ENGINEERING MANAGEMENT CHALLENGES FOR APPLYING SIMULATION AS A GREEN TECHNOLOGY

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Abstract

Modeling and simulation (M&S) can be used as a green technology by, e.g., conducting experiments with severe environmental impact as simulation in computers, or by evaluation of potential environmental impacts in detail in simulations before engineering solutions are realized. It is the task of engineering simulation management to ensure that simulation is applied appropriately and the results are interpreted correctly. This paper gives an introduction to important challenges the engineering management professional must be aware of when working with simulation as a green technology. Modeling paradigms, methods, and domains are introduced and evaluated regarding what knowledge the engineering simulation managers needs to be able to fulfill his tasks. Finally, the paper gives some examples of green M&S applications. As a result, the possibility and necessity to establish the profession of an engineering simulation manager is discussed.

Key Words

Conceptualization, Engineering Simulation Management, Green Technology, Modeling and Simulation, Modeling Paradigms

Introduction

The use of modeling and simulation (M&S) within engineering is well recognized. Simulation technology belongs to the tool set of engineers of all application domains and has been included into the body of knowledge of engineering management. M&S has already helped to reduce costs and increase the quality of products and systems and lessons learned are documented and archived.

However, M&S is a discipline on its own. Its many application domains often lead to the assumption that M&S is pure application. This is not the case and needs to be recognized by engineering management experts who want to use *M&S as a Green Technology*, which simulation without doubt is. What else is more advantageous for the environment than conducting test and experiments for new products in the virtual environment of a simulation? To ensure that the results of simulation are applicable to the real world the engineering manager must understand assumptions, conceptualizations, and implementation constraints of this emerging field.

Within this paper, the author tries to initially address the specific engineering management challenges that our community has to face when we become serious about applying simulation as a green technology. The focus lies on simulation support of systems engineering and the different roles that simulation can play that the engineering manager has to be aware of. The underlying idea is that whatever can be done by reliable and efficient simulation is going to not only avoid hazardous prototypes, but will also improve the overall quality and environment friendliness of the final system. Nonetheless, it requires profound understanding of what simulation can and cannot do in various phases of a project. This is the pivotal role of engineering simulation management.

Technically, simulation is well accepted. The 2006 National Science Foundation (NSF) Report on "Simulation-based Engineering Science" showed the potential of using simulation technology and methods to revolutionize the engineering science, including the discipline of engineering management. Among the reasons for the steadily increasing interest in simulation applications are the following:

- Using simulations is – as a rule – cheaper and safer than conducting experiments with a prototype of the real thing. One of the biggest computers worldwide is currently designed in order to simulate the detonation of nuclear devices and their effects in order to support better preparedness in the event of a nuclear explosion. Similar efforts are conducted to simulate hurricanes and other natural catastrophes.
- Simulations can often be even more realistic than traditional experiments, as they allow the free configuration of environment parameters found in the operational application field of the final product. Examples are supporting deep water operation of the US Navy or the simulating the surface of neighbored planets in preparation of NASA missions.
- Simulations can often be conducted faster than real time. This allows using them for efficient if-then-else analyses of different alternatives, in particular when the necessary data to initialize the simulation can easily be obtained from operational data. This use of simulation adds decision support simulation systems to the tool box of traditional decision support systems.
- Simulations allow setting up a coherent synthetic environment that allows for integration of simulated systems in the early analysis phase via

mixed virtual systems with first prototypical components to a virtual test environment for the final system. If managed correctly, the environment can be migrated from the development and test domain to the training and education domain in follow-on life cycle phases for the systems (including the option to train and optimize a virtual twin of the real system under realistic constraints even before first components are being built).

Simulation technologies are therefore another welcomed tool that engineering managers can use in order to fulfill their role of bridging the realm of managers and engineers. The case has been made repeatedly that simulation became the third pillar of scientific work: theory, experimentation, and simulation. It was therefore a logical step to integrate simulation education into the into the Body of Knowledge of Engineering Management (Tolk, 2007; Tolk, Rabadi, Merino, 2009).

The author posits that M&S is a new way of understanding the interaction among parts of a system and the systems as a whole and therefore allows engineers to dynamically change design decisions and immediately see the consequences. They can evaluate alternatives and options without creating risks or expensive prototypes, making simulation technologies not only financially attractive, but also very environment friendly, if the promises are kept and the resulting system is as good as expected. If this is the case, the level of understanding of complex systems supported by M&S surpasses other disciplines. The U.S. Congress recognized the contribution of M&S technology to the security and prosperity of the United States and recognized M&S as a *National Critical Technology* in its House Resolution 487 in July 2007.

However, simulation is more than just an application tool. Simulation is part of the new emerging discipline of Modeling and Simulation (M&S). The next section of this paper will introduce the main terms and definitions for the discipline of M&S as introduced in recent textbooks, such as by Sokolowski and Banks (2008) and Yilmaz and Ören (2009).

As the engineering manager is responsible for recommending the best available engineering solutions, the one section will introduce the modeling paradigms and how they can be applied in support of engineering tasks. Another section will apply the same question from the perspective of what application domains are relevant focusing on those that support engineers as a green technology. From both viewpoints, the relevant tasks needed to be conducted by Engineering M&S Management are derived in the last section of this paper.

Modeling And Simulation

The emerging discipline of M&S is based on developments in diverse computer science areas as well as influenced by developments in System Theories, Systems Engineering, Software Engineering, Artificial Intelligence, and more. This foundation is as diverse as that of engineering management and brings elements of art, engineering, and science together in a complex and unique way that requires domain experts to enable appropriate decisions when it comes application or development of M&S technology in the context of this paper. The diversity and application-oriented nature of this new discipline sometimes results in the challenge, that the supported application domains themselves already have vocabularies in place that are not necessarily aligned between disjunctive domains. A comprehensive and concise representation of concepts, terms, and activities is needed that make up a professional Body of Knowledge for the M&S discipline. Due to the broad variety of contributors, this process is still ongoing (Ören, 2007).

Although the terms "modeling" and "simulation" are often used as synonyms within disciplines applying M&S exclusively as a tool, within the discipline of M&S both are treated as individual and equally important concepts. Modeling is understood is the purposeful abstraction of reality, resulting in the formal specification of a conceptualization and underlying assumptions and constraints. M&S is in particular interested in models that are used to support the implementation of an executable version on a computer. The execution of a model over time is understood as the simulation. While modeling targets the conceptualization, simulation challenges mainly focus on implementation, in other words, modeling resides on the abstraction level, whereas simulation resides on the implementation level.

The observant reader will have noticed that the title of this section is "Modeling *And* Simulation" and may have asked him/herself: why is "*And*" capitalized? The reason is that conceptualization and implementation – modeling and simulation – are two activities that are mutually dependent, but can nonetheless be conducted by separate individuals. Management and engineering knowledge and guidelines are needed to ensure that they are well connected. Like an engineering management professional in systems engineering needs to make sure that the systems design captured in a systems architecture is aligned with the systems development, this task needs to be conducted with the same level of professionalism for the model that has to be implemented as well.

In summary, three activities have to be conducted and orchestrated to ensure success: a model must be produced that captures formally the conceptualization, a simulation must implement this model, and management processes must ensure that model and simulation are interconnected and on the current state (which means that normally the model needs to be updated in case the simulation is changed as well). The engineering simulation manager must therefore be an expert in modeling and the formal representation of conceptualization, in particular using mathematical means, including new options, such as ontology. He also must understand the computational limits and numerical constraints in general and regarding simulations as executions of models in particular.

Modeling Paradigms and Methods

One of the reasons the terms modeling and simulation are often used interchangeably is that many simulation tools support the modeling process, and some modeling tools support executing a simulation based on their artifacts. Examples are modeling support for integrated simulation development environments, such as Arena (Kelton, Sadowski, Sturrock, 2007), or the system engineering software package CORE developed by Vitech Corporation. In both cases, developing a conceptualization as an abstraction of reality and the execution thereof in form of a simulation are merged. While such an approach ensures that conceptualization, implementation, and alignment are optimally orchestrated, the decision to use such an a priori integrated approach should be an informed one. Which model paradigm to use may easily become a decisive factor for the success of applying simulation technology within a project. The reason is that not everything can be expressed with every modeling paradigm. Choosing a modeling paradigm – explicitly or implicitly by choosing a tool that is based on such a paradigm – therefore limits the expressiveness available to the model developer. Each paradigm in general, and each implementing tool in particular, limits by its syntactical and semantic constraints the options for models. As Buede (2009) describes, it is necessary for the engineering manager to understand that every modeling technique is a language that is used to represent some part of reality. Each symbol has a predefined meaning (semantics), and the rules on how to combine these symbols define the syntax. If, e.g., the modeling technique is limited to capture sequential processes, it is not possible to describe parallel execution within this technique. If a modeling technique assume discrete events, it is not possible to use this for continuous descriptions without numerically make them discrete.

For engineering managers, this observation is not new. There is a strong relation to model-based systems engineering (MBSE). A survey of MBSE methodologies (Estefan, 2007) looking at advantages and disadvantages of modeling methods designed to support design of systems – such as the Object-Process Methodology (Dori, 2002) or the System Markup Language (OMG, 2006) – made the same observations regarding the enabling or hindering effects of syntax and semantics of tool- and method-supported modeling. However, while traditional applications focus on models of real systems trying to mimic them as virtual representations, this is not a limit for M&S applications. Looking at the advantages of simulation-based engineering enumerated earlier in this paper it is in particular the domain of systems that are not models of an existing real system that is of interest (as it is the case in the design phase of new systems as well). Therefore, it is of critical importance that the engineering manager knows the advantages and limitations of possible modeling paradigms.

Within the discipline of M&S, three modeling paradigms are distinguished: Monte-Carlo simulation, discrete event simulation, and continuous simulation. Although agent-directed simulation is not necessarily a model-paradigm on its own, as it is a metaphor applicable in conjunction with other paradigms, it is often addressed as the fourth paradigm. Hester and Tolk (2010) furthermore include pure mathematical analysis as well as systems dynamics to describe the spectrum of applicable M&S methods supporting complex system engineering.

Analytical Mathematical Models

For engineering managers, analytical mathematical models often directly translate into Operational Research (OR). Generally, if a problem can be solved analytically, it should be done. If such a solution is feasible, the use of simulation would be counterproductive. However, many methods, such as heuristic optimization for domains like inventory and storage, are based on limiting assumptions. In this case, instead of looking for a closed solution, the use of a simulation may be of benefit. Another example is game theory. Although as a stand-alone method only of limited use, the ideas are often used to improve other approaches. Parsons, Gmytrasiewicz, and Wooldridge (2002) describe, e.g., how game theory and decision theory has been successfully applied within agent-based systems.

This idea of using mathematics as the foundation for other solutions must in fact be generalized. What is often not perceived is that at the heart of every simulation are algorithms that are based on analytical mathematical models. Every process within a simulation system is a computable function, and as such is governed by the findings of computational mathematics. As such, the engineering manager needs to have a basic understanding of problems like decidability and computational complexity.

Continuous Simulation

Whenever a system's description relies on differential equations, like it is often the case when dealing with physical system with mechanical components, electrical circuits, thermal effects, hydraulic elements, etc., continuous simulation may be the method to choose in support of the system engineer. In continuous simulation, the state variables describing the characteristics of the system change continuously with time.

One of the particular challenges the engineering manager has to be aware of when using digital computers implementing continuous simulation is the fact that digital computers do not operate using continuous time. Instead, all digital operations are triggered in discrete time steps. As a result, numerical approximations are needed to solve differential equations underlying this modeling paradigm. The problem is that with each approximation an error is introduced: the numerical solutions is close to the real behavior, but not necessarily the same. In fact, it is nearly certain that some variation will occur. The engineering manager must be aware of such numerically introduced errors and what they mean for the reliability of simulation-based decisions. In particular when a system is highly dependent on the initial states and small variations can result in enormous differences in the result – such as it is the case when systems are close to or within chaotic behavior (Devaney, 1989) – such concerns can become pivotal for the success of the supported system engineering task.

System Dynamics

A M&S method based on the principals of continuous simulation design to model sustainability and stability in dynamic systems was developed by Jay Forrester at the Massachusetts Institute of technology (MIT). The objective of this effort was to help decision makers to better understand dynamic behavior structures of complex systems. In other words, this paradigm captures dynamics of complex systems, frames the problem, displays the components and relations, and helps to discuss alternatives, effects, etc.

System dynamics uses only few building blocks, namely cumulative variables (stocks), derivative variables measuring the change (flows), directed associations connection these variables (causal loops). All these building blocks have well define meanings and are easy to communicate with stakeholders and customers even if they do not have a strong engineering background, which makes system dynamics a beneficial tool for communications. It also allows to directly connect the model with executable code segments. Forrester used this approach to educate people in systems thinking, in particular how things within such a system change over time. In his own words: “System dynamics combines the theory, methods, and philosophy needed to analyze the behavior of systems not only in management, but also in environmental change, politics, economic behavior, medicine, engineering, and other fields.” (Forrester, 1991).

System dynamics assumes cause-effect-loops between system variables on the macro-level of a system and even allows to model the context or environment as part of the approach. The use is normally to gain insight into the general behavior of the system and identify if chaos or catastrophes can emerge within a complex system. One of the main contributions of system dynamics is the visualization of the effects of multiple non-linear connections between variables that can create often counter-intuitive results in the system following control decisions of system engineers.

Monte-Carlo Simulation

Within the standard Monte-Carlo simulation a deterministic simulation model maps input parameters to output parameters without modeling time explicitly. The simulation model is used to iteratively evaluate the model by feeding random variables and evaluate the resulting outputs applying statistical analysis. Many applications do not require a time-driven approach to support the what-if analyses required to support management decisions. Often, the time aspect is either not known or considered to be irrelevant for the decision. In particular in connection with spread sheet programs, this paradigm is often applied in practice, see e.g. (Barreto and Howland, 2005). In order to apply this paradigm, a profound knowledge in statistics in necessary.

Discrete Event Simulation

Besides system dynamics, discrete event simulation is one of the most important paradigms in practice. It models a system as it evolves over time as a series of system states that are triggered by events at discrete times and that change the state instantly. Events and resulting state changes are simulated in chronological order. In order to be able to do so, the events must be stored and delivered in the right order, which is normally accomplished by the use of event lists. Furthermore, a simulation clock representing the time within the simulation, as well as an appropriate time advance algorithm are needed.

In particular when discrete event simulations are executed in a distributed environment, the synchronization of time advance and governed event lists is a very challenging task, leading to many orchestration efforts the engineering simulation manager must be aware of: synchronization of parallel time events, avoidance of handling events between simulations that are in their logical past, dealing with different scope, resolution, and structure of simulated entities in different participating simulations, and more.

The Discrete Event System Specification (DEVS) formalism specified in (Zeigler, Kim, Praehofer, 2000) was developed to support solving these tasks. It is well established and frequently used in academic organizations, but there are even more discrete event simulation systems used in practice that are and have been developed with such a formalism supporting them. Two IEEE standards support interoperability between discrete event simulation systems: IEEE 1278 Standard for Distributed Interactive Simulation (DIS) and IEEE 1516 Standard for Modeling and Simulation (M&S) High Level Architecture (HLA). An introduction would go beyond the scope of this paper, but the engineering simulation manager should be aware of both standards, their application domain, and respective assumptions and constraints.

Agent-directed Simulation

The agent metaphor was developed and applied in parallel in a multitude of application domains in very different disciplines, such as social sciences, biology, cognitive psychology, computer science, and more. Therefore, there exist many – often insufficiently aligned – viewpoints as well as definitions. In Yilmaz and Ören (2009), an approach was made to give definitions in support of systems engineering. These definitions are used in this paper as well. The agent metaphor uses agents that are interacting in a situated environment. Agents perceive the environment and other agents and act within the environment. They should be autonomous (acting with human input), flexible (learning to react appropriately), and exhibit social capabilities (act with or against other agents or agent populations).

Agents are not an alternative to non-agent models but are often combined with other modeling paradigms (Yilmaz and Ören, 2009). To emphasize the association of agents and simulation, the agent-directed simulation (ADS) community distinguishes between the following distinct yet interrelated areas:

- First, simulation for agents – or agent simulation –, that is simulation of systems that can be modeled by agents in engineering, human and social dynamics, military applications, and so on.
- Second, agents for simulation can be grouped under two sub-categories, namely (a) agent-based simulation, which focuses on the use of agents for the generation of model behavior in a simulation study, and (b) agent-supported simulation, which deals with the use of agents as a support facility to enable computer assistance by enhancing cognitive capabilities in problem specification and solving.

Agents are often used in connection with other model paradigms, e.g., they can use Monte-Carlo approaches internally to support their decision making process, or they can be embedded into a discrete event simulation and maybe even take the place of a human decision maker in advanced training environments. They are also often seen as the most effective way to embed social components into simulations otherwise dominated by physical processes. However, as they may introduce emerging effects to simulations, they are also posing new challenges for engineering simulation managers when it comes to validity and trust, as will be addressed later in the paper.

Mixed or Heterogeneous Approaches

Hester and Tolk (2010) emphasize the need to identify the appropriate M&S method for a certain phase and the necessity to align the approaches between the different phases. They use the example of traffic simulation in support of the Virginia Department of Transportation (VDOT), which decided to assess six identified alternatives that may have the capability of managing congestion at the Hampton Roads Bridge Tunnel (HRBT) supported by simulation-based studies conducted by the Virginia Modeling Analysis and Simulation Center (VMASC). Hester and Tolk show how to use system dynamics on the macroscopic level to gain insight into the patterns of traffic flow, applying discrete event models on the meso level to identify bottlenecks and areas of particular interest, and finally using agents on the micro level to better understand the influence of individual behavior of traffic participants in 'hot spots' of particular interest, such as toll booths or entry/exit ramps, or in certain situations, such as accidents, construction areas, traffic lights, etc.

The engineering simulation manager must know the advantages and disadvantages of the different paradigms. He must bridge the gap between the conceptualists and the implementers and must also ensure the knowledge transfer between the phases. As a lot of knowledge is captured in the various models and simulations used in the phases, he must also ensure that results, assumptions, and constraints are effectively communicated and potentially supported by standards.

Domains of Simulation

While the focus in the last section laid in the syntactical and semantic constraints of what simulations can do by evaluating the modeling paradigms in some detail, this section will look at the pragmatics of simulation applications: what are the simulation systems being used for?

In principal, simulation systems are used for two purposes: (a) to better understand a phenomenon of a system or the environment the system will perform in, or (b) to represent the knowledge about how a system or the environment thereof performs in an executable way. These are not mutually exclusive purposes. Actually, the role of the simulation will likely change over the lifecycle of its support. In early phases of a project, it will be likely necessary to gain a better understanding of the system and its environment. In later phases, this understanding will be used to improve the models used as well as the implementing simulation to provide these insights to train new engineers, to support decisions of system managers, to provide reliable testing environments, and to solve other problems regarding the system that require such knowledge. It is the role of the engineering simulation manager to understand these relations and their constraints and recognize when the simulation is used properly. In particular when the system constraints change, it may be necessary to reenter the understanding phase, which requires another use of the simulation support than using it in the problem solving phase of applied knowledge.

Similarly, it is necessary to distinguish if the simulation is used for (a) exploration of options or (b) analysis of alternatives. While exploration evaluates feasibility of options, analysis compares them. Both approaches use metrics, but while for feasibility evaluations only simple success metrics are needed, the analysis option requires to measure the success leading to comparable results, which as a rule requires multi-criteria utility approaches. Furthermore, the engineering simulation manager needs to understand and apply the principles of good experimentation, such as observability and traceability of effects, repeatability of the experiment, and control over the input parameters. In particular when the simulation experiment is mixed with human inputs, this task can become very challenging.

As stated before, systems engineering is concerned with the whole life cycle of a system, from the first idea to the retirement. The consistent use of simulation and the transferability of results and assumptions becomes key to success. As an example, the different metrics used in various phases need to be aligned. Tolk, Litwin, and Kewley (2008) give an example from the military domain: simulation is often used in the design phase for exploration of options. The desirable options are analyzed in the early stages of the procurement phase, again supported by simulation. Once the system is built, it is tested in a live and virtual-constructive environment, which means that simulation is a standard technology to stimulate the system under test. Finally, soldiers are trained to use the system, often starting with simulators that mimic the system under development before the real system is built. The engineering simulation manager must ensure that aligned metrics are used and the constraints and assumptions are communicated. He must also understand that system components, systems, or the environment representing context and external systems can be simulated in support of systems engineering. It is, e.g., possible to simulate a future component, integrate this virtual functionality into a real systems, and use a simulated virtual environment as well. In this case, the engineering simulation manager must orchestrate both integration efforts – virtual functionality into the real system, and real system into the virtual environment – as well as metrics and assumptions and constraints of the supporting simulation systems.

Finally, the engineering simulation manager must understand that M&S enables more knowledge processing than applied computational activities, i.e., executing a simulation system with given input parameters to produce predefined output parameters or provide an environment for training. Ören (2007) envisions M&S as systemic activities and system theory-based simulation to support analysis, design, and control as well as M&S as a model-based activity. This drives M&S towards knowledge generation and knowledge processing. A recent PhD thesis by Padilla (2010) applied M&S to discover new theory from existing theory regarding understanding. While a concrete application of these ideas for green simulation technologies is not obvious it can be hypothesized that progress in this field will benefit simulation as a green technology as well. New environmental impact connections may be discovered using M&S as a systemic activity, or the communication of knowledge being captured as executable simulation components that can be reused by different projects are enabled based on knowledge generation and knowledge processing applications.

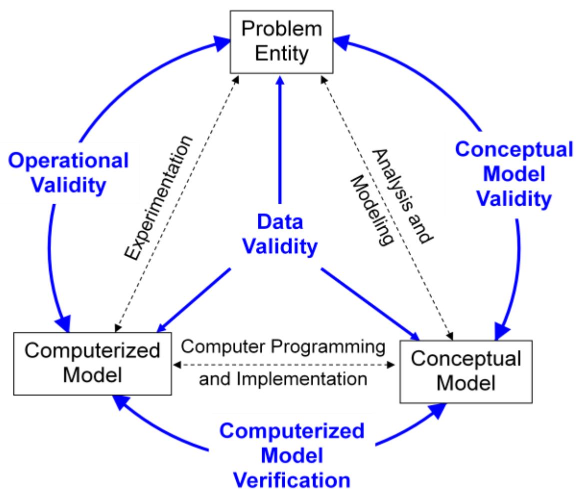
Consequently, it must be one of the task of the engineering simulation manager to observe – and where possible actively participate in – these emerging and new developments, as they will influence the use of simulation in the engineering management domain significantly.

Credibility of Simulation

One of the central roles of engineering managers in general is to mediate between customers, managers, and engineers. When simulations are used within engineering solutions, it is necessary that all stakeholders and team members use them assured that a particular simulation this is the best option available. If simulation systems are used to solve problems by representing the knowledge about how a system or the environment thereof performs, it is necessary to show that the model represents the correct systems, interactions, and phenomena of interest, and that the simulation system implements this model correctly. To fulfill these requirements, validation and verification are conducted to increase the credibility of a simulation based solution.

According to Balci and Sargent (1984), a model is considered valid if its response accuracy is within acceptable range for its intended purpose within respective experiments. In other words, the to prove validity, the accuracy of modeling needs to be evaluated. As such, validation answers the question: Are we building the right thing? Verification evaluates the transformation accuracy from the valid model to its correct implementation. The question answered by verification is therefore: Are we building the thing right? The engineering simulation manager must become the broker for a fair comparison of real systems, modeled systems, and simulated systems. Sargent (2000) explained these relations between system to be model, conceptual model, and simulation using exhibit 1 and introduced special terms to facilitate the discussion on validation and verification.

Exhibit 1. Modeling, Validation and Verification



Furthermore, the engineering simulation manager must ensure that the terms fidelity, resolution, and credibility are not confused within the team. Fidelity of a simulation is the accuracy of the representation when compared to the real world system. The resolution of a simulation is the degree of detail and precision used in the representation of real world system. Credibility is the level of trust in a simulation. In particular when visualization is used to better communicate simulation results, some customers tend to assume that higher resolution of the presentation equals higher credibility of the results. This is not the case, as Roman (2005) pointed out for training simulation. It is possible that a very low resolution model that aggregates many values is highly trusted. It is often the role of the engineering simulation manager to educate all stakeholder and team members accordingly.

In particular within the US Department of Defense, validation and verification is often followed by accreditation, which is a formal process to officially recognize the applicability of a simulation systems for the use in a certain domain with a given intent. It should be recognized that this is impossible when simulation is used for exploration. If simulation is used to better understand the possible behavior of a system, accreditation makes only limited sense. It is necessary, however, to evaluate if the system to be explored is modeled correctly, and that the model is correctly transformed into a simulation.

The engineering simulation manager must ensure that simulation based results can be and will be trusted. He must understand the principles of validation and verification.

Examples of Green Applications

To avoid the impression that applying simulation is a pure academic idea without any reference implementation, this section gives some examples of relevant simulation studies and even ongoing ideas for standard developments. The selection of examples has been conducted on the basis of awareness by the authors and is by no means intended to be exclusive.

Immersive Engineering within Procurement

The Armament Research, Development & Engineering Center of the US Army is evaluating product and systems designs before they are accepted for the army. It is well known that within the last decade the use of computers in engineering design increased significantly. In parallel to designing, evaluating these product designs using computers rather than building prototypes has significant potential not only to increase efficiency but also to reduce environmental effects. Kleis (2010) describes an immersive engineering process that is based on system engineering tools as well as Six Sigma management tools. Using virtual environments and manufacturing, products and system designs are used to build virtual representations thereof. These artifacts allow engineers, managers, and decision makers with their staff to 'see, feel, and smell' the product when evaluating it. The reduction of negative environmental effects are obvious: no resources are wasted for the production of prototypes that exhibit flaws or design mistakes, no prototypes need to be retired and recycled, no production and storage space is wasted, etc. As in addition to planning and decision cycle following (Kleis, 2010) is reduced down to 35%, the remaining environmental impact is reduced furthermore.

High Occupancy Vehicle Lane Planning

The use of simulation for traffic planning is described in Hester and Tolk (2010) as an example for better systems engineering supported by various M&S methods. How to extend these ideas and effectively include environmental impact factors into performance assessments is presented by Sisiopiku and colleagues (2010) in more detail. The research presented in their paper was conducted in support of the Regional Planning Commission of Greater Birmingham in Alabama. The question to be evaluated was the assessment of high occupancy vehicle (HOV) lanes to the main interstates around Birmingham, AL. At hand was the decision whether to convert lanes to become HOV lanes, to add new HOV lanes, or not to add any HOV capability. Using a commercial simulation tool, Sisiopiku and colleagues conducted several simulation experiments with the objective (a) to determine the impacts of various HOV strategies on traffic operations especially as they related to mobility and the environment, and (b) to quantify the project costs and user benefits from potential implementation and identify strategies with the highest potential return for the investment. Of particular interest for this paper on applying simulation as a green technology are the environmental impact factors. The following metrics were used to look at these impact, (see Sisiopiku et al., 2010, p. 5):

- Total HC emissions (grams/mile)
- Total CO emissions (grams/mile)
- Total NO emissions (grams/mile)
- Total fuel consumption (gallons)

This study conducted by Sisiopiku and colleagues is a first step. To be improved, it needs among others to take into account that building new HOV lanes require space, it may require new satellite parking places to support their use, and other factors. However, the contribution regarding use of simulation to take environmental factors into account are trend setting.

Simulation for Sustainable Manufacturing

The last example given in this paper shows that the idea of applying simulation as a green technology is taken seriously by industry and government. In support of using simulation in manufacturing, industry partners and government, represented in particular by the Manufacturing Simulation and Modeling Group within the National Institute of Standards and Technology (NIST), are currently developing the Core Manufacturing Simulation Data (CMSD) specification as a standard under the guidelines, policies, and procedures of the Simulation Interoperability Standards Organization (SISO), see (Leong, Lee, Riddick, 2006). The draft for this standard is expected to pass the balloting process before the end of 2010.

The Department of Commerce recently identified sustainable manufacturing as one of its high-priority performance goals, and defined sustainable manufacturing as the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound (Shao, Bengtsson, Johansson, 2010, p. 159). Therefore, the life cycle assessment must be improved to support better evaluation of environmental impacts. Extending the CMSD to capture sustainable manufacturing data, including factors and metrics, is one option.

However, engineering managers are well aware that a full life cycle approach including all phases is necessary to truly understand the environmental impact of decisions and to trade-off alternatives. The emission of a producing factory, e.g., is an important factor, but if the transportation of all components to the best factory results in higher negative environmental impacts due to transportation, this is not the right approach. If risk is included and some of the components to be transported are high environmental risks in case of an accident, this must be taken into account. Simulation application supporting the engineering manager are therefore needed, point solutions are necessary contribution, but not sufficient. The engineering simulation manager must therefore be aware of such requirements as well as of the resulting need to compose or federate supporting simulation solutions, which is particularly challenging if the simulation was not designed to support distributed execution as described earlier in this paper.

Another application example for such connected problems and how to use M&S in support of their solution in the domain of logistics is given by Bruzzone and colleagues (2009). In general, many potential applications of simulations exists to decrease negative impacts on the environment already. It is the role of the engineering simulation manager to ensure that the correct models and simulations are identified and applied correctly.

Engineering Simulation Management

The observations made in this paper may raise the possibility that engineering simulation management may become a significant contribution of engineering management in the future. This paper showed that the simulation knowledge described in (Tolk, Rabadi, Merino, 2009) is necessary, but not sufficient. In particular a profound understanding of modeling and supporting modeling paradigms and the resulting challenges for the execution thereof in simulations is needed. The engineering simulation manager must therefore understand the conceptual phase of modeling, the engineering phase of mapping, and the technical phase of execution, including numerical approximation constraints and challenges for distributions, including conceptual and technical orchestration of executables. He should know supporting standards and current developments thereof.

Exhibit 2. Checklist for Engineering Simulation Management Experts

Domain	Level of Experience	Domain	Level of Experience
Modeling	Understands modeling as conceptualization	Operations Research	Knows and can apply analytical tools and methods
Simulation	Understands simulation as implementation and execution	Model Paradigms	Knows when to apply Monte Carlo, continuous and discrete simulation
Numeric	Is aware of discrete nature of computation and possible errors	Agent-directed simulation	Knows advantages of all three agent-directed concepts
Model Spectrum	Understand the options of M&S methods and can recommend appropriate solutions	Simulation Standards	Knows which standards are available to support mixed and heterogeneous support
Model Domains	Understands the difference between exploration and optimization applications	Credibility and Validation	Knows the difference between credibility, resolution, and fidelity and knows how they relate to validation and verification
EM BOK Simulation	Knows and can apply the Engineering Management Body of Knowledge	Green Simulation	Understand all aspects of simulation sufficiently to recommend applicable and correct support

This list is neither complete nor exclusive.

If these skills are mastered, he will be able to play a pivotal role in applying simulation as a green technology, as the amount of prototypes will be reduced, the environmental impact of decisions will be better understood, and systems will perform more environmental friendly from their early conception to late retirement. Exhibit 2 offers a tentative checklist regarding the necessary experience and education for engineering simulation management experts.

Summary

The American Society for Engineering Management understands engineering management as the art and science of planning, organizing, allocating resources, and directing and controlling activities that have a technological component. This paper shows that and how simulation can support this role and understanding in general and as a green technology in particular.

To be able to do this, a sufficient knowledge in the domain of modeling and simulation is needed. Kossiakoff and Sweet (2002) define the role of a systems engineer in major system development projects as bringing specialist together that are characterized by different fields and disciplines with their own languages, experiences, and knowledge bases. The systems engineer needs to ensure that these diverse track converge in support of developing and producing a new system. The role of the engineering simulation manager is similar: he has to bridge the virtual worlds of M&S and the engineering world to allow successful application of modeling approaches and simulation systems to minimize negative environmental effects, either by avoiding unnecessary experiments and prototypes that could be supported by virtual systems (Kleis, 2010), or by decision supports for the real system under development by clearly analyzing and communicating environmental challenges (Sisiopiku et al., 2010).

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