Integrated Framework for Modeling & Simulation of Complex Production Systems

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ABSTRACT

The time-consuming and challenging tasks of large-scale simulation modeling; knowledge collection from disparate sources, model building and validating, and multiple-scenario simulation runs to find best solutions are generally distributed between several specialized tools. Because manufacturing and business systems are complex systems encompassing many different sub-systems and because different domain experts are involved in designing, implementing, and maintaining the different sub-systems, it is becoming imperative that descriptions from different domain experts are captured, stored, integrated with data from legacy information systems and used to design multiple simulation models of the enterprise systems. This paper presents the concept and a framework for capture and maintenance of multiple descriptions and its applicability in manufacturing systems modeling and simulation. It presents a knowledge-based approach to supporting the integration of multiple descriptions with data collected from legacy status data for use in the design and generation of valid simulation models. This effort, On-Demand Simulation and Scheduling (ODSS), created an adaptive modeling and simulation framework with knowledge management tools, automated generation of simulation models, experimentation environment and seamless integration with the legacy systems for users in the dynamic context of Maintenance, Repair, and Overhaul (MRO).

INTRODUCTION

Today's manufacturing and business systems are complex systems encompassing many different sub-systems such as production process, material handling, material storage, shop floor control, and order release. The manufacturing and business systems in today's world so complex that attempting to capture descriptions from a single domain expert or from any one point of view cannot be guaranteed to be complete. In most organizations, different domain experts are involved in designing, implementing, and maintaining the different systems and sub-systems. Domain experts often view a system from a perspective that is heavily conditioned by their roles in the organization. And, frequently, a domain expert may have detailed knowledge involving only some aspects of the system. It is therefore becoming more and more imperative that the descriptions from different domain experts are captured, stored, and used toward designing realistic simulation models of manufacturing systems. In addition the time frame within which a simulation result is needed to support decision-making has continued to shrink. The focus of this paper is to present the concept of an integrated environment to capture multiple descriptions, extract model architecture and parametric data from legacy enterprise planning and monitoring systems, and generate manufacturing systems models and simulations to address questions in “real-time”. The knowledge based approach to integrating multiple descriptions with legacy data in order to generate a valid model is the result of many years of research in the process and logic of the human skill in model design, and the representation of the system description in a model independent fashion. Basic technology components implemented in the ODSS tool include (i) process knowledge collection based on the IDEF3 method that creates a library of reusable “template” models; (ii) automated simulation model generation which results in the generic process models customized for each individual entity; (iii) convenient experimentation environment including Wizards that guide the user through the model instrumentation steps and provides him with default options; (iv) a web-based graphical user interface that enables sharing of the simulation results and on-line collaboration; (v) data exchange with legacy databases and with MS office tools, MS Project® and Excel®. The components in the ODSS system have been refined by implementing actual self-maintaining, on-demand simulation capability in the inherently complex maintenance, repair, and overhaul (MRO) environment.

Delivering a single interface, web-based, integrated framework of legacy data sources, knowledge management tools, automated generation of simulation model, and experimentation guidance for a non-technical user in the very dynamic and tumultuous MRO context of large aircraft systems is the context of the current ODSS project. Technical enablers and components included: 1) the IDEF3 Process Capture Method (ProSim™); 2) the ontology driven description capture environment (TAV™), 3) a rule-based simulation execution engine (eSim™), 4) a simulation based planning and scheduling engine (WorkSim ™), and 5) a simulation configuration advisor (SimWizard ™).

The technical viability of the approach has been successfully validated at the Oklahoma Air Logistics Center through application on the E-3 Programmed Depot Maintenance, Avionics repair daily shop scheduling, KC 135 Dock Plan Analysis, and B1-B Major Job Labor Utilization Analysis.

Background

The importance of multiple views in information systems related disciplines has been recognized by several authors. For instance, in software engineering literature, the need to use multiple views of the software architecture (system developer and system user views) was emphasized early on and has been carried through to the concept of frameworks of systems architectures. Database management system (DBMS) researchers, in particular, have explored the concept of multiple views in great detail. In the context of modeling and simulation, the notion of multiple views has mostly been focused on the underlying worldviews embodied in a particular modeling language. The simulation tools that are available today provide support (although limited) in modeling some sub-systems (like process system and material handling systems in AutoMod), but they do not provide support for modeling a system from different views or at multiple levels of abstraction.

There are two primary advantages in the use of multiple descriptions in generating simulation models.

1. Models generated from multiple descriptions tend to be more realistic and efficient in answering questions about the system. This is because multiple descriptions provide more information than a single description and highlight biases present in a domain expert's understanding of a situation. The way a problem is viewed drastically influences the way a problem is solved.
2. Multiple descriptions facilitate the model design process itself. Because multiple descriptions provide more information than a single description, they will greatly aid the conceptual model design process.

Our approach in attempting to unify multiple views is unique in the sense that it is *description-driven*. This approach is based on the premise that problem situations drive the capture of descriptions about the system and the set of questions that needs to be answered. This evolving system description base will be maintained by a knowledge based tool allowing facts about the system to be captured and consequently carried over or shared between analysis situations. This approach shifts the focus to reuse of the *facts* on which the model is based, instead of the *models* themselves. The description-driven approach toward building simulation models is based on the Air Force IDEF3 method (www.idef.com).

Challenges of the MRO Domain

MRO management is highly unpredictable and complex. Over 200 engineering support requests (202s) are made per month just for the KC-135s, and at least 10% of the changes are made late in the depot cycle (at post-dock)--this for a process whose basic nature precludes detailed knowledge of the existing work content prior to initiation of the repair work. Modeling is the only way to understand such complex systems. Decision makers at different levels require different degrees of abstraction. There is no "silver bullet" that serves all purposes. To be effective, a modeling environment must interoperate with the myriad of existing systems through a common portal. Moreover, the modeling environment must provide a running picture of change--from current baseline to desired future baseline. An immersive –road map is necessary to identify future actions and provide the type of situation attunement necessary to move from the current baseline and realize the desired "world" state. Simulation provides the mechanism for managing change.

Customer satisfaction is based largely upon the stability of the product. In the world of Maintenance, Repair, and Overhaul (MRO), variation is the hard reality—means and medians are the abstractions. Inability to squeeze out and eliminate the variability in the process generates instability in the system and, subsequently, loss of customer goodwill.

Current depot-based planning and scheduling systems require that the time to repair be quantifiable and used in subsequent planning, resource acquisition and coordination, and scheduling activities. However, the mean and median are gross abstractions for the highly variable nature of the repair work. The time to repair is based upon several populations of failed and/or aging items. The composite distribution—constructed and used in practice due to the inadequacies of the MRO information acquisition mechanisms—exhibits such a large (wide ranging) variance that any point estimate used to describe the distribution is basically arbitrary and of no consequence. Work content inspections result in no fewer than six types of outcomes:

- Nothing is wrong,
- A little direct labor is necessary to correct the deficiency;
- A little direct labor and indirect material is needed;
- More direct labor and direct material is required;
- Go ask for help (this is not covered) to generate an engineer support request [202], and
- Reiterative (another inspection is needed due to results of this one).

This information remains with the mechanic and/or supervisor. To the planner, it appears that variability has no bounds (to the mechanic, the variability for the “time to repair” measures is very large) and that each part is its own population (each new type of work seen requires changes to the resources). New facilities and GSE need to deal with (i) unforeseen fleet grounding events and (ii) new item configurations. Moreover, (i) new skills are needed within the labor force in order to perform tasks efficiently and consistently and (ii) new parts/part acquisition methods are needed to deal with the repair of items that have exceeded their original design life. Hence, current planning and scheduling systems are flying blind – not because data cannot be collected, but *because the right data is not being collected*.

The figure below illustrates what is seen and unseen by the legacy depot information systems.

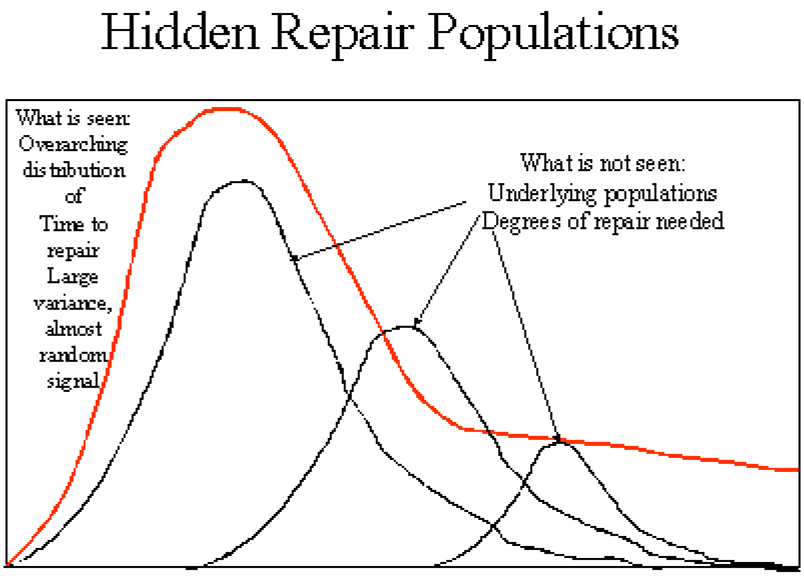

Figure 1: Legacy Depot Data Systems Visibility

Further, aging systems are those systems that are in the process of, or are at the end of, their designed lives. MRO of aging systems is a perpetual battle between the desire to bring the work item (through repair) into a state of "as new" and the desire to mitigate costs and time constraints and return the work item to the field "as capable." The figure below summarizes the aging phenomenon superimposed on the classic failure curve model.

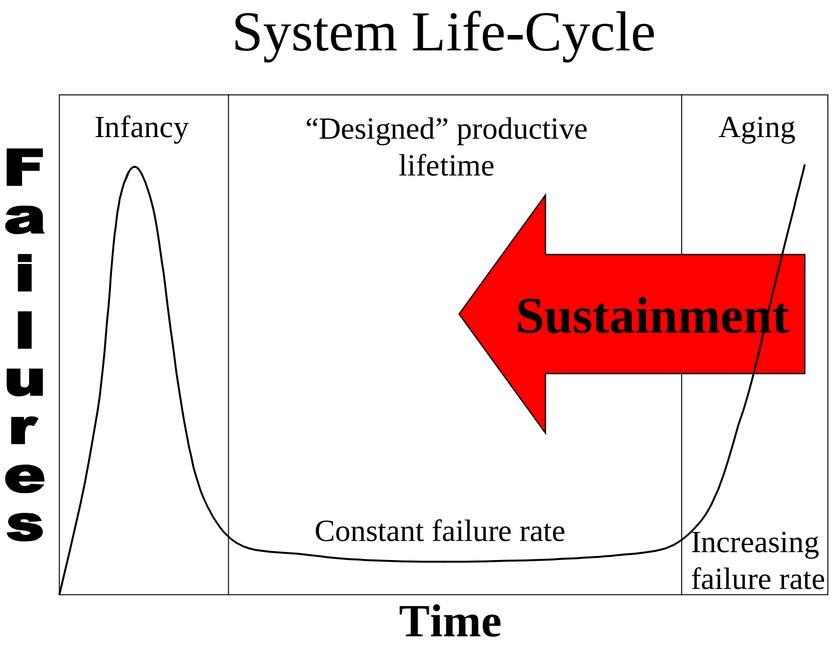

Figure 2: Aging Phenomenon versus Classic Failure

ODSS Solution Concept

The central innovations on which ODSS is based include a set of enabling technologies that lead to adaptive reconfiguration of simulation models over extended periods of time. The adaptive reconfiguration and optimization are accomplished by the innovative application of soft computing and knowledge discovery techniques. The technical viability of these enabling mechanisms has been proven by implementations of intelligent simulation reconfiguration agents in multiple application domains.

A chart of the basic technology components is shown below. ODSS is a system of technologies that collectively enable the user to develop, on demand, a simulation-based analysis, planning, and scheduling capability from their desktop for the purpose of process-centric capacity constrained analysis and schedule generation. The tool-suite is targeted for near, mid, and far term planning and scheduling decision scenarios. Each component in the ODSS system has been designed specifically to address issues germane to the logistics and MRO environment. The subsequent paragraphs introduce each component and its role in the ODSS paradigm.

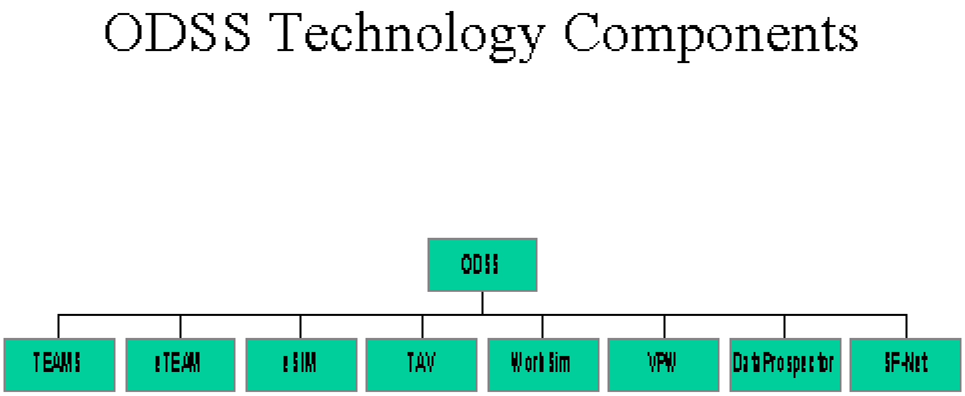

Figure 3: ODSS Technology Components

TEAMS

TEAMS is a re-configurable and scalable framework for spaceport operations analysis (including process modeling, simulation, asset management, scheduling, and product-process-technology dependencies) for NASA Kennedy Space Center. Because it operates over the Internet and uses a generic web-browser as a client, the TEAMS solution provides platform-independence and enables collaborative process design and systems modeling and analysis over geographically dispersed locations.

eTEAM

The eTEAM tool was designed to support the enterprise wide technology portfolio management and systems development based on frameworks of systems architectures. The tool offers web-based collaboration capability to the users in support of the complete system analysis, engineering, development, deployment and support lifecycle. The ultimate goal of the ODSS is to reuse these systems architectures as the baseline system descriptions for generation of analysis supporting design trade studies and decision support applications supporting systems operation management. In addition, each analysis assignment can, in fact, be treated as a “system development” in eTEAM. Thus its planning, budgeting, execution, maintenance and management can be handled with the support of the eTEAM tool.

eSIM
The eSIM technologies comprise a class of hybrid rule-based, discrete-event, and continuous model processing engines. These engines have been developed from to address shortfalls in the currently available technologies used to simulate operational rules and policy dominated systems architectures in MRO and other logistics operations.

TAV
The TAV technology serves as the core information backbone and relation manager for the ODSS tool-suite. The underlying architecture of the TAV uses meta-data concepts to allow for the design and generation of domain specific description capture capabilities / components that are then used to capture the evolving system descriptions needed to support expansion of the ODSS application into new domains. This provides a scalability to ODSS in addition to its high re-use capability.

WorkSim
WorkSim automates the generation of planning and scheduling applications using simulations generated off of domain descriptions. This automated generation capability offers the option to generate multiple solutions and identify the cost/performance trade-offs for each solution. The ODSS scheduling engine leverages key features of the WorkSim deployed capability.

VPW
The VPW component addresses the need for a web-based graphical user interface that expedites constraint capture, alternative formulation, experiment definition, and analysis result presentations/visualization. The VPW provides an important collaboration enabling capability for the ODSS.

DataProspector / Personal Data Prospector
KBSI’s DataProspector™ toolkit provides automated support for different activities in the “knowledge discovery” process inherent in ODSS, including (i) problem definition, (ii) data preparation and validation (including data assessment and repair), (iii) data mining, (iv) analysis result integration, and (v) result interpretation and knowledge delivery. The DataProspector™ is currently being deployed in many different data-mining applications in both large-scale and data-constrained situations. This capability to adapt to knowledge discovery in data-sparse environments and the ability to support text, signal, and image inputs as well as transactional data inputs is key to supporting the ODSS requirements.

The B1B Capacity Planning Implementation

ODSS technology has been applied to the modeling and simulation of the B1 production line at Tinker Air Force Base. The developed tool provides Production Engineers with an advanced environment that allows them to significantly raise the efficiency of their modeling and simulation activities. Although trained and experienced as simulation analysts, creation of one single WITNESS® simulation model of the entire production process, even at a major job level of detail, as well as running the experiments on such a model, and, subsequently, processing the results can take a very long time. For a given set of modeling assumptions, the analysis can take anywhere from a week to several months, and the typical goal of an analysis assignment is to compare several models constructed under different modeling assumptions.

The rationale behind the B1-B project was to apply the ODSS technology to enhance the analysis capability associated with major job analysis: to make it more flexible, rapid, and accurate. The goal of the analysis efforts is in support of the Planners and Schedulers as well as to evaluate suggestions concerning process re-engineering. Thus, the ODSS was configured to support:

- Easy generation/reconfiguration of simulation model from a description of the production situation;
- Seamless link to simulation software (in this case, WITNESS®);
- "What-if" configuration and design option management environment;
- Estimation support for the stochastic model parameters;
- Analysis of the simulation trace produced by WITNESS® and customized reporting; and
- Hot start for the simulation based on the current work in progress status.

The system description repository started with the establishment of the reference process models describing the B1B PDM production; model development can be performed in (i) PROSIM®, (ii) Microsoft® Project, or (iii) Excel. In this implementation all three input forms were employed. The major jobs and their precedence relationships were provided in the form of MSProject and ProSim files. The required man-hours by skill type required for each major job and were provided in Excel files.

The analysis generation capability was configured to support two basic types of analysis:

1. Analysis with ***constrained availability*** where the user defines the daily amount of available labor resources.
2. Analysis with ***unconstrained availability*** assuming that any amount of labor is available upon request and the aircrafts are serviced immediately starting with the induction date.

The tool can also be used in a hybrid mode, where some of the resources are constrained and the others are not. For example, the facilities can be treated as a constrained resource and labor as an unconstrained resource and vice versa.

The analysis can be performed in deterministic or stochastic modes. In the ***deterministic*** mode all the parameters of the master network are defined as constants; these parameters include the amount of hours by skill type required to perform the job and the duration of the job. The main purpose of the deterministic analysis is to produce the simulation trace and estimates of the depot capacity and labor requirements. In the ***stochastic mode*** the user will define stochastic function for the master network parameters (such as resource requirements and durations) that are treated as fixed values in the deterministic mode.

The resulting system is being used to assist in analyzing labor requirements for the B-1 production line at Tinker Air Force Base. The tool is being used by the Production Engineers who support the B-1 Master Scheduler with a capability to determine workload levels by skill type and by shop corresponding to the current work in progress and future aircraft inductions under different maintenance policies.

Benefits & Conclusion

The ODSS will enhance proven technology for rapid creation and application of simulation modeling for Depot management decision support. The evolving capability uses a combination of integration of multiple sources of system descriptions, automated model generation, data mining and knowledge discovery methods to automatically reconfigure and apply systems simulation models. Because it incorporates description, model, and analysis results portal capabilities, the ODSS solution will enable collaborative depot shop systems modeling and analysis over geographically dispersed locations. The benefits of the proposed innovation to current and future OC-ALC/commercial depot process design and analysis initiatives are summarized in the following.

(A) Reduced Simulation Lifecycle Costs: ODSS technology will significantly reduce the time, effort, and cost required to develop, deploy, and maintain complex analysis models. This benefit will accrue through (i) rapid reconfigurability of simulations through the knowledge based model generation mechanisms and (ii) reduced cost of model maintenance through reconfigurability and through increased re-use of simulation life cycle information at the domain level and at the design level over extended periods of time. The proposed description-based approach to simulation development will enable future support analysts to rapidly respond to decision-maker requests starting from libraries of domain descriptions, analysis process models, as well simulation models.

(B) Simulation Agility: ODSS enables end users to *rapidly* and cost effectively reconfigure / reparameterize simulation models (including their architectures) in response to constantly changing problem needs and requirements. This capability is achieved through the reconfiguration mechanisms and the description-based approach to simulation development. This capability will help systems developers use simulation as a mechanism for responding rapidly to unpredictable changes in customer needs and requirements and environment changes. We refer to the rapid response capability as *simulation agility*.

(C) Affordable, High-Performance Depot process: The application of ODSS to the design of OC-ALC depot process will lead to the rapid deployment of a *cost-effective* and *high-performance depot process*. This will be enabled through the exploration of multiple depot process design options through simulation-based analysis. The use of a simulation-based approach to depot process design and acquisition will allow for effective *verification/validation* of depot process operations (and maintenance) early in the development life cycle. This will result in significantly *reduced depot process life-cycle costs*.