Modeling-Simulation-Analysis-Looping: 21st Century Game Changer

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Abstract. What if you could present to your boss and customers the expected performance characteristics of a new system in its target mission environment during concept development and before the first requirement or line of software is written? This paper follows up our IS 2014 paper, Uncertainty Quantification (UQ) in Complex System of Systems (SoS) Modeling and Simulation (M&S) Environments, and presents a new technique for system modeling and simulation that enhances insight and decision making based on quantified performance data. We describe how graph computing technology, readily available open source toolboxes and different systems thinking can "change the game" for systems engineers in the 21st Century.

Introduction

In our 2014 IS paper, we introduced a technique for quantifying uncertainty bounds about a predictive simulation conducted on a defense related Scientific Technology Transfer (STTR) project. Fast forward two years and we present the refined approach using a Power & Energy Use Case exploring the performance of a 'smart grid' of distributed renewable power generation to include weather variations. This is a network of networks problem similar to defense Command and Control challenges found in System of Systems. INCOSE and the systems engineering domain provide a solid foundation from which to leverage modern Information Technology (IT) to gain new levels of engineering insight. We have observed that current, and indeed, future complex System of Systems challenges require a perspective that must break new horizons. As INCOSE expands our defense heritage into new domains, we must also carefully consider what got us here, what we can use from that foundation built on the shoulders of giants, and what can be accomplished with that foundation. Reuse of tools, techniques and mathematics from the SE toolbox used in new ways are powerful. Future challenges require new tools and techniques and a heavy dose of systems thinking, responsibility, and accountability for engineering to be successful and lead change into the new century.

Our research in exploiting uncertainty quantification (Marvin & Garrett , 2014) in systems thinking is at the intersection of requirements, model based systems engineering, data analytics, and information technology. Project timelines and resources drive us to achieve early, rapid and quantified results. Future systems and SoS are all about Big Data analytics and novel use of software-based tooling. Engineers know from experience that the end game of system development is typically a continuous grind that finds all the deployment problems are in the interfaces, and most of those problem interfaces are in software, communications and IT networks. As you will discover, we ascribe to the notion that "requirements are an illusion." We have thought through this dilemma and boldly embarked in new directions that we will describe.

Future SoS are all about network interfaces (i.e., sensor nets, communication nets, decision nets) and Big Data and are bounded by uncertainty in our knowledge about combined effects of nonlinear, stochastic processes that must be harmonized to achieve desired outcomes. There is a need for new thinking about how systems engineers deal with this complexity. Add to this, a global competitive market driven by the need for speed, and imperatives for data driven decisions, the systems engineering "Vee" begins to break down. By exploiting the historical works in systems science, including rigorous mathematics, embracing modern software engineering tools and techniques, and through clever systems thinking, solutions to complex problems can be found. Our journey is but one example of what future developments may hold. We envision a future with a full toolbox of tools and techniques that allow rapid applications and adjustments for the right tool at the right time in the development lifecycle. The lifecycle is iterative and concurrent starting with software and Information Technology (IT) conceptualization and design. We, as technology leaders, need to be willing to reach into the toolbox and grab new tools, try them out, determine their applicability and reach for another tool as necessary.

We present our Power & Energy Prototype Use Case in this paper as an example of how we as systems engineers can realize INCOSE strategic objectives as follows:

1. Systems Engineers in the boardroom – systems engineering influence in the executive suite to facilitate informed, prompt, data driven decisions having a direct impact to the enterprise bottom line

2. Movement away from our defense heritage where the community is more focused now on buying commodities and into adjacent domains where Research & Development (R&D) is needed to drive disruptive innovation – Industry Outreach

3. New tools and techniques manifest in methodology and life cycle process improvement – recognize the future is about integrating software (much of it now open source) with

an IT infrastructure, e.g., the Internet of Things, and not the hardware that is now a commodity

Ours is but one Use Case, but we share it as a step toward successfully meeting the INCOSE Vision 2025. Meeting the grand challenges and even bigger opportunities of the 21st century will take innovations in tools, techniques and processes far beyond this one example. The only way to realize this future state is to write it.

Modeling-Simulation-Analysis-Looping (MSAL) - A New Technique

MSAL is an iterative methodology using graph-based models to define a mission environment, a mission model and mission threads. This approach provides a means to address network complexity and system/SoS control, particularly impacted by uncertainty in multi-dimensional performance space. Figure 1 below shows the MSAL concept, an iterative approach of an intimately connected 'real world' of systems and SoS and an associated 'runtime environment' of design and testing via modeling, simulation and analytics. There are a combination of new techniques and tools that enable an ecosystem applicable to any domain and extensible in multiple dimensions.

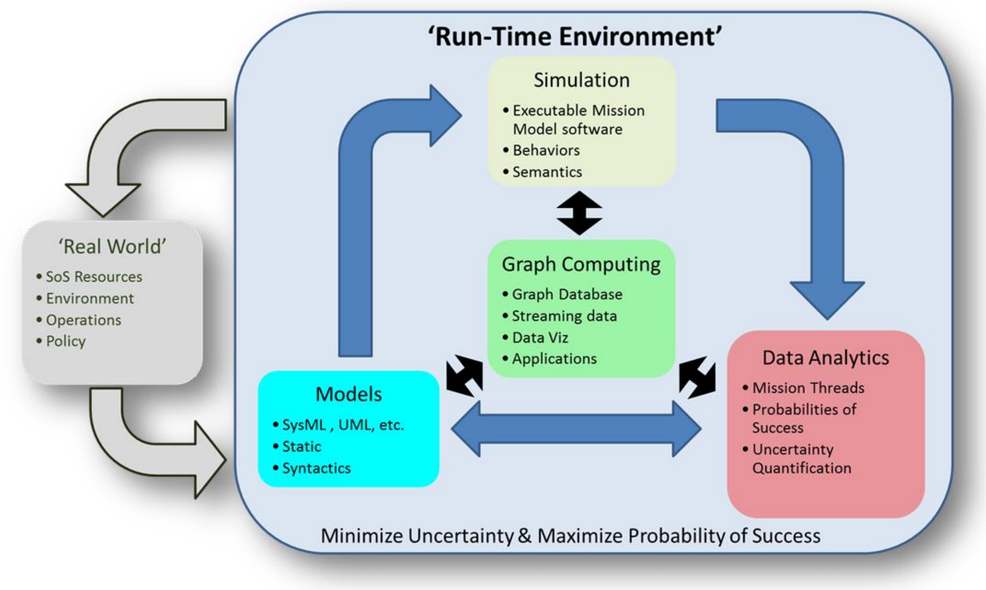

Figure 1. Model-Simulation-Analysis-Looping (MSAL)

The foundation of MSAL is on a graph database (Robinson, Ian; Webber, Jim; Eifrem, Emil; Neo Technology, Inc., 2013) and graph computing environment provided by IBM System G (IBM, 2014). The graph foundation allows us to incorporate models and explicitly associated agent based simulations and data analytic operations at nodes. Edges transport, reformat, parse data between nodes, but they don't change the state of the data. The resulting "mission model" built on a graph database retains exact spatial relationships for "simulation" where dynamic behaviors are incorporated and the resultant tools compiled and executed. Analysis is done on the resulting simulation data with a variety of open source and COTS tools. This innovative mission model approach uses Sandia National Labs Dakota tool for parametric, multi-parameter, single or multi-objective optimization and UQ analysis (Bauman, et al., 2009 (updated April 2013)). The prototype of the above approach on a Power and Energy use case simulates a smart grid with a distributed control structure with significant and distributed photovoltaic penetration. The results simulate performance at the network feeders under unknown conditions (weather that influences photovoltaic output with various battery storage configurations and smart controllers).

Simulation is heavily exploited in MSAL and is used iteratively to investigate the performance space. Specifically, the MSAL technique uses parametric studies to determine parameter sensitivity, optimization to understand multi-dimensional parameter interaction associated with meeting a mission goal and forward propagation of uncertainty to bound the 'goodness' of the optimized performance surface. Typically, there are many iterations between the three techniques where "good enough" is reached when an acceptable level of uncertainty is achieved. As a simulator of the electric distribution system (prior to future deployment on real power systems), we are employing Pacific Northwest Lab (PNNL) GridLab-D to provide an unbalanced three phase representation of the utility distribution system (GridLab-D, n.d.). GridLab-D was selected for use in our prototype because it is a well-formed, and object oriented agent-based simulator with good performance and widespread acceptance. In our work, we have emphasized development of the MSAL technique and looked for representative agent based models with good performance and acceptance. We are using all the above components in our Power & Energy Use Case. We found these tools through exhaustive research on the web, and networking with academic and IT experts. Continued searches for tools will benefit future efforts.

Note on Data Science. Systems Engineers prepare yourself! Decisions are increasingly made based on computational simulations in Big Data. The ship has left the harbor and SE needs to get in and stay in the middle of the emerging confluence of simulation science and data science that leads to communications and ultimately decision making (Whitaker, et al., 2015). The development of MSAL is an example of systems thinking in action where integrated systems, software and Big Data play complementary roles in future complex systems and System of Systems.

MSAL Design and Ecosystem

Here we build the MSAL approach and context to accomplish the remainder of the objectives. We have done this for the general case as well as the specific Power and Energy Use Case. Figure 2 below is a graph of how MSAL activities (nodes) are connected by data (edges) to perform MSAL. Also shown in the figure is the System Modeling Language SysML) Activity Diagram which extends naturally into the graph network representation. It is important to note that In the figure, M nodes represent Modeling, S nodes represent simulation, D nodes represent Data Analysis (the A in MSAL). L, or looping (not shown in the diagram), is executed by iterating through the nodes across the edges in the graph network. The enabling technology is graph computing represented by the G nodes.

In our Power and Energy Use Case, the simulator is GridLab-D. The graph data base is System G. Dakota is an extensible interface that drives iterative system analysis (Labs, n.d.). Dakota orchestrates the simulation and thefore drives the parametric study and optimization. Both Dakota and System G contain powerful data analytic middleware that perform the data analytics activities.

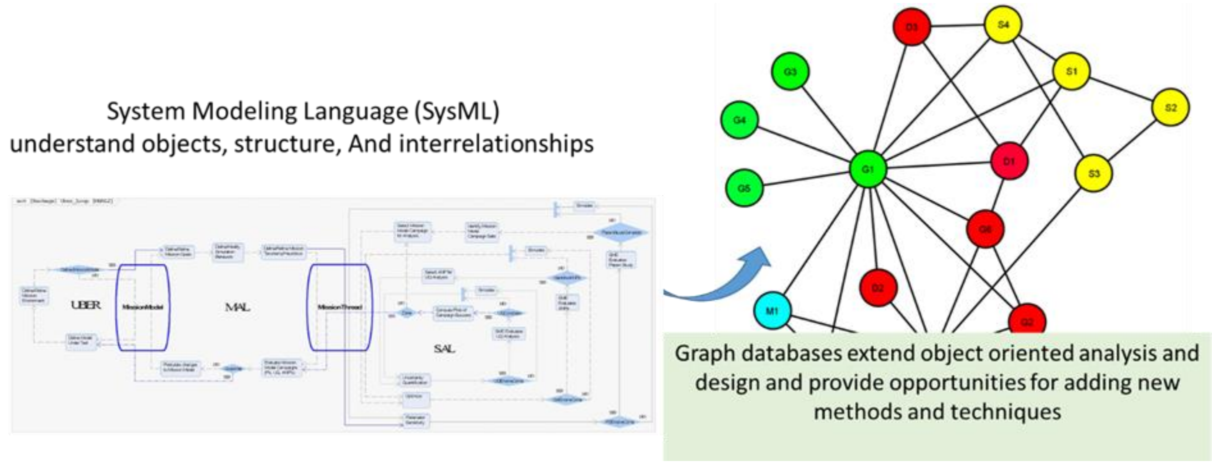

Figure 2. MSAL Architecture

We developed MSAL using SysML diagrams to communicate the objects and activities needed, in our view, to get at the things that matter in complex systems. We know the issues are in the data interfaces. Agent Based Models can be very good at simulating deterministic components of a system or System of Systems. But how do we get at the holistic simulation of a system when the agent only simulates one or at most a few components? Here is where graph theory comes in. We proposed to network the agent based sim into a graph to achieve this holistic view. Furthermore, analytics tools cannot answer our questions about System of Systems performance unless we can perform those analytics across well-posed data networks. Finally, to completely understand performance characteristics, we need to execute the data networked agent based simulator over the plausible performance space. This requires large numbers of iterative simulation runs stepping through the ranges of many combinations of input parameters.

With the above graph structure, looping and iterating through a top-down hierarchical approach accomplishes what is shown in Figure 1. The following sections provide an overview description of the components, steps and techniques in our MSAL construct.

UBER Loop

The purpose of the Uber Loop is the intersection of the real world with the virtual run-time environment. The Uber loop starts with the establishment of a Mission Environment that defines the System of Systems and the determination of a Model Under Test. The Mission Environment is the ontology describing the stakeholders, resources, operations, policy, and mission goals for the SoS. The Model Under Test is the architecture, design and subsequent hardware and software of the tactical systems and employed SoS. It is a subset of the Mission Environment and is modeled graphically using a variety of graph-based artifacts, e.g., SysML and UML. The Model Under Test is a composition of sub-models, which achieve their own objectives, or missions, in concert with each other in pursuit of the composite mission goal.

Model-Analysis Looping (MAL)

The purpose of the MAL is to create the static models that are abstractions of the real world. The MAL is completely in the run-time environment.

The key component of MAL is the Mission Model, an abstraction of the Model Under Test. The model under test is the real world; the mission model is an abstracted version of the real world. There are many mission models for one Model Under Test. Hence, the mission model is an abstraction that represents a single sub-model of the Model Under Test.

Mission Threads for each mission model are created for key mission goals. Each mission thread is a sub-graph that explicitly defines the event sequencing through the prosecution of a mission starting with the introduction of a stimulus and ending with the completion of the mission goal. A Mission is composed of multiple mission threads. This graphical representation of the SoS is called the event space. A SoS is generally multi-mission (or at least some of the pieces are). Thus, a SoS has a number of missions and many possible mission threads for each mission.

Graph analytics are conducted on iterations of mission models and/or historical archives of other relevant models looking for characteristics such as complexity, centrality, density, etc. This enables us to reduce the number of mission models to the ones with the most impact on the Model Under Test. For example, inference testing for pattern recognition can be conducted between multiple mission models. Through inference testing, a plausible set of 'good enough' mission threads can be established. The MAL allows early modeling of mission threads across diverse component systems within the SoS to provide constraint and structure for subsequent architecture development. The goal is to find the most plausible "structures" on which to conduct the SAL described below.

Simulate-Analysis Looping (SAL)

The purpose of the SAL is to test the dynamic behavior of a mission model along a goal-based, mission thread via simulation to quantify both performance and uncertainty. SAL is completely in the run-time environment and is Live, Virtual, Constructive (LVC); many simulators are appropriate depending on the mission goals being queried. After iterations of the MAL and SAL, the updated mission model is returned to the Uber Loop to update the mission environment and the model under test.

The first step of the SAL is to drive the simulation by one-at-a-time parameter sensitivity studies. Key variables are selected and then binned to run optimization campaigns and calculate local uncertainty for areas of noteworthy performance (ANP).

Power and Energy Use Case

Our primary objective in the Power and Energy Use Case prototype is to demonstrate near real-time, optimized control of a Smart Grid using a sensor network of streaming data and predictive simulation to interpolate or extrapolate from the empirical data when there is a change (or apparent change) in context feeding a distributed, hierarchical control network. The controls exploit structured data and allow for dynamic reconfiguration of the grid. This goal requires the ability to exploit structured and unstructured data, i.e., simulation predicted changes to the network configuration(s). The Baseline Model Under Test is a representative utility with network control and device data. The extensibility of our MSAL approach on the Power & Energy Use Case provides the ability to move into Big Data environment typical in the utility industry. Our Power and Energy Use Case has the following objectives:

1. Use MSAL to demonstrate operational optimization and decision making for electric utility distribution systems. This will lead later to an integrated model of generation, transmission, distribution, and customer usage.

2. Extend distribution system models and analyses to incorporate and vary high PV penetrations with advanced inverters, dynamic weather models for demand and PV impacts, distributed energy storage, and emerging voltage control devices for distribution transformers.

3. Confirm and extend work in modeling uncertainty in simulating and controlling electric distribution circuits with distributed PV deployments. Uncertainty stems from weather, consumer behavior, solar intermittency and other real world considerations being factored into the solution.

4. Establish an MSAL ecosystem for distribution system control where multiple objective functions can be optimized under uncertainty. The goal is to deploy and test our solution in the "real world" thus providing the technical and economic basis for commercializing this technology for the electric utility marketplace.

Power and Energy Use Case MSAL Results

Establish Mission Model For An Electric Utility

The Mission Model starts with a GridLab-D model (IEEE 37 Node baseline) shown in Figure 3 below. Using this model, we have developed a baseline of today's "business as usual" utility grid. From this baseline, we can define a Smart Grid control network including the required SensorNet and communications required to supplement baseline conditions and enable the overall control. The Uber Loop is represented by the baseline model.

Figure 3 is the Mission Model for our Power and Energy Use Case. It is a graph that is built in the graph computing environment. The graph software capability allows us to easily include a complex control network, smart devices and other components, as needed, to reflect the real world. The GridLab-D agent based simulator is represented by the graph and layers of architecture, data interfaces, data movement and control can be added through the extensibility of graphs. This is a key feature of our MSAL approach and a powerful addition to the model based systems engineering toolbox.

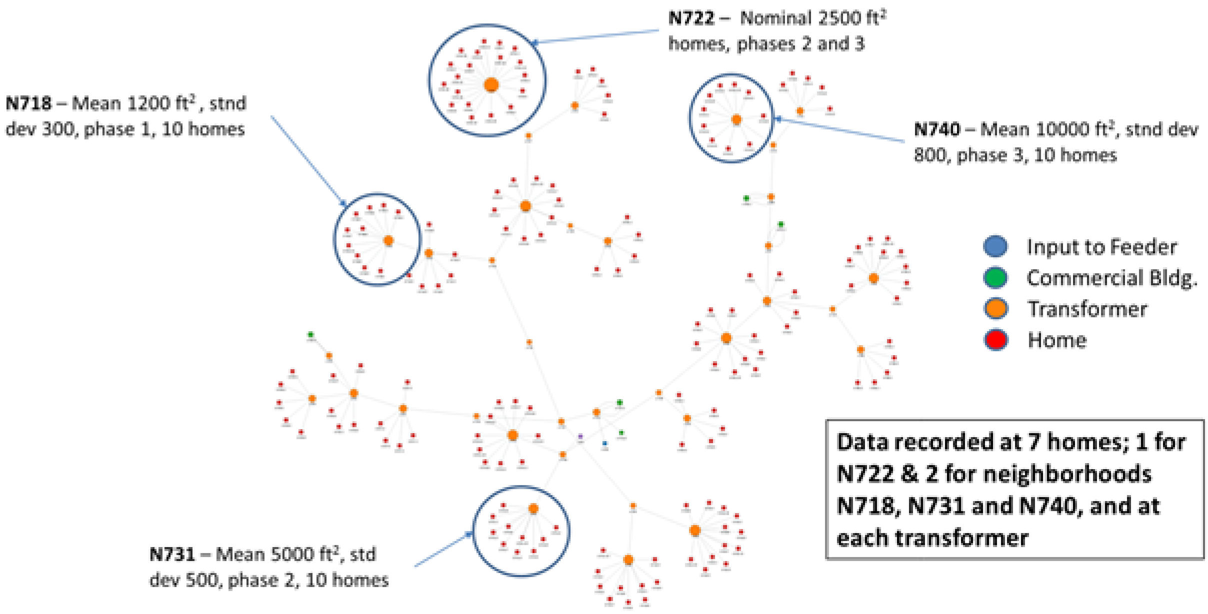

Figure 3. Mission Model for IEEE-37 Node Bus Model

We create the Mission Model because it sets up efficient data management and analytics capabilities. The Mission Model built as a graph provides the data structure that preserves the correct (as reflected in the Mission Model) spatial and temporal relationships of data input and output.

Using a graph database comes with additional systems engineering tasks. These include: defining the baseline database schema, GridLab-D input data, and other input data. Finally, there is system thinking that applies to the objective functions or the questions we want answers to out of all this activity. In our Power and Energy Use Case, that is to optimize at each level of the control network. Defining all this early in the Modeling section of MSAL impacts much of the downstream effort.

Engineering with the MSAL Approach

With the MAL in place, our attention turns to the SAL and engineering studies. We perform studies on input parameters to understand sensitivity and behavior of inputs. In the SAL, we want to determine parameter sensitivity through simulation studies. SAL leverages the GridLab-D Agent Based Simulator to drive hundreds of model runs to get at the parameters of interest. In this complex model (of a complex system) we cannot find a deterministic answer. We need to study parameters in isolation to understand what is important and why.

Figure 4 below shows the results of one of these studies. This study is an example of driving a simulator (GridLab-D) with our selected simulator driver (DAKOTA) to yield a study of Solar Penetration. The Solar Area was held constant at 1052 square feet and 100% cloud cover was scheduled from 11:00-13:00, and 16:00-18:00. The blue peaks represent the cloudy intervals and maximum load (and voltage variance) on the system. The troughs around 10 and 16:40 represent full sun and solar generation. In this study, the clouds are skewed to slowly track across the grid. Note how the trough around 16:00 widens (voltage variance is decreasing) as solar penetration percentage increases. We are interested in understanding how voltage variance behaves with changes in Solar Penetration (the target of this parameter study) and Solar Area.

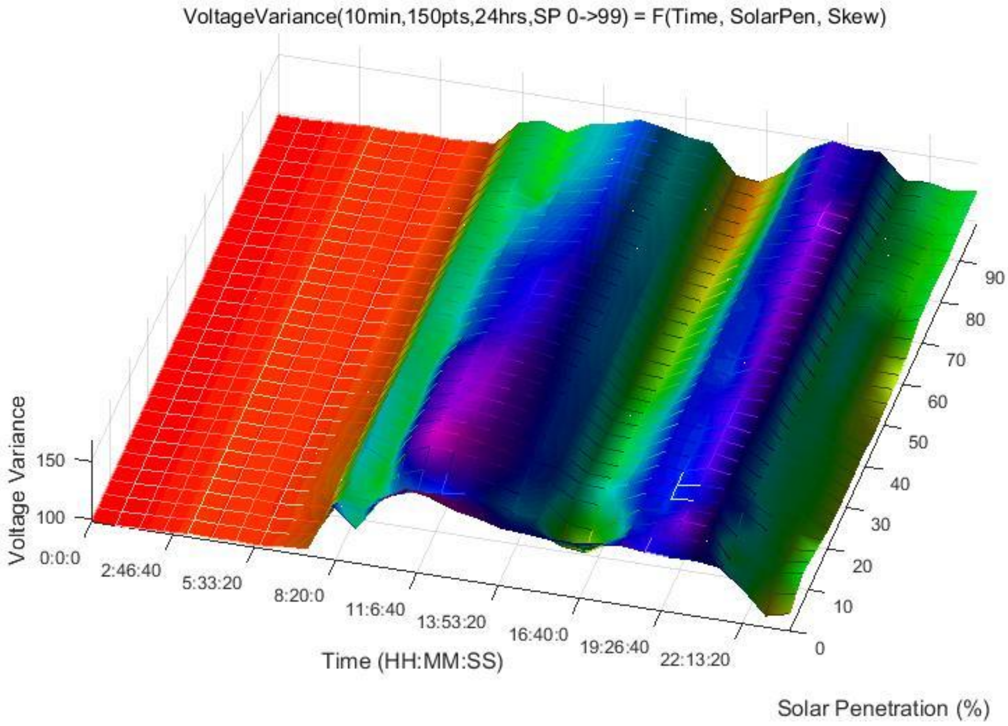

Figure 4. Parameter Sensitivity Study

Figure 5, below, is a two parameter optimization study using SolarArea (SA) and SolarPenetration (SP). The objective function was Voltage Variance, or Voltage Variance as a function of SA and SP. There were 150 sample inputs generated by Dakota. The "Skew" refers to the use of a simplistic cloud model. For our model we found that solar generation has a stabilizing influence on the grid and hence the voltage variance shows a minimum where solar generation is at a maximum (ie at maximum solar penetration and solar panel area).

This SAL process guides the investigation of the modeled phenomena and facilitates understanding of the influence of parameters or combination of parameters on the model and hence the "Real World" system. It acknowledges that parameters are interdependent and provides an approach to getting at an understanding of how well this Power & Energy Model behaves. The bonus is that if we don't understand what these results are telling us, we can change the model and rerun parameter and optimization studies to get additional data to provide a better understanding.

Our experience and exposure to large system developments indicate that a rigorous approach to hammering out this level of understanding is not typical in practice. If systems engineering is going to make a difference in future complex systems and meet strategic objectives of becoming the "go to" resource in the organization, approaches like SAL must become the norm. Systems engineers need to investigate every aspect of system performance as it is reflected in models. In most cases, this won't be a deterministic answer. The non-linearities and combinatoric effects of input parameters must be understood.

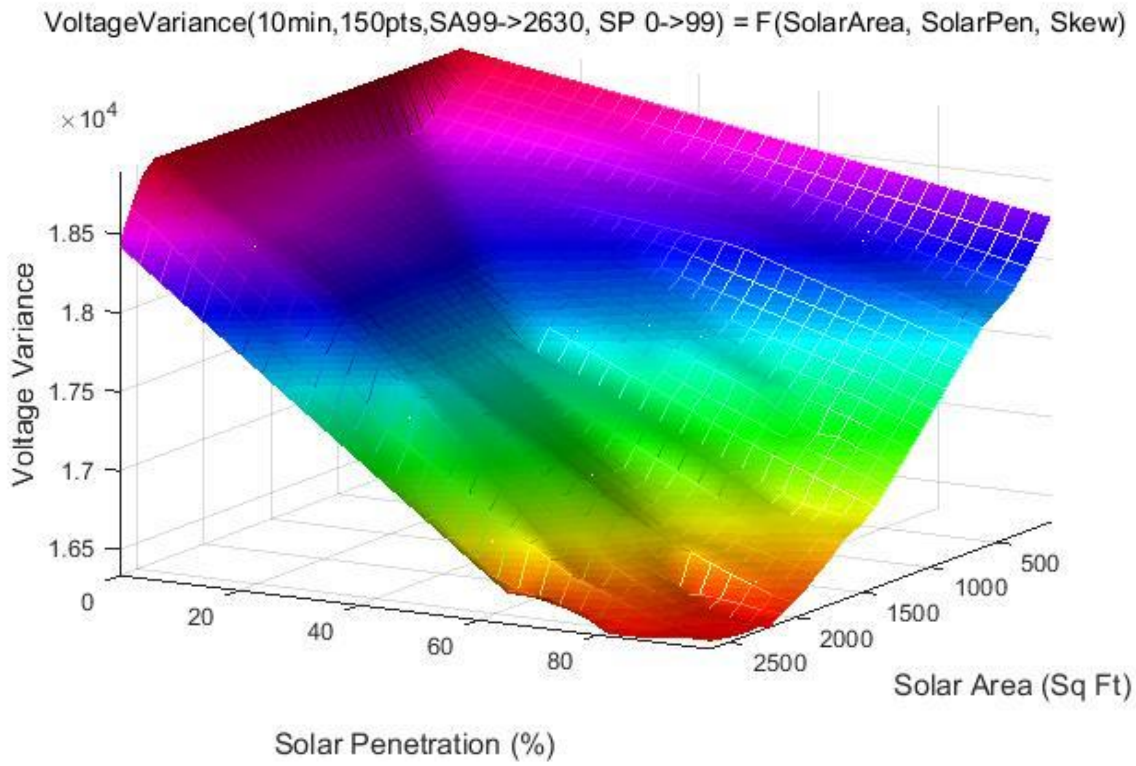

Figure 5. Optimization Study

In the case of our Power and Energy Use Case, SAL provides the test harness to accomplish the following additional types of studies: 1) Forward propagation of combined aleatory and epistemic uncertainty to define local uncertainty, 2) postulate new variable definitions to reduce uncertainty and new mission model to reduce uncertainty, and then iterate through the SAL, and 3) results of specific objective functions for subject matter experts to study and drive deeper understanding of the use case.

Each simulation run creates an instance of a mission thread. The integration of multiple instances of mission threads and subsequent use of Bayes (or Markov or creedal) statistics create macro uncertainty about the mission thread. We can also calculate the probability of success, Ps, for meeting mission goals and bounding macro uncertainty. There can be thousands of runs in each SAL campaign. From SAL results, new mission models are postulated and a new MAL to SAL cycle begins again.

Formulate the Utility Distribution System Model

In the Power and Energy Use Case, our forward plan is to develop a Mission Model of a Utility Distribution model which adds supervisory control and data acquisition (SCADA) and Smart Meter data models to our existing power and energy models. Here, we will use our experience and familiarity with IBM System G graph database technologies, analytics and visualization to build the schema for a hybrid System G data store. Our plan builds a full 2000+ bus model of an electric distribution system including smart meters, distributed PV, storage and demand response models based on the standardized IEEE 8500-node Test Feeder. This IEEE test case provides a benchmark for the power systems analyses community. The 8500-node Test Feeder represents a large radial distribution feeder and provides a challenging circuit for distribution studies. The 8500-node Test Feeder includes many elements that may be found on a North

American medium voltage (MV) distribution feeder: multiple feeder regulators, per-phase capacitor control, feeder secondaries, and service transformers (Arritt, EPRI and Dugan 2010). We have selected this Test Feeder as a natural extension of the IEEE 37 node Test Feeder we have used on our current Power & Energy Use Case. The extension to an 8500 node Test Feeder will demonstrate the ability to scale and build a test harness for a Big Data base source and abstract utility system data – SCADA and Smart Meter coupled with weather and other ancillary data.

We are careful to stay close to proven test cases such as the IEEE 37 and 8500 node feeders. We are not interested in costly and time consuming model development which leads to costly and time consuming software developments. Instead, we look to the well posed models and solutions that can be leveraged "off the shelf" to investigate and iterate through our MSAL construct. This proposed approach frees up resources and enables system thinkers to move to new horizons. Find the things that matter, experiment quickly and establish Innovation as a System (Bosch, 2015).

With our model now complete, we can develop a base Use Case using a large IEEE test system of over 2000 nodes. Now we turn attention to developing uncertainty models for demand, weather, solar, consumer, and other elements impacting control and decision making issues. The model built on the System G graph database allows us to conceptualize Use Case Scenarios representing a range of PV, DR, EV, and Storage penetrations on the distribution systems. We can also execute a range of Use Case Scenarios to produce a comprehensive set of results that cover the range of scenarios. Now we can demonstrate and execute graph based analytics to analyze Big Data problems against a proposed uncertainty quantification study.

In our Power & Energy Use Case development, The MSAL ecosystem is set up and has established a system representation of the real world. We can now simulate the real world in a run-time ecosystem collecting data from hundreds, thousands or millions of executions – and collect the data in real time. Realizing the possibilities, we are reaching to advanced tools to analyze and interrogate this data. This data is in fact reaching "Big Data" levels, but fear not, we accommodate that in a scalable fashion and have proposed further research with the US Department of Energy, as well as regional utility companies.

Visualize Results

With the ability to conduct data intensive studies established, we recognize the imperative to be able to communicate results in such a way that they are useable (Hey, Tony; Tansley, Stewart ; Tolle, Kristin ;, 2009). We are utilizing visualization capabilities to "see" decision enabling results for the system operators, planners and decision makers. In this regard, we have already worked with IBM on graph visualization, as well as evaluating a host of open source visualization tools such as VTK (VTK, n.d.).

Visualization is important because it supports a path for communications to decision makers. In order to become the hero, you need to effectively and unambiguously convey your results. If the results we produce cannot be visualized and understood, stakeholders cannot grasp the importance of our innovative techniques and what they mean to their business. We expect to leverage current work on visualization and an interesting twist that has to do with "trust." In this study, we need to understand the observer perspective, check for understanding and accommodate the perceptual and cognitive ability of our customers. There is much to do in this area and systems engineering is well-positioned to take a global leadership role in this area.

Develop Holistic Control Optimization Algorithms

We are now free to research and innovate in a variety of dimensions. Here we formulate control algorithms in terms of objective functions and constraints in the face of uncertainty quantification. We can now also test proposed algorithms on IEEE 2000 bus distribution system model spending time on what the intensive analytics can tell us about our model which can use Big Data sources.

Objective functions are important because they help us formulate the questions we want to answer. MSAL provide the scalable lens through which to view and analyze results. The innovation in our approach provides the ability to access data where it resides, stream it if necessary and perform a full suite of Big Data analytics to get at the answers we need. Establishing the MSAL structure on a graph using agents (IEEE test feeders) also on the graph allows us to transform potential into engineering action. This action requires subject matter expertise and systems thinking. Our future line of business is in complex control of Smart Grid operations as a function of PV, DR, storage and other dependent and independent parameters.

Graph Database Integration and Results

While the MSAL process allows for well-formed models and simulations, we believe the payoff in the technique lies in the graph database facilitated analytics. Figure 6 shows one analytic study directed at classifying results of the simulation. The objective here was to characterize the GridLab-D simulation output and use it as a template for classifying new results. The classifier is visualized as a 24-hour clock and allows results from new simulation runs (green dots) to be imposed onto the graph. Excursions from the norm are represented by yellow (warnings) and red (alerts) diamonds. In this example a linear discrimination testing algorithm is used as the classification engine.

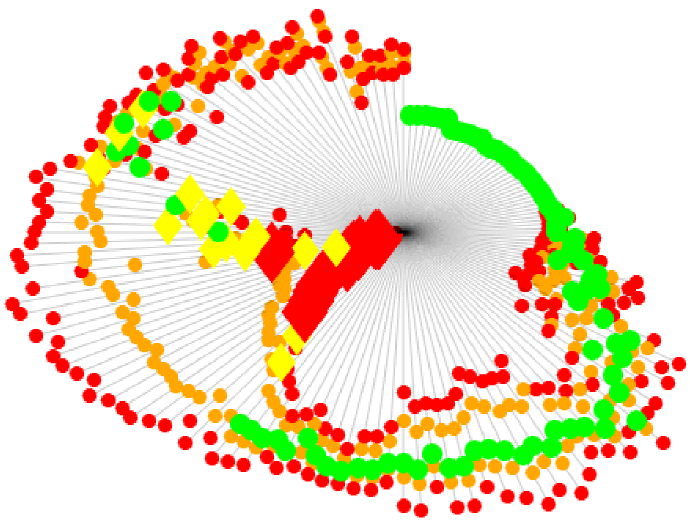

Figure 6. Data Classification Example

Summary

We reported on the work of Prime Solutions Group, Inc systems engineers addressing the topic of Uncertainty Quantification in an INCOSE IS 2014 paper titled, Uncertainty Quantification (UQ) in Complex System of Systems (SoS) Modelling and Simulation (M&S) Environments." The work is the result of a 2012 Department of Defense Scientific Technology Transfer (STTR). This IS 2016 paper reports on our progress through prototype development and present results achieved.

The study of UQ in modelling and simulation environments has motivated our investigations into a variety of modelling and simulation topics. As our research has progressed, we bumped into limitations and constraints in current systems engineering tools. We looked to SysML as a model based systems engineering tool and found that modern SysML tools did not allow for multi-digraphs and full extensibility. The tools are good for understanding system context, but fall short when it comes to accurately modelling data flows and interfaces present in the real world. Further investigation led us to social media and the use of graph theory. The value of graph computing in social media, Google and Facebook is well developed. Systems engineers have much to gain by leveraging the value of graphs these domains have exploited.

Bibliography

Archana Asthana-Daniels . (2014, July 10). Big Data Conversation . IBM .

Arritt, R. F., EPRI, & Dugan, R. C. (2010). Transmission and Distribution Conference and Exposition, 2010 IEEE PES . IEEE Xplore (pp. 1-6). New Orleans : IEEE.

Bauman, L. E., Adams, B. M., Bohnhoff, W. J., Dalbey, K. R., Ebeida, M. S., Eddy, J. P., . . . Vigil, D. M. (2009 (updated April 2013), December). "DAKOTA, A Multilevel Parallel Object-Oriented Framework for Design Optimization, Parameter Estimation, Uncertainty Quantification, and Sensitivity Analysis: Version 5.4 User's Manual," . Sandia Technical Report SAND2010-2183.

Bosch, J. (2015). Strategy & Innovation. Retrieved from Boschonian: http://www.boschonian.com/Boschonian/Welcome.html

Garrett, R. K. (2011). Managing the interstitials, a system of systems framework suited for the ballistic missile defense system. Systems Engineering, 14(1), pp. 87-109.

GridLab-D. (n.d.). Retrieved from http://www.gridlabd.org/

Hey, Tony; Tansley, Stewart ; Tolle, Kristin ;. (2009). Fourth Paradigm. Seattle: Microsoft Corporation .

IBM. (2014, Oct). IBM Watson. Retrieved from http://www.ibm.com/smarterplanet/us/en/ibmwatson/

Labs, S. N. (n.d.). DAKOTA. Retrieved from https://dakota.sandia.gov/

Marvin, J. W., & Garrett , R. K. (2014). Quantitative SoS Architecture Modeling. Procedia Computer Science . Elsevier.

Robinson, Ian; Webber, Jim; Eifrem, Emil; Neo Technology, Inc. (2013). Graph Databases. O'Reilly.

VTK. (n.d.). Retrieved from http://www.vtk.org/overview/

Whitaker, R., Thompson , W., Berger, J., Fischhof, B., Goodchild, M., Hegerty, M., . . . Wendelberger, J. (2015). Workshop on Quantification, Communication, and Interpretation of Uncertainty in Simulation and Data Science. Washington DC: Computing Community Consortium.

Biographies

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Joe has served in a variety of positions in government, industry and small business entrepreneur. His career has seen roles as a Chief Systems Engineer, Systems and Software Acceleration Architect, and Program Manager. As founder and PSG President he has provided senior systems engineering technical assistance to government customers on complex space system developments. He also works with business and economic development community to realize strategic vision as well as leveraging professional and technical associations into the work at PSG.

An Expert Systems Engineering Professional, he serves as the Assistant Director for Industry and has served as the Very Small Entity Working Group Chair. Current member of the System of Systems Working Group and IS 16 Technical Review Committee.

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Jeff Schmitz is a Software Engineer with 30 years of experience working within academic, semiconductor, and defense arenas. His skills include scientific programming, graphical user interface design and development, modeling and simulation (climate, electric grid), equipment control, database design and development, and factory automation. Current responsibilities include for innovative and fundamental research in System of Systems (SoS) parametric and statistical analysis of complex modeling and simulation environments. His major objectives are to research, evaluate, develop and transition novel algorithm approaches from academic research into operational deployment.

Jeff serves as a Principal Investigator on current PSG SBIR projects with the Air Force Research Lab and Department of Energy.

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Robbie has been a Software Engineer in the defense industry for 12 years, primarily in data control systems. He ventured briefly into the commercial realm taking on a position as the Director of Engineering for a customized logistics software company. He is currently a Senior Software Engineer, supporting research projects and support contracts for both the Department of Defense and Department of Energy.