Immersive Visualization and Course-of-Action Simulation: Towards a Decision Support Simulation System for Data Driven Businesses

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ABSTRACT
One of MITRE's Agile Enterprise initiatives targets making silo-ed data available to the enterprise. As part of the overall initiative, this research applies a Model-Based Systems Engineering (MBSE) approach with the Systems Modeling Language (SysML), discrete event simulations (DES). The goal is to draw from enterprise data to enable a Decision Maker (DM) to evaluate alternative Courses of Action (COAs) based on numerical insight. Partial results have been realized using a MongoDB to structure relevant enterprise data and present them in a flexible, but common format. Currently, the coherent data view is made accessible to the user via several selected visualization tools – collectively referred to as Immersive Visualization – representing the information in an enterprise context. We propose that using SysML with DEVS makes all characteristics of the enterprise accessible in the form of attributed entities. That is, by including simulation-required components, the information can now be transformed into knowledge. This is accomplished through obtaining numerical insight into the dynamic behavior of the enterprise by identifying and executing performance measures for COAs. Using SysML to specify the simulation components allows storage of these alternative actions in the same MongoDB as one additional component of the enterprise model. This paper describes a prototype, current research, and planned research to provide Decision Support Simulation Systems for Data Driven Businesses.

Author Keywords
Big Data, Course of Action Analyses, Decision Support Systems, Enterprise Data, Visualization

ACM Classification Keywords
I.6.3 SIMULATION AND MODELING: Applications
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INTRODUCTION

According to Giachetti [1], an enterprise is a complex, socio-technical system that comprises interdependent resources of people, information, and technology that must interact with each other and their environment in support of a common mission. Such an enterprise system is rarely designed and implemented from the top down. In most cases, enterprise systems result from independently merging several formerly operating groups into a new organization. These groups come with their own infrastructure, their own business models, their own information technology, and their own data models. The Department of Homeland Security is an example where former independent organizations were reorganized and aligned in support of a new common objective. In the commercial sector, many international companies can be used as examples as well, in particular when national companies are bought and integrated into the international business sections.

In all examples, the heterogeneity of data models and information technology solutions results in challenges to support decision making at the enterprise level. Decision support systems are needed to help a Decision Maker (DM) compile useful information from raw data and document sources originating from these heterogeneous information technology solutions. Furthermore, personal or educational knowledge – that can be static or procedural – and business models and strategies to identify and solve problems and make decisions should be identified and used.

Prior work included a prototype where data of varying scope, resolution, and structure were aligned to compose an enterprise repository. Data was then visualized to support a DM in evaluating alternative courses of action (COAs). The current effort is aimed at modeling COAs using the Systems Modeling Language (SysML) [2] and using simulation to produce numerical insight into the behavioral interdependencies of the various COA alternatives. The proposed solution is domain agnostic and can be applied in support of enterprise system solutions that support COA evaluations for all domains.

RELATED WORK AND EXISTING SOLUTIONS

Several recommendations have been presented in related venues to address the problem of overcoming process- and data- heterogeneity. They can be categorized into three solution families:

1. Mandating a common information exchange data model that potentially can be standardized: Both existing simulation interoperability standards implement this solution. DIS [3] standardizes Protocol Data Units that need to be used for information exchange between the simulators. HLA [4] defines a Federation Object Model (FOM) that provides the information exchange means. In the international Command and Control world, the use of the Joint Consultation, Command and Control Information Exchange Data Model (JC3IEDM) is a practical example [5].

2. Providing data mediation services that help to map alternative solutions to each other: Within the US Department of Defense, the Net-centric Data Strategy provides guidelines and mandates method to support operationally relevant data into each other. The implementing mediation services can be provided by a common infrastructure, but they still need to be configured. The Semantic Web initiative produced many impressive results, such as the one described in [6].

3. Use of metadata to support data reuse by interpreting the data in different contexts: In particular within various Big Data initiatives, methods and technologies were developed to take structured and unstructured data that differ in volume, velocity, variety, variability, value, and veracity, which are distributed among a variety of different platforms to produce aggregates for analysts to make informed decisions based on derived data. To do this, data are broken into initial components that can be recomposed into information exchange elements as needed by the analysts.

As shown in [7], the mathematical branch of model theory can be applied in general to provide the foundation for information exchange evaluation and in particular to analyze if the information required can be produced in the source system and accepted by the target system.

The developed prototype uses an approach from the third category and structures enterprise data in a MongoDB [8]. The current research is to visualize COAs in SysML, and to use simulation to gain numerical insight into the dynamic behavior of the alternative COAs. To this end, we build on previous work:

- As shown by Shuman [9], ***SysML by itself is not rich enough*** to support simulation in general. These results are consistent with the research of Mittal, who looked into the extensions of DoD Architecture Framework (DoDAF) artifacts to generate executable artifacts [10].
- Possible ***extensions have already been evaluated and presented***. Examples of utilized published research relating SysML to the Foundational subset for executable UML (fUML) [11, 12], Colored Petri Nets [13], or DEVS [14, 15].

In summary, successful approaches exist that resolve silo-ed data issues by creating enterprise data repositories as well as utilizing standards-based solutions to describe alternative COAs using SysML like approaches.

IMMERSIVE VISUALIZATION OF ENTERPRISE DATA

The research work conducted so far focused on creating an enterprise data repository and visualizing the resulting information for the DM. The coherent data view is made accessible to the DM via several selected visualization tools – collectively referred to as Immersive Visualization (IV) – that represent the information in an enterprise context. The IV approach uses web standards and frameworks built upon a MEAN (MongoDB, Express.js, Angular.js, Node.js) technology stack. The environment runs across platforms, is distributed, and highly composable [16]. The following subsections describe completed and on-going IV work.

Creating an Enterprise Data Repository

MongoDB is an open source, cross-platform database designed for scalability and agile development. Within the project, MongoDB was used to bring the individual data views of enterprise wide communities together without enforcing a limiting data standard. As a NoSQL database, MongoDB takes a document-oriented approach to persisting data as binary JSON (JavaScript Object Notation) objects that, by default, don't require or enforce a schema definition. This flexibility helps the sample data keep pace in a rapid prototyping environment where schemas are frequently updated and refactored.

Within the MEAN (MongoDB, Express.js, Angular.js, Node.js) software bundle, Mongo acts as the persistence layer along-side the Node.js server, Express.js server-side framework, and Angular.js client-side framework. The following Figure 1 shows the interplay of the MEAN components in a distributed environment.

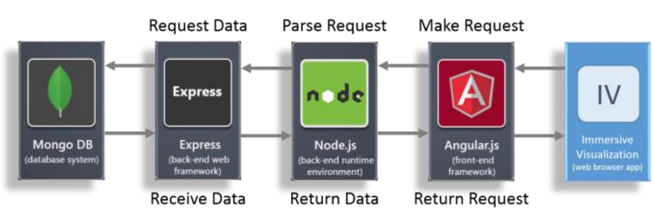

Figure 1. Using the MEAN Stack for IV

In contrast to older web application architectures such as J2EE (Java 2 Enterprise Edition) or LAMP (Linux, Apache, MySQL, PHP) whose components are written in multiple languages, all components of the MEAN stack are written in a single language: JavaScript. This simplicity allows a single developer or small team to build a complete web application much faster. And, since data requires little or no transformation from retrieval in the database to rendering in the browser, performance is very fast. The MEAN stack also provides a clean file structure and separation of concerns for the many components of a web application, which helps manage the software's growing complexity.

The IV team chose the MEAN stack for its speed, flexibility, simplicity and clean separation of concerns. These attributes let the team take an agile approach to developing the initial prototype, a method that included meeting frequently to identify any changes in requirements, verify new use cases or user interface mockups and demonstrate the current working capability. Meeting frequently let the team quickly confirm or correct both the high-level direction of the system and the low-level details of the user experience. And the technology stack allowed for any changes to be made very quickly, often in the same day.

The dataset behind the initial prototype was developed by Rick Haberlin, former Navy with a doctorate in Systems Engineering and Operations Research, and Jorge Soler, the point of contact and Subject Matter Expert for Air Force Special Operations Command (AFSOC). Haberlin and Soler drafted several different spreadsheets of unclassified data that defined associations between resource categories, programs and missions. Shawn Chin, the lead developer, translated the spreadsheet data into JSON using Comma Separated Values (CSV) as an intermediary format. The resulting JSON was persisted in the MongoDB and translated into the appropriate format for each visualization.

Visualizing the Enterprise Data

Government agencies are facing unprecedented pressure on their mission and budgets. A new approach and tools are needed to help leaders provide informed decisions about limited resources. An interactive IV environment facilitates better decision making processes and provides decision makers a visual, interactive environment to facilitate making tradeoffs, and understanding the multiple dimensions of available options. In this manner, DMs are able to identify allocations that better align with strategic goals and with greater transparency.

The project team developed an architecture and working prototype for a flexible, adaptive environment using web standards and frameworks built upon the MEAN technology stack, as introduced above. The environment runs across several platforms, is distributed, scalable, and highly composable. Working closely with a MITRE Air Force Special Operations Command (AFSOC) representative provided clarity on strategic planning and the interrelation of various planning documents. By examining a number of existing modes of interaction with data visualization, the project team was able to develop a best of breed implementation that provides a DM with greater perspective across the assigned portfolio. To provide realistic visualizations, DoD budgetary program documents were parsed at the Program Element (PE) level into a machine-readable format for inclusion into the database. Creation of a realistic demonstration required close collaboration with the MITRE Acquisition Decision Support System (ADSS) team supporting AFSOC and the Air Force Civil Engineering Center (AFCEC). The effort culminated in a working concept demonstration of an interactive, multi-view budget allocation environment based on a scripted user story of an AFSOC use case.

DMs face a daunting number of critical decisions and are frequently deluged with information, not all of which is relevant to the current decision to be made. The IV construct allows creation of “decision spaces” which are customized to a particular DM and decision type. Our working prototype is a customized decision space focused on the DoD Programming, Planning, Budget, and Execution (PPBE) process, specifically for AFSOC. Ongoing work includes development of Risk Identification and Mitigation, and Strategic Assessment COA decision spaces and their respective frameworks, introduced below. Each decision space provides a catalog of recommended views and is tailorable to illustrate data most relevant to appropriate decisions for a unique DM.

Frameworks

Each decision space is built on a generalized framework that allows customization to data applicable to the DM’s domain and preferences. By standardizing these frameworks, we are able to scale the IV environment to specific classes of decision problems across multiple domains. As previously discussed, our prototype was built on a framework to support the PPBE process. Current research focuses on two additional capabilities.

- The *Risk Identification and Mitigation* framework will not only allow DMs to visualize technical, programmatic, and business risks, but will also illustrate the effect of mitigation strategies over time.
- The *COA Comparison* framework will provide multiple views of cost vs. performance for baseline ‘as-is’ technologies and proposed solutions to gaps identified as part of a capabilities-based assessment. The next section will give more details on this effort.

Both frameworks are under development. The remainder of this section will focus on the PPBE prototype developed so far and applied for supporting an AFSOC use-case.

Example: Decision Support Tools for Programming, Planning, Budget, and Execution

The PPBE IV environment provides a catalog of views to inform the DM for anticipated decisions.

Colors of money

There are five major categorizations of dollars appropriated to the DoD budget: Procurement; Military Construction (MILCON); Manpower; Research, Development, Test and Evaluation (RDTE); and Operations and Maintenance (O&M). Dollars within an appropriations category typically cannot be spent in another category, so it is important to understand the allocation of available dollars across the portfolio when it comes time to make budgetary trades. For example, if the DM desires to speed up the delivery of an acquisition system, resources to accomplish this must come from Procurement funds, thereby slowing down one or more other programs.

The IV environment provides a number of views that illustrate the contribution of the appropriation categories including the overall Budget Summary, Mission Support, Program Support and Program Element. From these views, the DM is informed about the effect of moving appropriations between programs.

Budget

Of immediate importance to the DM is a clear understanding of his assigned budget. He must be able to view the budget across the entire domain, visualize both discretionary and non-discretionary appropriations, identify major investments across the Future Year Defense Plan (FYDP), and anticipate programs at risk.

Drawing from the MongoDB, multiple views are provided. From the Budget Summary View the DM can observe his Total Obligational Authority (TOA), the proportional distribution of his varying appropriations categories, and his anticipated growth based on the previous year's budget. He may also compare another budget (e.g. prior year) to visualize the changing domain using adjacent views. The Budget Summary view also provides drill-down capability identifying contributors down to the PE level. Similarly, Program Budget Summary views support understanding of multiple resource category support to individual programs. By displaying multiple programs support summaries simultaneously, the DM can perform real-time tradeoffs between programs while keeping his overall portfolio below his TOA. Similarly, given a known amount for a budget adjustment or anticipated program, programs can be adjusted to free resources. A Geographic Effects view provides a visualization of resources drawn from a geographic location to indicate possible consequence associated with adjusting resources from a particular program or PE (Figure 2). In this example, the radius of the circle is defined by the budget assigned to that location.

Figure 2. AFSOC Budget Geographic Effect

The DM is also concerned about the influence that accelerating or delaying a program will have on mission effectiveness. A Technology Roadmap view provides an illustration of a capability to be delivered over time, categorized by appropriation. In the IV PPBE framework, the Program Budget Summary view is related to the Technology Roadmap view through an algorithm coded in JavaScript. Adjustments to the Program Budget Summary result in an acceleration or deceleration of the technology delivery, resulting in a change in capability. Similarly, adjustments to the Technology Roadmap shift resources on the Program Budget Summary. These adjustments are all collated in the Overall Budget Summary which illustrates the DM's TOA.

Budget COA Comparison

Anticipating a budget adjustment, the DM must identify which program or programs will have to absorb the reduction in resources. The DM has an idea of the relative importance of each mission. However, he needs to understand how much of his budget is tied up in each mission, and from this he can determine if his budget is aligned with priorities. If not, then misalignments are targets for anticipated adjustments.

The IV PPBE framework connects resources to capability through a set of relationships between budget data, program appropriations, mission appropriations, capability roadmaps, task effects, and capability effects. Budget data is provided by the DM organization in the form of budget sheets, or a database. Program appropriations specify the support from each of the five categories to each individual program. Mission appropriations combine the programs that support each mission to identify how they are supported by the appropriations categories. Adjustments to these appropriations categories accelerates or decelerates capability, captured in technology roadmaps as discussed above. Delivery of this programmed capability over time produces changes to the Task Effects which are reflected in Capability Effects. The relationships between tasks and capability reside in the Acquisition Decision Support System (ADSS) developed to support AFSOC. ADSS data is ingested by the Immersive Visualization server to populate appropriate views.

COURSE OF ACTION COMPARISON

The current research will focus on the use of SysML and simulation technology to provide insight into the behavioral interdependencies of various COA alternatives. The proposed solution is domain agnostic and can be applied in support of enterprise system solutions that support COA evaluations for all domains, starting with providing the option to analyze alternative COAs and describing what-if scenarios as SysML models.

To accomplish these research goals, three objectives have to be accomplished.

- First, the system dynamics <u>describing</u> alternative COAs in computable form need to be provided.
- Second, the alternatives need to be <u>visualized</u>. We decided to provide the results in the same format as the operational data so that a side-by-side comparison between the current situation and all possible alternative outcomes with the same graphical interface and semantics allowing the DM to utilize the new feature without having to learn new concepts.

- Third, we needed a way to store our algorithms in the enterprise repository to ensure their clear documentation as well as their potential reuse in related or follow-on projects.

As described in this section, we decided to use SysML and DEVS to visualize and analyze the dynamics of alternative COAs. Several methods exist to capture SysML model content in MongoDB constructs that will also be evaluated during this year's research work. The flexibility of the MongoDB allows us to store the results of the alternatives without technical challenges, so that the same immersive visualization techniques developed to present the operational data are applicable to the simulated results as well. Figure 3 illustrates the approach that will be followed during this year's research effort.

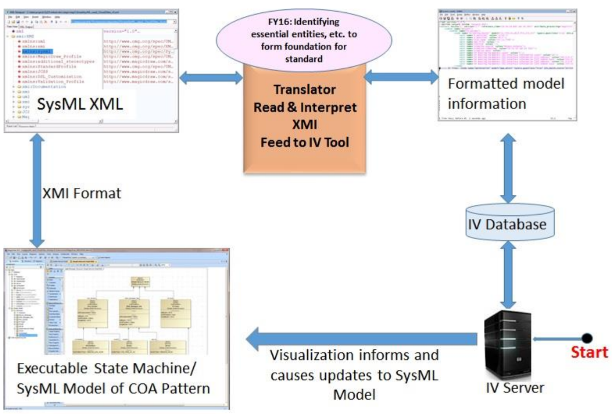

Figure 3. FY16 Research Approach

Describing the Alternative COAs

To describe COAs in computable form and to evaluate various alternatives for system dynamics, we looked for a solution that enables capturing all needed elements for simulating alternatives using some formalism. SysML has been identified as a general systems engineering modeling language. However, SysML was neither developed to be executed, nor is it based on a simulation formalism (see section on related work). Of particular interest to our research were methods and techniques to transform a SysML model to another formalism for conducting further modeling and simulation activities [17, 18, 19]. We decided to focus our research on mapping the state machines captured in SysML to the Discrete Event System Specification (DEVS) [20]. Nance [21] already established the time and state relationships in simulation modeling in general form, which justifies this approach. In addition to the already referenced approaches, several researchers are looking at an alignment of formal approaches to derive a meta-formalism that allows to express all special facets introduced by the individual approaches [22].

Table 1details the initially applied mapping from SysML state machines to Atomic DEVS.

State Machines in SysML	Atomic DEVS
∑: is a finite set of events (Action). Receive signal action	A set of input events X
∑: is a finite set of events (Action). Send signal action	A set of output events Y
S: is a finite (non-empty) set of states.	A set of states S (states in which the atomic DEVS component can be in)
S: is a finite (non-empty) set of states. Submachine state, Composite State	A set of states S (states in which the atomic DEVS component can be in)
N/A (TimeEvent in Activity)	The time advance function t_a (that defines how long the component remains in a state)
T is a finite set of transitions represented by the tuple t = (t′; so; e; c; a; sd), where: t′ is the transition name; so ∈ S is the origin state; e ∈ ∑ is the trigger event; c is a trigger condition; a ∈ A A is an action to be executed when the transition occurs; sd ∈ S is the destination state.	The external transition function δ_{ext} (that defines how an input event changes the state of the system)
T is a finite set of transitions represented by the tuple t = (t′; so; e; c; a; sd), where: t′ is the transition name; so ∈ S is the origin state; e ∈ ∑ is the trigger event; c is a trigger condition; a ∈ A A is an action to be executed when the transition occurs; sd ∈ S is the destination state.	The internal transition function δ_{int} (that defines how a state of the system changes internally)
Action with output pin? And output parameter. (A⊆ ∑): is a set of actions, where τ ∈ A represents the \null action" or \skip".	The output function λ (that defines how a state of the system generates an output event)

Table 1. SysML to DEVS Mapping

This mapping can be used to transform the data described in a SysML model and stored in the MongoDB into a discrete event simulation used to conduct analysis on the COAs based on executable versions of DEVS, such as those described by [23]. This mapping is neither exclusive nor complete, as it captures only a small fraction of both methods. However, it demonstrates the principles behind our research approach. Some practical constraints on creating executable DEVS models were recently discussed in [24], which also looked into coupled DEVS constraints in more detail.

In our approach, the entities described by state machines are derived from the data under evaluation. As discussed earlier, the Technology Roadmap view provides an illustration of a capability to be delivered over time, categorized by appropriation. Different decisions and priorities in the budgeting process can influence the roadmap significantly. The states are directly derived from the enterprise data, the causality is captured by the user using the SysML state machine artifact.

There are alternatives to mapping SysML to DEVS, as shown in [9], but the advantage of using a DEVS mapping is that the results are formally captured and can be used by industry to agree on standardized ways to insure interoperable results in various tool implementations. Another advantage is that this allows potentially to contribute to the next generation of SysML that comprises all components needed to support the execution of its artifacts, as envisioned by [22].

Visualizing the Alternative COAs

As discussed in the previous subsections, the entities manipulated to describe the alternative COAs are drawn from enterprise data. This also implies that the results of the evaluation are entities of the enterprise data. These entities have the same properties, but they will have different value content as alternative simulation results. We can therefore use the same immersive visualization scheme developed in earlier research and described in the immersive visualization section. Such reuse enables us to use the same presentation schemas to display current and alternative predictions side by side. It also enables prediction of a development path using real world data to check if the development is still on track. It is, however, highly recommended to use visual cues to clearly distinguish between real world enterprise data and simulated enterprise data to avoid confusion by the DM regarding what is being presented. The goal is to avoid decisions based on occurrences of rare events rather than more realistic and probable events.

From a technical perspective, visualizing simulation results is accomplished using a meta-tagged data set of needs to be displayed. The immersive visualization tools do not care what the data represents, as long as the needed data fields are populated.

Storing the Alternative COA

Within the research conducted so far we were able to ensure that SysML diagram elements, specifically state machine and activity diagram elements, can be mapped to schemas that are executable. Once modeled in SysML, the various COAs can therefore be executed as a simulation model using an expanded mapping from Table 1. This can either be done using DEVS execution platforms or, if preferred by the sponsor, by using tool specific proprietary solutions to execute the SysML description of the alternatives. The necessary input data are provided by the MongoDB.

As discussed before, this simulation can now produce “simulated enterprise data” showing the results of pursuing each alternative COA that as output data also can be stored in the MongoDB, using special tags to ensure that the pedigree of these data is well known.

Finally, SysML already leverages the OMG XML Metadata Interchange (XMI) [25] to exchange modeling data between tools, and is also intended to be compatible with the evolving ISO 10303-233 systems engineering data interchange standard in the future. This ensures that each COA algorithm captured using the potentially extended artifacts can be stored as a document within the MongoDB, so that it can be used to unambiguously document the various COA. It also allows for reuse of algorithms and COA in later phases of an evaluation or in similar use cases supported by the prototype.

CONCLUSION AND DISCUSSION

The templates from the *COA Comparison* framework will be rendered using a general purpose modeling language and notation (SysML). This will give the AFSOC subject matter expert access to a process flow model of the alternative COAs. Such a model will be used to validate the model content (data stored in MongoDB). Further, the data from the SysML model will be transformed into an executable discrete event simulation through automated means that are being developed as part of this research effort. Results from the simulation will be available to the DMs in the IV environment. Simulation results will produce numerical insight into the behavioral interdependencies of the various COA alternatives. The proposed solution is domain agnostic and can be applied in support of enterprise system solutions that support COA evaluations for all domains. It satisfies all three requirements formulated in the beginning of this paper.

Ongoing research will continue to contribute to the discussion how M&S solutions, such as the DEVS formalism, can be used to improve systems engineering processes and artifacts. It will also look into the question how new concepts, like how to use sematic technologies including triplestores to support the sponsor better in discovering, mediating, and reusing data and algorithms, as discussed in [26].

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