Technical Paper Abstracts

The following section lists technical paper abstracts in the order in which they appear in the program. The number shown before each abstract title indicates the presentation order in the session and track. Papers can be referenced in the CD ROM Proceedings

Session 1 Track 1: Education - Research & Design

1.1.1 Industry and Academia: Why Practitioners and Researchers are Disconnected

G. Muller, *Embedded Systems Institute*

The industrial world and the academic world have grown far apart. The distance between the worlds primarily originates from different goals and different means of support. This is a problem in the areas of systems engineering and multi disciplinary design. These areas are relatively young, providing lots of opportunity for research. Education in this area is scarce. Publications are tangible examples of the gap between the two worlds.

In this paper we discuss the needs of both communities with respect to publications, education, and research. The mutual understanding of each other's needs may help to bridge the gap between academics and industry.

1.1.2 Enabling the Researcher: Applying Systems Engineering to Research

F. Bulca, *MDS Sciex*

Methodologies utilized in research and product development have little in common. While the former thrives on freethinking and innovative creation, the latter is more dependent on a structured process.

A culture shift is required from a purely knowledge-driven academic environment to a commercial research environment that is more sensitive to budget and schedule constraints. In spite of these differences, systems engineering practices may be applied toresearch, helping the teams to produce favourable results.

This paper presents a case study related to the research phase of a commercial product development project in the biotechnology sector. The challenges in the research phase of the commercial project were handled through standard systems engineering practices, with new interpretations of established methodologies. Application of systems engineering practices significantly improved the rate of progress, produced a high level of stakeholder satisfaction and improved confidence in the results, thus indicating that systems engineering methodologies have a valid place in the research realm

1.1.3 The Core Competencies Of Systems Engineering

D.D. Cowper, *Suls Systems.Ltd.,* R. Allen-Shalless, J. Stoves, *Thales;* S.F. Brown, *BAE Systems*
J. Hooper, *Loughborough University;*
S. Hudson, *General Dynamics UK;* L. Oliver, *EADS Astrium*
K. Barnwell, *UK Ministry of Defence,*
A. Smith*, University College London*

This paper describes the work of an INCOSE UK Advisory Board working group set up to define the set of Core Competencies for Systems Engineering. The development of complex products (systems) demands a broad range of competencies from its system engineering resource. An agreed set of core competences would allow individuals and enterprises to establish an effective, transferable portfolio of skills, which can be deployed in systems projects. Such a set of core competences will also provide a framework for education/training and assessment. The working group recognized that in addition to core competencies, Supporting Techniques, Basic Skills and Behaviours and Domain Knowledge are important. This paper offers a set of core competencies for Systems Engineering and guidance on how to use them.

1.1.4 Structuring a Professional Systems Engineering Development Program

S.A. Sheard, M. Swayhoover,
Systems and Software Consortium, Inc.

This paper proposes an approach to growing the number of knowledgeable, experienced, capable senior systems engineers within an organization. The organization identifies candidates and ranks them against organization-specific Systems Engineering Quality Characteristics (SEQCs). Development plans for a cohort of selected participants are created based on the students' current and anticipated future roles in the organization. Feedback loops help guide the process, both for individual participants and for the systems engineering development program. The hope is to feed the increasing need for systems engineers and leaders to fill critical jobs on complex programs.

Session 1 Track 2: SE Application

1.2.1 Engineering Information Assurance for Critical Infrastructures: The DITSCAP Automation Study

S-W. Lee, G-J. Ahn, R. Gandhi,
University of North Carolina at Charlotte

Recent advances in information technology have transformed the way in which mission-critical services get delivered and are evaluated today. These services are heavily and increasingly relying on an interdependent crossed network of critical information infrastructures, spanning from private to government sectors. In order to enable such infrastructures to efficiently mitigate risks, optimize their security posture and evaluate their information assurance (IA) practices, we identify the need for a structured and comprehensive methodology for IA-aware critical infrastructure protection. In this paper, we focus on the automation study of the Department of Defense Information Technology Security Certification and Accreditation Process (DITSCAP) that is a standard for certifying and accrediting the information networks that comprise of the Defense Information Infrastructure (DII). We attempt to generalize a course of actions in DITSCAP that motivate our design principles and modeling techniques, supported by their theoretical backgrounds and demonstrable prototype interfaces to establish their appropriateness.

Keywords Information Security Requirements Engineering, Information Systems Certification and Accreditation, Critical Infrastructure Protection, Risk Assessment, Ontological Engineering.

1.2.2 Using an Enterprise Architecture to Assess the Societal Benefits of Earth Science Research

J.N. Martin, *The Aerospace Corporation*

An enterprise architecture for the Earth Science activities of NASA was developed to assist in assessing the capacity of scientific instruments in meeting the needs of society. It can also help them develop the right investment strategies and help scientists and engineers in their planning for system development, especially for complex space-based environmental sensors. The architecture contains about 3000 elements that are involved in earth science research: observation sources, sensors, instruments, environmental parameters, data products, mission products, observations, science models, predictions, and decision-support tools. The science models use observations from the space-based instruments to generate predictions about various aspects of the environment. These predictions are used by decision-makers around the world to help minimize property damage and loss of human life due to adverse conditions such as severe weather storms. The architecture is developed using both traditional and non-traditional SE tools and techniques. This paper will describe additional methods needed for the SE toolbox.

1.2.3 The Systems Engineering Approach To Warship Signatures Management

M. Manzini, M. Montigiani, *Orizzonte Sistemi Navali S.p.A.*

This paper presents how Systems Engineering (SE) is applied to the design of warship radar and infrared signatures. The two signatures are treated as a system, the “signatures system”. Starting from the system definition a SE approach is described which provides a way of managing the warship signatures, taking into account all aspects involved and the relevant interrelations. The need to use a concurrent approach to reach a successful system design is highlighted.

While modern technologies do permit “fully stealth” designs, these require very great efforts, often in contrast with the constraints imposed by a real project. The aim of this paper is to show how the system level vision of SE allows design of a cost effective system which provides the proper balance of technical and economical factors.

Finally, a brief description of the role of the system engineer is provided.

1.2.4 Towards Network Enabled Capability Delivery Through UK MOD Smart Acquisition

D. Kemp, *UK MOD – DDSA;* G.D. Payne, *QinetiQ*

This paper defines the approach the UK Ministry of Defence took to determine the changes needed to its Smart Acquisition approach in order to enable the delivery of Network Enabled Capability (NEC). It describes the background to both Smart Acquisition and NEC, the benefits led and evidence based approach used to define the way forward, the use of causal link analysis, fuzzy cognitive mapping and system archetypes to understand the issues that needed resolving and finally it describes the changes that are being made.

Session 1 Track 3: Modeling Tools

1.3.1 Modeling DoDAF Compliant Architectures

C. Sibbald, C. Kobryn, *Telelogic*

No industry is more demanding than aerospace-defense when it concerns the complete integration of software and hardware architectures. Tasked with defending our nascent Information Age economy, the aerospace-defense industry must be capable of waging Information Age warfare, whose key concepts include information superiority and network-centric warfare. By most quantitative metrics, aerospace-defense systems are among the largest and most complex ever constructed. The complexity of individual aerospace-defense systems (e.g., an aircraft) is frequently compounded when we integrate many of them together to form a system-of-systems (e.g., an air traffic control system) that satisfies more global requirements.

This white paper describes a technical approach for improving how we specify system and system-of-systems architectures using frameworks in general, and the Department of Defense Architecture Framework (DoDAF) in particular. The model-driven approach to architectural frameworks explained here, which is based on UML™ 2.0, Telelogic TAU® Generation2™, and Telelogic DOORS®, can substantially improve productivity and quality.

1.3.2 A Generic, Adaptive Systems Engineering Information Model

J.J. Simpson, *The Boeing Company;*
C. Dagli, S. Grasman, A. Miller, *University of Missouri–Rolla*

Systems engineering tasks generate large volumes of data and information that must be available over the lifecycle of the system. This paper outlines an information model designed to support existing systems engineering methods and practices as well newly developed techniques. Specific methods and models used for the capture, encoding and persistence of systems engineering information and design artifacts were given special attention during the evaluation, analysis and model design phases. A generic systems engineering meta-model was then developed and used as a basis for the systems engineering.

1.3.3 Potholes in the Road to Good Systems Engineering

James R. Armstrong, *Systems and Software Consortium, Inc.*

Over several decades of observing the practice of systems engineering, both in classrooms and on programs, several recurring problems have been identified. It was anticipated that lessons would be learned, and this set of problems would decrease significantly in occurrence, if not disappear completely. However, that has not happened. It seems that many of the problems are rooted in basic mental roadblocks. This compendium is assembled as a watchlist of some of these roadblocks for new and old practitioners.

1.3.4 Object-Oriented Development For DoDAF System of Systems

S.P. Stanilka, *The Boeing Company;*
C.H. Dagli, A. Miller, *University of Missouri – Rolla*

The Department of Defense Architecture Framework (DoDAF) provides architectural artifact examples for modeling complex system of systems within the information-centric and hardware-centric global battlespace theater. This framework is utilized by all U.S. government agencies and military branches that procure military hardware and plan for tomorrow's strategic evolution in the armed forces. This framework must be adopted by those business organizations who wish to market their products to the U.S. military. The models mandated by the DoDAF do not always align with the software development methods and production processes utilized in the commercial enterprises who position their products for acquisition into the network centric military markets. This is especially true for software industries where object oriented analysis and design methods have become entrenched as an industry standard. This paper analyzes object oriented development of complex systems and compares the artifacts produced through this method with artifacts produced through the structured architecture techniques described by the DoDAF. The comparison provides an evaluation of the commonality and gaps between both ideologies.

Session 1 Track 4: SE Management

1.4.1 Governing Systems Engineering as an Enterprise Competence - A Benchmark Study with Pertinence to the US Department of Defense

W.P. Mullins, *Consultant;*
M.A. Wilson, *Strategy Bridge International, Inc.*

DoD is reinvigorating SE capabilities so that "system of systems" structures can now be engineered. A benchmarking review reports approaches to the achievement of SE competence in a Research, Development and Engineering Center. For SE competence management most SE organizations contacted reflect tailoring to local and historical conditions more than the effects of integrated development. Current SE governance practices are analyzed here on a continuum between composite models termed the "Strong Form Model" and the "Methods Model." Systems-engineered Competence Development Plans appear to be in order to address growing dynamic complexity inherent in the "system of systems" environment.

1.4.2 Performance-Based Earned Value

P. Solomon, *Northrop Grumman Corporation*

Performance-Based Earned Value (PBEV) is an enhancement to the Earned Value Management Systems (EVMS) industry standard. PBEV supplements EVMS with principles and guidelines for true integration of project cost, schedule, and technical performance. It is derived from standards and capability and maturity models for systems engineering and project management.

PBEV overcomes several shortcomings of EVMS. EVMS specifically excludes the measurement of product quality and is silent on risk management. In contrast, PBEV bases earned value on product quality requirements, technical performance, and technical maturity. It also incorporates the outcomes of risk management into revised plans and the Estimate at Completion (EAC).

PBEV supports agile systems development because it is scalable to match the project risk and is responsive to changing product requirements. PBEV evolved from lessons learned in both the U.S. defense industry and the commercial software industry in India. It is also cost-effective. The principles and guidelines of PBEV provide a framework for process improvement.

1.4.3 Estimating and Optimizing System's Quality Costs of Transport Helicopter Avionic System Upgrade

A. Engel, S. Shachar, I. Bogomolni, *Israel Aircraft Industries (IAI)*

This paper depicts IAI's real-life experience in estimating and optimizing system's quality costs associated with upgrading a transport helicopters' avionic system. This pilot project was conducted at Lahav, the military aircraft division of the Israel Aircraft Industries (IAI) in conjunction with the SysTest project. SysTest was a European Commission R&D project chartered with developing a systems Verification, Validation and Testing (VVT) methodology and a process model for estimating product lifecycle cost, risk, quality, time, etc.

The SysTest endeavor and IAI's pilot project are described briefly. Thereafter, the paper presents a case study where the overall quality costs are estimated based on the current VVT strategy established at Lahav/IAI. Our findings showed that the actual performance of VVT process amounted to 34% of the quality costs. The appraisal risk cost (expected cost associated with the detection of defects during the VVT process) amounted to 6%. Notably, the impact risk cost (cost emanated from not performing VVT as part of the VVT strategy) amounted to 60% of the quality costs. At the same time, a significantly improved VVT strategy, reducing the cost of quality by over 25%, is readily available.

Our conclusion is that the current VVT strategy at Lahav/IAI is clearly not a most efficient one. Less cost-effective VVT activities are performed at too high a performance level and visa versa. We assert that systems' VVT is performed at many organizations based on "engineering intuition" and, plainly, this is not a good yardstick. We are currently starting to apply a formal VVT optimization methodology in a large IAI program, developing a state of the art communication satellite.

1.4.4 Towards a Collaborative Engineering Environment to Support Capability Engineering

Wayne Robbins, S. Lam, C Lalancette, *Defence R&D Canada*

This paper presents the challenges and lessons learned during the realization of a prototype collaborative engineering environment to support capability engineering under the auspices of an R&D Technical Demonstration Program within the Canadian Department of National Defence. The definition and motivation of capability engineering is discussed, followed by the role, relevance and approach taken towards enabling collaboration within it. The basics of the collaborative environment, both as a system of systems and as it was applied to a departmental use case are highlighted, with specific emphasis on the breadth of issues that arise, including application, technical, organizational, personnel, cultural and process.

Session 2 Track 1: Enterprise Systems

2.1.1 Revisiting the Notion of System - Organizations and Enterprises as Systems

A. Faisander, *MAP systéme*

This paper reports on a study performed for NATO about the opportunity to tailor and use the ISO/IEC 15288 standard as well as Systems Engineering concepts for such an Organization. The objective of applying the standard and SE concepts was to help prioritise, rationalise or align processes, activities and organisations.

The result of this study was a report for NATO including explanations of the concepts and their potential application, rules for tailoring the standard, as well as a set of recommendations. The recommendations are not reproduced in this paper; only the "system aspects" are considered here, along with its application to NATO as a complex Organization. Some considerations about ANSI/EIA 632 are added to introduce the notion of "enabling product" and "enabling systems".

This paper discusses how the notion of System can be applied to an Organization and extends the application to Enterprises. The discussion revisits the concept of System in light of current engineering studies and coming back to fundamentals, provides a more precise and more complete definition of this notion. This enhanced definition of System rationalizes the engineering of any kind of system and particularly brings benefits to Organizations and industrial Enterprises viewed as systems. Whether the idea of engineering Organizations and Enterprises as systems is attractive to engineers or others raises questions of feasibility and relevance. Organizations and Enterprises are composed of human beings, hence, defined as "Human Systems"; so the paper ends with some words about human factors that could help or hinder the adoption of these useful rational ideas.

2.1.2 Enterprise Architecture and Aesthetics

P. King, *VEGA Group PLC*

Enterprise architecture is the discipline of describing and analyzing the relationship between an enterprise's objectives and purpose, and the system of systems which the enterprise uses to help achieve those objectives. This paper makes the case for the importance of aesthetics in enterprise architecture. It proposes an enterprise architectural modeling language which addresses enterprise form, purpose and aesthetics. This language is a meta-model extension of SysML which uses the power of SysML to address the engineering aesthetic of enterprise architecture.

The paper is based on work carried out for the UK Ministry of Defence's Integration Authority to develop an "Integration Services Support Environment" (ISSE). ISSE uses the enterprise architecture modelling language to enable the consistent description, and hence analysis, of a large and heterogeneous system of systems. ISSE itself has been developed as a enterprise architecture modeling tool and as a repository of interconnected models of MoD's enterprise.

2.1.3 Engineering Enterprises Using Complex-System Engineering

B.E. White, M.L. Kuras, *The MITRE Corporation*

This paper summarizes a complex-system engineering (cSE) regimen for the deliberate and accelerated management of the natural processes that shape the development of complex-systems and proposes an approach for applying this regimen to enterprises. It also introduces a fundamental process of cSE, multi-scale analysis—a departure from the traditional, uniscale, reductionist analysis that underpins traditional system engineering (TSE).

Session 2 Track 2: Process

2.2.1 A Structured Method for Generating, Evaluating and Using Metrics

R.W. Kitterman, *Northrop Grumman Newport News*

This paper presents a method of generating metrics for a project, organization, process, or product. It first points out that metrics generation starts with a bounding of the area of interest. Then it shows how to examine the outputs associated with the area of interest for metrics on effectiveness that are stated in the general parameters of quantity, quality, cost and time. Next, the paper focuses on the area of interest's internal activities to develop metrics on efficiency, using the same general parameters. The paper then demonstrates a number of tests that can be used to evaluate the goodness of the metrics for use in a decision process. Finally, the paper discusses how metrics presentation has importance equal to metrics content and shows examples of good and bad ways to present metrics.

2.2.2 A Meta-Process Producing a Deliverable-Centric Process

M. Lizotte, C. Lalancette, G. Dussault, M. Couture,
M. Mokhtari, F. Bernier, *Defence R&D Canada Valcartier*
S. Lam, *Defence R&D Canada - Ottawa*

The current paper introduces the Iterative and Incremental Meta-process (I2M) being applied to develop a Capability Engineering Process (CEP). This simple method is founded on the assumption that such a CEP, and even any process, should be developed as methodically as engineering is performed for systems and software system development. This effort is performed as part of a major Canadian R&D effort called the Collaborative, Capability, Definition, Engineering and Management (CapDEM).

2.2.3 Observable States May Be Necessary When Using COTS Products

R. Botta, T. Bahill, *BAE Systems;*
Z. Bahill, *Boeing Integrated Defense Systems*

In order to use commercial off the shelf (COTS) products, the engineer must be able to prove that the COTS product is equivalent to the specified design. In most cases, this requires observable states, which are usually not available. Other techniques that have been used in lieu of proving system equivalence include creating multiple reset (or test) states and proving input/output equivalence with respect to these initial state pairs, designing built-in self-tests, building observers to estimate the system states and adding extra outputs that imply the states. This paper also gives examples where states are necessary and unnecessary in modeling systems.

Session 2 Track 3: Modeling - Sys ML

2.3.1 SysML - An Assessment

E. Herzog, A. Pandikow, *Syntell AB*

SysML is a new standard language for system modeling, built on top of the new version of the popular UML and tailored for the specific needs of systems engineers. In this paper we present a brief overview of the SysML along with observations on the language and some challenges facing the systems engineering and tool vendor community.

The purpose of the paper is not to criticize the outcome of the SysML standard but to evaluate its strengths and weaknesses and identify areas for future improvement.

2.3.2 Verification of Selection from Product Line Requirements

H.Kaindl, *Vienna University*,
M. Mannion, *Glasgow Caledonian University*

A product line is a set of similar products e.g. spacecraft mission planning systems, mobile phones, and it facilitates reuse. From a given model of product line requirements, the requirements for new single systems in the product line can be selected. However, verifying that the selected requirements of any single system satisfy the variability constraints in the product line model is difficult especially when the models are large and complex. By modelling variability in the product line requirements using propositional calculus, a logical expression can be developed for the set of product line requirements and selection verification can be achieved by showing that the logical expression is satisfied. A case study using real-world requirements provides empirical evidence of the computational feasibility of this approach. This paper presents formal semantics of variability representation in product line requirements and their use for verification of selection for single systems.

2.3.3 Modeling High-Level Requirements in UML/SysML

M.C. Hause, F. Thom, *Artisan Software Tools*

Modeling requirements with the Unified Modeling Language (UML) can be confusing for both first time and experienced systems engineers. Often this is due to inexperience with UML, or a reliance on object-oriented techniques, where it is necessary to identify objects as the starting point for evaluating a potential system.

When modeling requirements, however, this is normally the "pre-object" stage, where identifying potential objects can mean defining the solution rather than defining the requirements. The techniques described in this paper focus on the UML/SysML diagrams that do not require objects, and are therefore better suited to this early part of the systems engineering lifecycle. In addition to expressing the requirements in a pure form, they help to identify system interaction, potential interfaces and the characteristics of these interfaces, and algorithms and equations. They also provide a means to achieve handover and traceability to subsequent stages of development, when object-oriented techniques may be more appropriate.

Session 2 Track 4: SE Management

2.4.1 A Case Study Example of the Role Matrix Technique

K. Callan, C.E. Siemieniuch,
M.A. Sinclair, *Loughborough University*

The paper outlines the Role Matrix Technique (RMT) - a paper-based method for resourcing processes with identified human roles. It was developed in use over a number of projects, where the aim was to explore alternative allocations of roles to processes in order to find the most appropriate configuration of roles, responsibilities, interactions, activities etc. All stakeholders in a given process can generate a common understanding of roles and responsibilities, along with the interactions between roles. The overall picture is generated graphically, by means of a bottom-up approach. Once, trained in the basics of the method, it should be applied by stakeholders familiar with the process under scrutiny, and who also have an awareness of the critical interactions between the human roles involved. The paper provides an overall rationale for the method and then goes on to discuss the three main stages involved: modeling the process of interest; identification and allocation of the roles required to process activities; and the representation of these roles within the Role Matrix – this is where the key innovation lies. The paper finishes with an evaluation of the RMT.

2.4.2 QuARS: Automated Natural Language Analysis of Requirements and Specifications

R.W. Ferguson, D. Goldenson, *Software Engineering Inst.;*
G. Lami, M. Fusani, S.Gnesi, F. Fabbrini,
National Research Council (CNR), Italy

Requirements analysis is a nontrivial, tedious, error prone and time consuming process. This paper describes a tool that automates identification of requirements defects that exist because of inadequate use of language for the purpose intended. The paper also describes results of using the tool on actual requirements documents from different industries. Our results show that the tool identifies defects that often escape detection by human inspectors.

2.4.3 Extreme Leadership for Systems Engineers

T. Fossnes, *Norwegian Defence Materiel Agency*

There have been numerous attempts to identify and analyze the multiple factors that contributed to the "tragedy" on Mt. Everest in May 1996. As the leader of a challenging project some years ago, I recognized many of the same human behavioral patterns between my project and Mt. Everest events. This paper presents my observations as well as a mapping of how Project Management /Leadership (PM), Systems Engineering (SE) and Supportability/

Integrated Logistics Support (ILS) are integrated for each of the 2 systems respectively, and how these complex systems and human behaviour mutually influence each other. In my experience, Systems Engineers leading a project share many of the challenges of a leader taking a group of mountaineers to the top of Mt. Everest – and visa versa. In my capacity as Technical Program Chair of INCOSE 2004 in Toulouse France, I was privileged to organize and conduct the special session called "Management under Extreme Conditions". This paper is a continuation of the dialogue begun in that session.

Session 3 Track 1: Application - Transportation

3.1.1 Systems Engineering for the Development of a Decision Support System to Help Manage the Railway Wheel - Rail Interface

V.H. Thanh, C.Z. Roberts, J.S. Williams, A.B. Stirling, K. Madelin, *The University of Birmingham*

Interactions and interrelationships between the railway wheel and rail are complex, and managing them effectively would require an integrated systems approach. This paper describes how systems engineering has been applied to the development of a decision support system for the management of the railway wheel – rail interface. This work can be considered as a case study on the application of systems engineering in the railway industry. Stakeholder requirements, system functional requirements and architectural design of the system are described. A brief description of the prototyped system and its initial applications are also included.

3.1.2 Quantitative Assessment of Expected Space Mission Return in Terms of NASA's Institutional Goals

K.E. Shelton, G. Rodriguez, C.R. Weisbin, A. Elfes, *Jet Propulsion Laboratory*

NASA high-level goals of Science, Exploration, and Inspiration present challenges to quantitative analysis. A quantitative method of comparison would assist in future mission design and understanding the return from missions in terms of the high-level goals. In this paper, we propose a method to assign quantitative metrics to model potential return from future missions in NASA's high-level goals in Science, Exploration, and Inspiration. The method uses the high-level goals and engineering metrics to build a hierarchical metric tree. We have selected a set of seventeen future missions, which span a multitude of goals, to help define the metrics and provide a test set; human exploration missions have been included but at this stage the data is still limited. We demonstrate herein the results of the model by closely examining three missions from our test set; the integrated return from these missions is equivalent despite the disparate objectives and approaches of the missions themselves. We conclude by discussing future areas of research.

3.1.3 Applying Quantitative Methods for Architecture Design of Embedded Automotive Systems

O. Larses, *Scania CV*

Architecture design is often referred to as an art, performed in the conceptual stages of a design process. However, it can be supported by quantitative methods. At the highest level of abstraction a goal oriented approach is applicable. This can be realized by a keyfigure based methodology similar to the management directed Balanced Scorecard.

The automotive industry requires that a system architecture is optimised not only for a single product, but for reuse over a range of products, and also for reuse over time with continuous improvements. To achieve these goals the product should be modular. Keyfigures are useful for managing trade-offs but do not easily describe modularity. For this purpose DSM (Design/Dependency structure matrix) and cluster analysis is more useful. A combination of the methods is proposed for design of automotive control system architectures. The proposed method has been applied and evaluated in architectural work at Scania CV.

Session 3 Track 2: Reliability

3.2.1 Development of a Sustainable Process for the Generation, Validation, and Application of Human Reliability Assessment within the Engineering Design Lifecycle

G.A. Ng, M.A. Sinclair, C.E. Siemieniuch,
Loughborough University

This paper describes the activities that were undertaken during a twelve-month study investigating the application of Human Reliability Assessment (HRA) within a major international systems company. It is hoped that this paper might act as a template for other companies wishing to re-evaluate their HRA processes and in order to develop sustainable processes to manage the generation and application of HRA along the engineering life cycle. The paper deals primarily with describing a process by which the HRA activities can be maintained and developed corporately.

The initial findings of the study were that there was a general lack of confidence in the results of current HRA activities and these activities differed in scope and detail depending on the customers and the platform's historical use of HRA. In order to overcome these differences and to foster best practice, the Capability Maturity Process was developed for HRA activities across the company to be owned, managed and maintained internally.

In addition a framework is suggested for HRA activities undertaken during the product development process. It is envisaged that this framework be tailored to allow the depth and appropriateness of different HRA techniques for different systems. Some common HRA techniques are presented together with a description of how they would fit into such a framework. The timeliness of the HRA activities were also considered, in that they can be applied at different stages of product development (early in the concept to screen out high level risks, down to activities leading up to qualification and certification of the product).

3.2.2 Four Strategies for Reliability - Improving Robustness to One-sided Failure Modes

D.P. Clausing, D. Frey, *MIT*

Reliability is one of the most important characteristics of a system. To be reliable a system must be robust – it must avoid failure modes even in the presence of the broad range of noise factors such as harsh environments, changing operational demands, and internal deterioration. In this paper we focus attention on "one-sided" failure modes, which occur only on one side of a range of noises. Four effective strategies are presented for achieving improved robustness to one-sided failure modes by conceptual improvements. Each strategy is illustrated through two examples from industrial practice.

3.2.3 Systems Reliability Demonstration

A. Zonnenshain, Z. Benyamini, *RAFAEL*

This paper discusses the issue of system Reliability Demonstration. The classical reliabilitydemonstration methods are discussed, as well as the difficulties associated with application of these methods in today's complex system and competitive project environment. Some insights are discussed, regarding the changes required in reliability demonstration methodologies, in order for them to be effective in today's environment - from both RAFAEL's experience and trends throughout the world. The methods presented are being successfully implemented in several projects.

Session 3 Track 3: SE Application - Business

3.3.1 Quantifying Cost Risk Early in the Life Cycle

C.R. Kenley, *Kenley Consulting, LLC*,
J. Nail, *Bechtel SAIC Company, LLC.*

A new method for analyzing life cycle cost risk on large programs is presented that responds to an increased emphasis on improving sustainability for long-term programs. This method provides better long-term risk assessment and risk management techniques. It combines standard Monte Carlo analysis of risk drivers and a new data-driven method developed by the Hoy and Hudak (1994). The approach permits quantification of risks throughout the entire life cycle without resorting to difficult to support subjective methods. The Hoy-Hudak methodology is shown to be relatively straightforward to apply to a specific component or process within a project using standard technical risk assessment methods. The total impact on system is obtained using the program WBS, which allows for the capture of correlated risks shared by multiple WBS items. Once the correlations and individual component risks are captured, a Monte Carlo simulation can be run using a modeling tool such as Analytica to produce the overall life cycle cost risk.

3.3.2 The ABCs of AFs: Understanding Architecture Frameworks

R. Siegers, *Raytheon*

Numerous architecture frameworks have emerged over the past decade, but the contents and purposes of these frameworks are quite diverse. A framework typically addresses topics such as methodology, product description, reference models, categorization, or classification, but no single framework fully covers all aspects of the architecting process. Many users mistakenly believe that these frameworks represent distinct alternatives to the architect and that they must identify a single one to facilitate or guide their architecting efforts. The reality is that architecture frameworks (or parts of frameworks) must be unified in order to provide a comprehensive architecting solution. The purpose of this paper and presentation is to provide an overview of several architecture frameworks in use today, along with recommendations on the unification of key elements of specific frameworks.

3.3.3 How to Routinely Assure Project Success

N. Malotaux, *N R Malotaux – Consultancy*

Evo, short for Evolutionary Project Management Methods, is rapidly and frequently applying the Plan-Do-Check-Act cycle, not just for the development of the project-result, but also for the project organization and even on the methods used. We organize the work in weekly Task-cycles. Task-cycles feed bi-weekly Delivery-cycles by which we optimize the requirements and check our assumptions. We use TimeLine to create and maintain the total project scope and to connect the Project Result, through the Deliveries, to the work organized in Tasks. Evo combines Planning, Requirements Management, and Risk Management into Result Management, with a fanatical view on ROI. This paper explains the basics of this Evolutionary approach and practical details people can start applying immediately. People who think that this approach costs too much work are proven wrong by those who start applying the Evo methods: Projects coached by the author realized significant better results in significant shorter time.

Session 3 Track 4: SE Management

3.4.1 A Framework for Understanding Uncertainty and its Mitigation and Exploitation in Complex Systems

H.L. McManus, *Metis Design;*
D.E. Hastings, *Massachusetts Institute of Technology*

A framework to aid in the understanding of uncertainties and techniques for mitigating and even taking positive advantage of them is presented. The framework is an attempt to clarify the wide range of uncertainties that affect complex systems, the risks (and opportunities) they create, the strategies system architects can use to mitigate (or take advantage) of them, and the resulting system attributes. Current and developing methods for dealing with uncertainties are projected onto the framework to understand their relative roles and interactions.

3.4.2 How the Pro-Active Program (Project) Manager Uses a Systems Engineer's Trade Study as a Management Tool, and Not Just a Decision-Making Process

A. Felix, *NAVAIR Weapons Division*

This paper takes the Program (Project) Manager's (PM or manager's) point of view in strategic decision management when trade studies are used as the decision-making tool. The application of trade studies as a tool in the strategic decision management process transcends commercial and defense industries. Industry, government, and academia projects can benefit from using this robust, structured decision-making process discussed herein as a management tool in overseeing and providing guidance in the project's direction. The trade study created and developed by the systems engineer for decision-making should follow a clear pre-defined decision-making process. Such a process would result in unambiguous interpretation and understanding thereby improving buy-in from all stakeholders. The focus of this paper is the major stakeholders' acceptance, buy-in and in understanding the underlying information and knowledge used in the trade study decision-making process.

The PM is responsible and accountable for the successful execution of a program (project) given the necessary resources. As part of those duties, he/she is responsible for making the major decisions of the program and will also be accountable for those decisions. The leadership/ executive management can and should ask the PM to explain, defend, and demonstrate the decision-making methodology used in each major decision. Those demanding answers may include but are not limited to Director level, Vice-President/ President of an organization, Board of

Directors, contracting agency, Government representative, and/or any other sponsoring stakeholder. There may also come the expectation by major stakeholders to reproduce the major steps in the methodology of the decision-making process. This expectation should in-turn, be demanded by the PM and come as no surprise to the systems engineer developing the decision making study thus establishing and enforcing accountability. The process used for the trade study in arriving at the recommended decision, as a matter of good engineering/business practice, should be documented and archived in the program artifacts for future reference.

3.4.3 Engineering a Corporate Memory: Some Practical Insights

M. Young, *Defence Institute*

The requirement for a Corporate Memory / Knowledge Management capability originated in the South African Army's Directorate Army Logistics, as well as the Defence Institute as a means to facilitate knowledge sharing and preservation. Both parties stand to benefit from this initiative and the development was thus undertaken as a joint venture. The system engineering process, as tailored for the development of the Knowledge Management system, is presented in the paper. The current status of the development effort is detailed to provide a perspective of where we currently are. The paper further details future initiatives and also shares lessons learnt with the reader.

Session 4 Track 1: Enterprise Systems

4.1.1 Bridging Systems Engineering Views with A Structuring Matrix

D J. Battersby, *BAE Systems SEIC,*
C. Holden, *Airbus UK, Flight Physics*

This paper describes how a single information representation based upon Design Structure Matrix (DSM) may be used to provide a unified information visualization applicable across a range of key systems engineering domains. This supports both the planning and technical architecting of a system and as such may be valuable as a link between these areas and the more abstract lifecycle model. The ability to restructure the matrix through clustering and partitioning also supports systems engineering by providing an improved understanding of the whole system. This understanding is facilitated by the use of clearly defined attributes assigned to the links within the matrix.

4.1.2 A Model-Based Requirements Database Tool for Complex Embedded Systems

M.B. Bennett, R.D. Rasmussen,
Jet Propulsion Laboratory

It has become clear that spacecraft system complexity is reaching a threshold where customary methods of control are no longer affordable or sufficiently reliable. At the heart of this problem are the conventional approaches to systems and software engineering based on subsystem-level functional decomposition, which fail to scale in the tangled web of interactions typically encountered in complex spacecraft designs. Furthermore, there is a fundamental gap between the requirements on software specified by systems engineers and the implementation of these requirements by software engineers. Software engineers must perform the translation of requirements into software code, hoping to capture accurately the systems engineer's understanding of the system behavior, which is not always explicitly specified. This gap opens up the possibility for misinterpretation of the systems engineer's intent, potentially leading to software errors. This problem is addressed by a systems engineering methodology called State Analysis, which provides a process for capturing system and software requirements in the form of explicit models. This paper describes (1) how requirements for complex aerospace systems can be developed using State Analysis, (2) how these requirements inform the design of the system software, and (3) how this process has been aided through a State Analysis Database (SDB) and supporting multi-platform client. The SDB provides a productive, collaborative development environment for State Analysis that is shared by both systems and software engineers.

4.1.3 Evolving to Intelligent Systems Engineering: Findings of the IS2004 Panel

J. Ring, *Innovation Management, Inc.*

Organizers of INCOSE International Symposium 2004 posed six themes regarding the future of systems engineering. In response a panel, "Evolving to Intelligent Systems Engineering," took a position on each theme based on ideas already being explored in the Intelligent Enterprises Working Group, IEWG. Four panelists supported, or not, 23 specific assertions regarding the six themes. During the ninety minute session vigorous interaction with the panel audience occurred. At the end, 67 attendees kindly completed a poll designed to gauge the degree of consensus with the 23 assertions. The poll results are reported and analyzed in this paper.

Also included are responses to the same poll by a voluntary subset of 18 INCOSE Fellows prior to the panel session. These results highlight several possibilities regarding the future of systems engineering for consideration by SE practitioners and educators.

Session 4 Track 2: Systems Architecture

4.2.1 Introducing the Role of Process Architecting

J.E. Kasser, *University of South Australia*

The work done in the development of systems is currently split between the three interdependent and apparently overlapping organizational roles of systems architecting, systems engineering, and project management, which interdependently produce a product to (the correct) specifications within the constraints of resources, budget and schedule. This paper first identifies a reason for the overlapping roles, and then attempts to resolve the difficulties in defining the roles of systems engineering, systems architecting, and project management, and the difficulty in defining the body of knowledge for systems engineering by identifying a gap in the functions performed by the three organizational roles, when viewed from the perspective of planning and implementing the development of a system, via the Roles Rectangle. A gap, which when filled by the new defined role of process architecting, has the potential to bring some order into the current chaos and resolve many if not all of the current difficulties.

4.2.2 Family-of-Systems Architecture Analysis Technologies

P.P. Jain, *Information Systems Sector;*
C. Dickerson, *BAE Systems*

The United States Department of Defense (DOD) transformation initiatives have the potential to significantly improve operational effectiveness and efficiencies by having the right information at the right time at the right place to make critical time-sensitive warfare decisions. Realizing these operational benefits requires interoperability among complex families of systems. New computer-aided analysis technologies, methods, tools and simulation environments are needed to enhance understanding of the complex behavioral relationships among thousands of entities to 1) support DOD acquisition decisions to evaluate alternative Capability-Based-Acquisitions (CBA) 2) evaluate relative merits of multiple concepts of operations feasible in complex scenarios. This paper describes a set of executable model abstractions and a set of analysis technologies needed to build Family-of-Systems architecture analysis tools and the simulation environment. It proposes a CBA system engineering process linking the tools supporting these abstractions, analysis technologies and artifacts captured according to DOD Architecture Framework (DoDAF) standard.

4.2.3 Network Centric Architectures: Are We Up To The Task?

S.T. Booth, *Vitech Corporation*

The emergence of network centric architectures and the achievement of information superiority is the new paradigm that is being embraced by the military's next generation of systems to be developed and deployed. The changes dictated in this new architecture are instigating revolutionary changes throughout the DoD. These changes should have an equally profound effect on system integrators in terms of integration practices and policies that will allow network centric architectures to be realized within budgetary and schedule time constraints. The purpose of this paper is to identify key issues currently limiting the effectiveness of system integrators in their efforts to architect network centric architectures and offer suggestions on how to strengthen the integration process through the application of model-based systems engineering, integrated information repositories, and teams that have both a vertical and horizontal architecture definition and integration responsibilities.

Session 4 Track 3: Measurements & Analysis

4.3.1 Generic Measures of Effectiveness for Systems

T.C. Mackley, *Cranfield University*

The development of systems projects is often beset by problems because important parameters are not considered during their development. This paper sets out to determine a generic set of parameters for measuring the effectiveness of a system solution that can be used to compare different solutions, assess their development or consider strategies for replacement when in service. By consideration of a number of methods and models currently used within the domain of systems engineering, an attempt is made to produce a comprehensive list of measures of effectiveness.

4.3.2 Engineering and Implementing RMS Engineering's DTC Metric

G. Stratton, Q. Redman, E. Casey, *Raytheon Missile System*

Architecting a product requires a defined set of requirements for the finished product; e.g. size, weight, volume, range, power, color, cost, payload, etc. One very necessary requirement is the anticipated product production cost. Failure to set the production cost requirements at design kick-off allows for unexpected and unacceptable production costs. Previously, all too often, programs were allowing establishment of the production cost goal to slip, or they would wait for their customer to establish it for them. Raytheon Missile Systems' (RMS) Engineering Directorate has specified that all development programs will now establish a production cost goal using the Design-To-Cost (DTC) metric described within this paper and will monitor their design progress towards meeting this goal. Each program's DTC metric is now collected monthly and reviewed by senior management. This paper discusses creation of the RMS DTC metric, the metric's details and its implementation across RMS.

4.3.3 Systems Engineering Measurement Primer: A Metrological Evaluation

T.L. Ferris, *Systems Engineering and Evaluation Centre*

The paper presents the results of an investigation of the INCOSE Systems Engineering Measurement Primer from the framework of measurement theory. This approach to the Primer is outside the scope of the claims of the Primer, and so is not entirely fair to the authors of the Primer. This investigation is conducted in order to contribute to the development of measurement processes suitable for use in systems engineering and also to provide a theoretical framework for measurement of systems engineering processes.

Session 4 Track 4: Requirements

4.4.1 A Hybrid Requirements Capture Process

J.D. Daniels, R. Botta, *BAE Systems*;
T. Bahill, *The University of Arizona*

Systems engineers traditionally produce a system requirements specification containing shall-statement requirements. However, the rapid adoption of use case modeling for capturing functional requirements in the software community has caused systems engineers to examine the utility of use case models for capturing system-level functional requirements. A transition from traditional shall-statement requirements to use case modeling has raised some issues and questions. This paper advocates a unified requirements engineering method in which use case modeling and traditional shall-statement requirements are applied together to effectively express both functional and non-functional requirements for complex, hierarchical systems. This paper also presents a practical method for extracting requirements from the use case text to produce a robust requirements specification.

4.4.2 Quantifying the Evolution of Goals in Requirements Engineering: A Study on the Quality Assurance Review Assistant Tool

K.M. Cooper, T. Chowdhury, L. Chung,
The University of Texas at Dallas

Goal-oriented requirements engineering is becoming increasingly important, as goals help to specify requirements, provide rationales to stakeholders, and detect causes behind requirements conflicts. Measuring and understanding the manner whereby goals are understood and modeled over time can have a vital implication to many aspects of software development. Despite the importance, however, there seems to be little help available in measuring the evolution of goals. This paper presents a scheme for quantifying the evolution of goals in requirements engineering. This paper also presents a case study for this scheme using a groupware application, called the Quality Assurance Review Assistant Tool (QARAT). The data collected are analyzed in relation to several conjectures regarding the structural evolution of the goals over 11 iterations. Ultimately, studies such as these can be used to help improve cost estimation, project planning, and risk analysis activities.

4.4.3 Developing Requirements for Technology Driven Products

L.S. Wheatcraft, *Compliance Automation, Inc.*

New technology development is often a mainstay in product development, yet projects responsible for developing products based on new technology frequently are over budget, delivered late, poor in quality, and fail to meet customer and user needs and expectations. Two things that contribute to these problems are: 1) failing to define the product requirements up-front and 2) failing to adequately manage the maturation of the enabling technology(s) needed. This paper introduces several key approaches and processes that address these issues and the many challenges of developing and managing requirements for technology- driven products.

Session 5 Track 1: Education - Research & Design

5.1.1 A Meeting of the Minds: A Successful Systems Engineering Experiment Using Concept Maps for Effective Communications

C.A. Calimer, *Boeing Inc.*
J.L. BeVier, *John L. BeVier & Associates, LLC.*

An informal experiment was conducted to test the effectiveness of communicating Systems Engineering concepts with customers using Concept Maps. The goal was to understand systems engineering concepts and techniques with customers using non-

technical diagrams, as well as to establish that the systems engineers had more-accurately captured customer needs.

In short, the experiment was about creating a more customer-friendly vehicle that enabled dialog between the customer and the engineer, without asking the customer to comprehend "Systems Engineering-speak". This paper describes the customer/engineer communication problems found during the experiment, compares the effectiveness of Concept Maps and Use Cases for this experiment, describes Concept Map basics and the customer's reaction to them, and describes the proposed Systems Engineer's use of Concept Maps. The authors note that there are other, successful systems engineering communication methodologies and endeavors. They were not addressed in this experiment.

Never-the-less, the result of the experiment was an enthusiastic and successful meeting of the minds, resulting in a successful shared customer/engineering vision. We offer our Concept Map findings for serious consideration in establishing both customer-friendly and Systems Engineer effective communications.

5.1.2 An Approach to Developing R&D Standard Processes

Y.H. Hwang, J-G. Park,
Electronics and Telecommunications Research Institute

With the increase of complexity of man-made systems and software and the enlargement of the expected quality level for R&D outcomes in today's R&D environment, it has become increasingly necessary to effectively define the R&D standard processes tailored for our organization and projects. To meet these needs, we defined the R&D standard processes based on the international standards for systems and software engineering and on our traditional work methods and applied them to our ongoing projects. We will improve our defined R&D standard processes continuously by monitoring our processes and products and checking feedback from application results. In this paper, we introduce the R&D standard processes developed by our organization, the E Research Institute in Korea, and define the requirements and approaches used for their development. We compare our defined R&D standard processes with ISO/IEC 15288 which is the international standards for systems engineering.

5.1.3 Work Practice in Research: A Case Study

N.G. Martin, *Xerox Corporation*

Work practice analysis is a type of Ethnography that studies individual and group work. It has been developing at Xerox over the past 20 years. Recently, it was applied by a research group studying text mining. It showed flaws in the group's initial understanding of the problem and redirected the group's attention from classification to clustering. In addition, it led to the development of a novel approach to text mining. Further study showed that the novel approach is widely applicable. We describe work practice in general, then provide a case study of the application or work practice analysis to the gathering requirements for text mining. We conclude that work practice analysis in specific helps bridge academic results and industrial practice.

Session 5 Track 2: Systems Architecture

5.2.1 Architecting Ontological Systems

A.R. Terrill, *The Boeing Company;*
C. Dagli, *University of Missouri-Rolla*

Recent emerging technologies such as internetworking and the World Wide Web have significantly expanded the types, availability, and the volume of data accessible to information management systems. In this new world, there is less emphasis on isolated devices and greater emphasis on information exchange. This shift is making knowledge management and application integration key issues in computer technology. In order to stay competitive, a company is held hostage by how it understands, maintains and accesses its data. Data comes from many sources, containing a variety of types and formats. One possible way to tackle this complex data problem is to implement an ontology, a unifying framework that facilitates communication through a shared understanding and vocabulary of a system. It enables communication between systems that are independent of system technologies, information architectures and application domain. This paper describes the importance of ontologies in knowledge management and provides the basis on how to architect such an ontological system.

5.2.2 Addressing the System of Systems Challenge

M.A. Wilson, *Strategy Bridge International, Inc.;*
J. Boardman, *Elipsis, Inc.;* A. Fairbairn, *JBA, Ltd.*

The top-down systems engineering strategies that worked well in the 20th century do not adequately address the complexity and interdependencies of today's higher-order systems that often must operate seamlessly with huge and disparate legacy systems. Soft management issues, such as organizational culture, also play a vital role in the organization's system of systems, often called the extended enterprise. Strategy must be formulated—and appropriate deployment mechanisms designed—for the system of systems level.

System of Systems (SoS) has become a popular buzz word among systems engineering practitioners, but what does it really mean? Some professional literature traces the origins of SoS to problems with systems that "nobody owns," while the U.S. Department of Defense has recognized that Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) systems must be seamlessly integrated with weapons systems in order to achieve optimal SoS effects. This paper offers an explanation of key SoS concepts and proposes some useful practices that the authors have found useful to address the complexities of large-scale integration of SoS assets across the extended enterprise (EE).

5.2.3 Obsolescence Management for System-of-System Hierarchies: A Technology-Based Approach

T.E. Herald, *Lockheed Martin*

Many systems face a similar obsolescence issue, which is that the desired system deployment life cycle is much longer than the life cycle of the constituent parts (hardware and software) that make up the physical architecture. Thus, the system baseline must evolve over its operational life cycle just to remain functionally viable. This problem is compounded as the size of the system grows toward network-centric system-of-systems and as the use of commercial technologies and products increases. Thus, the challenge is to perform technology assessments that facilitate the forward planning of technology evolution on the system of interest. A corollary challenge is to perform this planning while simultaneously optimizing the life cycle affordability for the customer.

This paper provides a methodology for taking current technology information and transforming it into a system evolution plan (the term system being used in the most general sense to encompass sub-assemblies through system-of-systems) using affordability as the optimizing variable for technology change incorporation.

Session 5 Track 3: Education

5.3.1 What Can a Project Manager Learn from an Actor? Improving Professional Skills through Analogical Thinking

G. Backlund, J. Sjunnesson, *Combitech Systems AB*
E. Josephson, *The Royal Dramatic Theatre, Sweden*

A project manager with a holistic systems engineering perspective, encounters dilemmas and must make decisions on a daily basis. Traditional skills development programs are not well-suited for these persons. Based on knowledge theory, a program has been developed that focuses on the practical knowledge that an experienced person has developed. The Dialog Seminar method has been used and tested on a group of project managers. At the final seminar of the program, the group met the well-known Swedish actor Erland Josephson, and through analogical thinking, the project managers improved their understanding of their own professional roles through comparison with those of the actor and the director. The result is an awareness of the dilemmas, an ability to see them and meet them with improved security, and also insights on how they could improve their project management skills.

5.3.2 Didactic Recommendations for Education in Systems Engineering

G. Muller, *Embedded Systems Institute*

Teaching systems engineering differs from teaching a mono-disciplinary course, because the focus is much more on skills and less on transferable facts. The teacher must trigger a learning process in the students that stimulates the student to become active with the subject in a perceptive, reflective, and explorative way. This paper provides a number of recommendations for interaction, illustration, soft skill development, the use of media and student feedback.

5.3.3 i-pub – Towards Electronic Access to INCOSE Publications

E. Herzog, A. Pandikow, J. Andersson, *Syntell AB*

Over the years a large number of high quality papers have been published at INCOSE symposia and conferences. However, the knowledge encoded in these papers is not easily available to INCOSE members. Symposia papers are generally only available to the attendees of the symposium where the paper was published, and then only in a format that does not supports structured access, considering today's technical possibilities.

In this paper, we propose the implementation of an internet-based INCOSE publication database (i-pub) for facilitating access to INCOSE published papers. Results from initial prototyping activities are presented and an available COTS-based software system is proposed for implementing the system.

Session 5 Track 4: Requirements

5.4.1 RAS-Centered Requirements Analysis

J.O. Grady, *JOG System Engineering, Inc.*

System engineers for years have used the requirements analysis sheet (RAS) as a means of connecting the functions identified for a system under development with the corresponding performance requirements and product entities that should accomplish those requirements and functions. But we have commonly not extended the utility of the RAS to cover every requirement found in a specification. This paper extends the RAS to include every requirement that would be found in a system or hardware specification but it is no problem to extend it further to contain all requirements. Work continues to extend the concept to the several software modeling methods (modern structured analysis, early OOA, UML, and DOD AF). The content of the paper resulted from research undertaken during re-write of the author's book "System Requirements Analysis" in preparation for its re-publishing by Elsiver Publishing in November 2005.

5.4.2 Why Are Requirements So Hard To Get Right?

J.W. Carl, *Harris Corporation*

There are many instances in the history of system developments that illustrate how difficult it is to discover and understand system requirements in the same way that stakeholders understand them. This has resulted in cancellation of some programs, and has resulted in cost and schedule overruns on other programs. Misunderstanding of requirements is an acute problem in the development of systems for government agencies, but it appears in commercial developments, too, where it takes the form of products that fail to meet market expectations (the Ford Edsel is a classic example).

This paper examines the deep reasons why requirements expressed in language are so hard to convey from a stakeholder to a supplier or from consumers to manufacturers. Semiotic concepts are summarized and bolstered with physiological and psychological evidence about the phonemic, syntactic and semantic properties of language. The paper concludes that language is profoundly arbitrary, whether spoken or written, whether in words or in pictures. It is therefore incumbent on all of us to remember the strong principle of communication: each party to a communication must work hard to understand what the other is trying to say. Such effort is one main thing that will help understand requirements. Additional help comes from development methodologies that quickly lower the level of abstraction by demonstrating solutions as early as possible, and by requesting feedback from stakeholders. Automated tools can also help.

5.4.3 Real Requirements: How to Find Out What the Requirements Really Are.

T. Gilb, *RPL*

This paper gives advice to help you find the requirements that really matter to your stakeholders. It focuses on stakeholder value delivery as the appropriate level, rather than the technical solutions that so many specify as their requirements. It suggests several specific methods for determining what the real requirements are. This includes some technology unique to this author, such as the Impact Estimation method.

Session 6 Track 1: Education - Curricula

6.1.1 Towards a Structure for Systems Engineering Research

T.L. Ferris, S.C. Cook,
Systems Engineering and Evaluation Centre;
E.C. Honour, *Honourcode, Inc.*

This paper discusses the need for the development of a framework for Systems Engineering to facilitate recognition of Systems Engineering as a discipline and to provide a fundamental basis for advancing the practice of Systems Engineering. Systems Engineering concerns the development of systems that satisfy the real needs of those who call for the systems to be created. Such systems are not tangible things that can be analyzed as objects to be inspected and described, but rather these systems interact with their users and stakeholders in a complex manner, where the introduction of the system perturbs the pre-existent situation, resulting in a need for sophisticated methodologies to analyze and predict outcomes of system creation and deployment. The paper exposes and discusses a range of research methodologies that are appropriate for contributing to the development of a coherent framework of research in Systems Engineering.

6.1.2 Systems Engineering Degree Programs In the United States

W.J. Fabrycky, E.A. McCrae,
Academic Applications International, Inc.

The authors and colleagues have observed a widespread need for general information regarding the availability and characteristics of Systems Engineering (SE) degree programs. This paper provides a compilation of SE academic programs in the United States, giving insight regarding administrative structure, academic content, accreditation status, and a benchmark for the continued advancement of these degree programs. Description and analysis is offered by the authors to establish a baseline that may be utilized to assess the future of existing and developing degree programs. The model for description and analysis utilized in this paper will be extended to the international domain in the near future.

6.1.3 Conceptual Design of an Environment for Systems Engineering Education

D.M. Buede, J. Ring, *Innovation Management Inc.;*
F. Bolling, *University of Michigan-Dearborn*

A major problem in the teaching and learning of systems engineering is one of feedback concerning the quality of what we do: we often do not get any, and when we do, it is very late and imperfect. Accordingly, both initial learning and retention suffer. One of the few engineering domains involving complex systems and in which feedback is fast and quite accurate is racing, e.g., race cars!! Our proposed solution for the academic problem is a studio for modeling the “design, test, and operation of race cars”. This laboratory stresses the breadth of systems and systems engineering rather than the depth that is typical of classes in other engineering disciplines. The proposed studio can be used for capstone design and project courses at both the undergrad and grad courses.

Session 6 Track 2: Systems Architecture

6.2.1 Systemes Engineering: Driving the Evolution to Actionable Architecture

J. Popkin, *Popkin Software*

Systems engineering is a well-developed, proven practice in both the commercial world and the US government. Enterprise architecture, while comparatively new to many federal agencies, brings together proven commercial and government architecture and modeling best practices from the last three decades. Systems engineering is a key thread in any enterprise architecture initiative. With its enterprise view, architecture builds a thread through systems engineering and relates it to broader enterprise IT efforts.

This paper examines the role and value of systems engineering in architecture development. How do the two relate to each other? Both utilize standards; both deliver a common platform that facilitates communications and information sharing among users.

Systems engineering delivers an actual product—a system; enterprise architecture delivers a blueprint. Both deliver interoperability, yet systems engineering deals with product development while enterprise architecture deals with alignment and management. Systems engineering provides information for decision support, but this is not the primary goal. Enterprise architecture delivers a blueprint for decision support, not for product development. Both disciplines share a relatively long history of practice.

We will discuss how systems engineering is related to broader architecture efforts. The importance of systems engineering as part of an architecture roadmap, and ultimately, a decision support tool, will be explored. We will also look at the trend toward 'actionable' architecture that integrates systems and mission, goals and capabilities into one view. 'Actionable architecture' offers improved decision support for IT in areas such as technology investments, gap analysis, cost reduction and improved efficiency.

6.2.2 Measuring the Performance of the Risk Management Process

B.B. Roberts, *Futron Corporation;*
R. Kitterman, *Northrup Grumman Newport News*

Measuring the performance of the risk management process is difficult in that there is generally no physical outcome to measure. The best risk management processes ensure that nothing "bad" happens, hence nothing to measure. Even when something "bad" happens, it could have been predicted by the process, accepted by the project, and the project got a bad roll of the dice, and the project may even face cancellation. But would that outcome indicate that the risk management process malfunctioned? So the problem faced by the risk management community is that either a good or a bad outcome can be a result of the performance of the risk management process or simply good or bad luck.

The professionals in the risk management community and the measurement community have posed several possible ways to measure the performance of the process. Those techniques are presented along with suggestions as to how the project manager may use the metrics to make adjustments to the process.

6.2.3 Modeling ISO/IEC 15288 & Tailoring Enterprise Systems Engineering Processes for an Organization's Success

L. Walker, *Lockheed Martin Corporation*

Tailored and integrated organizational processes are fundamental drivers for organizations to achieve efficiency and success. The organization's processes represent the means to achieve the organization's business objectives in terms of communications, functionality and systems related products. Developing the organization's processes architecture model must integrate both managerial and technical systems development efforts to produce efficient tasks and products.

This document addresses the complexity of capturing the ISO/IEC 15288 "Systems engineering-System life cycle processes" systems management and engineering processes and their outcomes in an integrated architecture model. Several significant issues and concerns are identified that relate both to the standard's contents and to tailoring the standard to an organization's processes. Assumptions for tailoring the model are identified, in addition to topics that developers of integrated and organizational processes need to consider prior to development of their integrated and tailored processes.

The four topics addressed are:

1. Systems Engineering Standards and ISO/IEC 15288's unique perspective
2. The importance of modeling a standard and an organization's processes
3. The modeling of ISO/IEC 15288 including tailored perspectives
4. Modeling an organization's integrated processes to meet a customer's objectives

Session 6 Track 3: SE Principles

6.3.1 The MSOCC Data Switch Replacement: A Case Study in Elicitating and Elucidating Requirements

J.E. Kasser, *University of South Australia;*
C. Mirchandani, *Lockheed Martin*

This paper is a case study of a situation in which a soft-systems methodology coupled with an object-oriented approach for viewing the requirements was used in a complex environment to gather a set of requirements. By considering the cost, priority, and risk attributes of the requirements, as well as clarifying the wording of the requirements for verifiability, an optimal systems architecture and development process was achieved in a relatively short period of time compared with the standard systems engineering process. Moreover, the Systems Requirements Review was deemed complete and comprehensive by the customer.

6.3.2 Some Really Useful Principles: A New Look at the Scope and Boundaries of Systems Engineering

H.G. Sillitto, *Thales UK*

In the search for a description of systems engineering that is precise and suitable for use outside the traditional defence/aerospace domains, this paper examines three emerging or "rediscovered" systems engineering concepts. These are the "generic reference model", the "system value cycle", and the notion of systems engineering as the management of emergent properties. They are shown to be useful in tackling some "classic problems" in systems engineering for which the standard definitions give little guidance. The problems include agreeing on the system boundary, understanding what is a "good" system, making the business case for systems engineering, and applying systems engineering outside the requirements driven context common in the defence industry. The place for innovation in the engineering of successful systems is illustrated with reference to successful and well-documented World War 2 era platform systems. The paper seeks to identify definitions and principles that clearly distinguish "systems engineering" from other disciplines and are robust enough to be useable and relevant in both academia and industry, and to enhance the business case for systems engineering.

The strategic choices discussed in the paper can be clarified by organising them into a three-layer framework of "principles", "practices" and "information structures".

6.3.3 Practical Applications of Complexity Theory for Systems Engineers

S.A. Sheard, *Systems and Software Consortium, Inc.*

This paper provides a basic background in chaos and complexity theory and shows systems engineers how to improve the way they work in accordance with their increased awareness of the complex nature of systems, enterprises, and the environment. As systems and the enterprises in which they are developed become increasingly complex, systems engineering as learned and taught in the twentieth century should be supplemented by principles learned in the new sciences of complexity and chaos. Awareness of complexity theory can help practicing engineers perform their tasks differently on projects, in ways ranging from understanding the problem space and making models of the environment early in the life cycle, through managing changing requirements, designing differently, and identifying and managing risks, to supporting changing project management approaches.

In addition, a science of complex systems engineering is being formed. This involves developing a formal theoretical backdrop for the heuristics that systems engineers have experientially found effective in architecting and developing complex systems. Complexity theory is enriching efforts to develop this advanced system engineering approach and practices.

Session 6 Track 4: SE Process

6.4.1 Adapting SEER Cost Estimating Tools to Evolution ary Acquisition

E. Stump, *Galorath Incorporated,* D. Ferens, *AFRL/IFEA*

In recent years, the U.S. Department of Defense (DoD) has emphasized improvements in acquisition processes. We have found that most of these called for little or no change in our SEER cost models, but a current initiative does seem to call for significant changes. This initiative is called evolutionary acquisition.

Evolutionary acquisition shares many features with conventional DoD acquisition methods of the late 20th century, but does introduce unique features that need to be accounted for in an up-to-date cost modeling system.

This paper discusses some of the major changes in DoD acquisition practices that have recently been formalized in the DoD 5000 series documents, and how we are responding to them by experimenting with design changes in the SEER tools.

6.4.2 Capability Engineering Process within Canadian Defence: Some Engineering Issues

M. Couture, M. Mokhtari, M. Lizotte, C. Lalancette,
G. Dussault, , F. Bernier, *Defence R&D Canada -Valcartier,*
S. Lam, *Defence R&D Canada – Ottawa*

Some managerial and technical problems related to the transition of the Canadian military acquisition from the Threat-Based Planning to the Capability-Based Planning are identified in this paper. A simplified example of military acquisition illustrates recommendations that were made in the Collaborative Capability Definition Engineering and Management (CapDEM) project to guide the work surrounding the conception of a new Capability Engineering Process. Some elements of solution for the support of such a process are also presented.

6.4.3 Requirements Management, from the RFP to the Project

R. Jakacky, O.R. Doty, *ITT Corporation*

System Engineers during preparation of proposals for new contracts often overlook requirements analysis as a vital step in producing a comprehensive and compliant proposal. The rigor required for a traditional requirements analysis goes by the wayside in the rush of tight deadlines, limited staff, and the stress of proposal production. Once the program starts, the team then performs requirements analysis with the initial task of reconciling the requirements with the proposed offering. This reconciliation often uncovers compliance issues not identified during conceptual design, or discovers that there may be alternate solutions for the set of requirements.

A well thought out and streamlined requirements assessment process, implemented during the proposal, facilitates the development of system concepts that are complete and compliant while still satisfying demanding proposal preparation schedules. The assessment process then feeds a set of well-analyzed and structured requirements directly into the post-award contract work that reduces the need for reconciling the offering to the real program.

ITT Aerospace/Defense Division developed and deployed this process with great success in reducing compliance and coverage issues during the proposal phase and providing a solid foundation for beginning the new program. This process is also in deployment to another division of ITT.

Session 7 Track 1: Research

7.1.1 Integrating Views in a Multi-View Modelling Environment

J. El-khoury, O. Redell, M. Toerngren,
The Royal Institute of Technology (KTH)

The development of modern technical systems requires the close collaboration of various specialist teams and engineering disciplines in order to reach the expected complex functionality. Even though working with the same system towards the same goal, developers from the different domains use their own specific tools, providing their own specific views of the system to be developed. For the successful integration of the efforts from each of these disciplines, the different views produced need to be appropriately integrated, preventing any inconsistencies and divergences from creeping into the system design.

We present an approach to multi-view modelling which systematically integrates the two generally accepted complexity reduction techniques of hierarchical decomposition and multi-viewing. While these techniques are common practice in many modern design tools, the approach presented in this paper defines how the inter-view relationships can be used to tightly interweave the views' hierarchies. This provides a good basis for an information sharing environment enabling model based, multi-disciplinary development.

A small case study is used to exemplify how the proposed method simplifies the process of allocating system functions to a hardware architecture in a truck.

7.1.2 Sea Level Requirements as Systems Engineering Size Metrics

R. Valerdi, *USC Center for Software Engineering;*
J. Raj, *San Diego State University*

The Constructive Systems Engineering Cost Model (COSYSMO) represents a collaborative effort between industry, government, and academia to develop a general model to estimate systems engineering effort. The model development process has benefited from a diverse group of stakeholders that have contributed their domain expertise and historical project data for the purpose of developing an industry calibration. But the use of multiple stakeholders having diverse perspectives has introduced challenges for the developers of COSYSMO.

Among these challenges is ensuring that people have a consistent interpretation of the model's inputs. A consistent understanding of the inputs enables maximum benefits for its users and contributes to the model's predictive accuracy. The main premise of this paper is that the reliability of these inputs can be significantly improved with the aide of a sizing framework similar to one developed for writing software use cases. The focus of this paper is the first of four COSYSMO size drivers, # of Systems Requirements, for which counting rules are provided. In addition, two different experiments that used requirements as metrics are compared to illustrate the benefits introduced by counting rules.

7.1.3 Accelerating the Development of Senior Systems Engineers

H.L. Davidz, D.J. Nightingale,
Massachusetts Institute of Technology

As more senior systems engineers are needed to handle the increasing complexity of contemporary systems, there is an increasing need to accelerate the development of these senior

professionals. However, the process of efficiently developing a senior systems engineer is not well-understood. To compact this problem, the skill set needed by senior systems engineers continues to broaden as system complexity increases and as system boundaries expand. In order to better understand the mechanisms that most effectively and efficiently develop these individuals, this article discusses enablers, barriers, and precursors to this development process. In addition to reviewing related literature, specific interventions currently used to accelerate systems thinking development are discussed. Findings from ongoing research related to this topic provide preliminary information about current understanding and practice. Better understanding of systems thinking development provides a foundation for educational interventions and employee development in systems thinking for engineering professionals across industry, government, and academia.

Session 7 Track 2: SE Application-Business

7.2.1 Development of an Integrated Facilities Management Baseline at a Federal Agency Using a Systems Engineering Approach

R. Thurau, *National Geospatial-Intelligence Agency*
C. Dagli, D. Enke, *University of Missouri at Rola*

The National Geospatial-Intelligence Agency (NGA) has implemented an integrated facilities' management program covering its many buildings, operations, and site locations. In conjunction with organizational structure development, a commercial-off-the-shelf (COTS) computer aided facilities management (CAFM) system was implemented to integrate data collection and user control. These facilities' management aspects include tracking building floor space usage, employee locations, AutoCad building designs, equipment inventory, operations and maintenance scheduling, etc. The systems engineering process included a spiral architecture development model, initial and recurring data validations, a risk management review, and multiple phases of tracking requirements and change control. Formal configuration management boards (CMB) were a critical element of development and continuing operation of CAFM. Use of an open systems interface design to allow exchange of data between CAFM and related databases from Human Resources and Security Departments was essential. By replacing the many separate legacy facilities programs with an integrated CAFM package, more complete data information was collected which allowed for better control and operation of facilities resources and improved strategic facilities' planning.

7.2.2 Learning from Lessons Observed - Mitigating Resistance to SE Process Change

T.H. Holzer, *National Geospatial-Intelligence Agency*

Changing a Systems Engineering process culture is difficult. There can be organizational and individual resistance to change that needs to be effectively overcome. As good systems engineering practices call for, at the start of the change activity the process change team needs to look back on the problems faced by similar programs. Most importantly, the team must learn from those 'lessons observed' and implement improvements in conducting their activity. Fifteen critical lessons observed about resistance and the mitigations applied are summarized. A highly successful process improvement program was achieved by applying mitigations learned from earlier problems. The lessons apply to changing SE processes in a government and commercial organization. For anyone seeking to change the culture and systems engineering processes, acquisition methods or business methods, these findings are their head start to identifying problems and reducing change activity failures.

7.2.3 Tailoring Systems Engineering Lifecycle Processes to Meet the Challenges of Project and Programme Applications

R. Adcock, *Cranfield University*

The application of Systems Engineering to real world problems relies upon an understanding of lifecycle and process. Many attempts have been made to produce generic models of Systems Engineering process, which can then be applied to real world problems. More recent Systems Engineering (e.g. ISO/IEC 15288 and ANSI/EIA 632) standards have taken a more abstract approach. The standards describe a lifecycle and process framework, and give guidance on how to tailor the framework to specific problems. This paper explores the approach taken by the standards to describe Systems Engineering in this way. The difference between a project and a programme are defined; and the application of lifecycle tailoring to each is discussed. Finally, a generic lifecycle framework is described, and examples of its application given.

Session 7 Track 3: Modeling

7.3.1 Managing Effectivity of SE Work Products

D.K. Smith, *UGS Corporation*

This paper describes an approach to embedding product effectivity in Object-Oriented Systems Engineering (OOSE) databases that automatically generates effectivity information for objects in the database and has the potential for significantly reducing SE database size by reusing elements common to different product configurations.

7.3.2 Enhanced Interoperability for Systems Engineering Data by a Transformation Report

R. Eckert, W. Mansel, *EADS Deutschland GmbH;*
G. Specht, *University of Ulm*

In industry, product data exchange via STEP ISO 10303, is an established method. In case of heterogeneous CASE Tools, e.g. in Systems Engineering applications, it is very often difficult to guarantee a defined level of data quality. This paper analyses the state of data transformation and exchange as well as offering a solution for schema mapping and integration by means of a transformation report which can be used in systems engineering. The report records individual transformation steps, during the exchange, between two different tools. It supports the understanding of the data exchange process and helps to rectify incomplete or incorrect transformed data. The proposed framework was validated using gateways between the Statemate and Teamwork CASE tools.

7.3.3 A Lifetime Extension Strategy for Simulation Models

S. Grainger, *General Dynamics C4 Systems*

Using a systems engineering approach, a lifetime extension strategy for legacy simulation systems is presented. This lifetime extension strategy establishes a bridge allowing legacy simulation systems to participate in a larger more diverse simulation community. Previous recommendations to solve this legacy simulation problem have been narrow in scope viewing the solution in terms of a single technical solution. However, like systems engineering, this strategy describes a solution using a multilayered interdisciplinary approach. This approach takes advantage of existing technologies across the hardware and software spectrum and presents a five-year convergence strategy.

Session 7 Track 4: SE Application-Security

7.4.1 Methodology Selection for the Engineering of Defence Systems

L.J. Vencel, *Vcorp Consulting Pty Ltd;*
S.C. Cook, *Systems Engineering & Evaluation Centre*

The nature of problems encountered in the system engineering domain has over the past thirty years grown in complexity. The integration of technology with human activity systems to produce complex capabilities has required a continual change in our definition and application of systems engineering. This paper examines the typology of problems associated with the development of modern complex systems and combines the ideas of system engineering and cognitive problem solving to propose a set of attributes that may be used to characterise system engineering problems. It is proposed that this set of attributes is sufficient to enable the selection of methods, tools and techniques necessary to solve the problem.

7.4.2 Extending Systems Engineering Frameworks for Special Application Areas: Case Study Safety and Security

L. Ibrahim, *U.S. Federal Aviation Administration;*
C. Wells, *I-metrics LLC*
R. Bate, *Software Engineering Institute*

Several standards, models, and frameworks provide systems engineering best practice. There are also many standards that address special applications of systems engineering. If an organization is already working on improving its systems engineering processes using a general model, how might it additionally address standards and best practice in related fields of interest in an efficient, effective way?

This paper describes a new construct, called a Application Area, designed for extending existing systems engineering frameworks with practices and guidance specific to a particular application. The construct is illustrated by means of the Safety and Security Application Area that was developed using this approach.

7.4.3 Integrated Communications Architecture for Homeland Security

Y. Lean Weng, T. Kok Sin Stephen
Defence Science and Technology Agency

The fateful event of September 11 in the US and subsequent terrorist attacks in many countries had changed the world. We now live in a world of troubled peace, a far more dangerous world for many of us. A well-networked security force will have comprehensive situation awareness to respond to unconventional threats like terrorism, low intensity conflict and even SARS. Conventional military communications has proven to be ineffective especially in urban environment where high-rise buildings hinder the electromagnetic wave propagation of VHF and UHF communications. In Singapore, a well-defined and integrated network centric based communications infrastructure is being put in place to link military and homeland security forces into an integrated force.

Session 8 Track 1: Research

8.1.1 Systems Engineering of Socio-Technical Systems

M. Ottens, M. Franssen, P. Kroes, I. van de Poel,
Delft University of Technology

In this paper we discuss how the increasing importance of socio-technical systems affects systems engineering. We start with a clarification of the notion of systems engineering by distinguishing two ways in which engineering design is involved with systems characteristics: in the object of design and in the design approach. Next we focus on system-like objects of design of a special sort: socio-technical systems. After presenting two examples, we indicate several tensions between the systems engineering design approach and the design of socio-technical systems.

8.1.2 Improving the VVT Process: Evaluating the SysTest Results in Six Industrial Pilot Projects

M. Hoppe, *Tech University Muenchen;*
A. Engel, *Israel Aircraft Industries*

Many companies experience extensive product rework and failure cost due to ineffective Verification, Validation, and Testing (VVT). Therefore, there is a great potential benefit in streamlining and optimizing the VVT process. To that end, a consortium of eight European companies, research institutes, and organizations conducted the SysTest project. The stated aim of SysTest was to "...decrease product development cost and time to market by 10%". SysTest intended to achieve this aim by developing a generic methodology and process model to support the process of systems' VVT. This paper describes the results of using the SysTest products in six industrial pilot projects. The diverse pilot projects have shown that the SysTest products are applicable in different industries. Specifically, each project was able to use most components of the SysTest methodology and process model and the pilot projects conducted by the industrial partners exhibited an average of nearly 8% project cost reduction with standard deviation of about 15%.

8.1.3 A System-of-Systems Approach for Application to Large-Scale Transportation Problems

T. Kang, D.N. Mavris, *Georgia Institute of Technology*

There is growing recognition of a class of problems known as "System-of-Systems" that draws parallels to the characteristics and philosophy of Systems Engineering, but with unique complexities that deserve separate focus and study. This paper first seeks to outline defining characteristics of System-of-Systems problems, and discusses the progression of research in related fields as well as the direction for ongoing research in this area. A key aspect in System-of-Systems research is the dynamic propagation of uncertainty across the stakeholder network. To investigate this phenomenon, a system dynamics model of a Personal Air Vehicle (PAV) manufacturer is first developed. Using Monte Carlo Simulation, the variability of the manufacturer's yearly net income over a ten-year period is calculated. Combined with the evaluation of uncertainty characteristics more prevalent in other stakeholders, this methodology provides guidance in determining robust strategies at the System-of-Systems level.

Session 8 Track 2: SE Application -Business

8.2.1 Agile Specification Quality Control: Shifting Emphasis from Cleanup to Sampling Defects

T. Gilb, *RPL*

Traditional Inspection is often uneconomic and ties up valuable staff resources. Shifting the emphasis from cleanup (that is, from identifying defects and then removing them), to merely sampling the defect level of specifications, produces significant benefits. It enables the quality level of specifications to be determined more rapidly. Consequently, the QC can be carried out more frequently. Systems and software engineers rapidly learn, through SQC feedback, to take standards seriously, which in turn reduces defect injection. Further, by analyzing where/how the defects occur continuous process improvement can be supported.

8.2.2 A Mark-Up-Language to Support the Exchange of Requirements During a RFQ

R. Kaffenberger, *Kaffenberger SE*

Requirements are the foundation of the project. Consequently the issues of requirements management and requirements engineering are emphasized in the context of the preparation of acquisition activities and during the early phases of the development project. In contrast, the role of requirements management and engineering during the acquisition phase has received negligible attention. In a world where sub-system developers compete against each others for development contracts offered by system integrators effective requirements management and engineering during the bidding phase is vital for success. A smooth exchange of requirements is needed in this situation but there are numerous obstacles. In this paper a solution for the necessary kind of requirements exchange is proposed. It is based on the possibilities of XML and the STEP information exchange standards.

8.2.3 International Standards for System Integration

R. Martin, *Tinwisle Corporation*

Missing from the repertoire of mechanisms for systems integration presented at past INCOSE symposia are the International Standards for process component integration being developed in the context of industrial automation. To improve the efficiency of beneficially constructed interactions between systems and system components, the international community is adopting a wide range of standards through formal development and review processes. For this presentation, the focus is on the standards efforts for industrial automation conducted by ISO TC184 SC5 working groups. The work products range from shop floor communication structures through enterprise level system concept management – all with a process centric orientation. Of particular interest are the enablers of interoperable supply chain components and support for systems throughout their lifetime.

Session 8 Track 3: Application-Commercial

8.3.1 Towards an Integrated Methodology for the Model-Based Development of Embedded Automotive Control Software

K. Buhr, *Technical University Berlin;*
M. Conrad, H. Doerr, I. Fey, *DaimlerChrysler Inc.*

The complexity of developing automotive control unit software can generally not be mastered without an efficient development methodology. The development discipline activities requirements, modelling / implementation and quality assurance are, for this reason, supported by individual methods. In order to optimally coordinate the methods with one another during their deployment, a structured integration of these individual specialised methods is, however, essential. The following paper, using the model-based development approach as an example, outlines the content and structure of an integrated methodology that provides such integration. Its use shortens development time and increases product quality by coordinating the deployment of individual methods over the course of the entire developmental process. The main components of this kind of integrated methodology are an interdisciplinary information model, process models with integrated procedures for the realisation of single development activities as well as guidance such as checklists, templates, and examples, among other things. In this paper, we present the experiences that we have gained at DaimlerChrylser Research in developing and applying such an integrated methodology.

8.3.2 System Engineering Issues in the Transformation to Service Oriented Architecture

M.R. Halley, *The MITRE Corporation*

The major problem facing enterprises today is the system engineering of large scale multi-enterprise “systems of systems”. These initiatives integrate dozens of legacy applications into a “system of pre-existing systems” that solves a new unexpected problem. A new paradigm called the Service Oriented Architecture (SOA) has been developed in hopes of managing the complexity and adaptability needed. By creating a macro system from loosely coupled modular components, SOA is a solution for the major roadblocks of large-scale enterprise change: inflexible technology, cross-organization initiatives, outdated strategic planning, and organizational inertia.

However, transitioning to an SOA is a difficult task. Since these projects involve little new software development, the system engineering organization takes the central role. These complex transitions involve uncoupling pre-existing systems, creating modular components, and loosely re-coupling these components via common standards. Current widely used enterprise architecture models deal well with static state architectures, but are very limited in the description of transitions between architectures.

This paper presents an overview of the issues facing systems engineers when transforming traditional enterprise architecture to a Service Oriented Architecture. The issues are collected together in a strategic issues framework which can be used to guide transformation planning and execution. The framework encompasses the seven transformation issues: a suitable business model, IT governance, enterprise SOA architecture, portfolio investment, risk management, change management, and technology management.

8.3.3 Renovate WBS Planning with Technology Roadmap for New Product Development

H-K. Lee, *Institute of Nuclear Energy Research;*
C-M. Liu, M-H. Lee, *National Tsing Hua University, Taiwan*

The new product development (NPD) project has been considered a challenging task in the management practice. In project planning, the Work Breakdown Structure (WBS) is one of the fundamental tools, but the terms “product” and “activity” are frequently confused and results in inefficiency in the support of project management tasks. By clarifying the nature of project planning and execution, an integrated method for WBS planning has been developed in this research. It includes the product-oriented WBS (P-WBS), the activity-oriented WBS (A-WBS), and the contract-out WBS (C-WBS). The technology roadmap is used to transform the P-WBS into the A-WBS. Using the proposed integrated WBS planning method as the basis, an integrated methodology for new product development has been given to align strategic management to project management. Finally, the successful application of this methodology to develop a project for the re-host of a full scope training simulator of a nuclear power plant in Taiwan is illustrated.

Keywords: New Product Development, Project Management, Technology Roadmap, Work Breakdown Structure (WBS).

Session 8 Track 4: Product Development

8.4.1 Implications of Sociological System Theory on Systems Engineering and Product Development

U. Pulm, *Engineering Design Centre EDC*

Systems engineering can be regarded as a part of system theory, which seems to be most up to date in sociology trying to understand complex social systems. This contribution gives an overview on the development and appearances of system theory, compares systems engineering and the modern sociological system theory and shows how to improve the design and development of technical systems by the use of those sociological insights. This regard covers a new understanding of complexity, of systems themselves, of communication being any coordination of activities, as well as respective media. The considerations finally lead to a dynamic organisation as well as to measures how to approach complex social systems.

8.4.2 Exploring Engineering Governance

J.V. Nendick, K. Callan, G.A. Ng, C.E. Siemieniuch,
M.A. Sinclair, *Loughborough University*

Over recent years a lot of effort has gone into improving corporate governance within public companies. But what about engineering governance? Companies which are involved in complex, systems engineering-based projects face a lot of risk. This risk should be minimised as much as possible through the implementation of Good Engineering Governance (GEG). Improved engineering governance would assure the numerous stakeholders involved in large projects that controls are in place to effectively manage the engineering function.

The GEG project at Loughborough University is looking at the stages needed to introduce an engineering governance framework into a large defence systems integration business. This paper looks at the initial findings of the GEG project and what is involved in the next stage.

8.4.3 What Question are You Trying to Answer? Identifying the Right Products for an Architecture Effort

M.S. Russell, *Anteon Corporation*

Determining what architecture products are needed to support systems development within a Systems Engineering process is a challenge. Existing documents, such as DoD's Architecture Framework Document, provide some guidance, but no defined product identification process. The method proposed in this paper provides a repeatable process for selecting the architecture products required to support a systems engineering lifecycle, defining the content of each product, and identifying each product's customer. The method has been successfully used by several DoD programs over the past five years.

Session 9 Track 1: Research

9.1.1 A Highly Automated CMMI-Driven Self-Organizing and Mapped (SOM) Document Library

D. Beshore, *Aerospace Corporation*

Over the past 10 years, systems engineering standards and process improvement models have matured to CMMI, IEEE/EIA 12207, and ISO 15288. A novel automated technique for rapidly capturing systems and software engineering specialty knowledge by 'relevance' algorithms while displaying the data in three-dimensional Self Organizing Maps (SOMs) has been developed. Tools are based on the author's REALM© (Requirements Enabled Automated Learning Method) process that is used to categorize and rank any size document set to any baseline document set, including websites. The examples in this paper illustrate a document set that represents nearly 3000 pages of content (past maturity models, process implementation procedures, handbooks, books, websites and tools). The highest scoring process definition documents related to the CMMI are a Systems Engineering Process Manual (***SEPM) and IEEE/EIA 12207***. REALM© has other applications: systems and software handbooks, standards, contracts, appraisals, assessments, audits, proposal requests (RFPs), proposals, design reviews, test plans, statements of objectives (SOO), work statements (SOW), business plans, etc.

9.1.2 Adaptive Test Process – Designing a Project Plan that Adapts to the State of a Project

V. Levardy, *Tech Univ Muenchen;*
T.R. Browning, *Texas Christian University*

Conventional techniques for project planning make the flawed assumption that all activities and relations are known and can be planned a priori. Iteration models show that iteration is a fundamental aspect of novel projects, but they also assume all activities and interactions are known. Of course, some kind of hypothesized project baseline (plan) is required for management. Such plans are acknowledged to be imperfect, so management reserves are kept for schedule and budget where possible. How big should these reserves be? This paper describes research on an improved approach to process planning and control whereby activity modes are allowed to vary and dynamically recombine based on the evolving state of the project as it progresses. If the project is behind schedule or over budget, then activities or iterations which would seem prudent from a technical performance standpoint may not be feasible as originally planned. Similarly, if a project is ahead of schedule or under budget, additional improvements versus the original plan may add value. What is prudent depends on the effect of any action on the overall value of the project. As such decisions are made under uncertainty, the proposed approach accounts for uncertainties and their impacts (risks) in the decision. By assuming from the outset—while formulating the project plan—that the project will adapt, it is possible to build an improved project plan, one that is more accurate, realistic and flexible. Additionally, the proposed method supports management decisions about potential corrective actions during project execution. This paper applies the approach in the context of system verification and validation (V&V) processes.

9.1.3 Modular Building Blocks for Manned Spacecraft: A Case Study for Moon and Mars Landing Systems

W. Hofstetter, E. Crawley, *MIT*

A method is presented for the selection of optimal modular building blocks for platforming of manned Moon and Mars landing systems employing modularity on the subsystem level; platforming shall here be defined as the reuse of designs across different systems. The motivation for platforming is the need to reduce overall Moon and Mars exploration architecture lifecycle cost by lowering spacecraft development, test, and fixed production cost, and to provide flexibility in system design to accommodate changes in the exploration architecture. The fundamental idea is to compute the surplus in functional attributes generated by using particular building block (module) sizes, then relate the surplus to a cost function, and finally select the building block sizes with minimal additional cost. Results are presented for modular crew compartments, propellant tanks, and engines. The proposed method is potentially helpful for platforming decision-making, as well as subsystem technology selection in a broad class of engineering systems.

Session 9 Track 2: SE Application

9.2.1 "...Is He in Heaven or is He in Hell that Illusive Systems Integrator?" Who's Looking After Your Systems Integration?

D.D. Cowper, *Sula Systems, Ltd.*,
M.R. Emes, A. Smith, *University College London*

Changes in supply chains, for example, due to increased competition, lower margins, and changes in customer enterprises, can cause enterprises to want to move up the 'food chain' and take on the role of systems integrator. This role comes with its own set of risks and implications for both customers and suppliers. This paper explores these issues. For example, being one step removed from component suppliers, what must an enterprise consider when deciding whether to move into the role of systems integrator or to pass this role along its supply chain? This will include identifying where the appropriate skills are within its organisations and establishing what its credibility would be in performing this new role.

9.2.2 Design for Six Sigma (DFSS) Integrated with Systems Engineering Toolsets...Systems Engineering Quality Into Products

G. Gianacakes, M. Sampson, *UGS*

This paper describes an approach to merging statistical design techniques with allocation relationships in a systems engineering design environment; actually associating statistical distributions and transfer functions with those relationships. This allows users to apply Design for Six Sigma (DFSS) techniques early in product development where systems engineers can develop conceptual designs that are "robust" or insensitive to change/variation—effectively systems engineering quality into products.

9.2.3 Successful Implementation and Application of Continuous Risk Management to Complex Systems Development in the Automotive Industry

H. Negele, *BMW Group;* T.M. Pfletschinger, S. Wenzel, *3D Systems Engineering GmbH*
G. Getto, *KuglerMaag+Comp. Ltd. & Co. KG*

Currently, more than 90% of the innovation in the automobile industry is driven by new ideas in the electric and electronic sector

(Frischkorn 2004). Due to the increased complexity of the electrics/electronics (E/E) system, car breakdowns today are more often not mechanical in nature, but are likely due to a defect in the electrics/electronics system (ADAC 2004). As a result the development of a more reliable automobile E/E system is a major concern for car manufacturers around the world in order to produce innovative and reliable cars and remain competitive.

Besides sound requirements engineering and effective project management, the key to dealing with the increasing complexity of E/E system development is to identify potential system problems throughout the development process and respond with appropriate actions to mitigate potential adverse impacts and thus achieve the project objectives. This issue can be accomplished by implementing a continuous risk management (RSKM) approach focused on the development of the E/E system.

This paper illustrates a practical, proven approach applied to new product development at the BMW Group. The approach enables proactive risk identification and mitigation to obtain more transparency in the development of the complex E/E system of an automobile.

Session 9 Track 3: SE Initiatives

9.3.1 Specialised Requirements Management system for Maintenance Service Industry

Y-C-K Chen, P. Sackett, *Cranfield University, UK*

Companies in major aerospace, automotive and electronics consumer products industries now consider Requirements Management important in realizing business performance. As companies review and enhance their product development processes they will increasingly demand various types of requirement management capabilities. There is lack of clarify on how to use Requirements Management effectively even in conventional product development applications.

This paper identifies a research and applications gap in the Maintenance and Service Requirements Management System domain. The authors identify the special needs of the sector classified as Requirements Derived Service Maintenance. Through a case study in high end mass market consumer electronics they illustrate the application of the requirement management technique in the maintenance service environment.

9.3.2 Enhancing Commercial Systems Engineering with Design For Six Sigma

C.M. Creveling, *PDSS, Inc.*

The advent of Design For Six Sigma and its integration with a commercial Systems Engineering process has systematically improved rigor in risk management during product commercialization. Many companies suffer from a lack of discipline and rigor as they develop and integrate systems within their commercial phase-gate process. DFSS is well known for helping “put the science and engineering back into product design” (Dr. Joseph Sullivan, VP Quality, Carrier Corp.). It is also recognized as “a shift from a deterministic to a probabilistic approach to product design” (DFSS: 15 Lessons Learned; Treichler, Charmichael, Kusmanoff, Lewis & Berthiez; Quality Progress, January 2002).

Organizations that focus on systems architecting, engineering, integration and assessment applied within their commercialization process, are recognized as having a more disciplined and comprehensive approach to improve cycle time, cost and quality. This paper defines DFSS and presents the integration of DFSS and

Systems Engineering. The goal is to demonstrate that a DFSS enabled Systems Engineering organization can measurably improve rigor and discipline in delivering critical parameter data for risk management and decision making during product commercialization. This presentation is, in part, derived from Chapter 7 of the text Design for Six Sigma in Technology & Product Development.

9.3.3 System Engineering Application to Knowledge Intensive Service Industry Development Strategy and Mechanism Formation

T.J. Wang, *Industrial Technology Research Institute*,
L. Chang, *Energy and Resources Laboratories*;
D. Chin, *Da-Yeh University, Taiwan*

The Taiwanese government realized the fact that the service industry has reached 67.8% of the national GDP in 2003, also recognized the successful outcome such as GE and IBM companies to shift from manufacturing to knowledge intensive service business. In order to keep a good momentum of GDP growth rate for Taiwan economic development, the government has to set out for a new industry development policy through Service Industry Program, which could meet with the needs of the existing service industry. It is very crucial to enhance their capabilities with modern technology and management, encourage them to join the feasible and profitable pilot system service projects. The major purpose of this program is trying to generate higher value added and/ or new business with innovation technology and new business model to create a new system service industry, which can be duplicated in the global market.

Session 9 Track 4: Process Improvement

9.4.1 The Axes Guiding Development of a Capability Engineering Process

M. Mokhtari, M. Lizotte, C. Lalancette, G. Dussault,
M. Couture, F. Bernier, *Defence R&D Canada - Valcartier*
S. Lam, *Defence R&D Canada – Ottawa*

Significant changes in the nature of military systems and the military environment require improvements of the current military systems acquisition process. The Capability Engineering Process (CEP), to be delivered through the CapDEM project, aims at improving military capabilities acquisition in the Department of National Defence and the Canadian Forces (DND/CF). However, opportunities to improve capability acquisition are too numerous to implement all of them within the CEP. This paper presents a structured approach to better orient the development of a CEP.

9.4.2 Improving Process Evolution Using Ideas from the Venture Capital Industry

D.P. Rogers, *University of South Australia;*
P. Beukman, *University of Canterbury*

This paper provides a coherent framework for process evolution and new product introduction. The approach overcomes common limitations with process evolution including:

- Opportunity driven; rather than directly linked or driven by an organization's strategic goals.
- Non-standard methods within an organization, for example, in the approach used for calculating return on investment if such explicit calculation exists.
- Neglect of resource availability, skill needs and organizational change management.
- Neglect of the timeliness or window of opportunity.

9.4.3 Seamless Engineering Process to Enhance Systems Engineering Effectiveness

J.R. Jolly, L. Shepard, S. Bean, A. Hough, *BAE Systems*

In order to effectively execute large and complex programs, an engineering process must be established that eliminates multi-disciplinary barriers. This process needs to be focused on the entire product development cycle and work to keep engineering disciplines from executing independently. This paper will describe the integration of the systems, hardware, and software engineering approach, the utilization of event driven, use case-based, object oriented design practices, and the use of an integrated tool suite to perform the requirements decomposition, traceability, architecture design, and multi-level documentation generation. The authors will also address how this process aids unit testing, system level testing, and regression testing methodologies throughout the product development and deployment lifecycles.

Session 10 Track 1: SE Principles

10.1.1 A Systems Approach to Process Infrastructure

J.R. Armstrong, *Systems and Software Consortium, Inc.*

This paper looks at several aspects of process infrastructure and maturity from the viewpoint of systems thinking concepts. To start, the paper addresses the position of process infrastructure relative to ISO 15288 (ISO/IEC, 2002) enabling systems. Next, the paper looks at the impact of multiple standards on the infrastructure and the programs using it. A third view is the use of a systems approach to deal with the problem of multiple standards for how processes are implemented. The final view is how the common features implement both the science and engineering approach activities and how maturity levels address them.

10.1.2 Canadian Capability Engineering Process Foundations

M. Mokhtari, M. Lizotte, C. Lalancette, G. Dussault,
M. Couture, F. Bernier, *Defence R&D Canada - Valcartier*
S. Lam, *Defence R&D Canada – Ottawa*

This paper describes the fundamental characteristics (goals, scope, stakeholders, inputs/outputs and conception principles) upon which will be based the development of the first version of the Canadian Capability Engineering Process being investigating by the Department of National Defence and the Canadian Forces, to bridge the gap between the Capability-Based Planning and Acquisition processes.

10.1.3 Agile SYSTEMS ENGINEERING Versus AGILE SYSTEMS Engineering

R. Haberfellner, *Technical University Graz;*
O.L. de Weck, *Massachusetts Institute of Technology*

This paper explores recent developments in agile systems engineering. We draw a distinction between agility in the systems engineering process versus agility in the resulting system itself. In the first case the emphasis is on carefully exploring the space of design alternatives and to delay the freeze point as long as possible as new information becomes available during product development. In the second case we are interested in systems that can respond to changed requirements after initial fielding of the system. We provide a list of known and emerging methods in both domains and explore a number of illustrative examples such as the case of the Iridium satellite constellation or recent developments in the automobile industry.

Session 10 Track 2: SE Management

10.2.1 Requirements—The Good, the Bad, and the Ugly

J. Martin, *The Aerospace Corporation;* S. Arnold, *QinetiQ*

In our efforts to make system requirements "good," we often end up making them "bad." It is proposed that the real goal should be to make requirements BaD—balanced and dynamic. This paper describes why the so-called "good" requirements are really, in the larger sense, bad for success of the system and the organization that sponsors it. The paper will explain what it means to have "balanced and dynamic" requirements. Times have changed—the systems engineering discipline needs to change its methods to keep up with the global trade situation. For this, we need better tools and techniques that support the BaD approach.

10.2.2 Proposition of a Methodology and Tools for the Management of Innovative Design Projects

C. Baron, S. Rochet, C. Gutierrez, *LESIA*

This paper deals about the development of new methods and tools to support the management of projects dealing with the design of innovative systems. Currently, there are only few methods and virtually no tool making possible to ensure in a formal way of the design choices coherence with those of project management. This involves risks of incoherencies which can have technical and economical consequences (low quality, wrong deadlines, higher costs...). It is to fill this gap that we currently develop tools, in collaboration with academics and industrials partners, based on a specific representation integrating both technological and organizational data, which will help the designers and the project leader in their respective tasks. In this paper, we present a methodology which, thanks to the interaction of various tools, will lead to establish this project representation and assist the actors of the project in their choices of design and management and so reduces project costs, delays and risks.

10.2.3 Guidance on Tailoring of Systems Engineering Processes for Quick Reaction Capability (QRC) Developments

A. Richstein, *Space Technology Office*;
J.T. Nolte*, Northrop Grumman IT-TASC*

Although the very basis for establishment of the discipline of systems engineering is grounded in development of large, complex systems, the principles and processes are also extremely valuable for other types of systems. As discussed in (INCOSE Handbook 2004) the responsibilities of systems engineers, that include "requirements analysis, functional analysis and allocation, architecture/design, systems analysis and control, and verification and validation of the system", while "most apparent on large, complex systems ... are also important in the development, production, deployment, and support of much smaller systems."

A Quick Reaction Capability (QRC), the focus of this paper, is a type of system development characterized by deployment of a critical capability to satisfy an urgent need in which the normal acquisition process is accelerated. That is, the driving requirement is the timely delivery of the system to operations. In this paper, we provide guidance on tailoring the CMMI processes for QRC developments to achieve mission success while satisfying the shortened development schedule. We assert that identifying and implementing the right SE processes is of even greater value for conducting a QRC development, precisely because time is such an important consideration.

Session 10 Track 3: SE Process

10.3.1 The Producing System

A.S. Paul, *Howard University;*
G.A. Yerace, *US Army Research Laboratory*

This paper discusses the importance of the enabling resources (otherwise identified as enabling capacity or enabling capabilities) to the successful development of systems. It proposes the Producing System as a mechanism for planning, acquiring, deploying and managing these enabling resources as a system of interest, in addition to the delivered or required system, in the system development process.

10.3.2 A Conflict Resolution Approach to Capturing System Architecting Lessons Learned

C.J. Bryan, *The Boeing Company;*
C. Dagli, *University of Missouri - Rolla*

Success in system architecting is more likely if the lessons learned on other projects are captured and applied appropriately. This is especially true when conflicts between different requirements and needs are encountered. The TRIZ approach to innovation management can be used as the basis of a systems architecting tool for capturing methods used by experts to resolve architecture conflicts. The resulting tool is easily adaptable to any organization, is maintainable on a computer yet can be depicted on a few sheets of paper, allows specific solutions to be derived from general methods, and suggests approaches that may not otherwise be considered. The wide variety of sources available to an organization—heuristics, special reports, interview records, etc.—can be combined and analyzed to the determine the most commonly used techniques and when to use them, thereby raising the likelihood of successfully solving current problems.

10.3.3 10 Golden Questions for Concept Exploration and Development

D.C. Surber, *Raytheon Technical Services Company, LLC*

Project engineers and development teams must be able to quickly understand the customer's need. There are many tools, methods, and processes suggested for conducting "Concept Exploration" and "Concept Development". The author believes that there are "10 golden questions" which get the requirements elicitation done right. They apply to any Product (knowledge, good or service), system, or organizational structure. The "10 Questions" go a bit further than grammar school's: "who, what, where, when, why, and how." Interaction with the customer/user illumines a key aspect of the system solution, "How does failure affect customer satisfaction?" Asking, "What if the product, (seen at its various levels of decomposition such as, "system/product/component"), FAILS to satisfy these 'requirements'?", leads the designer to a better system solution. These answers take one to the next important discovery, answering, "How do we achieve mitigation and control of any critical failure modes and their effects on mission success, (through design, manufacturing, materials, and training)." This is the true purpose of the systems engineering lifecycle.

Session 10 Track 4: Process Improvement

10.4.1 Measuring the Lifecycle Value of a System

T.R. Browning, *Texas Christian University;*
E.C. Honour, *Honourcode, Inc.*

The goal of systems development is to produce enduringly valuable systems—i.e., systems that are valuable when delivered to their users and which continue to be attractive to their stakeholders over time. However, quantifying the lifecycle value (LCV) provided by a system has proven elusive. We propose an approach to quantifying a system's LCV based on the key parameters that have perceived value to the system's stakeholders. For this, we draw upon insights from the management, marketing, product development, value engineering, and systems engineering literature. By designing systems for maximum LCV, systems architects and engineers will provide dramatically increased value to their organizations. However, to provide maximum LCV, a system may need to be designed to facilitate adaptability to changing circumstances and stakeholder preferences.

10.4.2 System Integration Frameworks

J.J. Simpson, M.J. Simpson, *System Concepts*

An organizations ability to effectively create, deploy and use system integration frameworks is adiscriminating technical capability which will continue to grow in importance for the design, development and deployment of future engineered systems. Engineering activities utilized in large-scale systems integration processes are strongly associated with organized problem solving and complexity reduction. This paper outlines the relationships between systems, meta-systems, and integration frameworks as well as complexity measures, reduction and management. The primary thesis of this paper relates to the design and use of integration frameworks as a fundamental means of complexity reduction. A system "abstraction frame" concept is presented and related to classical systems engineering mathematics and practices. A proposal for a systems engineering language completes the content of this paper. A formal systems engineering language will greatly reduce complexity in the practice of systems engineering, as well as facilitate the solution of even more complex problems.

10.4.3 Putting Leadership into Systems Engineering - A Model for Systems Engineering Leadership Development

T.H. Holzer, *National Geospatial-Intelligence Agency*

Systems Engineers, at all experience levels, need to be capable in more than the field of Systems Engineering. They require solid leadership competencies in order to gain essential support within an engineering or program team, properly influence the technical and programmatic direction, and achieve the best program outcome. Therefore, as a Systems Engineer advances (and in order to advance) in their career, the importance of being and demonstrating performance as an effective leader should increase. This paper is based on direct observations where weaknesses in leadership skills were noted in engineers. A structured leadership development program for systems engineers is providing the necessary competencies to perform in their work environment. The case study highlights the need for increased emphasis on systems engineering leadership training and provides a leadership development model. Survey results and findings provided validate the program's performance towards its objective.

Session 11 Track 1: Measurements & Analysis

11.1.1 Calculations of Flexibility in Space Systems

R. Nilchiani, D. Hastings, C.Joppin,
Space Systems Laboratory, MIT

One of the important aspects of Engineering Systems design is the measurement of flexibility. In this paper, different measures for flexibility are applied to an orbital transportation network, which provides on-orbit servicing capability. The paper introduces provider-side as well as customer-side flexibility metrics that can be used to evaluate different architectures on the basis of their flexibility. These two sets of approaches to calculating flexibility for space systems highlight the different ways flexibility can be valued, be it in terms of flexibility metrics or real option values. The choice of methodology depends on the context and the engineering system in question, as well as what kind of outputs are expected. While the case studies discussed here are focused on space systems, these measures of flexibility can also be expanded to many other engineering systems.

11.1.2 A Case Study of Multi-Disciplinary Modeling Using MATLAB / Simulink and TrueTime

P. van den Bosch, *Oce-Technologies BV;*
E. van de Waal, *Imtech ICT Technical Systems*

A big challenge in the development of complex machines is to evaluate the effects of early design decisions. This is because of 1) the multi-disciplinary nature of such systems, and 2) the complexity of these machines. In this paper, it is demonstrated that it is possible to model essential system artifacts like timing and power usage for a complex machine, and obtain simulation results that can predict system behavior.

As a case study, a model of the paper flow in a modern high-volume printer / copier is made. This model focuses on timing and electrical power consumption. The model is validated using measurements on a real printer. It is shown that the model can be used to evaluate the impact of design decisions on the system.

11.1.3 The Nuts, Bolts and Duct Tape of Establishing a System Engineering Measurement Program

P.J. Frenz, *General Dynamics Advanced Info Systems*

While Software Engineering has a long history of conducting a measurement program, System Engineering (SE) is still in its infancy, in relative terms, in providing comparable measurement program guidance. This paper traces the establishment and institutionalization of a System Engineering Measurement Program.

Session 11 Track 2: Patterns & Model-Based SE

11.2.1 Requirements Statements Are Transfer Functions: An Insight from Model-Based Systems Engineering

W.D. Schindel, *ICTT, Inc., and System Sciences, LLC.*

Traditional systems engineering pays attention to careful composition of prose requirements statements. Even so, prose appears less than what is needed to advance the art of systems engineering into a theoretically-based engineering discipline comparable to Electrical, Mechanical, or Chemical Engineering. Ask three people to read a set of prose requirements statements, and a universal experience is that there will be three different impressions of their meaning. The rise of Model-Based Systems Engineering might suggest the demise of prose requirements, but we argue otherwise. This paper shows how prose requirements can be productively embedded in and a valued formal part of requirements models. This leads to the practice-impacting insight that requirements statements can be non-linear extensions of linear transfer functions, shows how their ambiguity can be further reduced using ordinary language, how their completeness or overlap more easily audited, and how they can be "understood" more completely by engineering tools.

11.2.2 Application of Patterns and Pattern Languages to Systems Engineering

C. Haskins,
The Norwegian University of Science and Technology

On the strength of the reception of the presentation introducing the concepts of patterns and pattern languages (PPL) during the INCOSE symposium in 2003, a tutorial on writing patterns for systems engineering was conducted before the symposium in 2004 and a Systems Engineering Patterns Working Group was formed. This paper builds on the trend and discusses important issues relevant to the application and actual use of PPL by Systems Engineers. These issues include exploration of the alignment of pattern languages to other languages, their structure and the important question of "how shall the SE community use pattern languages?" Once these questions are answered, the INCOSE may find itself poised to introduce an innovative communications technique into the SE community with the application of PPL.

11.2.3 Developing Section 4 Verification Text: Getting Early Buy-In from Industry & Government Stake holders

B.R. Haskins, J.M. Striegel, *The Boeing Company*

Defining, designing & building a Large-Scale Integration system is a daunting task. Even more daunting is proving that a system of that complexity meets the design requirements. The verification 'proof process' starts early on in a development program and the foundation is captured in the section 4 verification text, as defined in MIL-STD-961E, DoD Standard Practice, Defense and Program-Unique Specification Format and Content. There have been numerous technical papers written to ensure that the section 3 requirements are verifiable, but few papers have been written to describe how to develop quality section 4 verification text. This paper describes a formal verification approach for developing quality section 4 verification text, with associated verification planning data, and getting early buy-in from Industry and Government stakeholders in defining critical verification events, which is crucial to the success of any Large-Scale Integration system.

Session 11 Track 3: Application

11.3.1 What are Levels?

T. Bahill, R. Botta, *BAE Systems;*
E. Smith, *University of Arizona*

The most common mistake in modeling systems is mixing elements of different levels in the same model. This paper explains levels, shows how levels can be obtained with decomposition techniques, and gives examples of level models, architectures and frameworks. Examples are given which show the confusion that results when levels are mixed.

11.3.2 Development of an Object-Oriented Multi-Leg Route Choice Model on Transportation Network Simulation

E-S. Yang, E. Garcia, D. Mavris,
Georgia Institute of Technology

Due to its complexity, modeling of the transportation network involves a very large number of node choices for completion of a travel route. Conventional route choice models approach this problem from the mathematical point of view. In this paper, a System-of-Systems approach is used to model a Personal Air Vehicle (PAV) network, and a traveler's route choice model in a multi-leg travel scenario is proposed. Both the network and route choice model are designed using Object-Oriented (OO) programming techniques eliminating the usage of complicated matrix calculations as in many other mathematical models. The practical limitations of the shortest path problem are not usually in the solution itself, but in the application of it in the simulation environment. This paper also covers some of the most important concepts of the Traveling Salesman Problem (TSP) and an idea to tackle TSP is suggested with a modified model.

11.3.3 Acknowledging Uncertainty in the Provision of Defence Capability: Insights from Literature

E. Rajabally, *Systems Engineering Innovation Centre;*
S. Snape, P. Sen, *University of Newcastle*
S. Whittle, *BAE Systems*

Uncertainty pervades the world we live in although its presence is not always acknowledged in systems engineering. Its influence on providing systems-of-systems defence capability is not only amplified by the aggregation of uncertainty through the systems hierarchy but also by the ambiguity in defining such capability. Worryingly, a failure to account for uncertainty can ultimately lead to a failure to satisfy the customer. Dealing with uncertainty must begin with acknowledging, understanding and synthesising the insight that literature has to offer on the topic. Such insight is summarised in this paper by reviewing the pertinent literature on the topic. A number of formalisms for expressing uncertainty exist and the pros and cons of each are surveyed. Traditional means of uncertainty analysis are also reviewed as a basis for dealing with uncertainty in defence capability. Despite the emphasis on the provision of defence capability, the topics presented in this paper are relevant to systems engineering in general.

Session 11 Track 4: SE Management

11.4.1 From Waterfall to Evolutionary Development (Evo) Or How We Rapidly Created Faster, More User-Friendly, and More Productive Software Products for a Competitive Multi-National Market

T. Johansen, *FIRM AS;* T.S. Gilb, *RPL*

11.4.2 Managing Priorities: A Key to Systematic Decision Making

T. Gilb, *RPL;* M.W. Maier, *The Aerospace Corporation*

A central concern of systems engineering is selecting the most preferred alternatives for implementation from among competing options. The selection process is sometimes called tradeoff analysis, and is often built on the methods of decision analysis and utility theory. The process can be loosely divided into two parts, a first part in which one determines the relative priority of various requirements, and a second part, a design selection phase, in which alternatives are compared, and the preferred alternatives chosen.

This paper discusses the means of determining the priority order for implementing system changes. It also outlines the implications on the selection process of evolutionary systems development.

11.4.3 The Tradespace Exploration Paradigm

A.M. Ross, D.E. Hastings,
Massachusetts Institute of Technology

Over the past five years, researchers working on a number of system design projects in the Space Systems, Policy, and Architecture Research Consortium (SSPARC) at the Massachusetts Institute of Technology (MIT) have developed a process of value-focused, broad tradespace exploration for the development of space systems. The broad tradespace framework has provided insights into communicating and quantifying the impact of changing requirements, uncertainty, and system properties such as flexibility and robustness. Additionally, insights have been made in applications to more complex cases, such as analyzing policy effects on system cost and performance, as well as understanding the time-dependent effects of architecture and

design choices for spiral development. The tradespace exploration paradigm both broadens the perspective of designers in conceptual design to better understand the "physics" of the proposed solutions relative to one another, and focuses the designer on delivering systems of value to key system stakeholders.

Key Reserve

12.1 Design Evaluation: Estimating Multiple Critical Performance, Quality and Cost Impacts Based on Evidence and Feedback

T. Gilb, *RPL*

How should we evaluate someone's design suggestion? Is gut feel and experience enough for most cases? Is anything more substantial and systematic possible? This paper outlines a process for design evaluation, which assesses the impacts of designs towards meeting quantified requirements. The design evaluation process is viewed as consisting of a series of design filters.

12.2 Fundamental Principles of Evolutionary Project Management

T. Gilb, *RPL*

The Evolutionary Project Management method – abbreviated Evo – is arguably the best systems engineering project management method (Larman and Basili 2003). However, it is also probably the least known and the least discussed, so the aim of this paper is to shed some light on it. Evo is particularly good at dealing with large, complex, and innovative systems – it does so by breaking down the project into a series of numerous small incremental steps. Each Evo step is both an opportunity to deliver some useful results to the stakeholders, and an opportunity to learn more about the system.

12.3 Project Failure Prevention: 10 Principles of Project Control

T. Gilb, *RPL*

It is now well-known and well-documented that far too many projects fail totally or partially, both in engineering generally (Morris 1998) and software engineering (Neill and Laplante 2003). I think everybody has some opinions about this. I do too, and in this paper I offer some of my opinions, and I hope to lend some originality to the discussion. As an international consultant for decades, involved in a wide range of projects, and involved in saving many 'almost failed' projects, my basic premises in this paper are as follows:

- We specify our requirements unclearly;
- We do not focus enough on ensuring that the system design meets the requirements.