Massachusetts Institute of Technology
Engineering Systems Division

Working Paper Series

<u>ESD Terms and Definitions</u> (Version 12)

ESD Symposium Committee:

Tom Allen, Co-Chair
Howard W. Johnson Professor of Management
Professor of Engineering Systems

Joel Moses, Co-Chair
Institute Professor
Professor of Computer Science and
Engineering and Engineering Systems

Dan Hastings
Professor of Aeronautics and Astronautics
and Engineering Systems

Seth Lloyd
Associate Professor of Mechanical
Engineering and Engineering Systems

John Little
Institute Professor

Don McGowan
Associate Director, Office of Corporate
Relations

Chris Magee
Professor of the Practice of Engineering
Systems andMechanical Engineering

Fred Moavenzadeh
Professor of Civil and Environmental Engineering
and Engineering Systems

Debbie Nightingale
Professor of the Practice of Aeronautics and
Astronautics and Engineering Systems

Dan Roos
Professor of Civil and Environmental
Engineering and Engineering Systems

Dan Whitney
Senior Research Scientist, Center for
Technology, Policy and Industrial Development

October, 2001

ESD Terms and Definitions (Version 12)

The ESD Symposium Committee

October 19, 2001

I.   BASIC TERMS RELATED TO ENGINEERING SYSTEMS

Engineering – bringing to reality useful artifacts and algorithms that heretofore did not exist; in English, especially in England, the term is often associated with maintenance and operation, especially of engines, but the French root (ingénieur) is related to ingenious (ingénieux).

System – A set of interacting components having well-defined (although possibly poorly understood) behavior or purpose; the concept is subjective in that what is a system to one person may not appear to be a system to another

Engineering System – a system designed by humans having some purpose; large scale and complex engineering systems, which are of most interest to the Engineering Systems Division, will have a management or social dimension as well as a technical one.

System Environment – a set of conditions external to and affecting a system; environments include both natural and man-made conditions

Natural environment – natural surroundings and context (e.g., air, water); the natural environment can sometimes be considered the core of a system, with engineering systems providing interfaces to it

Complex system – a system with components and interconnections, interactions, or interdependencies that are difficult to describe, understand, predict, manage, design, or change.

> The concept of complexity has several meanings: dynamic (in the sense of complex behavior), and static or structural (in the sense that a complex system is composed of many components interconnected in intricate ways). In addition, while the complexity of a system can be a quantifiable and even an absolute quantity, what makes a system appear complicated to people is subjective (simplicity is in the eye of the beholder); how complicated the system appears depends on the nature of the interface of the system that is presented to its users.

> Interdependence – the relationship between entities that cannot exist or operate without each other; independent entities exist and operate without influence from each other; interdependencies may be intended or unintended

Interaction – the property of entities that exchange something material or immaterial that constitutes or contributes to their interdependence

Interconnection – the relationship between entities that are physically or abstractly connected and the connection provides the pathway for the interaction; software connections are often abstract

These three terms are clearly interrelated (pun intended). We distinguish at least three types of interdependence: one is the interdependence that may occur among components or subsystems in a given design of a system, a second is the interdependence created when global constraints (such as weight, volume, cost, or 2nd Law of thermodynamics) force a redesign, and a third is one that occurs as a result of subdivision of tasks or the management of the flow of materiel or information.

Components – parts of a system relative to that system; a component can be a system too if it contains other components

Large scale systems – systems that are large in scale and/or scope; such systems have a large number of components; as a result large scale physical systems will be distributed over a region that is large relative to its smallest components;

Designing –an open-ended human process whereby plans for useful artifacts and processes are created

Function(s) –broad: desired behavior(s) of a system or a component; these behaviors are presumably desired because they contribute to a stated purpose; more specifically, fundamental behaviors (not including the ilities – see below) of an engineering system that fulfill its stated purpose.

Requirements – the combined set of functions, ilities (see below), and constraints (e.g., weight, volume, cost, physical laws) that an engineered system is supposed to achieve, deliver, or exhibit; functions can be said to be what a system 'does,' whereas the ilities and constraints are properties that a system 'has'

Effectiveness –ratio of function(s) achieved to the totality of functions desired

Efficiency – ratio of function(s) achieved to resources used

Life cycle – The sequence of phases that an engineering system undergoes, which can be divided into three major parts: Conceiving, developing, and deploying. Conceiving includes identification of need/opportunity, initiation of requirement elicitation and gathering. Developing includes analysis, design, implementation manufacture or production, and testing. Deployment includes assimilation, use, maintenance, modification or upgrade, repair, retirement, dismantling, recycling, disposal, erasure or remediation, and possible replacement; replacement is a critical element in creating a cycle

Systems changes – multiple dimensions by which systems change, including the rate of change (e.g., evolutionary, moderate, revolutionary), the structural direction of change (e.g., top-down, bottom-up, networked), or the breadth of change (e.g., pilot initiatives, wall-to-wall)

II.   ILITIES AND RELATED SYSTEM ISSUES

Ilities- requirements of systems, such as flexibility or maintainability, often ending in 'ility;' requirements of systems that are not necessarily part of the fundamental set of functions or constraints

Flexibility – the property of a system that is capable of undergoing changes with relative ease. Such changes can occur in several ways: a system of roads is flexible if it permits a driver to reach from one point to another using several paths; flexibility may indicate the ease of 'programming' the system to achieve a variety of functions; flexibility may indicate the ease of changing the system's requirements with a relatively small increase in complexity (and rework)

Agility – ability of a system to be both flexible and undergo change rapidly

Robustness - demonstrated or promised ability to perform under a variety of circumstances; ability to deliver desired functions in spite of changes in the environment, uses, or internal variations that are either built-in or emergent (see below)

Fail-safe - ability to be guided to a safe state, if the system cannot deliver the full desired function due to failure(s)

Adaptability – the ability of a system to change internally to fit changes in its environment. In our definition above a flexible system is usually modified from outside the system. An adaptable system may undergo self-modification (e.g., a thermostat controlling the heating of a subsystem)

Scalability- the ability of a system to maintain its performance and function, and retain all its desired properties when its scale is increased greatly without having a corresponding increase in the system's complexity

> An increase in scope (that is, an increase in the system's functional capabilities) usually involves an increase in scale, yet scalability does not normally imply ease with increasing the scope of a system without unduly increasing its complexity. Such ease is usually related to the structure of the system's architecture (see below) and its flexibility

Modularity –the degree to which the components of a system can be designed, made, operated, and changed independently of each other

Safety- the property of being free from accidents (see below) or unacceptable losses

Durability – ability to deliver a specified level of function for a specified length of time

Sustainability – broad: maintaining economic growth and viability while meeting concerns for environmental protection, quality of life, and social equity; narrow: a property of an engineering system having optimal resource preservation and environmental management over time

Quality- ability to deliver requirements at a "high" level, as perceived by people relative to other alternatives that deliver the same requirements

Reliability – the probability that a system or component will satisfy its requirements over a given period of time and under given conditions

Repairability –the ability to be returned to the original state of function when some function is lost

Maintainability - the ability of a system to be kept in an appropriate operating condition; the system should also possess the property of repairability

III. DESIGN/MANUFACTURING CONCEPTS AND APPROACHES

Manufacturing – The processes by which materials are made, parts or components are fabricated from materials, and products are assembled from parts; software is implemented rather than manufactured

Manufacturing Systems – The equipment, processes, people, organization and knowledge, as well as the interactions of these that are involved in the manufacturing of a given end product

Lean Manufacturing – A pull based and flexible manufacturing system that is responsive to customer demand, where skilled workers, just-in-time manufacturing processes, and continuous improvement are combined to produce perfect first-time-quality output

Systems architecting - The process by which standards, rules, system structures and interfaces are created in order to achieve the requirements of a system; trade-off studies may precede the determination of system requirements

Systems engineering –a process for designing systems that begins with requirements, that uses and/or modifies an architecture, accomplishes functional and/or physical decomposition, and accounts for the achievement of the requirements by assigning them to entities and maintaining oversight on the design and integration of these entities; systems engineering originally arose in the context of aerospace projects in the 1950's, but has been applied more broadly since then.

> Systems architecting creates a system design at a high, abstract level, whereas systems engineering is often associated with refining such a design; by blending the two processes one accomplishes the assignment of functions to physical or abstract entities, and the definition of interactions and interfaces between the entities

Optimization – a process or methodology for maximizing the function of a system

Multi-criteria optimization – the simultaneous optimization of several criteria

Functional decomposition - the division of functions into sub-functions while retaining all inputs to and outputs from the level above; the decomposed elements perform all the functions of their parents in the decomposition

Logical decomposition – the division of information system components into their logical constituent parts

Physical decomposition –the division of physical systems into simpler subsystems and components

Integration –the act of anticipating or executing a combination of components of a system with the expectation that all system requirements will be achieved.

System structures – abstractions useful within systems in order to understand, control and facilitate the complex interactions – current possibilities include platforms, modules, networks, teams, and hierarchies, and subsets and combinations thereof

Hierarchy – Hierarchies create a ranking of elements in a system. In a layered hierarchy one of any pair of elements is above, below or at the same level as the other. In a tree-structured hierarchy one adds the possibility that a pair of elements have no hierarchical relationship.

Reuse –In the design of systems, repeated use or application in different places of the design of parts, manufacturing tools and processes, analysis, and particularly knowledge gained from experience; using the same object in different systems or at different times in the same system

Module – A part of a system that is constructed to have minimal, standardized interactions with the rest of the system (and is thus often reusable).

Platform –a module or set of components that splits a system into two parts so that changes can, in principle, be made on either side of the platform interface without affecting the other side as long as appropriate standards are followed; platform implementation: all parts or components on the side of the platform interface farther from the end user, namely the parts or components needed to achieve the desired abstract interface.

Integral architecture – an architecture in which the number of functions or behaviors is significantly larger than the number of designed entities or components

Modular architecture – an architecture in which the number of functions is roughly comparable to the number of designed entities or components; an architecture in which the interactions and interfaces between the components are relatively simple

Interfaces – a boundary or interconnection between systems or their components that define or support interrelationships; interfaces may be intended or unintended

IV.   RISK/UNCERTAINTY/SAFETY IN DESIGN/MANUFACTURING AND OPERATION

Ambiguity – open to having several possible meanings; may also be uncertain

Uncertainty – related to being not clearly or precisely determined

Accident – an undesired and unplanned (but not necessarily unexpected) event that results in (at least) a specified level of loss (called a loss event); losses can be economic losses, losses of human lives, losses of function, losses of time, etc.

Hazard – a state or sets of conditions that, together with worst-case external conditions, can lead to an accident

Risk – the level of hazard combined with the likelihood of the hazard leading to an accident, and the duration or exposure of the hazard; a combination of the likelihood, severity and lack of detectability of an accident or loss event

V.   MANAGEMENT AND RELATED SOCIAL SCIENCE ISSUES

Enterprise – a defined scope of economic organization or activity, which will return value to the participants through their interaction and contribution

Lean enterprise – an enterprise that delivers value to its stakeholders, while minimizing waste (waste can be in terms of materials, human lives, capital, time, physical plant, equipment, information, and energy)

Learning Organization - an organization that systematically reviews its experience with its internal and external environment and acquires knowledge in order to improve its functioning

Negotiation – an interactive process aimed at communication and agreement among multiple stakeholders who have both common and competing interests

Socio-technical systems – broad: systems in which both human and non-human elements interact, where the social or management dimensions tend to dominate

Socio-technical systems design – the design of work systems that attempts to optimize human psychological and physiological dimensions along with the technical aspects

Policy studies – studies of courses of action, chosen from alternatives, that guide present and future decisions by, for example, governmental bodies

Interdisciplinary – involving two or more academic disciplines or professional practices

VI.   GENERAL CONCEPTS AND APPROACHES RELATED TO SYSTEMS

System point of view – a conviction that system behaviors are qualitatively different from the behaviors of a system's components, that system design requires doing more than designing the components, and that special effort is required to understand systems and their behavior over and above what is required to understand any individual component

System thinking – includes holism, an ability to think about the system as a whole; focus, an ability to address the important system level issues; emergence (see below), recognition that there are latent properties in systems; and trade-offs, judgment and balance, which enable one to juggle all the various considerations and make a proper choice

System theories –theories that attempt to explain the interacting and combining behavior of a system as well as how the interaction of its components contribute to the behavior of the system

System Modeling – vocabularies, symbols, rules, and representations (behavioral, structural) that make use of the vocabularies, symbols, and rules for the purpose of displaying and predicting the structure and behavior of systems, or which represent in symbolic form or operational ways one or more aspects of the system under study

Emergent properties – properties or behaviors of a system that are discovered (i.e., properties that were there but latent), those that emerge spontaneously over time or space, and those that arise in response to behavior of other systems and environments; in a hierarchical view of systems, emergent properties show up at one level of the hierarchy, but not at lower levels

Synergy –mutually advantageous behaviors or properties that exist only because distinct elements are joined or can interact

VII.   SYSTEM THEORIES

General Systems Theory – Originated by Bartanlaffy in the 1950's; an approach to modeling systems using sets of differential equations

Cybernetics – Originated by Norbert Wiener; models systems using feedback processes

System Dynamics – Originated by Jay Forrester; used to model systems in the social sciences and management; uses networks of nodes and feedback relationships amongst them

Complexity theory (in the sense of the Santa Fe Institute) – a set of approaches to understanding systems that encompasses chaos theory and related theories; used to understand biological systems as well as physics-based ones.

Complexity theory (as used in computer science) – approaches to the analysis of the computing time and effort required by various algorithms; usually relies on techniques in combinatorics and logic

Operations Research – a scientific approach to executive decision-making, including problem formulation, mathematical modeling, and system optimization.