Risk Reduction and Training using Simulation Based Tools – 12180

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ABSTRACT

Process Modeling and Simulation (M&S) has been used for many years in manufacturing and similar domains, as part of an industrial engineer's tool box. Traditionally, however, this technique has been employed in small, isolated projects where models were created from scratch, often making it time and cost prohibitive. Newport News Shipbuilding (NNS) has recognized the value of this predictive technique and what it offers in terms of risk reduction, cost avoidance and on-schedule performance of highly complex work. To facilitate implementation, NNS has been maturing a process and the software to rapidly deploy and reuse M&S based decision support tools in a variety of environments. Some examples of successful applications by NNS of this technique in the nuclear domain are a reactor refueling simulation based tool, a fuel handling facility simulation based tool and a tool for dynamic radiation exposure tracking. The next generation of M&S applications include expanding simulation based tools into immersive and interactive training.

INTRODUCTION

Time plus Cost equals Quality. This fundamental business equation stands the test of time. In today's business environment, however, schedules are getting more aggressive and budgets are shrinking. Simple algebra necessitates that the equation be balanced. Sacrificing on quality is not an option, especially in the nuclear domain, where the risk is not tolerated. Thus, the answer is to introduce another element, which allows the time available to be used more efficiently while maximizing the return on investment by enabling better informed decision making. Modeling and Simulation (M&S) may be one such element. M&S provides an environment for experimentation in a domain where experimentation would otherwise not be possible, and allows for exploration of a variety of different alternatives. It's hard to think about M&S as a new methodology. In fact, the origins of computer simulation as we know it today are found in the Manhattan Project era. What is new about today's M&S is how it is applied, i.e. the type of problems and kinds of tools that are deployed to attack them. Every engineer today uses some form of M&S as a tool. The application is often constrained to a specific domain or a limited set of problems. At Newport News Shipbuilding (NNS), an M&S group has been working to create a capability to build M&S based decision support tools that are flexible, reusable and can be expanded to address complex system of systems problems. These tools have proven effective in the nuclear domain, where the nature of the processes does not allow experimentation or room for error. These M&S tools arm the decision maker with predictive capability and facilitate better, more informed decisions, which result in risk reduction, cost avoidance, cost savings and schedule certainty.

PROCESS SIMULATION FOR COMPLEX NUCLEAR SYSTEMS

M&S is a very diverse discipline. Today, many engineering disciplines rely on M&S techniques to design and validate complex systems. Process simulation is an area of M&S that has not been employed to its fullest potential. Process simulation refers usually to using Discrete Event Simulation (DES) techniques to represent systems that are comprised of some operations, often performed by people. Process simulation is most commonly used along with other Industrial

Engineering methods for design and improvement of manufacturing style systems. As such, there are many Commercial off the Shelf (COTS) tools available for process simulation that lend themselves nicely to manufacturing problems. These tools are also often designed to tackle relatively small manageable problems. For complex systems and difficult process development tasks outside the scope of manufacturing, however, these tools can be challenging to apply. Some software challenges include scalability, expandability, configuration management, interoperability and ability to represent unique and complex behavior. In addition, simulation models are themselves an investment of both money and time. In creating them it's important to ensure that investment is minimized while the returns maximized.

Over the years of working with multiple COTS tools, the Common Simulation Framework (CSF) was conceived at NNS as an alternative to commercially available simulation packages. The CSF is a component based stochastic discrete event simulation framework that is built upon the Java programming language. It is a flexible general purpose simulation tool used in a variety of domains. The CSF provides an Application Programming Interface (API) with which a software developer can write Java code representing a model. It uses a layered approach to provide functionality to the modeler. Some of the features of the CSF are 3D visualization, libraries of reusable components, ability to run models as standalone executables, creation of custom user interfaces, multi developer and configuration management support through widely available tools such as Eclipse, among others. The object oriented nature of CSF is geared toward scalable complexity, allowing for the creation of simulations as a series of building blocks. Customizable architecture provides the flexibility to address a wide range of decisions relevant to project management, while 3D visualization facilitates the intuitive grasp of M&S results. These features are essential for expandability and reuse of the model to support critical decision making as a project evolves from planning to construction to sustained operation.

The CSF software provides flexibility and reuse, and the process employed by the development team ensures that the simulation tools are developed efficiently and cost effectively. This process draws on the Agile Software Development (www. agilemanifesto.org) principles of iterative development. The process focuses on consistently connecting model development with the problem statement and analysis needs, ensuring development of valid and useful tools, utilizing sound statistical techniques and engaging the stakeholders throughout the development cycle. The Agile Software Development methodology allows the team to be flexible to changing assumptions, and deliver relevant solutions faster, while ensuring that customer needs are met. M&S is applied from a total lifecycle perspective. Instead of developing single purpose models, the team focuses on building reusable and expandable decision support tools that evolve as the needs change.

The CSF software and the Agile M&S process have been successfully used on many programs ranging from manufacturing models, logistics models, ship platform models and nuclear operations models. The following examples showcase these applications in the nuclear domain, specifically nuclear reactor and other related operations.

APPLICATIONS

Reducing risk with respect to schedule – dynamic planning

Requirements to meet aggressive deadlines or to fit a restricted schedule can act as catalysts for process improvements. Since the mid 1970's, NNS has performed new construction and Refueling & Complex Overhauls (RCOH).on Nimitz class aircraft carriers. RCOH is a massive undertaking and was described in a 2002 Rand Study as one of the most challenging engineering and industrial tasks undertaken anywhere by an organization [1]. The six plus year process is performed only once during a carrier's 50-year life and includes refueling of the ship's two nuclear reactors, as well as significant repair, upgrade and modernization work. Nuclear reactor refueling, in itself, is a highly complex undertaking involving well defined procedures, specialized personnel and equipment, and strict radiological controls. The high complexity and long duration of the activity poses challenging schedule and budget risk. In performing this work on the most recent ship, a new simulation tool was introduced to help support informed decision making and risk reduction. The idea for this tool originated at a LEAN process Rapid Improvement Workshop aimed at reducing the refueling redelivery of the ship to the Navy. The intent of this effort was to utilize M&S technology to create a decision support tool. Originally, the goal of the tool was to help quick evaluation of multiple operational strategies, later the tool proved to also be a valuable production support aid.

At the heart of this simulation tool is a process model of the refueling operations. To build this model, the simulation team consisting of software developers, analysts and subject matter experts (SME) gathered legacy documentation, such as procedures and logs, conducted numerous interviews and analyzed tracking data collected over the last refueling evolutions. Using this information, the team broke the process down into over 100 unique steps. For each step, the team defined a probabilistic distribution representing the time it takes to do the work, the number and type of people required (e.g. technicians and mechanics), as well as the necessary equipment (e.g. cranes and special tools). The team also defined any constraints the system was operating within. These included such restrictions as surrounding work stoppage during a heavy lift. Finally, in researching the operations, the team separated productive work from work stoppages. Modeling work stoppages as distinct random events helped to quantify the effects of uncertainty on the refueling process performance metrics.

The foundation of the resulting tool was a dynamic stochastic (Monte Carlo) discrete event simulation, depicting reactor refueling operations. This simulation supports planning and decision making by dynamically assessing how schedules and decisions play out in light of typical uncertainty. The tool was designed in such a way to support any number of alternatives the decision maker may need to assess to establish the best work process. For example, the user is able to dynamically modify any number of parameters, such as number of people available, their qualifications, types of shifts, sequence of operations, and even add and remove discrete operations. The resulting analyses allowed a thorough assessment of the operational strategies with respect to not only schedule but also manning and other cost elements. The ability to "see" into the process also revealed dependencies and possible choke points. These analyses provided decision makers with realistic completion dates and allowed them to create a plan for success with minimum sensitivity to unknowns.

As mentioned above, the key to obtaining return on investment from simulation based tools is their reuse as project managers move on to subsequent critical decisions. With this in mind, the refueling simulation was transitioned from a planning phase tool to an essential element in execution phase decision making. Specifically, one of the main challenges in a complex production environment is predictability. Even the best plan or strategy can be thrown off by unexpected events such as weather disruptions, attrition of workforce, or temporary equipment outage. Consequently, once production is off track, there is a lack of visibility into the affect on completion of work or the threat of potential conflicts with other operations. A stochastic process simulation can help mitigate that risk by providing insight into likely outcomes given typical variability. In the case of the refueling simulation, it realistically captured not only the operations but the likely "gotchas." The data from a previous refueling was the source of probabilities and typical delays associated with equipment break downs, weather outages, etc. Using this data to generate random problems in simulation runs, the tool provided the decision makers with insight into the range of possibilities with respect to work progression. However, to be truly predictive, the tool needed to take into consideration not only changes to the plan in the future, but also the current state of operations. To accomplish this, the model was synchronized daily with ongoing operations. That is, actual status and completion data was fed into the model so that all of the events that have passed were no longer represented by probabilistic variables, but instead were played out as they did in reality. The simulation then provided a projected range of performance going forward from the current state of operations. This projected range of expected outcomes allowed project management to then assess, on-demand and rapidly, a variety of strategies to ensure successful project completion.

Figure 1 shows a sample chart generated from the simulation, indicating progress to date (Actual), planned progress (Original Projection), and simulation projected range of performance outcomes from current state on (Model Projected) As a result of utilizing this tool among other process improvements, the refueling evolution was completed on schedule and within budget. This tool is currently being used in planning for refueling of the next and future ships.

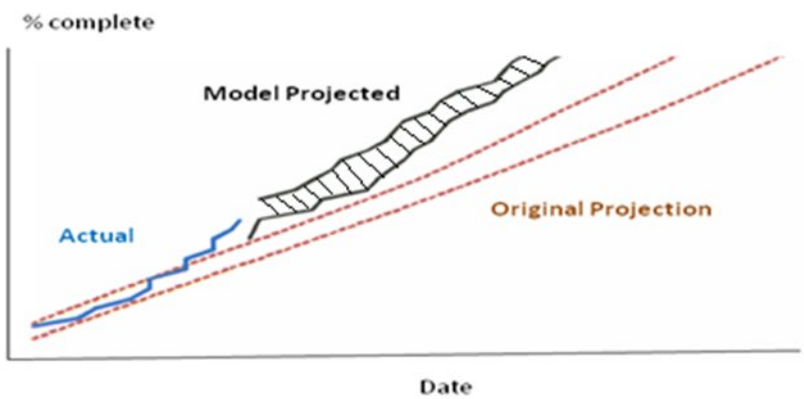

Fig 1 Sample chart from the reactor refueling simulation

Reducing risk with respect to cost – analysis of trade offs

Space restrictions, equipment locations, and procedures are among some of the constraints involved in operating a production facility. A Spent Nuclear Fuel (SNF) handling facility deals with additional constraints such as uniquely shaped large equipment and radiological controls. For this type of nuclear complex, traditional tools do not allow decision makers to predict uncertainties, assess schedule and throughput risks, or to perform operational trade-off studies to quantify and manage production cost versus performance. In constructing a new fuel handling facility, NNS developed a simulation based decision support tool utilizing the CSF to offer predictability, validate operational strategies and alleviate project risk.

To develop this tool, the team set out to capture all the relevant aspects of the facility: 3D representation of the building, derived from a Building Information Model (BIM), processes, equipment, people, cranes, containers, etc. One of the most important considerations for this model was the cranes. Since most of the equipment in the facility required a crane to transport, these resources played a critical role in the production throughput. Typical COTS process simulation tools treat cranes as basic transporters with little fidelity to the movement and no concept of collision avoidance or three dimensional movements. For this model, the team created a Smart Crane component, utilizing robust 3D spatial capabilities within the CSF. The

CSF allows for entities and planned routes to be represented as three dimensional shapes. This allows for dynamic route planning, path finding and collision detection. The Smart Crane is a way to capture human decision making patterns as part of the simulation. The cranes in the model are self aware; they take into consideration and dynamically reassess the environment around them to plan their moves, just as a crane operator would do. Figure 2 shows the shaded paths being planned for the cranes operating simultaneously.

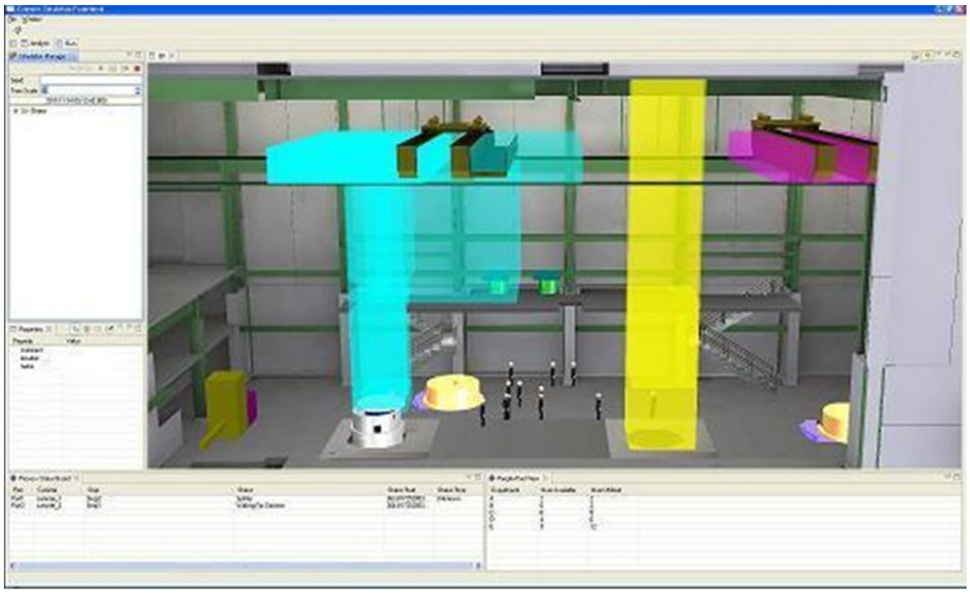

Fig 2: Model visualization of a facility with Smart Crane path planning

By utilizing M&S to create a virtual representation of the facility, its processes, resources and variable parameters, the team created a tool for the decision makers to use throughout the facility's lifecycle. The first major focus of this tool was on the efficiency studies. This involved analysis of alternatives to determine the best equipment and storage layouts, to assess different operational strategies to validate schedules. Equipment location plays an important role on throughput. Ineffective layouts generate bottlenecks and introduce non-productive idle time. Additionally, equipment layouts require design and fabrication of unique fixtures and shelves. By evaluating the feasibility and value of a specific layout with respect to operations, the tool provided a basis for well-informed decisions.

The next phase was geared toward manning assessments and training requirements. In this phase the tool was used to forecast manning levels required to support operations, evaluate various team sizes and understand the impact of manning levels and shifts on production. The tool also helped to determine qualification and training requirements by identifying demands on various types of personnel.

The tool continues to be used today for many facets of facility planning, such as capital expenditure assessments. When it comes to purchasing a multimillion dollar piece of equipment, the decision cannot be taken lightly. Traditional approach to this decision making requires extensive analysis of historical data, as well as subject matter expertise to interpret how the data applies to the new facility. But, most importantly, it takes time. Using the simulation tool, the assessment boils down to updating simulation parameters and observing the results. This approach is not only more efficient but it provides the decision maker with a way to measure the value of the capital expenditure in terms of schedule or throughput. This method can result in significant cost savings; such was the case at the NNS facility. Although efficiencies gained from an additional set of equipment were observed, they did not offset the cost of that additional equipment. In this case, the simulation based decision support tool helped prevent a costly investment, which despite its intuitive appeal, had little pay off potential. As the facility comes online, this tool will evolve into a dynamic production support tool, similar to the refueling simulation tool described above.

Reducing risk with respect to exposure levels – process based exposure prediction

Since 2007, NNS has been planning for the inactivation of an aircraft carrier. To support detailed planning, protect the workforce performing the decommissioning work and support ALARA (As Low As Reasonably Achievable) initiatives associated with radiation exposure, the team at NNS set out to develop a process simulation based aid for radiation exposure predictions.

Many sophisticated tools are currently used to model radiation fields, many of them in 2D (i.e. isodose curves), some are visualized in 3D. The one aspect shared by these tools is that they are static. They provide a detailed representation of the radiation fields in the environment at a specific point in time. In decommissioning operations, the radiation sources change dynamically, making it difficult to use static tools to estimate exposure accumulation for personnel as they move in and out of changing fields due to changes in environment. The proposed solution combined static calculations with a dynamic process simulation for a more accurate gauge. The tool is comprised of two components. The first component is a process simulation, representing the decommissioning operations. The process simulation is constructed using the CSF based refueling simulation, described above, as a foundation. By reusing the library of simulation building blocks, the development team is able to focus its efforts on building the additional capability. Here, a major focus is on personnel location. The team delineated each individual task in terms of not only durations and work stoppages but also specific work areas and how personnel moved through these areas during the course of operations.

The second component of the tool is an algorithm that represents the radiation fields. The radiation exposure algorithm is designed to allow for the presence of both a general area radiation field and a set of radiation emitting elements within the environment. This is made possible due to the level of spatial awareness available within CSF. Individual elements are modeled using a set of simple three dimensional approximations (point, line, cylinder, sphere, etc). Each of these elements is then decomposed into a set of point sources. The calculation for a single point source is taken from Glenn F. Knoll's Radiation Detection and Measurement [2]. The exposure rate for a given point source , is given by

$$= \Gamma * — \qquad \text{(Eq.1)}$$

where Γ is the exposure rate constant, is the activity of the source, and is the distance between the source and the location at which the calculation is taking place. Finally, total exposure at a point in space is given by the sum of all in the environment plus the contribution from the general area field.

The two components work together to create a dynamic environment for tracking exposure levels. As part of the input data, the model is given the radiation sources associated with the operations and their locations. As the operations are executed in the simulation and the corresponding sources move in and out of the environment, the algorithm continuously recalculates the fields. This allows the simulation to track each individual's accumulation based on where that person is at any given point in time and what the fields are where that individual is standing. This method mimics the way dosimetry measures radiation exposure real life. Model visualization in Figure 3 shows visual cues for when personnel reaches various levels of exposure accumulation.

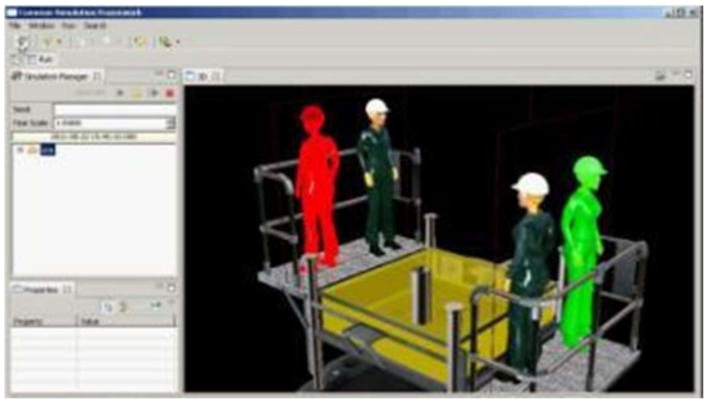

Fig 3 Radiation exposure model visualization

The resulting accumulation levels are used to conduct a number of analyses. The data is used to quantify the risk associated with working a specific operation, the relative benefit of particular work positions or the payoff of creating a team to breakdown complex jobs into simpler, more efficient tasks. The data also supports ongoing projections and estimations conducted as part of the decommissioning planning and execution work. By identifying the personnel and tasks with the highest accumulation potential, the tool helps focus the ALARA initiatives on the big ticket items. In addition to predicting radiation exposure accumulation, the tool serves as the experimentation platform for evaluation of process improvements, new shielding or other ALARA initiatives. This tool allows the user to quickly assess and quantify the value of the proposed improvement, facilitating evaluation of many more ideas than can be considered with traditional methods.

The tool is not only useful to aid in ALARA initiatives and accurate exposure projections but also to minimize risk with respect to schedule. Understanding how the accumulation was acquired helps determine the manning requirements, qualification and cross-training needs. This, in turn, results in manning plans that are not compromised by exposure limits. For jobs where there may be multiple radiologically burdened worksites, models for each worksite can be linked to achieve a comprehensive, enterprise-wide approach to ALARA. Furthermore, the process simulation component offers the same dynamic planning benefits as the ones described above as part of the reactor refueling simulation tool. The tool can be expanded to quickly assess sensitivity to unknowns. For example, instead of representing sources at fixed levels, they can be represented as a range or a distribution of possible levels. To accomplish this in the tool requires simply changing the input, but the results are a wealth of information generated from the simulation.

Training the next generation workforce - immersive interactive training

Due to the complex nature of nuclear operations, extensive training is required in virtually every aspect of the work, from safety procedures and equipment usage to security and proper conduct. As such, the domain offers an ideal environment in which immersive interactive simulation based tools can be used as a successful method of training. Research and development efforts are currently being conducted at NNS to explore the use of this technology for procedural training.

The next generation of students, who have grown up with constant visual interactive and immediate stimulation in the form of TV, video games and social media, are less receptive to conventional, lecture style methods. Interactive simultion based training tools provide immersive environments where students are afforded the opportunity to interact with and learn about equipment, as well as work through procedures much like they would in reality. These tools are equally well suited for team training where students interact with other members of a team to develop their specialized skills and interactions. The benefit of immersive training tools lies in the ability to create dynamic, real-time visual representations of conscious choices made by the student without interrupting live operations or assuming the risk inherent to inexperience. Simulation tools can be expanded into engaging interactive aids for various purposes. Familiarization training offers a student a virtual representation of the real system, where the student is free to explore the facilities, equipment and how these come together as part of the operations. Procedural training facilitates training of individual operators or a team of operators in a collaborative environment for any number of procedures to get the most out of limited hands on training. Similarly, these simulation tools provide the ideal environment for planning, training, and pre-briefing complex evolutions. Interactive, immersive simulation based training is ideally suited for emergency response organizations where the availability of time and facilities for large scale multidiscipline team training is at a premium. The simulation environment also supports training on a wide range of unplanned events that are difficult or undesirable in live training scenarios.

The M&S team at NNS is working on a prototype for crane and rigging operations training. Some of the features planned include learning modules for safety, equipment familiarization and operation, and inspection procedures. This tool offers a safe and collaborative environment for reinforcing good safety habits, learning the response procedures, and training an individual or a team. It is also a cost effective method of procedural training of a large or geographically dispersed workforce requiring frequent refresher training. Tied to a learning management system, this environment facilitates creation of custom scenarios for specific learning objectives and trainee needs.

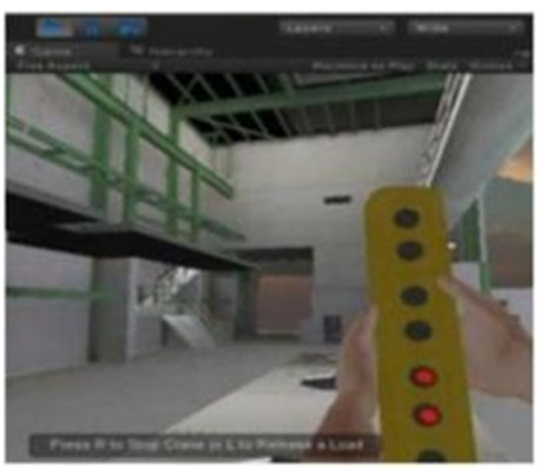

Fig 4 Crane operator training user view

CONCLUSION

The applications discussed here take a tool box approach to creating simulation based decision support tools for maximum utility and return on investment. This approach involves creating a collection of simulation tools that can be used individually or integrated together for a larger application. The refueling simulation integrates with the fuel handling facility simulation to understand every aspect and dependency of the fuel handling evolutions. This approach translates nicely to other complex domains where real system experimentation is not feasible, such as nuclear fuel lifecycle and waste management. Similar concepts can also be applied to different types of simulation techniques. For example, a process simulation of liquid waste operations may be useful to streamline and plan operations, while a chemical model of the liquid waste composition is an important tool for making decisions with respect to waste disposition. Integrating these tools into a larger virtual system provides a tool for making larger strategic decisions. The key to integrating and creating these virtual environments is the software and the process used to build them.

Although important steps in the direction of using simulation based tools for nuclear domain, the applications described here represent only a small cross section of possible benefits. The next generation of applications will, likely, focus on situational awareness and adaptive planning. Situational awareness refers to the ability to visualize in real time the state of operations. Some useful tools in this area are Geographic Information Systems (GIS), which help monitor and analyze geographically referenced information. Combined with such situational awareness capability, simulation tools can serve as the platform for adaptive planning tools. These are the tools that allow the decision maker to react to the changing environment in real time by synthesizing massive amounts of data into easily understood information. For the nuclear domains, this may mean creation of Virtual Nuclear Systems, from Virtual Waste Processing Plants to Virtual Nuclear Reactors.

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