Systems Engineering

An Introduction

Acknowledgement : these notes are partly based on the Wikipedia article on Systems Engineering.

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

and

“Systems Engineering Principles & Practice”, A Kossiakoff & W N Sweet (Wiley 2003)

Definition:

Systems Engineering is an inter-disciplinary approach to making and deploying successful systems.

Why do I need to know about it?

Because your job will almost certainly be done in the context of a 'bigger picture' and the ideas behind Systems Engineering will place your contribution in context and give you insight and a clearer view of how your activities interact with those of others.

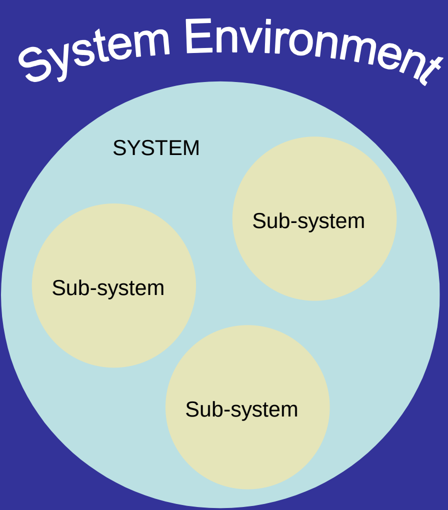
What is a system?

A **System** (from the Latin *systēma*) is a set of entities, real or abstract, comprising a whole where each component interacts with or is related to at least one other component and they all serve a common objective.

Any object which has no relation with any other element of the system is not part of that system but rather of the **system environment**.

A **subsystem** is a set of elements, which is a system itself, and a part of the whole *system*.

Every division or aggregation of real entities into systems is arbitrary, therefore it is a subjective abstract concept.



Examples of some hierarchies

"System of Systems"

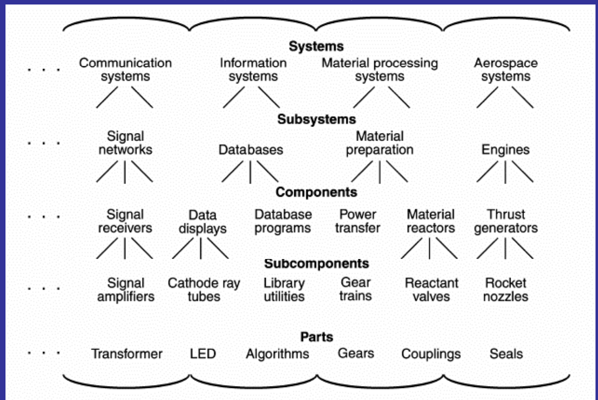


Fig. 2-1 System design hierarchy.

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What's the problem?

Why do we need Systems Engineering?

System development often requires contributions from diverse technical and non-technical disciplines. Consider the (extreme) example of a project to develop a nuclear-powered submarine. A non-exhaustive list of major 'stakeholders' in the project is:

- Central government departments
- Local government departments
- The public
- Defence contractors
- Marine architects
- Civil engineering consultants
- Shipbuilders

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The basic question addressed by Systems Engineering is this :

How do we co-ordinate all the stakeholders to achieve a successful project?

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Why is this difficult?

Each of the stakeholders is normally focused on their own particular contribution to the system. They will have their own goals and ambitions, their own local definition of 'success', their own constraints and a very limited perspective of the project as a whole.

Examples:

- the Government wants to secure the future defence of the country
- the local councillor seeks re-election by bringing jobs to the region
- the junior engineer wants the experience that leads to professional qualification (and promotion!).

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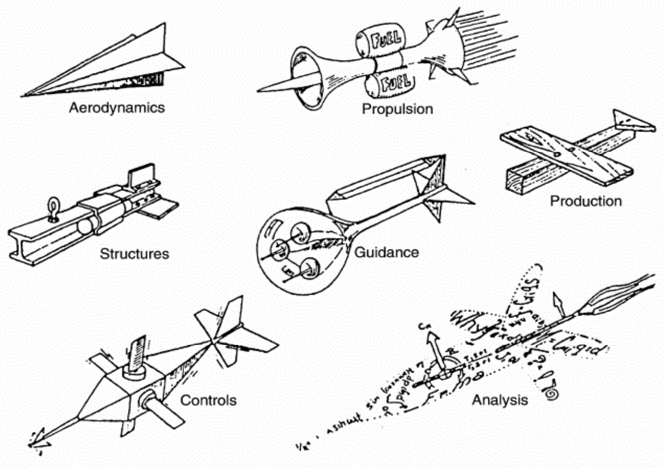

Fig. 1-2 The ideal missile design from the viewpoint of various specialists.

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Symptoms of project failure

- A system built of contributions from various sub-system groups which, although individually successful, does not perform as a total system.
- Problems appear at sub-system interfaces.
- Unforeseen (and unwelcome) system properties arise as independently designed sub-systems are integrated.
- Cost over-runs, schedule delays, an under-performing system.

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The real problem is this : the interactions between the parts of this system are inherently complex. Their individual behaviour is often not well-defined and understood. The aggregated behaviour of the system may consequently be poor - and this will certainly hinder the achievement of a successful project. Two behavioural characteristics are particularly difficult to manage.

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System sensitivity - small changes or omissions made at the lower levels of the system actually have a profound influence on the course of the project (e.g. NASA 'O' rings temperature specification eventually leads to Challenger disaster and curtailment of Shuttle programme).

Emergent behaviour - where the system evolves procedures and rules, each one of which may be locally sensible, but which together lead to unintended 'emergent' behaviour. These behaviour patterns have NOT been explicitly expressed by management and may be detrimental to the goals of the project. Typically, they are difficult to recognise and exerting corrective control may also be very difficult.

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What is the antidote?

Systems Engineering takes a holistic perspective of the system and integrates all of the stakeholders' efforts to ensure that their various subsystems work with one another. Defining and characterizing the subsystems, and the interactions among them, is therefore an essential part of systems engineering. In short, Systems Engineering:

- integrates various disciplines and specialty groups into a team effort;
- forms a structured development process that proceeds from concept to production to operation and disposal;
- considers both the business and technical needs of all parties;
- has the goal of providing a quality product that meets the user needs.

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Brief History

- Bell Laboratories : inter-operability of different parts of the US telephone system
- WW II - increasingly complex military systems, e.g. operational research (OR) to optimise difficult logistics problems (optimum deployment of men and materials);
- 1950s : Complex systems theory begins to develop;
- 1960s : USAF regulations on Functional Analysis; Systems dynamics modelling (Forrester);
- 1970s : Structured analysis techniques (e.g. Yourdon Systems Method - YSM) are developed and are applied to commercial, software, I.T. and engineering systems;

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Brief History (cont)

- 1995 : establishment of INCOSE - International Council on Systems Engineering - as a professional society.
- 1990s : Systems Engineering support tools (e.g. DOORS for textual requirements capture and management) are developed.
- 2000s : Increased use of modelling techniques at all stages of the systems engineering process – standards such as UML (software engineering) and SysML (systems engineering) are agreed and the software tools to support them are developed.
- Simulation Based Design evolves.

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Related fields

Systems Engineering is intrinsically inter-disciplinary. It draws upon the ideas and concepts of many related fields, which include:

- Software Engineering
- Control Systems
- Operations research
- Reliability Engineering
- Safety Engineering
- Human Factors Engineering
- Business Process Engineering
- Quality Assurance and Control
- Cognitive Systems Theory
- Complex Systems Theory
- Management Theory and Practice
- Systems Biology
- Financial Engineering

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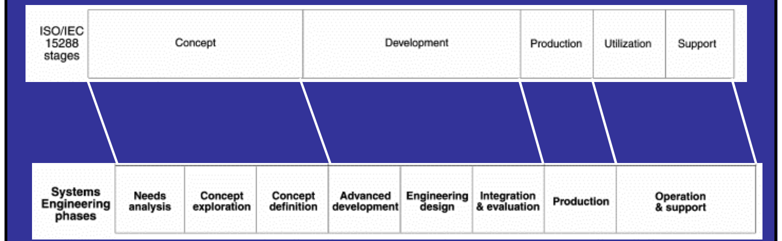
The Systems Engineering process

The SE Life-Cycle as defined in ISO/IEC 15288.



Each succeeding phase adds **a further level of requirements or specifications to serve as a basis for the next phase. Each phase produces an increasingly detailed** definition ('materialisation') of the system until the final product or service has been achieved.

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The systems engineering method can be thought of as the systematic application of the scientific method to the engineering of a complex system. It can be considered as consisting of four basic activities applied successively:

- **Requirements analysis** – formulates the objectives as a set of requirements
- **Functional definition** - translates the requirements into statements of function (specification)
- **Physical definition** - synthesizes alternative physical implementations
- **Validation of the design** - models the system in its environment.

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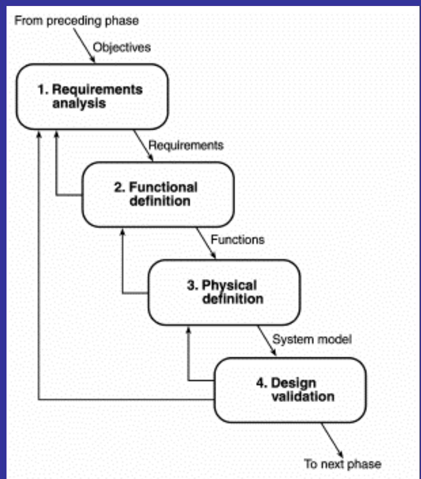
These four steps are applied during each phase of the life-cycle. As the system progressively materializes, the focus shifts from System-level during Needs analysis down to Component and Part levels during engineering design.



3-5 System engineering method top-level flow diagram.

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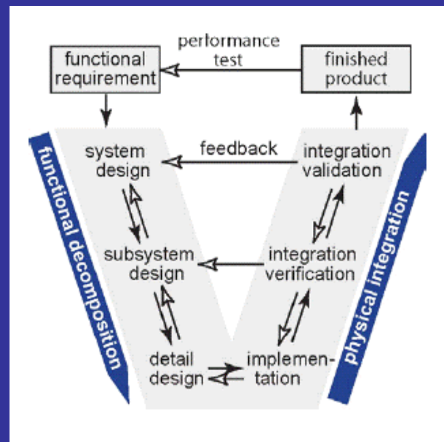
The Vee model of Forsberg and Mooz

The down stroke of the Vee represents functional analysis, the upward stroke physical synthesis.

The systems approach integrates analysis and synthesis.



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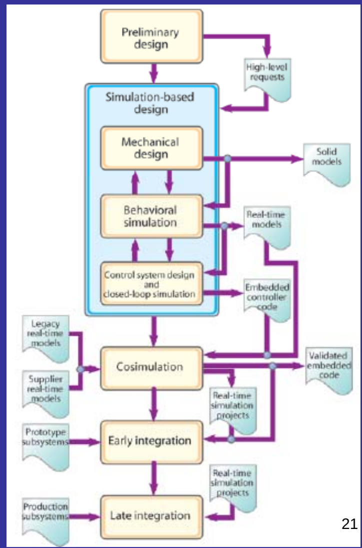
The simulation-centric process.

Systems Engineering often involves the modelling and simulation of the proposed system in order to validate assumptions or explore theories. The prime contractor and all the subsystem suppliers contribute simulation models for each simulation stage.



from : Simulation Centric Processes for Aerospace by Scott James (Applied Dynamics Systems International)

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Conclusions

- Systems Engineering is an inter-disciplinary approach to making and deploying successful systems.
- It has developed as a method for monitoring and controlling unforeseen behaviour that causes unsatisfactory performance at the total system level - and the budget and schedule over-runs which happen as a consequence.
- The current trend is to use computer simulations, at increasing levels of detail and veracity, for all phases of the SE process – the *simulation-centric* process.
- Standards exist for the SE process which procurement executives (e.g. Government, large companies) are increasingly insisting that their suppliers use.

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