through a robust systems engineering process.

Figure 1 shows the initial Concept of Operations for usage by an analyst. To help baseline the development process, a representative use case was selected and employed as the basis for system requirements that ultimately lead to low level requirements, API development and software modification. Focusing on tradespace analysis, the FACT user interface acts as the analyst interface. Users are able to modify a number of attributes of the warfare element under scrutiny. These attributes affect the performance of the warfare element and are displayed to users for their analysis and optimization of the element under study. FACT uses internal and external models to provide feedback to the user. For example, when users modify attributes of a sensor subsystem on an Unmanned Aerial Vehicle (UAV), they see the models affect that UAV's Probability of Detection.

When an attribute of the warfare element aligns with a capability available within the EASE simulation environment, users have the option to execute an EASE simulation and obtain results to see performance within the proper mission context. An example would be having the analyst optimize a platform within the FACT interface to discover the attributes the analyst believes to be most important and then EASE executing simulations to study the platform within multiple mission contexts. This presumes that the user has appropriate access (e.g. authentication via Common Access Card). For example, in determining the best platform to procure for the future force, analysts could design their perfect platform and then simulate that platform across multiple missions within multiple world locations and environments (e.g. deserts, forests, cold, hot, rain, dust, etc.).

IMPLEMENTATION DETAILS

Tradespace to Combat Simulation Automation/Execution

In order to achieve the integration between the tradespace analysis tool and simulation environment, FACT queries EASE for available simulation executions per a desired criteria via a Representational State Transfer (REST) interface (Fielding, 2000). Within the response is a list of available executions that include a list of capabilities for each execution. Capabilities are defined by parameters (inputs) and artifacts (outputs) available along with additional metadata. User types or individual identification are not a factor for the current implementation of the API. EASE assumes all users have access to the information that FACT queries.

In order to achieve integration, the addition of server-to-server communication was added to FACT. Previously, models executed by FACT were local to the FACT server. In this case, rather than handling everything internally, the FACT server implementation was enhanced to allow for data exchange with other servers via REST API's. Furthermore, the integration was implemented to be extensible to other simulation execution environments, and conversely, other tradespace analysis tools, should the ERS community determine that additional or alternate capabilities are required (Figure 2).

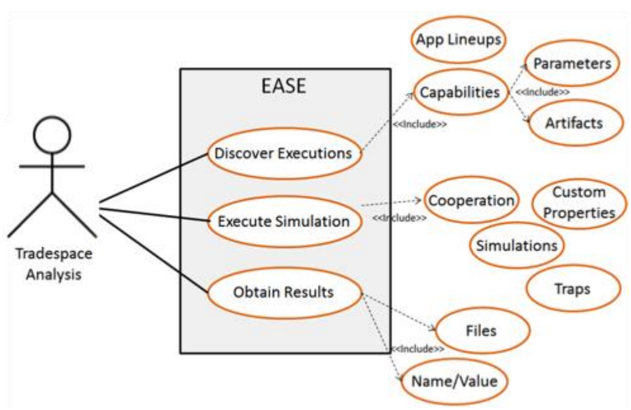

Figure 2. Use Case

Sequence Diagrams

The sequence diagrams in Figure 3 and Figure 4 represent the interaction between FACT and EASE. The JavaScript Object Notation (JSON) (ECMA, 2013) formatted data for/from the HyperText Transfer Protocol (HTTP) requests and responses from the EASE REST interface are in the API discussion later in this document. All data exchanged between FACT and EASE is JSON formatted. FACT queries for available executions, which include the capabilities that are represented within EASE. Each capability has parameters that are available for adjustment and artifacts that will be returned.

FACT shows capabilities to the analyst for selection based on the available parameters/artifacts. Choosing which execution to run is selected by the user based on the description and/or artifacts available for the execution. Since simulation lineups may represent many capabilities for each configuration, EASE provides a list of available executions including which capabilities are represented within each execution. The description is used to provide an explanation for each available execution and their lineups and scenarios. This description can help the analyst determine which execution is most appropriate for their analysis purposes.

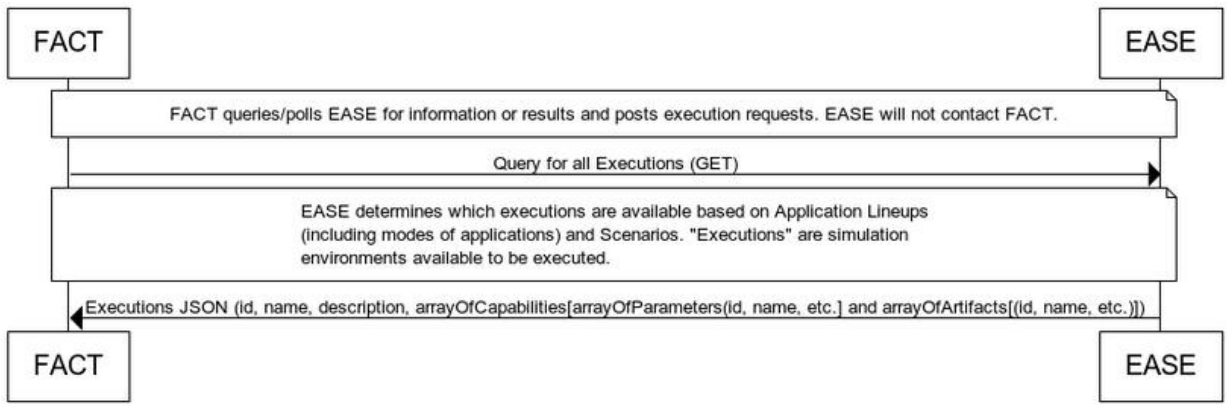

Figure 3. Query Executions Sequence Diagram

For each execution (or set of executions if the execute command denotes multiple runs), EASE returns a confirmation stating the task Identification (ID) (or set of task IDs if running multiple executions) for future reference when polling for results, when the execution(s) is(are) scheduled to be run based on scheduling of computing assets and expected time(s) of completion (including data collection script execution and data transfer time). Executions all have the same priority for this initial integration effort. FACT can wait until the expected completion time to query for results, but will receive a status of “RUNNING” (i.e. not yet completed) if queried before completion. In some cases, the expected completion time(s) may not be accurate (if the task gets postponed due to prioritization) so FACT accounts for the results not being available at that time and queries for results periodically until they become available. The results include a status value to report whether the task is *NEW*, *RUNNING*, *FAILED*, *KILLED*, or *COMPLETE*.

The results also include artifacts, which can be a variety of outputs from each simulation that were collected and available for FACT. The artifact identifiers are unique across all artifacts (across all capabilities). Querying for each artifact can also be done separately. The artifacts include name/value pairs or a Uniform Resource Locator (URL) for a file to download for the analysis user to be able to do more involved analysis using a database or log file.

FORCE PROTECTION USE CASE/PROOF OF CONCEPT

Representative Use Case

A representative use case was pursued, specifically securing endorsement of key stakeholders, integrating key M&S and providing useful analytical results. Towards this end, we identified the Training and Doctrine Command (TRADOC) Maneuver Support Center of Excellence (MSCoE), who is currently conducting Force Protection studies. These studies include modeling various sensor technologies to determine Concept of Operations (CONOPS) and Tactics, Techniques and Procedures (TTPs). A challenge for MSCoE is the constantly evolving sensor technologies as well as receiving sensor technologies that do not provide the right level of capability. The EASE-FACT prototype was demonstrated in this context by providing the ability to quickly modify sensor technologies while understanding the technology tradeoffs through the FACT interface. EASE then simulated these new sensor technologies in an operational environment using MSCoE designed scenarios. This use case provided an opportunity to demonstrate how tradespace analysis can support the combat developer, who in turn supports the materiel developer, while leveraging the investments of the S&T community, which developed many of the models and simulations required for this analysis.

Figure 5 shows a high level vision using a UAV for a route-clearing mission. In the scenario, the UAV flies ahead of a convoy, searching for potential threats and reports any back to the convoy. The scenario was designed by MSCoE and described as follows in the Puma Sensor (RoadRunner) Study Report (U.S. Army Maneuver Support Center, 2013):

> *Route Clearance is a critical mission for ground units in the current theater of operation. Route Clearance Patrols have recently bolstered their ability for mission success with the use of the Puma UAV. This asset supports the advanced location of hostile threats and or Improvised Explosive Device emplacements, and provides over watch for the unit in hazard areas or points of limited or no forward movement. The current Puma UAV sensor payload, Electro Optical, Infra – Red gimbaled system, is not well suited for the detection of emplaced explosive threats. The Road Runner sensor payload will enhance the ability for the Puma UAV to detect explosives hazards by incorporating a number of improvements such as forward motion compensation that improves image resolution, multi-spectral target discrimination, and near real-time change detection processing.*

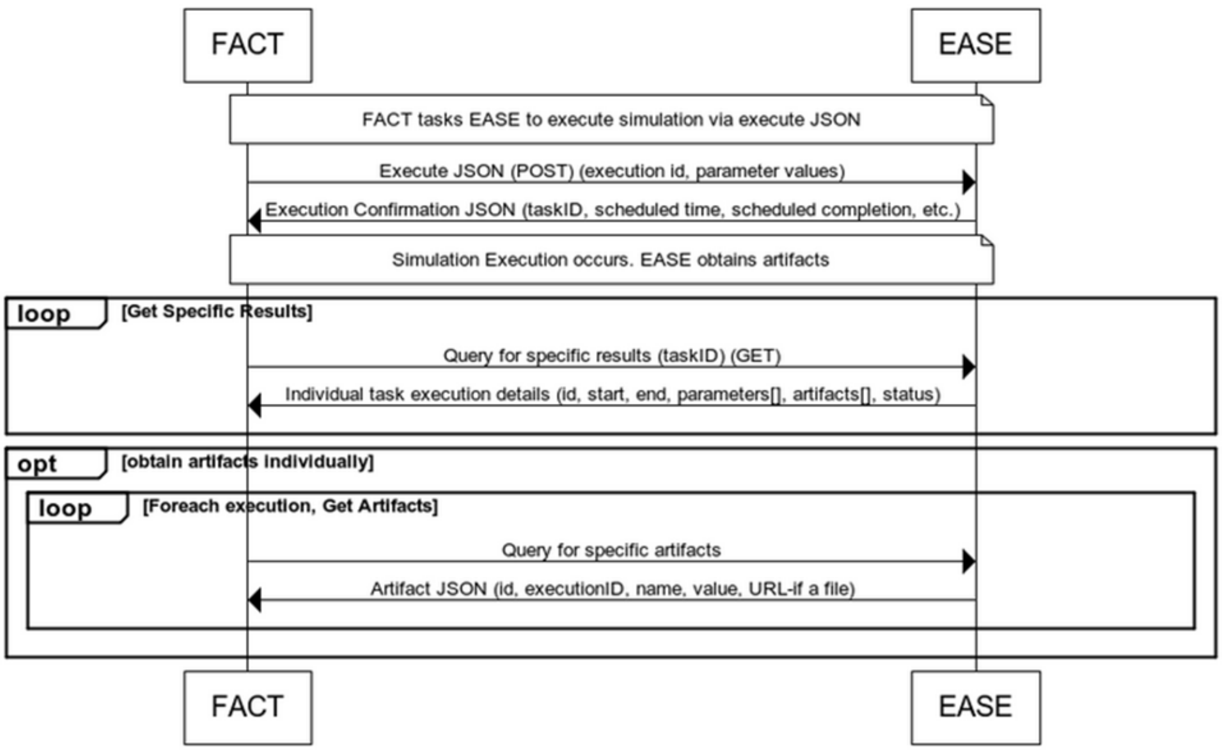

Figure 4. Execution Sequence Diagram

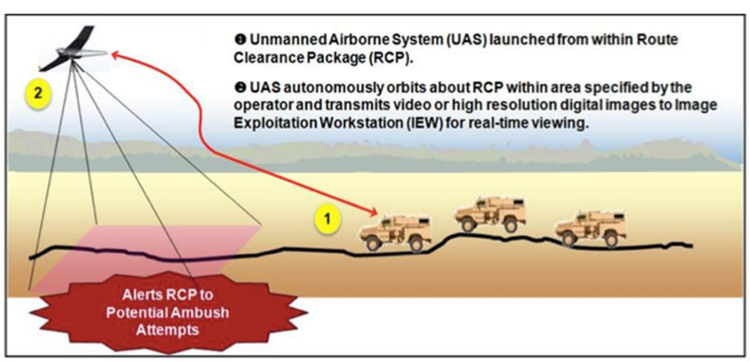

Figure 5. Representative Scenario: UAV Route Clearance (U.S. Army Maneuver Support Center, 2013)

Software and Simulation Development

Based on the FACT-EASE ERS concept, a prototype decision support tool implementation specific to the RoadRunner was developed. The interface developed was the basis for the integration required to demonstrate the use case; however, due to an aggressive schedule, some elements of the integration are more model or simulation specific than a full implementation in the future will allow. The team ensured the prototype produced notional data to demonstrate how this decision support tool benefited the stakeholder.

The simulation environment consisted of a single UAV flying a predetermined path taking images along the route while traversing McKenna terrain. A series of anomalies were included along the path for the UAV's onboard sensor to detect. The images taken by the UAV would be marked as "detections" if the UAV's onboard sensor perceived something in the image to be an anomaly. For each anomaly type, a Probability of Detection (PD) could be assigned in the simulation. For this phase, only a single anomaly type (and thus only one PD value) was used.

The general usage of the combined system for this phase is for a user to modify parameters of the UAV (e.g. altitude), sensor (e.g. aspect ratio and focal length) and targets (e.g. dimension) in FACT. These values were fed to the basic physics-based model for calculating PD (resident locally in FACT) to be passed to EASE as a parameter of the "Detect Mines" capability in the available execution. A basic physics model for calculating PD was added to FACT. This was not intended to be an accurate PD generation model but rather implemented to show the ability to have the outputs of local FACT models feed forward as the input to simulations orchestrated by EASE. With the FACT generated PD value, the user tasked EASE with starting an execution of the simulation.

The simulation is orchestrated by EASE, and the UAV simulation seeded with this PD is executed in operational models to determine the effect that PD has on the mission, measured in the number of detections produced by the UAV. A higher PD should yield more detections while a lower PD should yield fewer. Once completed, the user is presented with the results from EASE, including the number of detected anomalies and a set of snapshots from the image generator with their anomalies. Both of these results are provided in artifacts keyed to a particular task execution.

When queried for all executions available in EASE, a set of capabilities containing parameters was returned. FACT provides a drag and drop user interface for associating element attributes with one of the available parameters. This creates a link in code to carry the values of the FACT attributes and include them in the JSON data for executing the HTTP request. As a result, these attribute values are used as the parameter values in the task's execution.

When the results of a task's execution contains an artifact consisting of a zip file containing images, the FACT user interface retrieves the zip file and unzips it to a location on the FACT server where the web server can process the images. The FACT front end then retrieves them and displays them to the user in a light box user interface element.

Figure 6 shows one of the UI additions to support all of the steps to be performed in demonstration of the integration. A link to the new Simulation Center was added to the FACT home page. Currently it is geared toward EASE only; however, other simulation engines and orchestrators will be included as appropriate. The simulation center contains tabs for listing all previously initiated tasks (e.g. *NEW*, *RUNNING*, *FAILED*, *KILLED*, or *COMPLETE*), editing configured EASE task requests, and configuration of new EASE task requests (i.e. wiring of FACT attributes to EASE parameters).

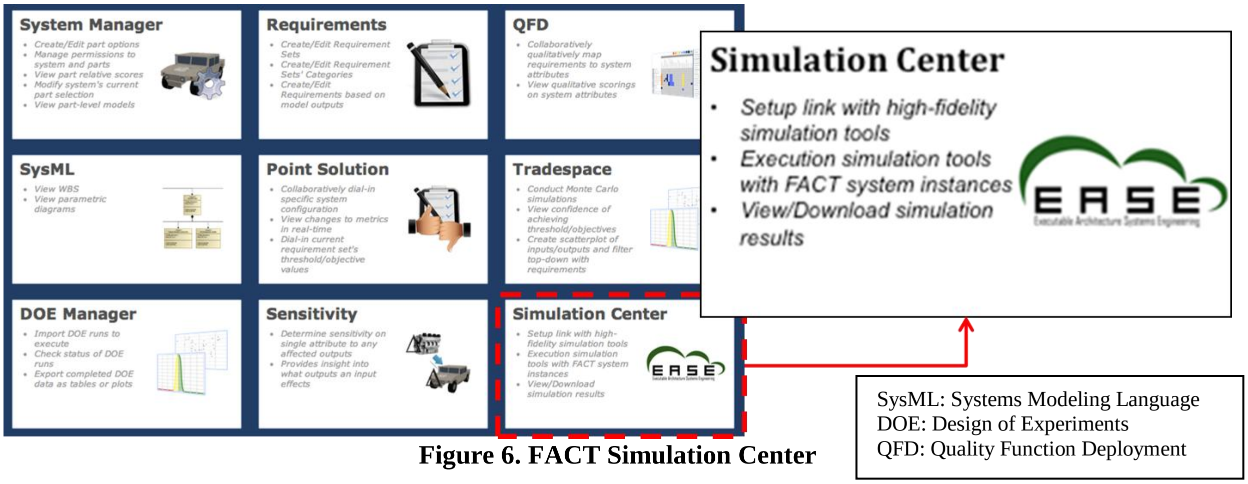

Figure 6. FACT Simulation Center

Figure 7 shows a new system class, UAV, in the FACT point solution page. On this page, users can tweak the values of the attributes of the elements of the UAV Work Breakdown Structure (WBS), which will affect the calculated PD value to be provided to EASE. The WBS provides the physical decomposition of the system of interest, to include environmental properties, down to measurable attributes of the lowest level components. Under the UAV WBS, only one component is shown, Sensor, which has attributes of aspect ratio, display height, focus number, frame rate, horizontal resolution, and pixel size. These attributes are related through parametric relationships to calculate PD. Additionally, a 3-Dimensional (3D) model of a UAV with a selectable sensor component was also added.

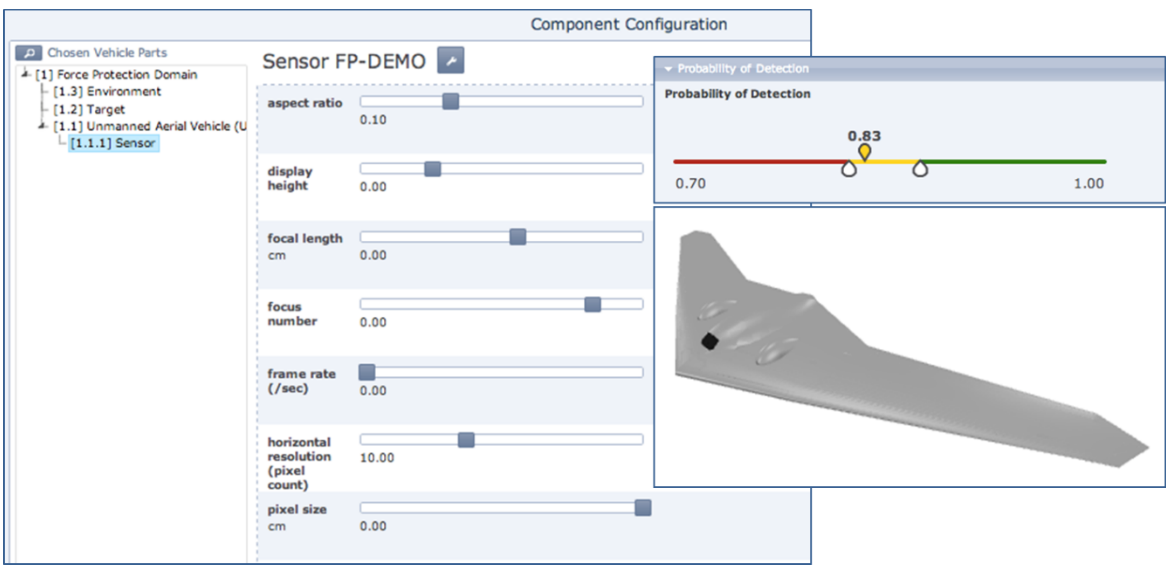

Figure 7. New System Class in FACT

Figure 8 shows the Simulation Center tab for configuration of a new EASE task request. The tree on the left shows the WBS for the currently loaded system. The attributes of the selected element of the WBS are contained in the center section. The right shows the parameters and artifacts that are available through EASE for the selected execution. Once a user has identified an EASE parameter or artifact that should be associated with a FACT attribute, the user would drag the attribute to the parameter or artifact, which will make the necessary data association to carry the values through.

RESULTS

The simulation environment provided computational and visual components. Figure 9 shows one of several simulation applications executing, specifically the Universal Controller software from Night Vision and Electronic

Sensors Directorate (NVESD) in the U.S. Army's Communications-Electronics Research, Development and Engineering Center (CERDEC). The map on the left shows the UAV (blue icon) flying a route over a road. The UAV has a sensor attached to it and there is an image generator creating the view at the top left. The yellow icons on the map are locations of anomalies found between historical data and the current image generated. The images from the sensor are stored as data artifacts from the simulation. EASE monitors those data artifacts and determines the number of anomalies as well as retrieving the snapshots taken by the sensor and providing both a zip file of snapshots as well as a number of detections back through the EASE API.

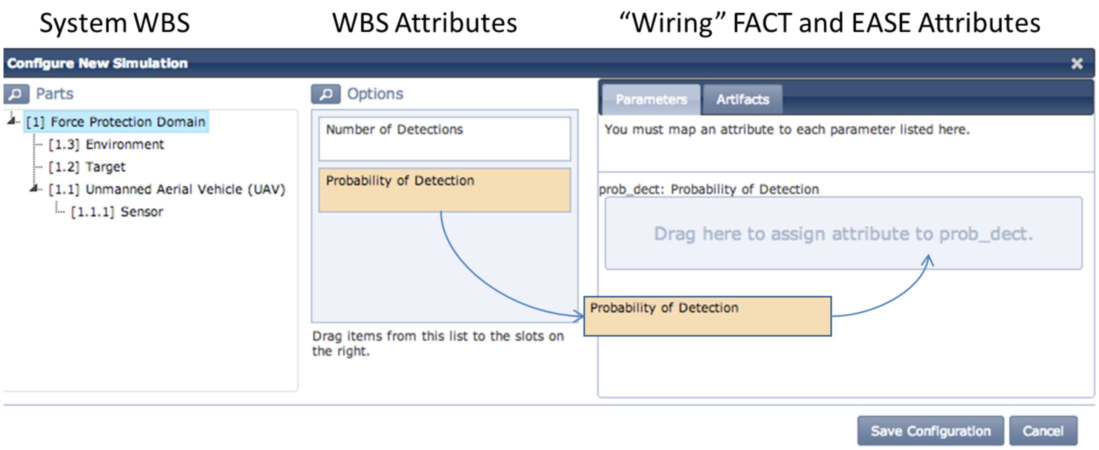

Figure 8. Executing EASE through FACT

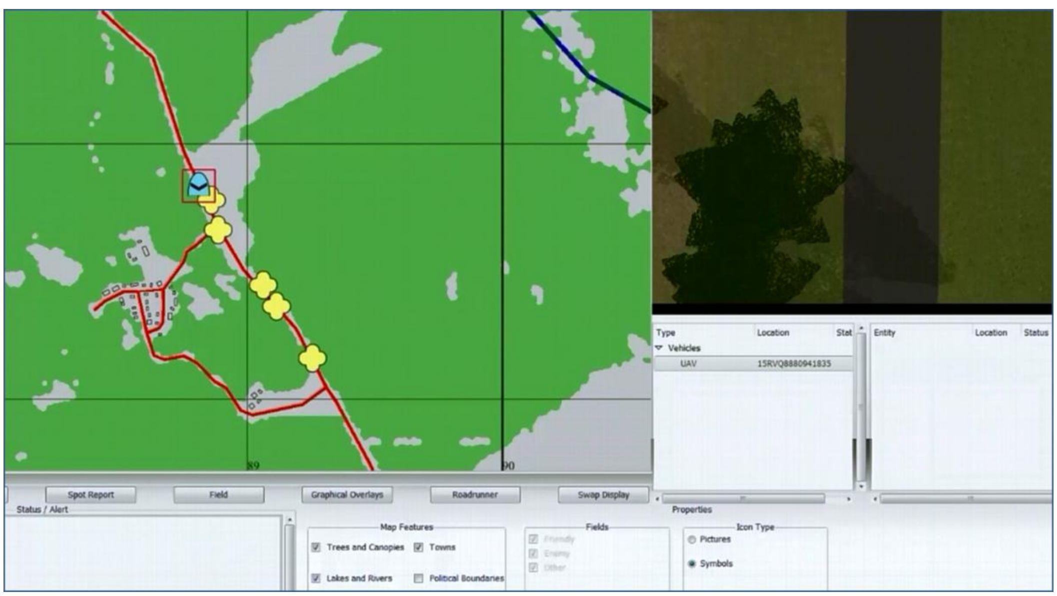

Figure 9. Universal Controller Execution through EASE

Figure 10 shows a bivariate scatter plot generated by FACT for a 200 simulation execution tradespace. This graphic specifically shows a general correlation between Target Dimension and Probability of Detection (of the target by the UAV sensor): the larger the target, the more likely it will be detected. Note the Pareto Frontier identified, which shows the minimum Target Dimension possible for a given Probability of Detection. Identification of the Pareto Frontier is critical in tradespace analysis; in this case, we do not want to "over size" the sensor, given that it is on an aerial platform. We therefore want the smallest possible sensor that can detect the smallest possible target, for the largest possible PD – a tradeoff. Figure 11 extends this concept by overlaying a heat map of PD over two target attributes: Dimension and Range (from sensor to target). The lower the PD, the "warmer" the colors (e.g. red, orange); note that these points correspond to targets that are smaller in Dimension, and father in Distance (to the sensor). The higher the PD, the "cooler" the colors (e.g. yellow, green); note that these points correspond to targets larger in Dimension and closer in Range to the sensor.

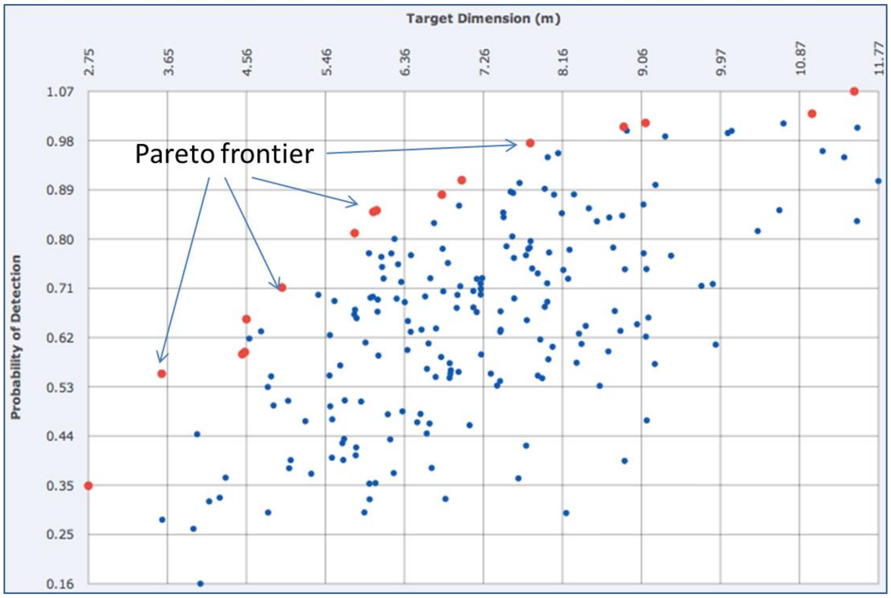

Figure 10. Tradespace Exploration showing Pareto Frontier

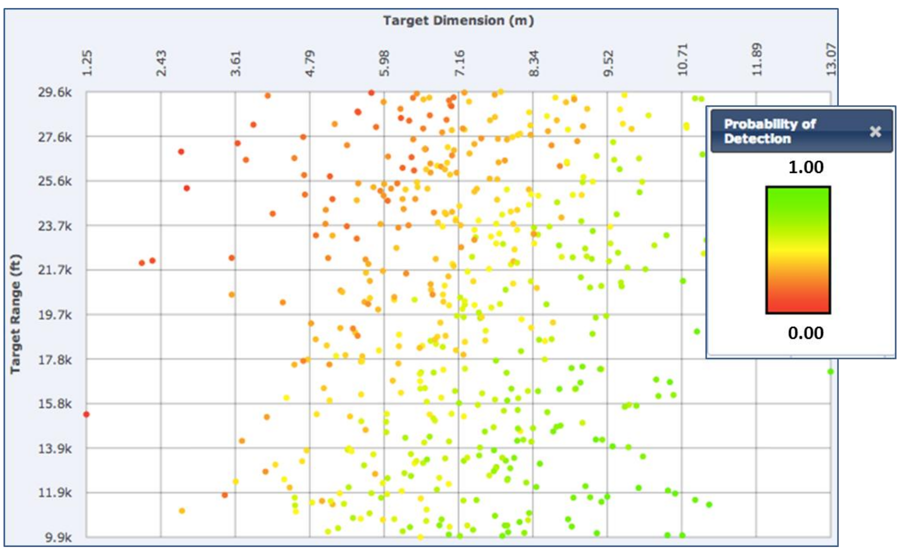

Figure 11. Tradespace Exploration showing Probability of Detection Heat Map Against Threat Attributes

SUMMARY

The development of a formal API between FACT and EASE addresses an ERS goal in the DoD S&T effort to provide new computational technologies and processes to address one of DoD's most pressing needs – transformation of its acquisition process. The automated connection of modeling, tradespace and simulation tools provides a digital thread between system design specifications and measures of effectiveness from a mission context perspective. The API creates the ability to develop system concepts and assess Measures of Performance (in FACT), sends those system concepts to a combat simulation to assess Measures of Effectiveness (through EASE), and back to FACT for a high-level trade study. Employing this API, the team was able to conduct a proof-of-concept demonstration using a Force Protection use case that allowed a user to tune parameters of detection on an unmanned platform simulated in an operational scenario to collect performance data to further populate the tradespace with Measures of Effectiveness. This effort effectively lays the framework for future simulation-enabled tradespace analysis that will be a pillar of ERS and can be adapted by other simulation efforts. For example, a technology of interest for deployment with a Marine Air Ground Task Force (MAGTF) could be simulated using the MAGTF Tactical Warfare Simulator (MTWS), similar to the simulation asset provided using OneSAF in this current study.

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