SYSTEM DESIGN AND OPERATIONAL EFFECTIVENESS (SDOE): BLENDING SYSTEMS AND SUPPORTABILITY ENGINEERING EDUCATION

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KEYWORDS

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ABSTRACT

The Charles V. Schaefer, Jr. School of Engineering at Stevens Institute of Technology, in partnership with Industry and Government Agencies, has launched a new education, research, and training program in *System Design and Operational Effectiveness (SDOE)*. This technical paper provides insight into the pedagogical underpinnings of the program's explicit focus on: a) synthesis, analysis, and evaluation activities during the conceptual and preliminary design phases, and b) system operation, maintenance, and support.

The SDOE program leverages a combination of web-based courses to increase portability and convenience for the participants, and week-long modules to promote classroom interaction and the development of team building, leadership, and organizational skills. The instructional approach and programmatic structure adopted has attracted commercial and aerospace industry as well as selected government agencies in the United States and Europe.

INTRODUCTION AND BACKGROUND

The increasing complexity of systems, the pervasive realities of global competitiveness, the enhanced focus on cost and profitability, and ever more challenging customer expectations have led a number of premier organizations in the defense and commercial sectors to assume the role of system integrators. These organizations are increasingly adopting an evolving business model: *Instead of focusing primarily on selling and providing systems, system elements, and products, a system integrator may need to focus on selling, providing, and then sustaining a capability, a function, or a solution*. In this context, the system integrator is often responsible for managing the physical and functional baselines beyond the development and deployment phases, to include the system operation and support cycles. While this role might and often does require the procurement of a significant percentage of the system's elements (hardware and software) from third parties and partners, the

system integrator might assume the overall program and system risk (performance, schedule, and cost) for integrating these into the comprehensive system. Accordingly, system integration might then be defined as the progressive linking and testing of system elements to merge their functional and technical characteristics into an overall and interoperable system.

System integration, and its derivatives across the life cycle, require additional discipline and a long-term perspective during the systems engineering and design phase. This approach includes explicit consideration of issues such as system reliability, maintainability and supportability to address activities pertaining to system operation, maintenance, and logistics. There is also a need to address real-world realities pertaining to changing requirements and customer expectations, changing technologies, and evolving standards and regulations. Accordingly, the SDOE program was conceived to address the educational, training, and research requirements of integrators and users of complex, multi-functional, knowledge and information intensive, and distributed systems. This paper only addresses the educational and training component of the SDOE program.

SDOE PROGRAM FOCUS AND OBJECTIVE

In a 1990 survey conducted at Virginia Tech, 78 graduate academic programs were identified as being listed under the category "systems engineering" (Swain, 1991). Of these, 73 were in the United States, with most programs addressing systems engineering in the context of a functional discipline such as electrical, industrial, or manufacturing, and offer degrees with the nomenclature aligned with the functional discipline. Nineteen of the 73 graduate programs in the United States offered MS or ME degrees in systems engineering, and of these only 11 had disciplinary affiliations, with 5 in Electrical Engineering and or Computer Science, 3 in Industrial Engineering, and 3 in other categories (Aeronautics, Information Systems, and Mechanical Engineering). According to this 1990 survey, only 8 programs in the United States appeared to offer an interdisciplinary educational experience focused on systems engineering. While a subset of these 8 programs offered courses or specialization in design methodology, none of these programs offered significant focus on system reliability, maintainability, and supportability, or the related issues of system operation, maintenance, and logistics support. Only two of the eight programs offered electives on subjects related to logistics support and supportability engineering. Logistics education, however, is a significant part of the educational offering at a number of universities in the United States. The focus of these programs is predominantly on important issues pertaining to supply chain management, inventory control, warehousing, distribution, and transportation. Business schools traditionally offer these degrees.

A number of studies conducted in the late 80s and early 90s identified areas of commonality in the development of programs in systems engineering. The Air Force conducted a project to evaluate existing engineering curriculum and to recommend methods for incorporating reliability and maintainability requirements into undergraduate and graduate programs (Final Report, 1988). This project included 13 academic and 16 industrial partners, along with 3 government agencies. The National Science Foundation sponsored an international workshop in October 1990 which included consideration of the inclusion of systems and concurrent engineering requirements into engineering curricula (Fabrycky, 1991). Similar research was also conducted at Virginia Tech resulting in several

published papers (Blanchard, 1990, 1991, 1993, 1993a; Verma, et. al., 1992). These studies were used to structure the systems engineering curriculum and programmatic structure at Virginia Tech.

The systems engineering education has evolved significantly since the early 1990s. In a more recent comparison of systems engineering programs, 23 departments offering "systems engineering" degrees have been identified (Brown and Scherer, 1998). According to the authors, a majority of these programs are fairly traditional industrial engineering programs, with only seven programs focused on a system analysis and design perspective. In this same study, the authors argue that, in its current state, systems engineering education in the United States has four primary threads:

1. Systems analysis and design,
2. Industrial engineering,
3. Traditional control systems, and
4. An eclectic mix of control systems with other topics.

The SDOE program is firmly rooted in complex system design methodologies, principles, and concepts, inculcates skills associated with abstract program solving to address design synthesis; and will address the quantitative modeling, simulation, and optimization techniques to address design analysis and evaluation. However, the design experience of the students also includes an explicit and formal focus on system reliability, maintainability, and supportability in equal measure. Accordingly, the synthesis, analysis, and evaluation activities beginning with need identification through system operation and support are addressed in a systems engineering context, defined as:

- A process focused first on need or deficiency identification, and then the translation of this need/deficiency into a system architecture through the iterative process of functional analysis, allocation, implementation, optimization, test, and evaluation;
- Incorporation of parameters to assure compatibility between various system interfaces (physical, functional, and operational interfaces, hardware and software interfaces, sub-system interfaces) in a manner that optimizes system definition and design; and
- Integration of performance, manufacturing, reliability, maintainability, supportability, global flexibility, scaleability, upgradeability, and other concerns into the overall engineering effort.

A key element of the SDOE program is to use project-based and case-based learning is used to enable understanding of the overarching "cause and effect" dependency between design and system operation/support as shown in Figure 1. Specific dependencies between system reliability and operation, maintainability and maintenance, and supportability and logistics are addressed using real-world case studies and examples.

The treatment of design synthesis, analysis, and evaluation, and its formal extension to include explicit inclusion of reliability and operation; supportability and logistics; and maintainability and maintenance is addressed within the SDOE program curriculum from the complementary perspectives of the complex system integrator and the user. Participants are exposed to issues relating to problem identification and problem solving through "hands-on" projects and exercises. Problems are defined from a long-term viewpoint and include concerns relating to operational and support phases.

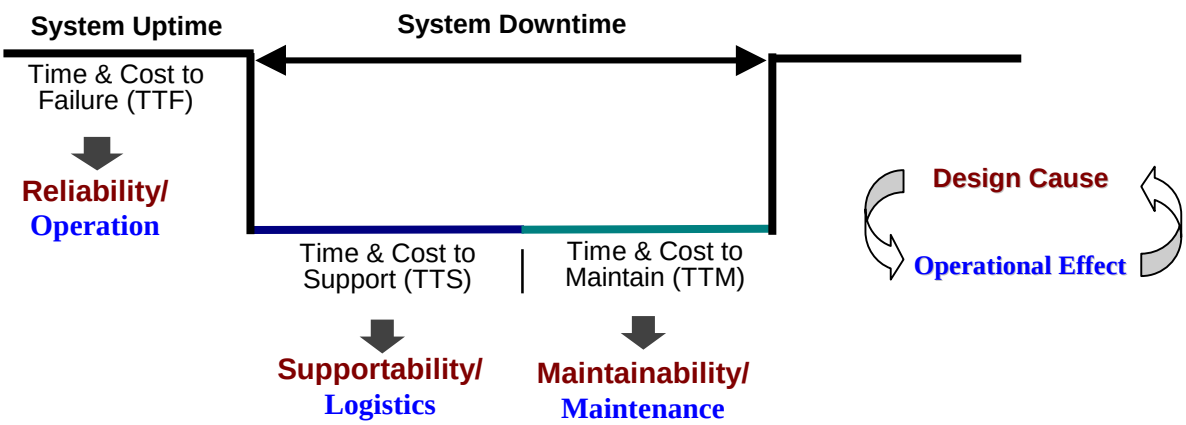

Figure 1. The SDOE program includes a specific focus on the dependency between system design and system operation and support.

SDOE PROGRAM STRUCTURE AND DELIVERY

The SDOE program has been structured to satisfy varying levels of educational and training requirements as depicted in Figure 2. At one end of the spectrum, the program offers a number of formal and focused intensive short courses on relevent themes (e.g., COTS-Intensive Open Systems Architectures), continuing through the option of a Graduate Certificate Program, a Master's Degree Program, and finally, to a doctoral program within the field.

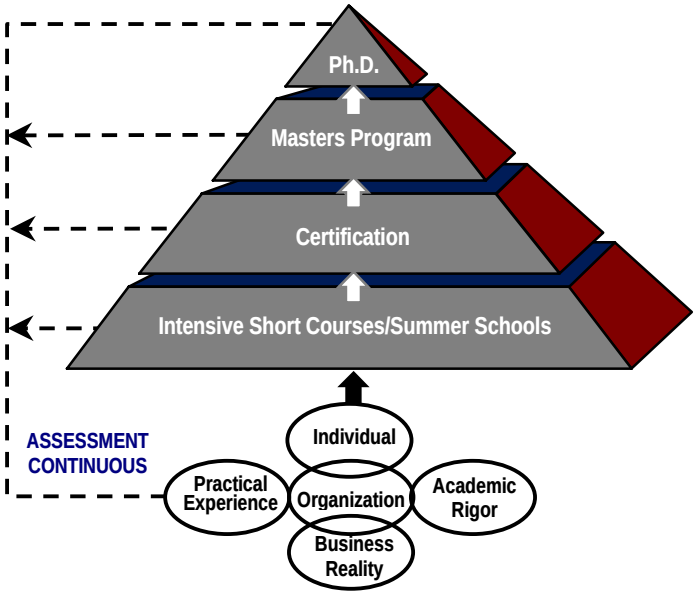

Figure 2. The SDOE program education and training structure.

The Master's Degree Program requires 30 credits, of which 12 are required core credits. Of the 18 elective credits up to 6 credits can be applied towards a project and report. The four core courses are:

1. System Operational Effectiveness and Life-Cycle Analysis
2. Integrated Product Development I
3. Project Management
4. Modeling and Simulation/Analytic Tools and Techniques

Candidates within the SDOE program have the option to select courses from a number of electives to specialize and focus on any particular aspect of system design and system operational effectiveness. A candidate seeking to specialize in system design and architecture can structure a program of study to emphasize abstract problem solving, needs assessment and requirements analysis; concept definition and development; system architecture definition and development; modeling and simulation; and

organizational theory. A candidate specializing in supportability engineering and logistics can structure a program of study to focus on supportability in the context of design, modeling and prediction; practices and tools to influence design for supportability; optimization of system logistics and the support infrastructure; and dependency between system reliability, maintainability, and supportability. Yet another example specialization could be system and project management. Example programs of study are shown in Table 1.

Table 1. Illustrative Programs of Study in the SDOE Program for a Master's Degree.

Elective Courses		
System Design and Architecture Development	**Supportability Engineering and Logistics Planning**	**System and Project Management**
1. System and Software Design and Architecture 2. Software Engineering 3. Integrated Product Development II 4. Computer Architecture 5. Human Side of Projects	1. Design for Supportability 2. Supportability and Logistics 3. Systems and Software Design and Architecture 4. Maintainability and Maintenance 5. E-Commerce	1. Technology Management 2. Total Quality Management 3. Advanced Project Management 4. Business Information Networks 5. Human Side of Projects
Core Courses		
1. System Operational Effectiveness and Life-Cycle Analysis 2. Integrated Product Development I 3. Project Management 4. Modeling and Simulation/Analytic Tools and Techniques		

* A project and report can be undertaken in lieu of up to 2 Electives.

To round out the educational program, a candidate could elect to undertake a project (equivalent to a maximum of 6 credits) to address a research question or a problem of interest. As such, students can create a specialization meeting their professional needs through the judicious selection of electives and the formulation of a relevant capstone project in concert with a faculty advisor.

The modes of instruction of the SDOE program have been structured to allow flexibility as shown in Figure 3. The core and elective courses will be offered through one of two delivery mechanisms: a) entirely web-based delivery, or b) week-long modular intensive seminars. This format minimizes the time away from "home base" while the live and intensive weeklong modules, and associated group exercises, ensure development of team building skills, leadership development, and the real-time negotiation and tradeoffs that characterize reality. Students will be given reading assignments prior to the beginning of the weeklong module, and subsequent to it, they will have to complete a homework project and assignment.

For additional information, please contact the first author at the address provided at the beginning of this paper, or visit http://www.stevens-tech.edu/SDOE.

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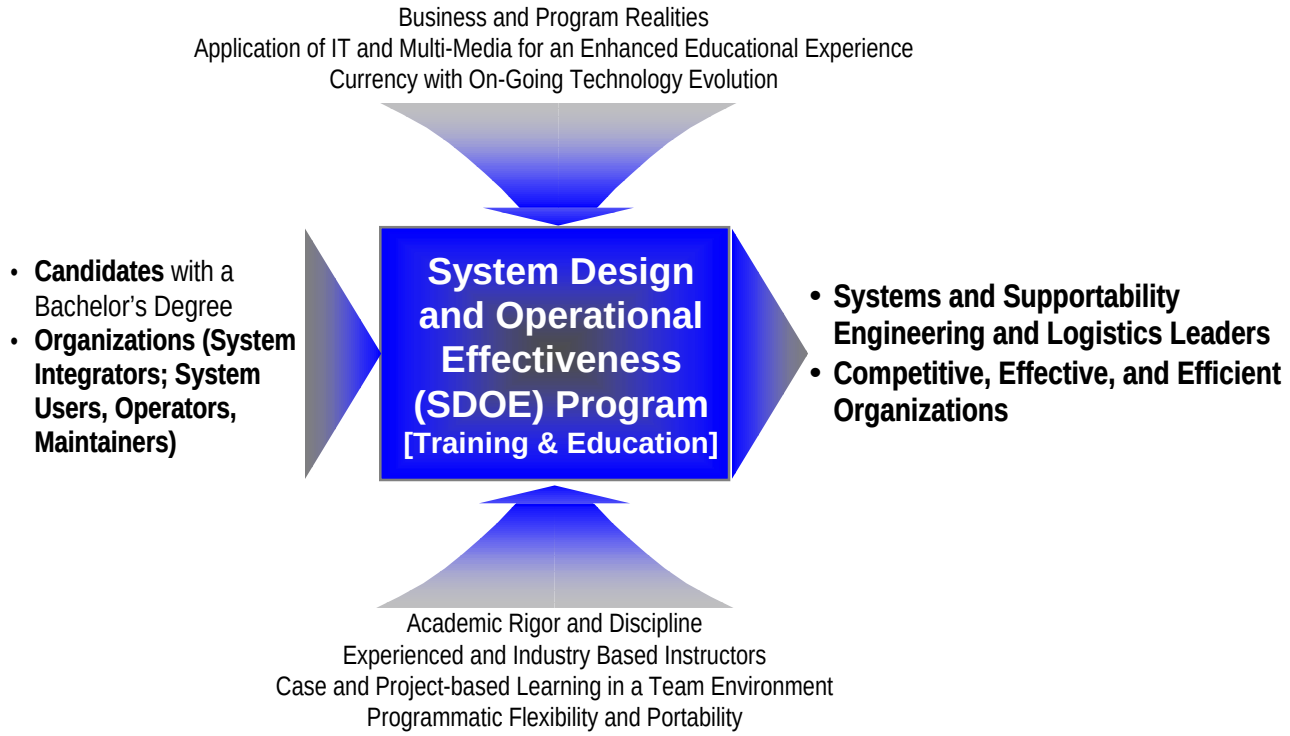

Figure 3. The overarching SDOE program vision.

REFERENCES

[Final Report, 1988] Final Report, "*Engineering Education Curricula Development Workshops*", U.S. Air Force Human Resources Laboratory, Dayton, Ohio, July 1988.

[Blanchard, 1990] Blanchard, B.S., "*Preparing Graduates for the Total Quality Management (TQM) Environment*", Proceedings, Second National TQM Symposium and Exhibits, Baltimore, Maryland, November 1990.

[Swain, 1991] Swain, R.E., "*A Comparative Evaluation of Interdisciplinary Systems Engineering Master's Program in the United States*", Master's Project Report, Virginia Tech, April 1991.

[Blanchard, 1991] Blanchard, B.S., "*Education and Training for Concurrent Engineering and Computer-Aided Acquisition and Logistics Support*", Proceedings, CALS and CE Conference and Exposition, Washington DC, June 1991.

[Blanchard, 1993] Blanchard, B.S., W.J. Fabrycky, W.K. Hoehn, and D. Verma, "*Concurrent and Systems Engineering Education and Training: A Unique Format of Instruction*", Computer Aided Acquisition and Logistics Support, Vol. 2, No. 3, Fall 1993.

[Blanchard, 1993a] Blanchard, B.S., W.J. Fabrycky, W.K. Hoehn, and D. Verma, "*Implementation of the Concepts of CE and CALS in the Academic Process: A Case Study Approach*", Proceedings, CE & CALS Conference and Exposition, Washington DC, June 1993.

[Fabrycky, 1991] Fabrycky, W.J., "*Education Group Report in Final Report*", NSF International Workshop on Concurrent Engineering Design, Hsu, J.P. (Editor), Austin, Texas, September 1991.

[Verma, et. al., 1992] Verma, D., A. Sols, W.J. Fabrycky, B.S. Blanchard, "*Computer-Aided Courseware for Systems Engineering Education and Training*", Proceedings, Second Annual International Symposium, National Council on Systems Engineering (NCOSE), Seattle, Washington, July 1992.

[Brown and Scherer, 1998] Brown, D.E. and W.T. Scherer, "A Comparison of Systems Engineering Programs in the United States", SMC Special Issue on Systems Engineering, 1998.

BIOGRAPHICAL SKETCHES

Dinesh Verma received the Ph.D. and the M.S. in Industrial and Systems Engineering from Virginia Tech. He is the Systems and Supportability Strategist at Lockheed Martin Undersea Systems, in Manassas, Virginia, where his duties include development of adapted systems and supportability engineering processes, methods and tools for complex system development. Dr. Verma concurrently serves as a Distinguished Service Associate Professor at the Stevens Institute of Technology.

Prior to joining Lockheed Martin, Verma worked as a Research Scientist at Virginia Tech and managed the University's Systems Engineering Design Laboratory. While at Virginia Tech and afterwards, Verma served in a consulting capacity with numerous companies to include Eastman Kodak, United Defense, PSI, VOLVO Cars (Sweden), Kongsberg Defence and Aerospace (Norway), Johnson Controls, Ericsson-SAAB Avionics (Sweden), and Motorola. His professional activities and research emphasize systems engineering with an emphasis on conceptual design evaluation, system architecture, design decision-making, life cycle costing, and supportability engineering. In addition to his publications, Verma has patents pending in the areas of system life-cycle costing and fuzzy logic techniques for evaluating conceptual system designs.

Bernard Gallois is the founding Dean of the Charles V. Schaefer, Jr. School of Engineering and George Meade Bond Professor of Materials Science and Engineering at Stevens Institute of Technology. Dr. Gallois was Head of the Department of Materials Science and Engineering at Stevens from 1988 to 1991. He received his engineering diploma from the Ecole Nationale Superieure des Mines in France and M.S. and Ph.D. degrees in Materials Science and Engineering from Carnegie Mellon University where he was a Fulbright-Hays Scholar. Amongst professional honors, he received the Best Paper Award in 1988 and the Howard Taylor Award in 1989 of the American Foundrymen's Society for his pioneering work on the lost-foam process, a casting process now used world-wide. His current interests are focused on undergraduate and graduate engineering education and particularly how the information revolution is transforming the engineering profession.