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Modeling Large-Scale Critical Enterprises

Regina M Griego, Ph.D.

Sandia National Laboratories Contractor to
National Nuclear Security Agency (NNSA)
1000 Independence Ave., S.W., GA-007
regina.griego@doe.nnsa.gov

Abstract

Enterprise modeling informs decision-making. Policy impact on a large-scale, critical enterprise can lead to long-lasting and possibly unintended consequences. The program implementation decision-space for senior leadership is highly complex and encompasses trade-offs between infrastructure, product, and critical skill equities. In a constrained environment, decision-makers must balance trade-offs between:

(1) critical skills growth and retention,
(2) sustainment of critical infrastructure,
(3) acquisition activities aimed at refreshing products.

This balance must be maintained in order to develop implementation plans that simultaneously meet national policy requirements and minimize program execution risk for the enterprise.

Modeling each of the areas independently provides important insight and opportunity to optimize and develop metrics. However, the real power and utility behind enterprise modeling comes from integration and representation of the interconnected dynamics of all its components.

This paper will outline an approach and progress for an Enterprise Modeling Consortium (EMC) for the National Nuclear Security Administration (NNSA) Nuclear Security Enterprise (NSE). The NNSA is a semi-autonomous organization under the Department of Energy (DOE). The NNSA NSE is composed of eight Government Owned Contractor Operated (GOCO) sites including three national laboratories, four production agencies, and a testing facility. The NNSA NSE includes the federal oversight organization in Washington DC and at the eight GOCO sites. The enterprise infrastructure encompasses over 6,000 facilities with a capital replacement value estimated at $37 B and a skilled workforce of over 20,000 staff. This infrastructure in both its intellectual (critical skills) and real property form (buildings and equipment) underpins the future sustainment of the US nuclear deterrent.

Introduction

The NNSA, through its Defense Program (DP) activities, is responsible for ensuring the safety and reliability of the U.S. nuclear stockpile. The planning, programming, budgeting, and execution of these activities at eight NNSA NSE sites involve complex dynamic processes between the sites. NNSA has limited analytical tools to form a broad and detailed view of the NSE that can illustrate the interaction of these dynamic processes and avoid the unintended consequences of actions. An effective way to address this shortcoming in analyzing possible outcomes is to integrate and extend existing enterprise data and program analysis models from across the NSE. This enhanced capability is called enterprise modeling.

The EMC was established by NNSA DP in July 2009 and is responsible for developing tools to integrate existing modeling capabilities, to address any modeling capability gaps that are identified, and to acquire and maintain enterprise modeling data. The goal of the EMC is to be the primary resource for DP to integrate and coordinate decision support by using enterprise data, modeling tools, and associated analysis capability to represent a broad range of NSE functions.

These functions cover three main application areas: stockpile, infrastructure, and critical skills. In the stockpile area, modeling and analysis are used to assess the ability of the NSE infrastructure to support various stockpile configuration scenarios required by the Department of Defense (DoD). In the infrastructure area, EMC tools are used to assess DP's ability to maintain the physical infrastructure necessary to meet requirements in design, assessment, transportation, storage, materiel production, maintenance, dismantlement, and surveillance. In the critical skills area, computational methods and analysis are used to assess the state of the NSE's workforce using a more rigorous approach.

NNSA NSE Enterprise Modeling

The EMC has drawn the definition of Enterprise Modeling from its extensive NNSA NSE modeling and simulation history. The NNSA EMC defines an enterprise model is a mathematical description of the products, people, and facilities that span the sites of the NSE. Enterprise models provide forecasts of the impact of proposed programmatic actions and highlight the potential unintended consequences of those actions. The use of such models can improve decision making for the aggregate enterprise.

Enterprise modeling is a way to integrate data and analysis tools to create an interconnected view of the products, people, and facilities of the NSE (Figure 1). Enterprise models are used to evaluate the ability of the NSE to adequately support the stockpile, its infrastructure, and the critical skills it requires. Decision makers use them to assess the integrated impact of programmatic changes across the NSE and to help develop more globally (vs. locally optimized) self-consistent solutions.

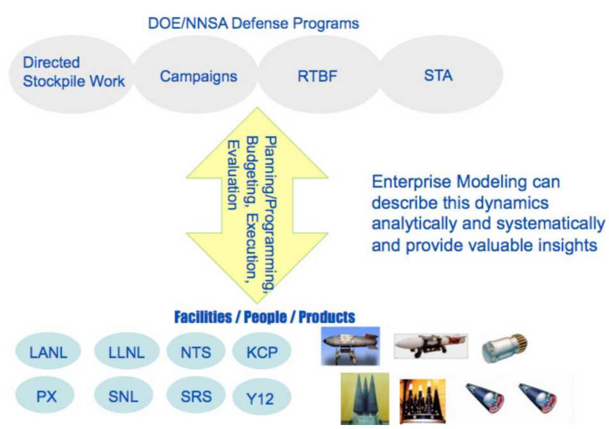

Figure 1. The NNSA/DP enterprise modeling problem space.

Taxonomy of Models

Integral Models. Integral models represent one of the most important classes of enterprise models as they treat the entire enterprise and the complexity of the interconnections between its elements—stockpile, infrastructure, and critical skills. They typically have large enterprise-wide scope but at sometimes lower resolution than constitutive models and represent a "top-down" macro-level approach to modeling. Examples of integral models may include multi-site enterprise representation, as well as coupling between design and production agency capabilities

Constitutive Models. Another important class of enterprise models is constitutive models, which typically have smaller scope but greater resolution than integral models and represent a "bottom-up" micro-level approach to modeling. Examples of constitutive models may include a multisite infrastructure models. Constitutive models also provide important inputs for methodologies that calibrate or convert micro-level information to macro-level models. The scope of the EMC is to provide DP with the tools to describe the state and dynamics of the NNSA enterprise. Key elements of this enterprise include the stockpile, its infrastructure, and its critical skills requirements. These key elements represent the three application areas of EMC activities.

Enterprise models – Integration and Abstraction. Enterprise models in the holistic enterprise context are created by integrating or abstracting across constitutive models. Constitutive models span multiple sites but typically treat only one aspect of an application area (e.g., products, people, and facilities), while integral models create explicit linkages between two or more constitutive model sets. Multiple integral models can be coupled to provide a broader policy context. This is a key technical vision of the EMC model development activities.

Enterprise models integrate across various data sources to provide NSE-wide assessments. To function, the constitutive and integral models rely on enterprise datasets as well as output from site models. Site models do not model the impact of the NSE overall, but instead represent a smaller site-specific view (e.g. to plan workflow and resource allocation issues at a particular site).

All three types of models are needed to support decision-making at the broader NSE level. However, the EMC focuses on the development and integration of constitutive and integral models. The EMC will rely on site models for data and for the calibration of integral models. More specifically, site models are presently out of scope for EMC governance and development, although they may be endorsed by the EMC when integrated into an enterprise tool.

Application Areas

Stockpile. In the stockpile application area, modeling and analysis are used to assess the ability of the NNSA infrastructure to support the stockpile. Traditionally, these "stockpile models" are used to evaluate whether the NSE has the available capacity to provide stockpile refurbishment rates and schedules, transportation, storage, materiel production, dismantlement, and surveillance necessary to meet military requirements. Equally important is their ability to evaluate other key aspects of the NNSA enterprise, such as technology maturation, design capabilities, testing, and certification.

Infrastructure. In the infrastructure application area, modeling and analysis tools are developed to predict the ability to maintain an NNSA infrastructure that is responsive to DP requirements in design, production, testing, transportation and storage, materiel production, and dismantlement, and surveillance. These tools help NNSA accurately consider the full lifecycle costs and capacity constraints involved in commissioning and starting up new facilities, recapitalizing existing facilities, and decommissioning and shutting down current facilities. Such projections can then be used to inform the stockpile models. They can also highlight the interdependencies between various components of the NNSA enterprise so that tradeoffs between costs and benefits can be analyzed.

Critical Skills. Over the last several years, there have been many efforts to characterize the state of the critical human capital associated with the nuclear enterprise, and to project its availability. The goal of these efforts has been to ensure that the NNSA enterprise maintains the skills needed to meet current NNSA requirements and to respond to its changing mission. In the critical skills application area, modeling and analysis are used to assess and inventory the state of the human resource, to evaluate the development of skill gaps created by funding or tasking issues, and to assess the extent to which programs external to the direct stockpile program help or hinder critical skill sustainment. In addition, these tools provide new methods for treating issues surrounding the aging workforce and the retention and sustainment of critical skills.

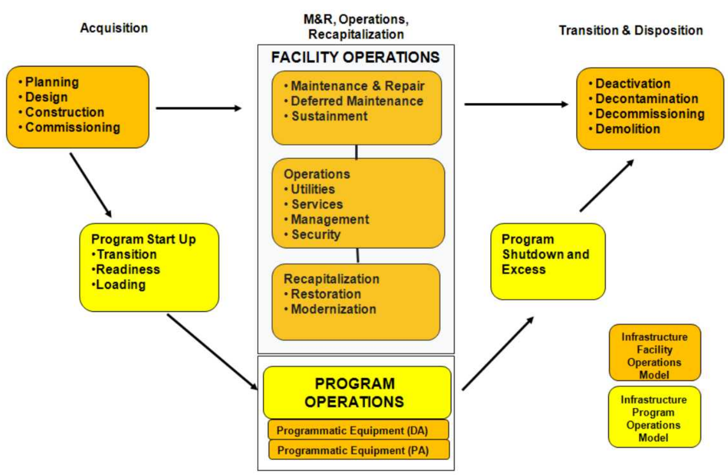

Figure 2. Full Life-cycle Representation of Infrastructure

EMC Modeling Results

Modeling Infrastructure Life Cycles

The analysis and evaluation of infrastructure life-cycles (Figure 2) involves specialists from several technical communities. There are construction and project staff that concentrate on real property acquisition activities. Other plant engineering communities focus on facility sustainment, namely, maintenance and repair, asset recapitalization, in addition to facility operations. Another distinct specialty involves transition and disposition (T&D), which relates primarily to decontamination, decommissioning, and demolition activities. We have developed models that represent all stages of the life-cycle.

One feature of projecting resource requirements over a decade or more is that the portfolio of real property will change as new construction adds new facilities and T&D processes will remove facilities from the portfolio. Figures 3 and 4 show current age and value of facility assets and a projection based on current planning.

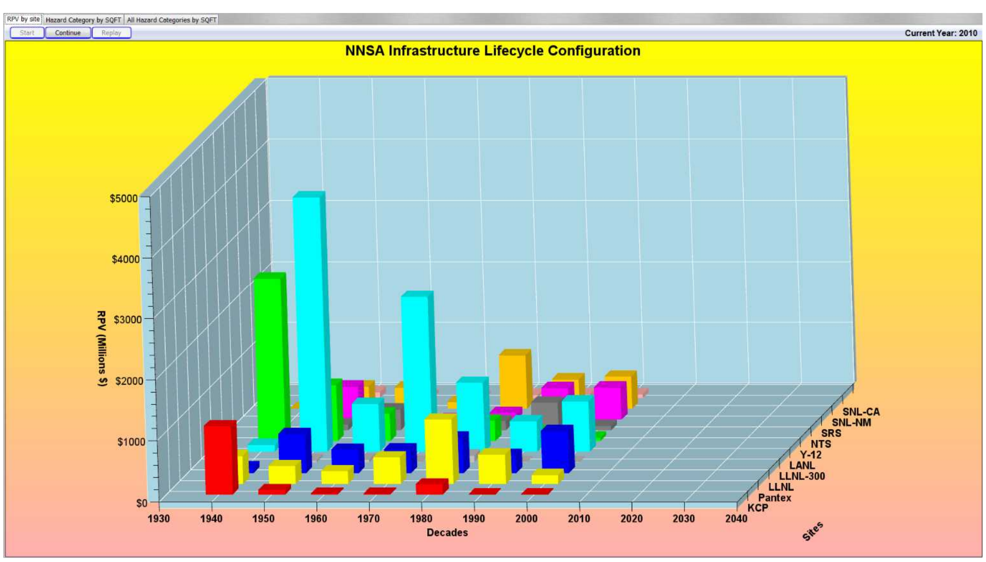

Figure 3. Initial age configuration of real property (c. 2010)

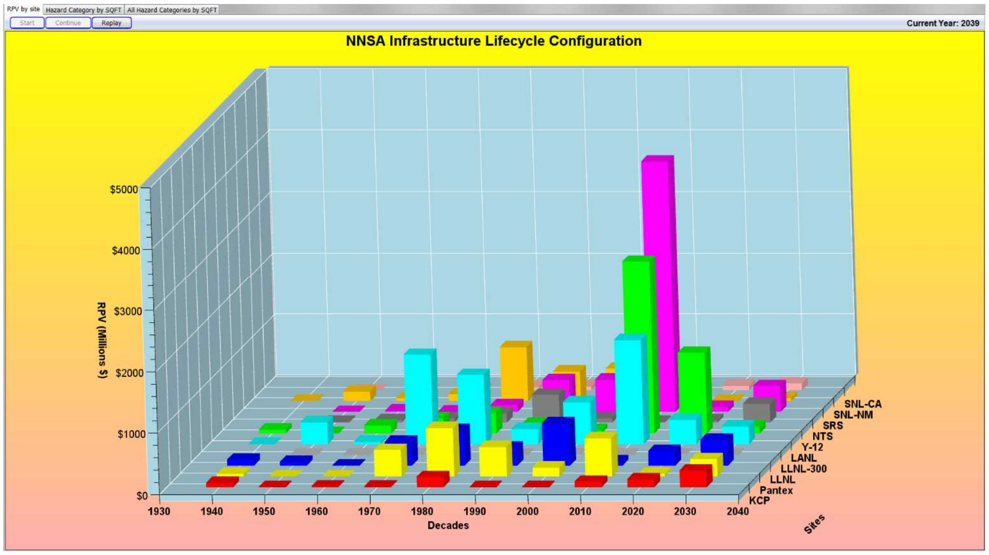

Figure 4. Projection and Distribution of Real Property (c. 2030s)

Parametric Estimation and Projection. For all sites, estimates were made for representative building, trailer, and other structures and facilities (OSF) models and then extrapolated to the entire site inventory. More specifically, we validated the existing facility inventory provided by the DOE Facility Information Management System (FIMS) and then used asset models—defined by inspection in the original study—as inputs to the parametric models. In addition to deferred maintenance, estimates are provided for sustainment, operations, and recapitalization requirements. These estimates are then assigned by asset type (and size, age, and location) to the overall inventory.

Site Inventories and Samples. For each site, an inventory of facility assets was defined with the assistance of site staff. These inventories included buildings, trailers, and OSFs and did not include deactivated or excessed assets, or assets specifically excluded by the site or NNSA Headquarters. In total, the study inventory included 3,396 buildings, 643 trailers, and OSFs. All values for this study were provided by FIMS. A summary of site inventories is shown in Table 1.

Table 1. DOE FIMS Summary of Site Inventories

Scenario: Base Scenario

	Buildings		Trailers		OSFs		
Site	**RPV**	**Count**	**RPV**	**Count**	**RPV**	**Count**	**Total RPV**
Kansas City Plant	$1,362,799,463	48			$397,363,915	20	$1,760,163,378
Lawrence Livermore Lab Site 300	$271,727,369	109	$2,842,018	13	$204,608,865	94	$479,178,252
Lawrence Livermore National Laborator	$3,755,293,951	296	$10,266,609	45	$1,566,081,562	101	$5,331,642,122
Los Alamos National Laboratory	$9,822,743,382	878	$111,810,422	289	$1,851,228,528	878	$11,785,782,332
Nevada Test Site	$1,098,424,044	373	$16,982,557	33	$1,466,494,387	725	$2,581,900,988
Pantex Site Office	$3,014,412,870	557	$8,906,998	70	$632,276,260	86	$3,655,596,128
Savannah River Site	$1,759,457,607	32	$1,981,897	7	$17,485,150	16	$1,778,924,654
SNL - California	$334,018,432	58	$8,694,857	14	$67,951,719	41	$410,665,008
SNL - New Mexico	$2,645,581,719	706	$85,391,487	154	$916,158,254	322	$3,647,131,460
Y-12 Site Office	$5,686,768,291	339	$8,682,997	18	$2,524,249,317	258	$8,219,700,605
Site Total	**$29,751,227,128**	**3,396**	**$255,559,842**	**643**	**$9,643,897,957**	**2,541**	**$39,650,684,927**

Table 2. Stratified Sample of NNSA Building Assets [A]

Asset Class (Usage Code)	Selected Inventory Count	Selected Inventory GSFT	Selected Inventory Percent GSFT	Sample Count	Sample GSFT	Sample Percent GSFT of Asset Class
Offices (100)	336	6,850,227	21%	81	945,692	14%
Institutional (200)	123	2,265,960	7%	25	228,539	10%
Housing (300)	39	217,605	1%	8	43,916	20%
Storage (400)	707	2,695,368	8%	39	271,389	10%
Industrial (500)	235	8,198,695	25%	22	583,105	7%
Services (600)	918	3,355,650	10%	71	512,191	15%
Laboratories (700)	408	9,642,986	29%	38	1,098,042	11%
Other (800)	6	8,942	0%	1	1,751	20%
Total	**2,772**	**33,235,433**	**100%**	**285**	**3,684,625**	**11%**

[A] Does not include deactivated or excessed assets. Based on data from FY08 FIMS.

Table 2 (2008 data) shows the total inventory of buildings by asset class, and the number of buildings sampled on the basis of a stratified (by asset class and age cohort) random sampling at the 85 percent confidence level. Note that mission life-cycle cost estimates for trailers and OSFs were *not* based on a sample, but instead were based on calculated estimates for their entire selected population. This was possible because of the relative simplicity of most OSFs and trailers.

Description of the Maintenance and Repair Models. The Maintenance and Repair (M&R) process begins with a component inventory of an asset. In this example, we use the Maintenance and Repair System (MARS) computational engine developed by Whitestone Research. Derived from asset plans, equipment inventory data, and on-site inspections, these components are organized into UNIFORMAT category level three elements and are identified specifically in terms of product characteristics, quantity, and output level; e.g. “Single-Ply Modified Bituminous/Thermoplastic Roof,” “Condenser, Air-Cooled, 60 Ton,” or “Pipe & Fittings, ¾” Copper.” Typically, a building model consists of 75 to 200 components.

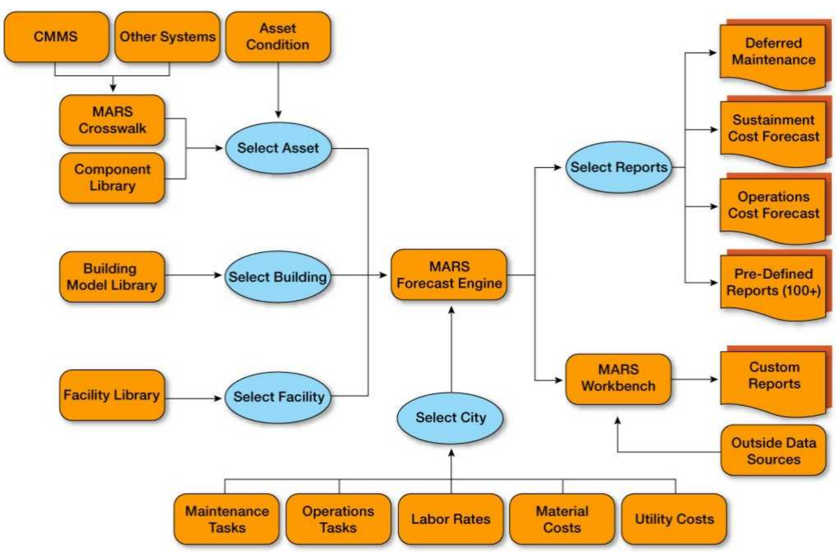

Figure 5. MARS Facility Cost Forecast System

Once the component inventory is completed, the models relate maintenance tasks from a pre-defined task library to each selected component. New components and related tasks are defined as necessary. Task frequencies for some sites were edited to reflect actual practice. Other calibration steps included modifying default values for contract and in-house labor rates, specifying site-typical mark-up for contract expenditures, and describing the utilization characteristics for each asset. Calibration of models to actual site activities and expenditures are a major feature of modeling

The frequency of each maintenance task determines both DM and the forecast of future required maintenance. While MARS generates estimates for three types of maintenance—

preventative maintenance & minor repair, service calls, and replacement and renewal tasks—only replacement and renewal tasks not done on schedule are counted as DM.[1]

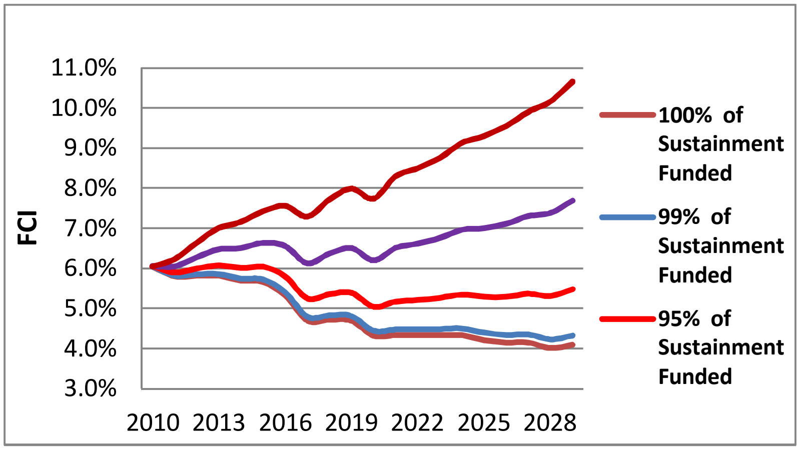

Figure 6. Total NNSA Facility Condition Index (FCI)

Projection results based on resource requirement (M&R calculation) and assumption of funding availability can then be used to project, for example facility condition index (FCI), which is a metric defined as fraction basis of deferred maintenance relative to the replacement plant value (RPV). In Figure 5 calculated example, FCI is computed for the entire NNSA real property portfolio comprising approximately $39.6B.

Operation Models. Models estimate operations costs other than maintenance and repair. These are based on the Facilities Operation Model developed jointly by the Department of Defense (DOD) and Whitestone Research. This model provides costs for ten services, including those mentioned in the Federal Real Property Council (FRPC) guidance[2]—utilities, cleaning and janitorial, and roads and grounds. Operations cost models provides estimates for Custodial, Energy, Grounds, Management, Pest Control, Refuse, Road Clearance, Security, Telecommunications, and Water and Sewer.

Modeling Infrastructure T&D. T&D costs were estimated using a collection of models and secondary sources. Primary resources include estimates from the Remedial Action Cost Engineering and Requirements (RACER) system developed in collaboration with the Air Force Civil Engineering Support Agency, the Facility Decommissioning Cost Model study prepared by Kaiser-Hill for the Rocky Flats Environmental Technology Site, the MARS system, and interviews with LLNL technical staff. [3]

T&D estimates are expressed as costs per square foot or "cost factors". Cost factors were generated for all combinations of usage code (128), hazard category (10), and level of contamination (4), a total of 5,120 cost factors. The level of contamination is determined by the hazard category. For example, a Hazard Category 2 Nuclear Facility was assigned a high level of contamination with primary contamination from Alpha, Beta, and Gamma radionuclides. Cost estimates are for structures only. Soil and groundwater remediation costs are not included.

Cost is heavily influenced by the level of contamination. Level of contamination is defined as a percentage of building area (GSFT) contaminated. Four levels are used: None (0 percent), Low (10 percent), Medium (30 percent), and High (50 percent).

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[1] This definition is consistent but more precise than the definitions of DM found in FASB Standard Number 6.

[2] Federal Real Property Council. *Guidance for Real Property Inventory Reporting.* Washington, D.C. August, 2006.

[3] Kaiser-Hill, L.L.C. *Facility Decommissioning Cost Model, Revision 3A*. May, 2000; MARS is a facility life-cycle cost model provided by Whitestone Research. It is currently in its eighth version.

Remediation of the contaminated area requires different levels of worker protection, as defined by OSHA.[4] Protection levels vary by phase and level of contamination. For example, sampling of a contaminated area in the transition phase requires the following levels of safety: A for 10 percent of the contaminated area, B for 30 percent, and C for the remaining 60 percent. Following decontamination activities performed during the deactivation phase, sampling during the decommissioning phase requires C for 30 percent and D for 70 percent.

Demolition and disposal costs are driven by the volume and type of construction materials. Our estimates cross reference construction type to usage code and calculate a volume per square foot. Level of contamination of the debris is also a key input to these costs.

Surveillance and maintenance costs are estimated as annual requirements and vary by the delay between the deactivation and disposal phases. Delay is determined by level of contamination, a high level of contamination implies is a ten year delay period, medium is a five year period, and low or no contamination is a two year period.

The maintenance tasks performed over this delay also varied by level of contamination. For low or not contaminated facilities, preventative maintenance and repair tasks (all replacement tasks were excluded) were performed for roofing and fire protection systems only. For medium and highly contaminated facilities, it is assumed the building has a negative pressure and incurs maintenance costs on air handling equipment, as well. A location index was then calculated to adjust costs to the remaining NNSA sites.

Modeling Critical Skills

Modeling the Critical Skills in competency-based organizations that are highly technical is difficult and critical to the overall viability of the NSE. NSE critical skills are the foundation of all DP activities. Starting in 2010 with nuclear laboratories critical skills and developed a model based on recent studies at the nuclear laboratories and general workforce concepts. Two different model views were created based on analyzing various sources of information a cohort-based representation of critical skills (Figure 7), which depicts career stages and a knowledge-base representation of critical skills mastery (Figure 8), which is based on experience and breadth of knowledge.

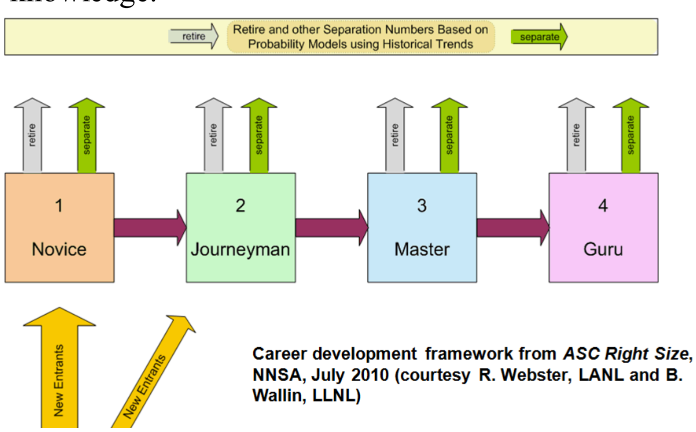

Figure 7. Cohort-based representation of critical skills

Supply and Demand-side Modeling. The modeling done used data maintained by the sites on careers of people and the assignments they might be able to assume. It was also done with an understanding of the future product work that was being planned. Therefore, this modeling took into account the supply and demand of critical skills for the nuclear laboratories with assignments germane to the NSE work.

HR Tracking. The nuclear laboratories had recently gone through a reduction in force and significant data was

[4] United States Department of Labor. Occupational Safety and Health Administration, "Occupational Safety and Health Standards". 29 CFR, Part 1910.

available to create the critical skills models based on analysis of HR information. That information includes initial conditions of the demographics and sigma mapping to extract DP critical skills. From the laboratories workforce data the hiring, retirement, retention, and separation information was available. Over 400 resumes were studied to understand career stages including career progression and participation in significant program activities. Laboratory program records for test activities and Science and Technology publication records were used to diagram career stages.

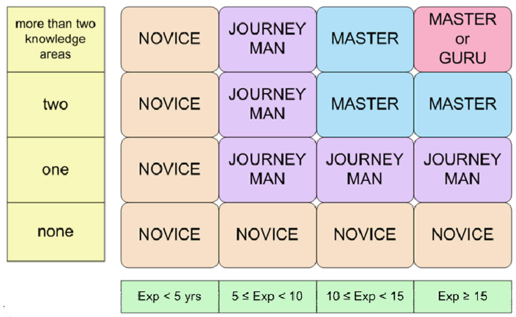

Figure 8. Knowledge-base Representation of Critical Skills Mastery

Programmatic Specialization. What an engineer knows and their level of mastery is critical to leading the next refurbishment program and passing knowledge to the next generation of engineers and scientists. There were on the order of 36 critical skills categories obtained in analyzing records. These critical skills include specializations based on key experience. An initial calculations of net present value of all the masters estimated an investment of over $40 Billion. This estimation included recruiting, retention, training, and participation in expensive development activities such as qualification tests.

Stochastic Models. We can now project trends in nuclear laboratory workforce as a function of planning scenarios, and examine dynamics of key variables. Monte Carlo simulations of career progression model show useful insights into long-term impacts of key variables. The goal of this modeling tis to understand how to maintaining a core capability ("Masters" population) over the planning cycle, 2010-2030.

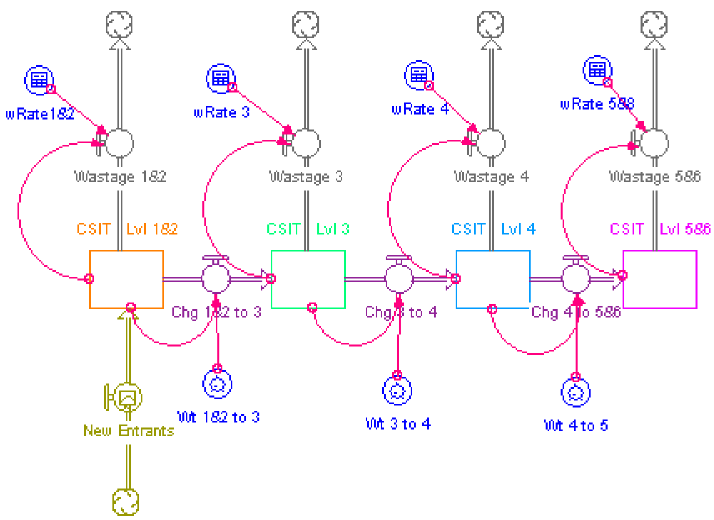

Figure 9. Example of Cohort-based Implementation in Dynamic Model

Product Modeling and Sustainment Planning

Planning stockpile refurbishment, maintenance, evaluation, and dismantlement for complex aging systems requires coupling the infrastructure limitations with the critical skills of the laboratories and production plants. With the Nuclear Posture Review (NPR) and New START treaties planning the stockpile continues to be a collaborative effort with the DoD. Annual requirements are negotiated with the DoD for the stockpile. These requirements are then further analyzed and decomposed into schedules that set the directives for the NSE. The EMC is participating in studies to figure out the most viable paths to refurbishment given a workload in maintenance, evaluation, and dismantlement. Since the systems are very technical and require a collaborated effort between sites modeling becomes an important tools to anticipating problems and creating an executable plan in a constrained environment.

EMC is creating several modeling tools including some that are based on process-based tools like ExtendSim (Imagine That Incorpoarated) and others that are based on large-scale mixed integer programming. This is a core area for the EMC and developing a robust response to scenario modeling is a key objective for stockpile modeling.

Future Work

Further Development of Modeling Capability

Verification and Validation and Baselining. Verification and validation (V&V) activities are crucial for developing accurate models and performing model and data sensitivity analysis. Although these activities may vary depending on the specific model, topical area, or data type, they may include enterprise data validation, the development of standard test case problems, or the evaluation of the applicability and limitations of a given model or dataset. They may also include the adoption of QMU methodologies and the cross-validation of models, including forward and backward calculation approaches.

Enterprise Data. Data protocols for the collection, maintenance, security, and integrity of enterprise data will be defined so that any EMC-generated scenario data is of archival quality. High-value enterprise datasets will be made available to modeling groups to support near-term enterprise analysis and V&V activities, and they may be expanded based on future results from model development and V&V.

Infrastructure. A full lifecycle treatment of programmatic equipment is needed for accurate resource projection and capacity analysis. The treatment of programmatic equipment is particularly needed to strengthen the coupling between the stockpile and infrastructure application areas. In a number of areas, infrastructure models are reaching a state of maturity that makes them amenable to more rigorous error and sensitivity analysis. Thus, continued refinement and V&V efforts for these models are required at all eight M&O sites.

Critical Skills. The EMC survey identified the existence of HR management tools a teach of the eight sites. In addition, a critical skills modeling set being developed uses a combinatorial graph tool to describe the relationship between the critical skills needed at the design physics laboratories and the funding received for DP B&R and WFO activities. EMC is also developing statistical Monte Carlo methods to project manpower sustainment for critical skills positions.

Creating the Larger Context for Enterprise Modeling

The EMC modeling is based on the extensive modeling and simulation history at the NSE national laboratories. As EMC moves forward and integrates with modeling done in the DoD creating a larger context for the EMC modeling becomes a tool to set the framework and integrate modeling capabilities. Using the DoD Architecture Framework V2 and the UPDM Standard will allow the NSE to develop common terminology and define ontology such as the use of the work “capability”. Figure 10 depicts a high-level view of Enterprise Architecture modeling from the International Defence Enterprise Architecture Specification (IDEAS) Group. Since the maintaining a nuclear deterrent has a fixed cost associated with maintaining capabilities it is important to clearly define the capabilities that must be maintained. EMC is working with other initiatives in the NNSA to better define capabilities and tie modeling capability to budget and other planning tools. Using concepts and metamodels provided in architecture frameworks will allow EMC to create a common framework for future modeling.

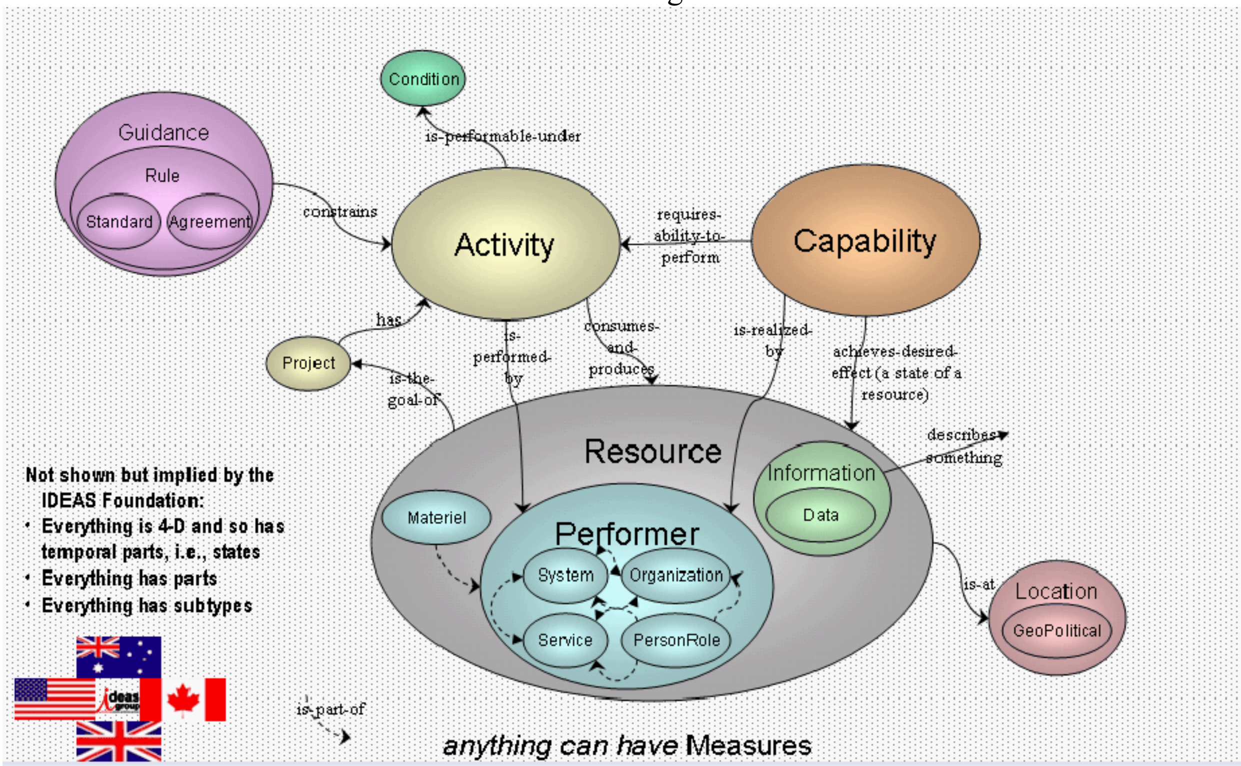

Figure 10. Concept Model from IDEAS for Enterprise Architecture Specification

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References

Citing. Cite references within the manuscript body using parentheses that enclose the last name of the author and year of the publication, for example "(Smith 1983b) described …" or "… was documented in (Jones et al. 1985)" or "…these findings (Smith 1992)." A trailing lower-case letter distinguishes multiple papers by the same author in the same year.

Reference list. Each entry in the list should use the style Reference. The list is organised alphabetically by the author's last name. Multiple entries with the same author are arranged chronologically. Italicize the name of a book or journal. Note the following examples:

Hause, Matthew, "Model-based System of Systems Engineering with UPDM", *Proceedings of the INCOSE International Symposium*, July 2010.

Shang, Cliff, "Modeling the Nuclear Enterprise". *Science and Technology Review*, December 2005.

Biography

Dr. Griego is a leader in the area of Requirements Engineering. Her academic and industry focus incorporates using modeling as a way to formalize problem understanding and develop requirements. She has been instrumental in enterprise modeling in various application domains throughout her career. She is a Past Technical Director for INCOSE and Founding President of the INCOSE Enchantment Chapter. Dr. Griego is on assignment to the National Nuclear Security Administration (NNSA) working in the Nuclear Weapons Stockpile Division as a Senior Systems Engineer and functions as a Systems and Enterprise Engineering Advisor. She is employed by Sandia National Laboratories. Dr. Griego has a Ph.D. in Computer Engineering (Research in Requirements Engineering) from New Mexico State University (NMSU), an M.S. in Computer Science from University of Colorado, an M.S. in Electrical and Computer Engineering from University of Arizona, and a B.S. in Electrical and Computer Engineering from NMSU.

Dr. Shang leads the M&S…..