A 5-day Systems Engineering Fundamentals Open Course - Detailed Content

Systems Engineering is the systematic application of Systems Thinking to the design and introduction of new systems. Applied correctly Systems Engineering provides considerable strategic advantage to an organization by reducing introduction times, improving system performance and reducing through life costs. Its relevance is the only proven approach to handling risks associated with highly complex products and services.

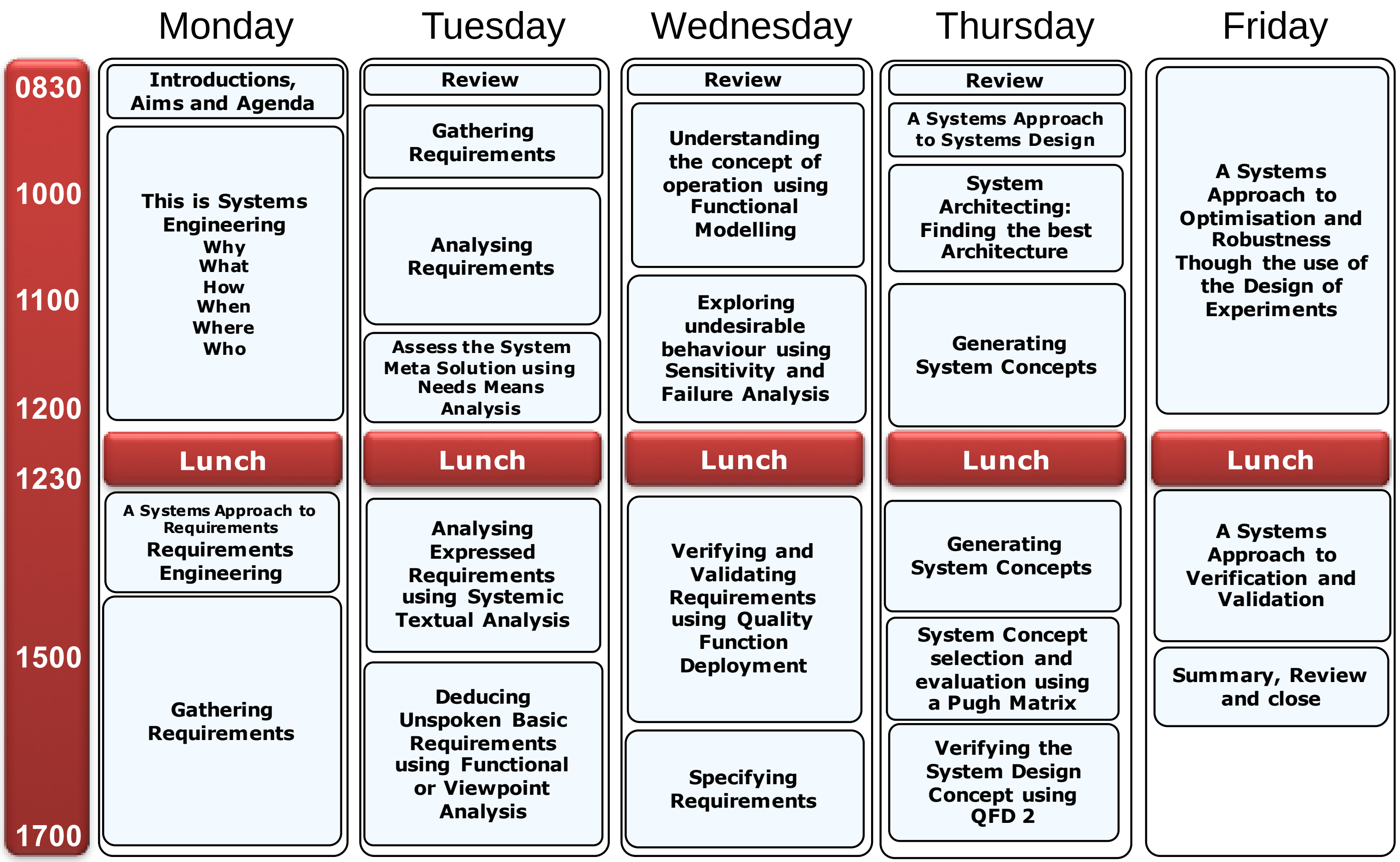
Applying Systems Engineering correctly, however, requires not only skills and knowledge but also a profound understanding of the underlying systems principles on which it is built. Education and training are therefore critical to the development of an organizational capability in Systems Engineering. This course is about educating and training participants in how to do Systems Engineering. Along the path, participants will also learn what it is and why it is like it is. Put simply; its purpose is to teach people how to design better systems.

Opposite is the block plan agenda for the 5-day Systems Engineering Fundamentals Open Course.

Details about each session can be found in the following table that outlines:

Session Purpose
Session Outcomes
Session Content
Session Exercises and Activities

The learning approach is based on the Kolb learning cycle with a significant proportion of the course set aside for exercises to reinforce the learning. Indeed, many of the small group exercises involve a case study that provides a practical focus for the course and enables the delegates to practise the methodology and tools presented.



Times: 0830, 1000, 1100, 1200, 1230, 1500, 1700

Monday
- Introductions, Aims and Agenda
- This is Systems Engineering: Why, What, How, When, Where, Who
- Lunch
- A Systems Approach to Requirements: Requirements Engineering
- Gathering Requirements

Tuesday
- Review
- Gathering Requirements
- Analysing Requirements
- Assess the System Meta Solution using Needs Means Analysis
- Lunch
- Analysing Expressed Requirements using Systemic Textual Analysis
- Deducing Unspoken Basic Requirements using Functional or Viewpoint Analysis

Wednesday
- Review
- Understanding the concept of operation using Functional Modelling
- Exploring undesirable behaviour using Sensitivity and Failure Analysis
- Lunch
- Verifying and Validating Requirements using Quality Function Deployment
- Specifying Requirements

Thursday
- Review
- A Systems Approach to Systems Design
- System Architecting: Finding the best Architecture
- Generating System Concepts
- Lunch
- Generating System Concepts
- System Concept selection and evaluation using a Pugh Matrix
- Verifying the System Design Concept using QFD 2

Friday
- A Systems Approach to Optimisation and Robustness Though the use of the Design of Experiments
- Lunch
- A Systems Approach to Verification and Validation
- Summary, Review and close

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Times	Session Name	Purpose	Outcomes	Content	Exercises and Activities
30 min	Introduction	To introduce the course in terms of: • Aims and objectives • Agenda • Administration • Participant's background • Expectations	Participants: • Are told the course aims and objectives, agenda and administration details • Know more about fellow participants • Have captured and reviewed their expectations	Course Aims & learning objectives Course Agenda Using a Quad of Aims to capture expectations	Individual Quad of Aims and small team Quad of Aims
180 min	This is Systems Engineering	• To explain the difference between "traditional" approaches to engineering and the systems approach • To explain the benefits of adopting Systems Engineering • To explain the relationships and nature of systems, Systems Thinking and Systems Engineering • To provide the theoretical underpinning of systems concepts and Systems Thinking • To explain the two dimensions of Systems Engineering: ○ Complexity ○ Lifecycle	Participants: • Know the difference between traditional engineering and systems engineering • Understand the relationships between Systems Thinking, Systems Approaches and Systems Engineering • Have had explained the concept of systems thinking • Introduced to key systems theory and properties • Know the Systems Approach to engineering systems and its origin in Systems Thinking • Understand that Systems Engineering is top down, universal and scalable • Know the basic phases of the generic Systems Engineering process and how it aligns to lifecycle processes • Understand the critical ingredients of Systems Engineering: ○ People ○ Process ○ Tools ○ Infrastructure	Issues of the traditional approach to design and Emergent Behaviour as a consequence of complexity. Systems Thinking as the approach to handling complexity: Systems Thinking concepts and principles: • Emergence • Purpose • Context • Sub-Systems - Abstraction • Behaviour as Events, Patterns and Structure • Feedback balancing and reinforcing Systems Engineering (SE) as a Systems Approach to system design Process: Top-down using purpose and context to manage complexity: • V diagram - SE is fractal and recursive • Checking = V&V Lifecycle view: • Lifecycle models including ISO 15288 • Lifecycles within lifecycles SE is replicated Tools: Simple tools to answer complex problems People: Roles but also SE is a team sport – it is concurrent and collaborative Infrastructure: Information and Knowledge management Summary	"Helium" Tube – to demonstrate emergence (15 min) 4-sentences – to demonstrate complexity (10 min) FLY to demonstrate mind set (5 min) Purpose exercise (15 min) Sharing Knowledge Exercise (10 min) Process Discussion (10 min) Tools Discussions (10 min) Infrastructure Discussion (10 minutes)

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Times	Session Name	Purpose	Outcomes	Content	Exercises
30 min	A Systems Approach to Requirements: Requirements Engineering	• To explain the importance of requirements in Systems Engineering • To highlight the common issues surrounding "customers" and their requirements • To introduce requirements engineering as a subset of Systems Engineering	Participants: • Know the key role requirements play in good engineering • Realise the common and specific features of requirements that result in the need for, and activities of, requirements engineering • Know the key activities of requirements engineering	Why requirements go wrong • Broad vs. Narrow markets • Static-Dynamic design concepts • Customer Chain implications • Requirements for Associated Systems • Enhanced Kano model (spoken vs. unspoken requirements) • Ambiguity • Change Overcoming the problems through a Systems Approach to Requirements = Requirements Engineering	User Requirements Exercise (15 min)
180 min	Gathering Requirements	• To explain the need for a Systems Approach to gathering requirements • To present a process for gathering requirements • To describe and practice using tools for gathering requirements	Participants: • Understand the need to gather requirements from all stakeholders • Recognise the range and scope of system stakeholders • Know the process for gathering requirements • Have practiced using key tools: ○ Requirement Elicitation Plan ○ Stakeholder Map ○ Affinity & Tree Diagram ○ Use Case ○ Analytic Hierarchy Process (AHP)	Customers and Stakeholders Gathering Requirements process Planning requirements gathering using the Requirements Elicitation Plan Identifying and selecting key stakeholders using the Stakeholder Influence Map Eliciting and capturing Requirements using Affinity Diagrams, Use Cases, Gemba visits and customer feedback Structuring and Prioritising Requirements Using Tree Diagrams and the Analytic Hierarchy Process Validating Requirements	Case study exercise using Stakeholder Influence Map (35 min) Case Study Exercise using Affinity and Tree Diagram (30 min) Case study Exercise using Use Cases (15 min) Case Study Elicitation Methods Exercise (15 min) AHP Exercise (20 min)
60 min	Analysing Requirements	• To explain the need to analyse any expressed or gathered requirements to generate the System Requirements • To define the Holistic Requirements Model • To demonstrate the importance of system functionality	Participants: • Understand the need to analyse requirements • Have explained the Holistic Requirements Model • Know and can apply the requirement categories of the Holistic Requirements Model • Understand the importance of system functionality as a system invariant and the basis for systems design	The need for requirements analysis to deduce and determine unspoken requirements A systems views of requirements using the Holistic Requirements Model The key role of Generic Functionality in Systems Engineering Using functionality to find unspoken requirements and problem division The systems approach to analysing requirements through a system of tools What the tools do Process and tool set	Analyse User Requirements using Holistic Requirements Model (25 min) Generic Functionality (10 min) Functionality in exploring design choices (10 minutes)

Times	Session Name	Purpose	Outcomes	Content	Exercises
45 min	Assess the System Meta-Solution using Need Means Analysis	To introduce the concept of the System Meta-Solution and how it can be used to scope the system of interest. To describe and practise the use of Need Means Analysis as a way of identifying selecting a system meta solution	Participants: • Understand the concept of a Meta-solution • Have successfully conducted Need Means Analysis on the case study problem	Concept of a system Meta-Solution Dangers of not considering alternative meta-solutions. Need Means Analysis principle and process the “so what” of Need Means Analysis	Case Study exercise using Need Means Analysis (15 min)
90 min	Analysing Expressed requirements using Systemic Textual Analysis	To introduce the Systemic Textual Analysis tool as a way of analysing written/expressed customer requirements to help identify and deduce missing requirements	Participants understand the approach of Systemic Textual Analysis and have successfully applied it to the case study problem	Textual analysis - the traditional approach to requirements analysis. Failings of classic textual analysis. Parsing expressed requirements using the Holistic Requirements Model Systemic Textual Analysis • purpose • outcomes • process Systemic Textual Analysis practise exercise	Exercise on the effect of ambiguity in written text: 4 sentence story (10 min) Systemic Textual Analysis exercise for the Case exercise (60 min)
100 min	Deducing Unspoken Basic Requirements using Viewpoint /Functional Analysis	To introduce the approach of using the “development team’ to determine the functional requirements of a system using: • Functional Analysis • Viewpoint Analysis	Participants: • Understand the approach to deducing unspoken requirements through system functionality • Recognise the need for top-down and bottom-up approaches • Have successfully deduced unspoken requirements using: o Functional Analysis o Viewpoint Analysis on the case study problem	Deducing “unspoken” requirements from the “engineer” Introduce: • Functional Analysis as bottom up tool • Functional Analysis Process • Practise using Functional Analysis • Viewpoint Analysis as a top-down tool to help the engineer deduce requirements • Describe Viewpoint Analysis purpose, outcomes and process. • Practise using Viewpoint Analysis on the case study exercise	Functional Analysis of Toggle Screw (20 min) Viewpoint Analysis of case study problem (60 min)
150 min	Functional Modelling	To explain the need to build functional/behavioural models of the proposed system. To introduce tools that can be used: • Context Diagram • Function Flow Diagrams	Participants: • Recognise the need for functional/behavioural modelling • Have successfully generated a functional model for aspects of the case study problem	Purpose of Functional Modelling Functional Modelling elements: • Function Flow Diagram • Function Specification • Flow Dictionary Functional Modelling process Constructing Function Flow Diagrams The Flow dictionary conventions and Function Specification conventions Using Functional modelling	Context Diagram (20 min) and Function Flow Diagrams for case study problem (60 min)

Times	Session Name	Purpose	Outcomes	Content	Exercises
120 min	Sensitivity and Failure Analysis	• To provide the theoretical basis for understanding undesirable emergent behaviour through system sensitivity and failure. • To introduce the concept of Robust Design and the loss function • To provide tools that allow for an early assessment of system sensitivity and failure as part of requirements analysis	Participants: • Recognise the dangers of emergent behaviour in complex systems particularly system sensitivity and functional failures • Understand the concept of the loss function and Robust Design • Appreciate the need for sensitivity analysis tools • Understand the Systems Approach to failure • Practise using Functional Failure Model and Effects Analysis	Introduction to impact of variation and the use of traditional tolerances and specification limits Introduction to the concept of loss functions and Robust Design. Applying the concept of robustness during Requirements Engineering as a qualitative approach Tools for Sensitivity and Failure Analysis • Flow Sensitivity Analysis • Functional Failure Mode and Effects Analysis ○ Failure modes and functions ○ Effects ○ Causes and Mechanisms ○ Prevention and Detection approaches ○ Design failure out and safety in	Functional Failure Mode and Effects Analysis for case study problem (30 min)
150 min	Verifying System Requirements and Stakeholder Requirements using Quality Function Deployment 1	• To explain the need to check for completeness and consistency in a set of system requirements • To explain the Quality Function Deployment methodology and how it provides a powerful requirements management tool to test and check the completeness of Stakeholder Requirements (URD) and System Requirements (SRD) • To provide practical experience of verifying the completeness and consistency of a requirements set using Quality Function Deployment phase 1	Participants: • Are introduced to Quality Function Deployment as a tool for managing requirements during new system introduction • Understand the nature and relationships between Stakeholder Requirements and System Requirements and how this can be captured and exploited using the Quality Function Deployment template • Experience using QFD 1 as a tool for verifying completeness and consistency of system design requirements	Presents the need to verify and validate requirements to check for completeness and consistency Introduces the use of Matrix Diagrams – Quality Function Deployment as a way of performing the crosschecking between the Stakeholder requirements (User requirements) and System (design) requirements Using QFD to flow down and verify up requirements How to construct and use a QFD phase 1 chart • The WHATs – stakeholder/user requirements • The HOWs – System Functionality • The Relationship Matrix and looking for structure • The HOW MUCHs completing the System Design Requirements Additional QFD analyses • The correlation Matrix – the roof • Competitive Assessments	Case study exercise to complete Relationship Matrix of a QFD 1 (45 min) Generating “how much” technical requirements (15 min)

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60 min	Specifying Requirements	To provide guidance and advice on how to specify requirements in terms of: • organizing requirements • documenting requirements	Participants: • Understand the importance of organizing requirements between and within documents • Know how to write good requirements • Understand the use of diagrams in specifying requirements	Introduce the success criteria for good requirements – structure and organization (inside documents and between documents) and writing individual requirements. Requirement attributes Diagrams in requirements Managing requirements	Case study exercise (20 min)
15 min	A Systems Approach to Systems Design	To provide an overview of the System Approach to Systems Design in terms of: • architecture and technology • how it relates to the meta-process of divergent and convergent thinking	Participants: • Understand the systems approach to design and how it encapsulates divergent and convergent thinking • Know the purpose and objectives of the Create System Design Concept Phase • Know the key process steps and what type of tools are appropriate	Reminder of key systems design principle – “there is always choice” Two sets of design decisions: technology and architecture Fundamental system design process	None
120 min	System Architecting	• To introduce the principles of system architecting and why it is important • To introduce the system concepts of cohesion binding and coupling. • To show how N^2 can help identify the “best” logical architecture	Participants: • Have an understanding of the importance of architectural design • Understand the key principles • Are aware of tools such as N^2 analysis to select appropriate architectures	Importance of architecture in system design Types of architecture: Key Design Rule – reduce interfaces Architecture design principles: • Cohesion • Binding and Coupling Logical System Architecting, N^2 Analysis Architecture optimisation Interface requirements and definition Interface design rules Managing interfaces using N^2 Matrices	Case Study N^2 Analysis Exercise (15 min)
90 min	Technological Concept Generation	To develop skills in team based creativity methods as applied to system design	Participants are able to use a number of simple creative thinking tools to generate alternative system solutions in structure and logical fashion for the case study problem using Function Means Analysis	The role of creativity in system design – but requiring a holistic and systematic approach. Barriers to creativity Use of creativity tools: • Brainstorming • Negative Brainstorming • Affinity Diagrams • Similarities and differences Organizing creativity through Function Means Analysis	Use Similarities and Differences creative thinking tool on case study exercise (20 min) Function Means Analysis case study exercise (45 min)

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60 min	Concept Integration	• To develop skills in integrating functional solutions into complete system concepts	Participants: • Understand the need for design integration and are able to apply the approach to the case study problem	Creation of whole System concepts through design integration. Using Function Means Table to aid Down-selection through objective criteria. Capturing design rationale Identifying candidate whole system concepts	Case study Concept integration exercise (45 min)
30 min	Concept Selection	• To develop skills in evaluating complete system concepts to eliminate and select	Participants: • Can evaluate complete system concepts using Pugh matrices to eliminate weak concepts • Have seen the use of Analytic Hierarchy Process in concept selection	Whole system concept evaluation and selection using Pugh Matrix Analytic Hierarchy Process in concept selection	Case study concept selection case study exercise using Pugh matrices (20 min)
30 min	Verifying System Solution Concept meets System Design Requirements using Quality Function Deployment phase 2	• To show how Quality Function Deployment phase 2 (QFD 2) can check that the selected system concept meets the system design requirements • How QFD 2 can ensure the complete and correct flow-down to subsystem level	Participants: • Understand how QFD 2 can check that the selected design concept meets the technical requirements • Understand how QFD 2 can identify critical system functionality and solutions • Understand how QFD 2 can help flow down requirements to sub-system level and ultimately component level • Experience using QFD 2	Verifying whole system concepts against design system design requirements using QFD 2. Analysing the QFD 2 relationship matrix for critical design aspects and features. Using QFD 2 to develop sub-system requirements.	Case study exercise QFD 2 relationship exercise (20 mins)
150 min	Optimise and Refine Concept System Solution and the Principles of Robust Design	To provide an overview of the Optimise and Refine System Concept Solution To provide an introduction to Robust Design and Design of Experiments as a way of efficiently exploring the design space	Participants: • Know the purpose and objectives of the Optimise and Refine System Concept Solution Phase • Understand the concept of the robust optimum and how it aligns to parameter design and tolerance design • Recognise the need to characterise the design space efficiently • Have an introduction to the power of Design of Experiments	Introduction to Optimise and Refine System Design Concept Process Solution space vs. Design Space Concept of the robust optimum. Understand the failing of one-factor at a time search methods. Recognise the power of the Design of Experiments: • Full Factorial Design o Main Effects and Interactions o Analysis of Means • Fractional Factorial Designs o Confounding o Orthogonal Arrays o Noise	Exercise to demonstrate the weakness of single factor at a time experimentation. Simple ½ fraction Design of Experiment exercise

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60 min	A Systems Approach to Verification and Validation	To introduce the Systems Approach to Verification and Validation emphasizing the need to undertake verification and validation as early as possible	Participants: • Understand the difference between Verification and Validation • Understand the system approach to Verification and Validation with the emphasis on performing V&V activities throughout system design • Recognise the need to generating V& V requirements from the system requirements	Explains the need for both Validation and Verification. Left shift towards measuring inputs rather than outputs. Determination testing vs. demonstration testing – V& V early. Big and small V&V activities Methods and Tools for verification and validation. Writing Verification Requirements.	Case study exercise writing Verification Requirements (30 min)
15 min	Course Summary	To remind participants of the SE journey To verify the expectations have been met	Participants: • Understand what they have accomplished	PowerPoint built story of the process and tools	