A course on "Introduction to Systems Engineering"
26th to 28th April 2018

This short course was designed and directed by Shri J Jayaraman. He was supported by S/Shri P S Krishnan, G Natrajan and Dr. Venkatanarayana Rao. 15 lectures were delivered by Shri Jayaraman and one lecture each by others.
33 of the 35 sponsored participants from NAL, BEL, ISAC, CDOT, ADE, LRDE, CABS, MTRDC and CAIR attended the course at DROMI, DRDO Complex, and CV Raman Nagar Bangalore.
Course material, distributed to the participants at the time of registration, comprised of indexed 1000 references, 12 case studies and lecture notes. Case studies illustrated tailoring aspects of SE.
Brief content of each lecture is given below:

Lecture 1 - System and its characteristics.
Defining system and its characteristics; Synergy, how to decide that an element is part of a system; Types of system - hard and soft; Simple to chaotic systems.

Lecture 2 - Why systems engineering
Criteria for successful, challenged and impaired/failed projects. The need for the application of systems engineering.
One would always look at return on investment as a measure of success of SE. SE effort is seen to improve project performance. Impact of SE was illustrated through some experiments with high school children and data of three universal holding fixtures through RFP to overall development.

Lecture 3 - Overview of SE
Origin of SE is traced through Descartes Scientific theory – Von Bertalanffy General System's theory - Systems theory – Systems thinking - Systems analysis - Systems dynamics. Importance of different way of thinking such as holism reductionism; Whole brain concept; Importance of context. Systems engineering process along with SE tailoring. Mayonnese jar example of philosophy to explain the SE to down approach.

Lecture 4 - Mission analysis
Mission analysis; Concept of Operations (CONOPS) is a part of mission analysis to capture operational requirements. Importance of writing a proper problem statement; Thinking map application to graphically assemble the knowledge as a system of interest; Lakshya Aerial Tow Target System was taken as the system of interest and taken through the course for illustrating the SE process application. Identification of stakeholders, their value used in prioritizing the requirements and the relationships between them.

Lecture 5 - SE case study LCA FCS
The SE process applied in the case of LCA FCS was explained in brief. Review and audit process followed both in the cases of hardware and software; Importance of documentation; Steps followed from data capture to testing and evaluation till date with some lessons learnt.

Lecture 6 - Introduction to QFD
Quality Function Deployment (QFD) developed by the Japanese to build in customer perceived quality into a product. It gives integration though out the life cycle of a system. QFD as applied to Tow Target to prioritise requirements and assign target values considering competition; Software QFD and application of QFD in cost worth analysis.

Lecture 7 - Graphical models used in SE
Advantages and disadvantages of various System models. Relationship between

different models; Time line diagrams. SysML is the new modelling language.

Lecture 8 - Requirements engineering I

Why, What and Essence of requirements; Types of Systems and Program Requirements, Non-functional requirements; Difference between requirements and specifications; Attributes of single and a set of requirements; Requirements Capturing of requirements, their analysis and categorization; Model based requirements & System modelling. Requirements rationale, flow down, allocation, verification and validation; Traceability and Change management; Requirements development process, originating /operational requirements; Top level requirements capture using CONOPS developed illustrated for Tow Target.

Lecture 9 - Functional Analysis form fit and function

Functions, functional thinking, functional classification, function, behaviour configuration, system function, functional classification, design for function logical and physical design , black box and white box views. Functional analysis and system technique (FAST) and its application to cost, reliability, size, weight, electrical power. Functional decomposition and logical simulation. Tow target problem was used to illustrate the principles of functions explained.

Lecture 10 - Interface analysis.

Interfaces, its characteristics, examples and elements; Types of interfaces, categorization / partitioning of interfaces, system interfaces, and interface properties; Interface analysis, tasks, its requirements and documentation, roles (intended and unintended effects) modularity, interoperability, N2 diagram, interface management and application to Tow Target problem was made. A novel method "Entropy Method to minimize interfaces" was highlighted.

Lecture 11 - System Integration, Verification and Validation

System integration, facets of integration, important issues in system design integration; System engineer (design integrator) performs virtual system integration at the design stage itself. Verification and validation were discussed in detail. Verification methods and techniques, stages of verification, CONOPS, requirements and system verification; Golden rules of verification, verification documentation, and the roles of systems engineers in verification; Validation CONOPS, requirements and system validation, validation methods and validation standards; Integration process activities, physical and purpose of integration process along with 777 Flight Controls design validation were presented.

Lecture 12 - SE case study Weapon locating RADAR Swathi.

SE process for the RADAR from needs identification to final configuration; some useful tips on how to handle the user and team as a systems engineer; Master test plan. The importance of building a team and working together to achieve success was emphasized.

Lecture 13 - Concept generation and selection

Need for generating a large number of alternative concepts; Concept generation processes like TRIZ, Lateral thinking etc.; Need for finalizing the criteria for selection to be selected first; a novel method of obtaining concepts from functions discussed with reference to Tow Target problem. Concept selection processes such as Pugh's concept selection, concept scoring, along with concept filter, controlled convergence; Minimization of interfaces w.r.t. Tow Target problem. Robust decision making at the conceptual design stage using belief maps and Fuzzy QFD were outlined.

Lecture 14 - Decision making

Decisions, System life cycle decisions, types of decision making, motivation for decision making, seven steps to decision making, intuitive decision making, common decision

making errors and biases, decision analysis and trade off study; Probability theory and utility theory are the foundations of decision theory. The terms decision matrix, decision tree were explained. Three types of decision making, under certainty, under risk, and under ignorance; Levels of decision making, game theory, multi attribute utility theory, conjoint analysis and analytical hierarchy process; Conjoint analysis was illustrated with Tow Target problem in selecting a passive lens against an active transponder.

Lecture 15 - Risk management

Risk, common terms used in risk, types of risk, risk breakdown structure, project risk factors, typical risk areas, risk event graph, risk management, qualitative and quantitative risk management methodology, standard risk model, risk criticality matrix, risk mitigation methods, risk monitoring methods. Risk analysis was performed with the problem Tow Target.

Lecture 16 - Failure Mode Effects and Criticality Analysis (FMECA)

The need for FMECA; its benefits, Evolution, Standards, SE and FMECA, Timing of FMECA, Types of FMECA, FMEA analysis techniques, Functional hardware approach, FMECA process, RPN and Military criticality analysis processes; Software tools and limitations of FMECA; A typical FMECA report was discussed.

Lecture 17 - Requirements II

Requirements analysis and what it means as applied to Tow target requirements; requirements validation plan for Tow Target along with requirements verification; Identification of technology and design drivers, objective hierarchy and weights as used to illustrate prioritize requirements of Tow Target.

Lecture 18 - Capture and Analyse top level requirements of an intelligent smart washing machine, a case study.

Controller is the system of interest. It is a middle out problem. As document for SE of the washing machine is not available. System engineering activities roadmap, problem statement, thinking map, system context diagram, external physical interfaces identified from system context diagram, stakeholder value chain analysis, CONOPS, top level requirements capture, black box white box views, architecture of washing machine, functional analysis different views, behaviour diagram, functional decomposition, internal interfaces identification from FFBD were illustrated. Harmful unintended functions were captured.

The intelligent controller was taken up and the steps repeated till functional view normal was reached.

Feedback: All the participants gave a positive feedback on different aspects of the Course. Technical contents, Quality of faculty and administrative arrangements were appreciated. Participants have good level of interaction as some of them were already exposed to the subject and the course proved to be a revision with added benefit for them.

The Organisers, IDST Bangalore, can be contacted for any further details.