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Embedding Simulation Education into the Engineering Management Body of Knowledge

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Embedding simulation education into the engineering management body of knowledge

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Abstract: The American Society for Engineering Management (ASEM) established a Body of Knowledge (BoK). As simulation is of growing interest to engineers in general and to engineering managers in particular, simulation is part of this documentation of domains of interest that characterise the profession. The basis for the Body of Knowledge comprises of established and accredited curricula and additional input from practitioners of the field. As it is essential to cover the basic topics and core competences as well as application specific domain knowledge, the simulation education for engineers is categorised into topics on simulation theory and simulation application.

Keywords: BoK; body of knowledge; curriculum; education; engineering management; modelling and simulation.

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1 Introduction

Engineering management bridges the gap between technical engineering processes and necessary administration and management processes. As such, engineering managers must be aware of developments that are happening in the technical domain as well as of possible support on the management side. Naturally, modelling and architecture approaches have been in the scope of the Body of Knowledge (BoK) for engineering management from its beginning, as models and architectures belong to the main tools of communication administrative and management needs in order to support technical solutions. With simulation, another logical element is added to the toolbox of engineering managers: executable models, or models executed over time! As stated by van Dam (1999) during his lecture at Stanford: "*If a picture is worth a 1000 words, a moving picture is worth a 1000 static ones, and a truly interactive, user-controlled dynamic picture is worth 1000 ones that you watch passively*". That makes simulation very interesting for engineering.

Generally, the significance of simulation for engineering was featured in several publications, pivoting in the 2006

NSF Report on "Simulation-based Engineering Science" which showed the potentials of using simulation technology and methods to revolutionise the engineering science. Simulation starts to replace traditional experiments on a significant scale, as simulations are – as a rule – cheaper and safer than experiments with a prototype of the real thing. In addition, simulations can often be even more realistic than traditional experiments, as it allows the free configuration of environment parameters as they are found in the operational application field of the final product, such as for deep water operation of the Navy, or the surface of neighbouring planets in preparation for NASA missions. Although the military is still leading in this domain, more and more industry domains are using the same ideas, such as the automobile industry and their virtual crash tests with new types long before they are introduced. Consequently, the *Modelling and Simulation in Engineering* journal aims at providing a forum for the discussion of formalisms, methodologies, and simulation tools that are intended to support the new, broader interpretation of Engineering. All these points contribute to the definition of the first application field of simulation in engineering: *simulation as a tool for engineers!* The engineering manager needs to understand the formalisms, methodologies, and technology applied in order to use simulation in projects he is responsible for.

In addition, simulation systems are applied as tools in more and more engineering domains and require to be managed. Not only in the military domain do simulation systems belong to very challenging information technology projects. Although the general domain of information systems is supported by good practices, such as documented in textbooks as Fuller et al. (2008), simulation systems are more than just huge information systems: as models are purposeful abstractions of reality, and simulation systems executed models on information systems, an additional layer of complexity is added to the information system challenge: how to mediate between viewpoints of different models? In other words, modelling and simulation opens a new challenging field for engineering management. Traditionally, the management of technology is a recognised area of expertise, as documented by Kotnour and Farr (2005). Archives like the *International Journal of Technology Management* or the *Journal on Engineering and Technology Management* already comprise several simulation related papers, such as Islo (2001) paper on using simulation to understand organisational systems. In addition, simulation is understood to be one of the leading innovation drivers since Schrage (1999) book on serious gaming.

Another domain of interest is prepared by the so called *executable architectures*. System architectures as blueprint standards for complex systems are an excepted tool. However, most of the current system architecture frameworks do not fully support the evaluation of the dynamic behaviour of a system, as the artifacts used in these frameworks deliver more or less snapshots of the systems. More and more software tools offer therefore the option to 'execute' a blueprint. This execution is a simulation in itself and as such of interest in the context of this paper.

In summary, modelling and simulation can be applied for developing a level of understanding of the interaction of the parts of a system – and of the system as a whole – in a new way. They allow engineers to dynamically change design decisions and immediately see the consequences. The can evaluate alternatives and options without creating risks or expensive prototypes. The level of understanding of complex systems supported by modelling and simulation surpasses most other disciplines. The decision to introduce simulation into the BoK for engineering management was a natural thing to happen.

In the following section, we will present how the American Society For Engineering Management (ASEM) organised their BoK to give an example how this can be done. We will cover the content to show where simulation finds its home, and we will describe the topics that are covered in the BoK.

2 Engineering management Body of Knowledge

The general criteria used to establish a BOK and evaluate the American Society of Engineering Management's (ASEM) decision process to develop the EM BoK against these criteria were summarised at the end of the development effort by Merino (2006a, 2006b, 2007). The development of the ASEM EM BoK was made possible because of the many EM undergraduate programs that are accredited by the Accreditation Board for Engineering and Technology (ABET) and EM graduate programs that are ASEM certified. After a two year development effort the ASEM Board of Directors voted to adopt the EM BoK on the 2007 Annual ASEM Conference. As the lead professional society for engineering management, ASEM had made the creation of an EM BoK its key strategic goal. Future plans for the EM BoK include the development of an Engineering Management Handbook based on the ASEM EM BoK.

The authors are convinced that professional academic education documented in form of curricula and the documentation of professional domains of interests in form of a BoK must go hand in hand, as solid research and education is not possible without understanding and agreeing on a common foundation. As like in every other living discipline as well, research continuously closes gaps and new teaching domains are introduced to meet the new demands of industry for professional education. As such, the EM BoK is a continuous work in progress. For the new discipline of M&S, this is in particular true and various changes are likely to occur in this section.

Engineering Management is not a new profession, so that the EM BoK could be rooted in a huge body of practical experience. Over the last 25 years, a number of papers analysed Engineering Management curricula and helped define an EM BOK in addition to these practical experiences, many of these efforts were conducted by Kocaoglu (1984, 1991) who introduced a consistent set of categories for undergraduate and graduate analysis. Furthermore, a number of authors analysed undergraduate and graduate programs providing alternative views, such as Farr and Bowman (1999) and Westbrook (2005).

Table 1 Categories and functional definitions for the EM BoK

1. Qualitative/conceptual courses
A. Individual people oriented
Typical course names: individual psychology; personnel management
B. Organisation or group oriented
Typical course names: organisational behaviour; management theory; teaming
2. Quantitative/methodical courses
A. Quantitative
Typical course names: statistics; operations research; decision theory; simulation
B. Methodical
Typical course names: systems engineering
3. Accounting/financial and economics courses
A. Accounting/finance
Typical course names: managerial accounting; financial accounting; cost accounting
Eng. accounting; financial management; managerial finance
B. Economics
Typical course names: eng. economics; macro or micro or managerial economics
4. Project related courses
A. Project management
Typical course name: project management
B. Capstone
Typical course names: capstone; special projects
5. Functional courses
A. Functional technical management
Typical course names: operations management; quality management;
Engineering management; R&D management; marketing management
B. Functional business management
Typical course names: marketing; engineering law; mgt. information systems
6. Engineering and science courses
A. Engineering courses
Typical course names: any with 'engineering' in title – except for engineering management;
Systems engineering and industrial engineering
B. Science courses
Typical course names: mathematics, chemistry or physics courses

ASEM decided to base the EM BoK on accredited and certified programs, in particular the Certification Program for Masters in Engineering Management and the ABET accredited undergraduate programs. The benefit of this approach is that it utilises the in-depth work of faculty and advisory boards to define outcomes. Faculty translates advisory board outcomes into academic disciplines that have corresponding bodies of knowledge. The results are programs with specific courses and topics.

Another alternative is to use an *Industry Survey* as the primary basis to establish an EM BoK rooted in practical requirements and current industry needs. While this approach clearly captures managers' needs later in their careers, it does not address many of the basic topics that need to be taught to students in various programs, such as mathematical foundations. Every discipline with practical applications – and as such do the authors see M&S – need to answer these questions: What are the *Core Competencies* – or academic basic topics – that are often assumed to be known by a member of the respective profession, and what are the *Application Domain Specific Needs* that need to be taught. A discipline with practical applications needs both categories.

This is recognised in the EM BoK in general and in the section on Simulation Education for Engineering Managers in particular. Table 1 shows the resulting functional definitions for the EM BoK, that also build the structure of the EM BoK. Simulation is categorised as one of the quantitative courses (category 2.A) and will be subcategorised in the next section. The neighbourhood to other disciplines in this category, in particular Statistics and Operations Research, is no coincidence.

In summary it can be seen that simulation is no longer an optional topic for engineering managers. Practical needs make a solid understanding of what M&S is and how its means can be applied for real world engineering problem a necessity that was addressed from the first efforts to build an EM BoK.

3 Simulation education for engineering managers

Simulation education for engineering managers is targeted at understanding the simulation technology as an engineer and being able to understand how to apply simulation in projects as a manager. As such, the engineering manager shall understand the technical engineering processes connected with simulation design and implementation as well as the necessary administration and management processes for simulation intensive projects. Consequently, two blocks are defined:

- *Simulation Theory for Engineers* builds the foundation necessary to understand the principles of modelling and simulation (Ross, 2006). Mathematical and computational foundations belong here as well as the theory of discrete event simulation, Monte-Carlo simulation, and data analyses methods.
- *Simulation Applications for Engineers* represent the practical use of modelling and simulation within projects. Simulation as an Engineering Method is

exemplified using the simulation toolkit ARENA (Kelton et al., 2006). The emerging simulation domain of Agent-Directed Simulation (ADS) (Yilmaz and Ören, 2005) is the third topic in this section.

In the following sections, we will motivate why the presented simulation topics have been selected for the BoK. We hope that the underlying process can be a guideline for other application domains of simulation as well.

3.1 Simulation theory for engineers

The first block of simulation education builds a solid foundation for engineers, which are the core competencies or academic basic topics. They comprise what engineering managers must minimally know in order to achieve and understanding of M&S in engineering as an applied discipline.

Models are purposeful abstractions of reality, and simulations execute models over time.

Engineers are in particular interested in system models and simulations thereof. In this case, simulation is used before the system is build or before an existing system is altered. In this context, a simulation is applied to find out if the new system – or the altered system – meets all specification (in particular regarding performance), if the provided resources are sufficient, and if the system remains stable when being executed. The underlying processes are normally not deterministic, so that the engineer needs to understand how to generate random numbers. As the simulation is executed on computers, he needs a basic understanding of algorithms and program languages as well. Also, he needs to be able to make use of the results of the simulation, which requires understanding of data analyses methods. Therefore, the following five blocks have been identified to be essential building blocks for engineers in general, and engineering managers in particular:

- *Mathematical Foundations* comprise the topics Probability, Random Numbers, and Generating of Random Numbers. Every student of engineering management needs to be able to understand how statistical principles can and need to be used in simulation and where the limitations are.
- *Computer Science Foundations* comprise Algorithms in Higher Programming Languages and the Introduction to Basics of Java/C++. While it is not necessary to become a programmer or software engineer, without the basic understanding of algorithms and their potentials and limitations a computer simulation cannot be understood and therefore not efficiently managed.
- *Discrete Event Simulation* compares Time-step vs. Discrete Event Simulation and introduces Queuing Systems as typical examples. While other simulation paradigms are possible, discrete event simulations play a dominant role in the current application environment.
- *Data Analyses* is not necessarily limited to simulation but can be generally applied in the context of setting up tests and experiments. They comprise Statistical Analysis, Variance Reduction Techniques, and Sensitivity Analysis. This block can be mapped one-to-one to operations research topics.
- *Monte-Carlo Simulation and Continuous Simulation* can be seen as the synthesis of related topics. It starts with Deterministic vs. Stochastic Models, introduces Markov-Chains, continues with typical statistical distribution, in particular the Poison Distribution and focuses on Monte-Carlo Simulation. It closes with continuous simulation, which is often used to simulate physical systems or systems that involve mechanical, electrical, thermal, or hydraulic components.

Within engineering management, simulation is often seen as the “500 Pound Gorilla in Operations Research” and there is some truth in this statement. However, while this foundation section focuses on this viewpoint, there is more to simulation than being part of operational research. The next section will give the broader application view being embedded into the EM BoK.

3.2 Simulation applications for engineers

Engineering disciplines in general are directed at applying knowledge to the benefit of the community. The application of simulation in support of engineering tasks is therefore of particular interest to engineering managers and plays a pivotal role in their education. While the theoretic part targets to build a strong foundation, the application part of simulation as captured in the EM BoK focuses on enabling students and practitioners of the field to use existent M&S applications are to develop M&S applications in support of system analysis, system design, system analyses, and general evaluation. Main focus is to apply the theoretic knowledge in the context of real world problems.

While several textbooks support the theoretic foundations, the application domain cannot be covered by such guides. It is important to use current journals and workshop proceedings to enrich the general principles. As a common component, the practice oriented book of Kelton et al. (2006) was chosen, as it deals with typical questions engineering managers must handle within simulation projects or projects using simulation. Although it uses a particular simulation framework for examples, the lessons are easily transferable to other discrete event simulations.

The application section comprises the following five blocks that have been identified to be essential building blocks for engineers in general, and engineering managers in particular

- *Simulation as an Engineering Method* introduces the various Types of Simulation Applications, explains the Problem Analysis and Solution Strategies in simulation centric projects, supports the students with engineering methods for Selection and Orchestration of Tools and shows the necessity for Risk Assessment and Uncertainty Management in such project.

- The block on *Discrete Event Simulation with ARENA* is tightly connected with the content of Kelton et al. (2006) and starts with the Introduction to ARENA. It continuous with Statistical Experimentation Design, which is broadly applicable in non-ARENA contexts as well, and exemplifies how to do Discrete Event Simulation with ARENA as well as Continuous Simulation with ARENA. Focus is not the tool, but the general principles of applying simulation in the engineering context.
- The final block introduces the student to the *Principles of Agent-based Modelling*. This is an emerging field and is just starting to be covered in engineering and engineering management textbooks. The EM BoK covers Individual Agents, the Reactive, Proactive, and Social Components of agents, and the Environment of Agents before going into the design and use of Multi-agent Systems.

The block on Principles of Agent-based Modelling has been significantly influenced by the recent contributions that ADS made to the engineering world. ADS consists of three distinct yet related areas that can be grouped under two categories. First, simulation for agents – or *agent simulation* –, that is simulation of systems that can be modelled 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 *agent-based simulation*, which focuses on the use of agents for the generation of model behaviour in a simulation study; and *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.

The simulation topics selected for the EM BoK ensure that engineering managers understand the potential and limits of simulation for engineering applications. They build a solid foundation for task specific additional education in simulation domains of interest, such as decision support, executable architecture, virtual experimentation, and many more. Several journals, such as Modelling and Simulation in Engineering and others, aim at providing a forum for the discussion of formalisms, methodologies, and simulation tools that are intended to support the engineering. It is likely that in particular the *Simulation Applications for Engineers* will be extended and enhanced with the growing importance of simulation in engineering in general and engineering management in particular.

4 Summary

This paper presented the way simulation and M&S education has been integrated into the EM BoK. Furthermore it was explained why simulation is so important for engineering in general and engineering management in particular. The authors agree with the findings of NSF (2006) that simulation-based engineering is revolutionising engineering. The simulation topics selected for the EM BoK are categorised into Simulation Theory and Simulation Application. The documented approach may be applicable to other discipline as well, as they are thinking about integrating M&S into their curricula and into the boundaries defining their profession.

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