Lecture 1: Introduction

31st Dec 2018

- Be punctual
- Sit in your Assigned Seats (Attendance)
- No Water and other breaks during class
- No Murmurs and Chit-chat in the class
- No Mobile Phones (Keep it Switched off)
- No Napping in the class

- Interactions Welcome
- Free/Open to Questions / Comments / Doubts

Course Structure

- Focus on Large and Complex Engineering Systems
- Mix of Lectures and Case Studies

- Grading
  - 1. Assignments 20%
  - 2. Mini Project 25%
  - 3. Mid-term Exams (1) 20%
  - 4. End-Semester Exam (1) 35%

  Details will be announced during the course

Course Faculty

- Dr K S Rajan
- Dr Kavita Vemuri

- Invited speakers

Course Books

PREFERRED TEXT BOOKS:
1. Systems Analysis, Design and Development by Charles S Wasson
2. Business Dynamics: Systems Thinking and Modeling for a Complex World. Irwin/McGraw-Hill, 2000. ISBN: 9780072389159.

REFERENCE BOOKS
1. Systems Engineering Handbook by NASA (electronic – PDF)
2. INCOSE Systems Engineering Handbook (electronic – PDF)
3. Complexity: Theory and Applications Book by Suh Nam-pyo
4. Axiomatic Design: Advances and Applications Book by Suh Nam-pyo

What is Engineering to you?

What does one mean by a System?

System can mean ...

- a system is a dynamic and complex whole, interacting as a structured functional unit;
- a system is a community situated within an environment;
- systems are often composed of entities seeking equilibrium but can exhibit oscillating, chaotic, or exponential behavior.
- A holistic system is any set (group) of interdependent or temporally interacting parts. *Parts* are generally systems themselves and are composed of other parts, just as systems are generally parts or *holons* of other systems.
- energy, material and information flow among the different elements that compose the system;

What is a System ?

- An integrated set of interoperable elements, each with explicitly specified and bounded capabilities, working synergistically to perform value-added processing to enable a User to satisfy mission-oriented operational needs in a prescribed operating environment with a specified outcome and probability of success.

'System'

- A group of *components* that work *together* for *a* specified *purpose*
  - Components - products (hardware, software, firmware), processes, people, information, techniques, facilities, services and other support elements
  - Together – integration of many
  - Purpose – is achieved by implementing many functions

Categories of Systems

- **Hard systems** — involving simulations, often using computers and the techniques of operations research.
- **Soft systems** — For systems that cannot easily be quantified, especially those involving people holding multiple and conflicting frames of reference. Useful for understanding motivations, viewpoints, and interactions and addressing qualitative as well as quantitative dimensions of problem situations.
- **Evolutionary systems** —This technique integrates critical systems inquiry with soft systems methodologies. Evolutionary systems, similar to dynamic systems are understood as open, complex systems, but with the capacity to evolve over time.

The systems approach

- **Interdependence** of objects and their attributes - independent elements can never constitute a system
- **Holism** - emergent properties not possible to detect by analysis should be possible to define by a holistic approach
- **Goal seeking** - systemic interaction must result in some goal or final state
- **Inputs and Outputs** - in a closed system inputs are determined once and constant; in an open system additional inputs are admitted from the environment
- **Transformation of inputs into outputs** - this is the process by which the goals are obtained
- **Entropy** - the amount of disorder or randomness present in any system
- **Regulation** - a method of feedback is necessary for the system to operate predictably
- **Hierarchy** - complex wholes are made up of smaller subsystems
- **Differentiation** - specialized units perform specialized functions
- **Equifinality** - alternative ways of attaining the same objectives (convergence)
- **Multifinality** - attaining alternative objectives from the same inputs (divergence)

Example 1. Braking System

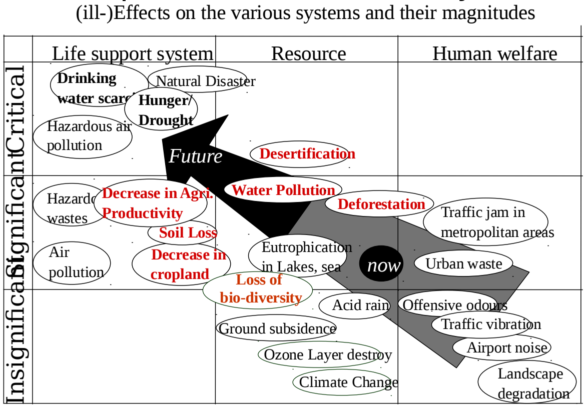
- Rather than trying to improve the braking system on a car by looking in great detail at the material composition of the brake pads (reductionist), the *boundary* of the braking system may be extended to include the interactions between the:
  - brake disks or drums
  - brake pedal sensors
  - hydraulics
  - driver reaction time
  - tires
  - road conditions
  - weather conditions
  - time of day

Example 2. Supermarket as a System

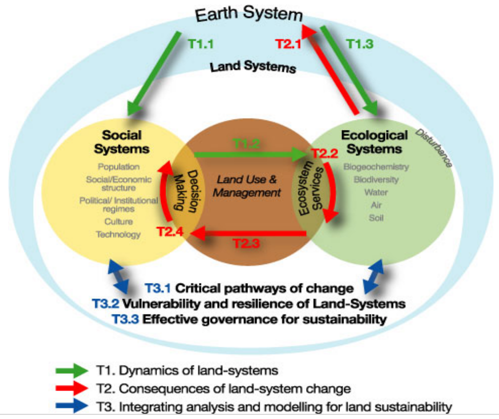
- Using the tenet of "Multifinality", a supermarket could be considered to be:
  - a "profit making system" from the perspective of management and owners
  - a "distribution system" from the perspective of the suppliers
  - an "employment system" from the perspective of employees
  - a "materials supply system" from the perspective of customers
  - an "entertainment system" from the perspective of loiterers
  - a "social system" from the perspective of local residents
  - a "dating system" from the perspective of single customers
- As a result of such thinking, new insights may be gained into how the supermarket works, why it has problems, how it can be improved or how changes made to one component of the system may impact the other components.

Example 3. Environmental System

(ill-)Effects on the various systems and their magnitudes

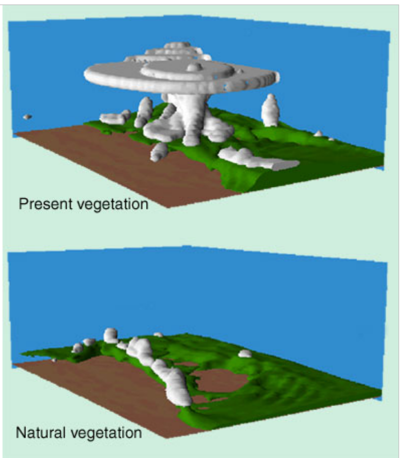


LAND as a SYSTEM:Analytical Structure



Changes in land use can dramatically alter weather patterns.

Models of cloud convection over the central USA show that storms can develop over current agricultural landscapes that would not have occurred over the original prairie land



Source: IGBP slide series

Systems Thinking

- **Systems thinking** is process of predicting, on the basis of anything at all, how something influences another thing.
- It has been defined as an approach to problem solving, by viewing "problems" as parts of an overall system (holistic), rather than reacting to present outcomes or events and potentially contributing to further development of the undesired issue or problem.
- It is a framework that is based on the belief that the component parts of a system can best be understood in the context of relationships with each other and with other systems, rather than in isolation.
- Systems thinking's focus is on effect, not cause.
- Consistent with systems philosophy, systems thinking concerns an understanding of a system by examining the linkages and interactions between the elements that compose the entirety of the system.
- Systems thinking techniques may be used to study any kind of system — natural, scientific, engineered, human, or conceptual.

http://en.wikipedia.org/wiki/Systems_thinking

Systems Engineering

- **Systems engineering** is an interdisciplinary field of engineering that focuses on how complex engineering projects should be designed and managed.
- Issues such as logistics, the coordination of different teams, and automatic control of machinery become more difficult when dealing with large, complex projects.
- Systems engineering deals with work-processes and tools to handle such projects, and it overlaps with both technical and human-centered disciplines such as control engineering and project management.
- In other words, systems engineering is a logical way of thinking.

http://en.wikipedia.org/wiki/Systems_engineering

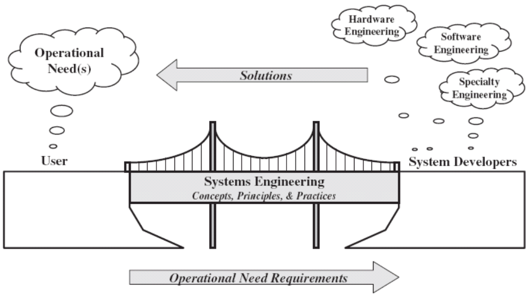


Figure 1.1 Systems Engineering—Bridging the Gap from User Needs to System Developers

Engineering Systems (1)

- Are large-scale, complex engineering challenges within their socio-political context.
- MIT defines Engineering Systems as the **engineering study dealing with diverse, complex, physical design problems** that may include components from several engineering disciplines, as well as economics, public policy, and other sciences.

http://en.wikipedia.org/wiki/MIT_Engineering_Systems_Division

Engineering Systems (2)

- A collection of engineered systems: Examples include large scale and complex engineering systems such as: the Internet, urban planning projects such as Boston's Big Dig, next generation air traffic control, healthcare reform, and network-centric warfare.
- Some Examples from India: Space Programmes, Delhi/Hyderabad Metro, IRCTC
- An approach in engineering based on systems thinking.
- MIT defines engineering systems as a multidisciplinary approach that does the same thing as Systems Engineering but has a management, policy, or social dimension as well as a technical one.

http://en.wikipedia.org/wiki/MIT_Engineering_Systems_Division#cite_note-0

Characteristics of Engineering Systems

- Technologically enabled: Networks & Meta-systems which transform, transport, exchange and regulate Mass, Energy and Information.
- Large-scale: large number of interconnections and components.
- Socio-technical aspects: social, political and economic aspects that influence them.
- Nested complexity: within technical system and social/political system.
- Dynamic: involving multiple time scales, uncertainty & lifecycle issues.
- Likely to have emergent properties.

http://en.wikipedia.org/wiki/MIT_Engineering_Systems_Division#cite_note-0

Complexity of a System

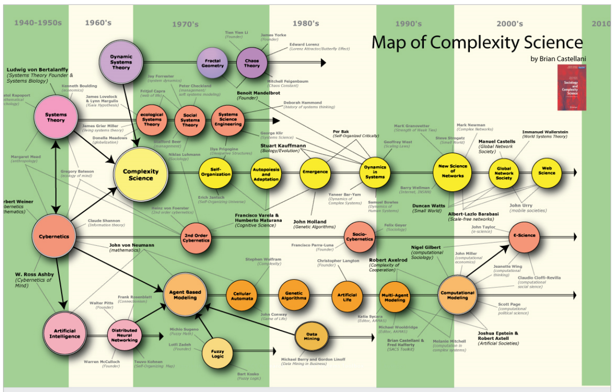
What are Complex Systems ?

Disorganized vs Organized complexity

Examples - development of smarter control algorithms, microprocessor design, and analysis of environmental systems

Need Methods and tools to understand and manage this complexity

Interconnections (& feedbacks) between the sub-systems are not always clearly known



Source: http://www.art-sciencefactory.com/complexity-map_feb09.html

Read

“Understanding the Value of Systems Engineering”

http://www.incose.org/secoe/0103/ValueSE-INCOSE04.pdf