LECTURE

7

SYSTEMS ENGINEERING - history

Zuzana Bělinová
Faculty of Transportation Sciences, CTU in Prague

LECTURE 7 – OVERVIEW

- Systems Theory and Engineering
  - History of systems thinking and theory
  - Founders of Systems Theory
  - History of systems engineering – projects
  - Organizations in systems theory and systems engineering

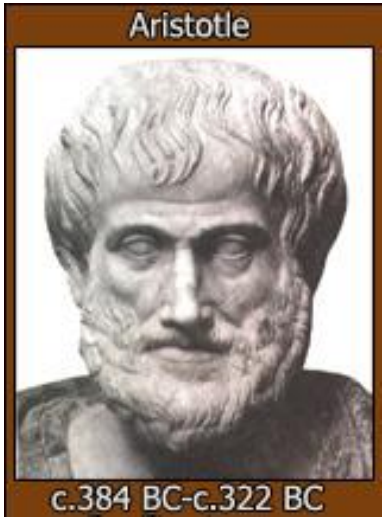
ORIGIN OF THE SYSTEMS THEORY – ANCIENT WORLD

Origin in philosophy

Ancient Greece

Aristotle (384-322 BC)

“The whole is more than the sum of its parts” -Metaphysica



ORIGIN OF THE SYSTEMS THEORY – MEDIEVAL TIMES

Gottfried Wilhelm von Leibniz (1646-1716)

- Philosopher, scientist, mathematician
- Parent of modern logic and analytic philosophy

Christian Wolff (1679-1754)

- Philosopher
- demonstrative-deductive, mathematical methods
- Follower of Leibniz

ORIGIN OF THE SYSTEMS THEORY – MEDIEVAL TIMES

Étienne Bonnot de Condillac

- philosopher, psychologist, logician, economist
- Friend with Jean-Jacques Rousseau
- Tract about system (1749): „...any system is not anything else then a distribution of different parts of any art or science with the known order, where all of these are mutually maintaining and where concluding parts are resolved by initiatory...“

ORIGIN OF THE SYSTEMS THEORY – MEDIEVAL TIMES

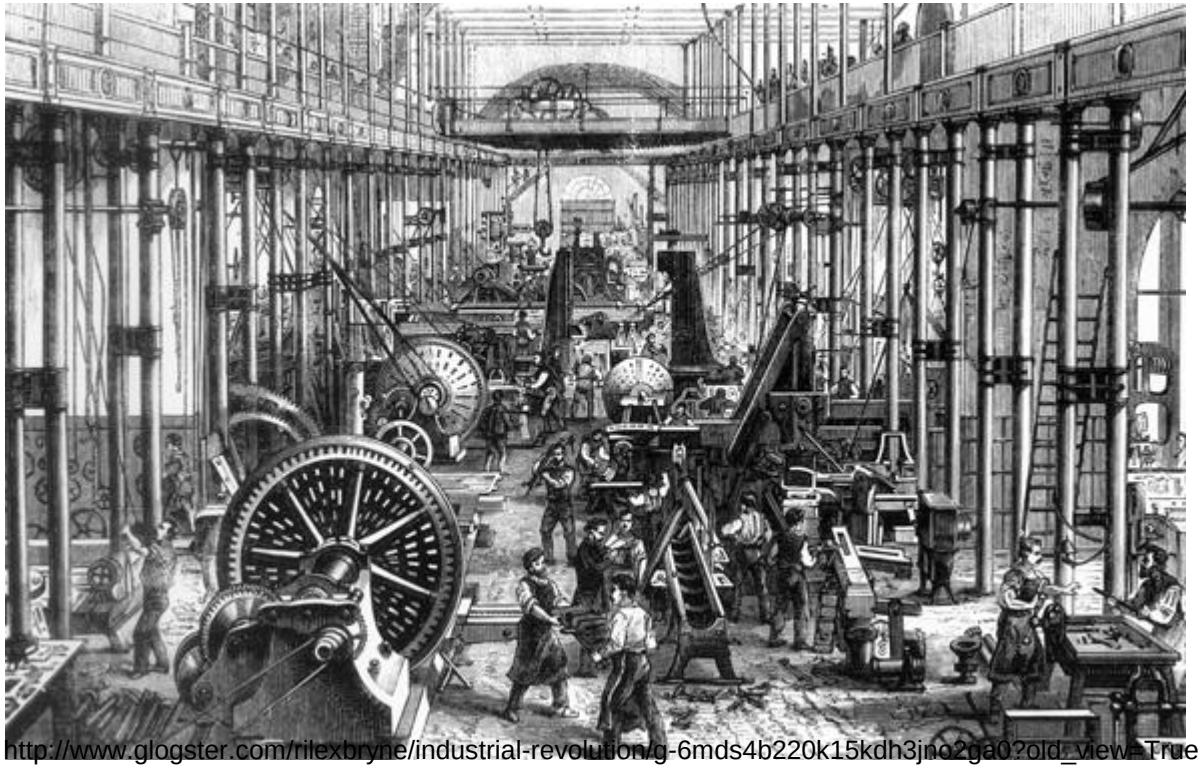
Johann Heinrich Lambert (1728-1777)

- Mathematician, physicist, astronomer, philosopher,
- distinguishing subjective from objective appearances
- Systems, system attributes – efficient, purpose, self-sustaining, etc.

SYSTEM THEORY DURING INDUSTRIAL REVOLUTION

Reductionism instead of holistic attitude

Development of economic theories,



http://www.glogster.com/rilexbryne/industrial-revolution/g-6mds4b220k15kdh3jno2ga0?old_view=True

SYSTEMS THEORY BACKGROUND – RECENT HISTORY

Beginning of 20th century

- Over-specialization of particular scientific subjects
- Lack of mutual correspondence and understanding among scientists not only of the distant, but even the neighbouring branches of science
- Rediscovering basically the same laws and knowledge in distinct branches of science

→ Systems Sciences formation using pieces of knowledge from the fields of biology, physics and social science

SYSTEMS THEORY BACKGROUND – RECENT HISTORY

1930s Ludwig von Bertalanffy publishes Organismic system theory

1955 William Ross Ashby publishes Introduction to Cybernetics

1968 Ludwig von Bertalanffy publishes General System theory: Foundations, Development, Applications

1960s Charles West Churchman incorporating ethical values into operating systems

1960s Hermann Haken – self-organization of non-equilibrium systems, development of synergetics

1970-1980s Second-order cybernetics developed by Heinz von Foerster, Gregory Bateson, Humberto Maturana and others

SYSTEMS THEORY BACKGROUND – RECENT HISTORY

1970s Catastrophe theory (René Thom, Erik Christopher Zeeman) Dynamical systems in mathematics.

1970s Russell Lincoln Ackoff – how systems thinking relates to human behaviour, „purposeful systems“

1977 Ilya Prigogine received the Nobel Prize for his works on self-organization, conciliating important systems theory concepts with system thermodynamics.

1980s Robert Rosen developing Complex Systems Biology

1980s Chaos theory David Ruelle, Edward Lorenz, Mitchell Feigenbaum, Steve Smale, James Alan Yorke

1980s Peter Checkland – Soft systems methodologies

1986 Context theory, Anthony Wilden

1990 Complex adaptive systems (CAS), John Henry Holland (professor of psychology, electrical engineering and computer science), Murray Gell-Mann (physicist. Nobel prize 1969 for theory of elementary particles), William Brian Arthur (economist)

Systems theory founders

SYSTEMS THEORY FOUNDERS

Ludwig von Bertalanffy (1901-1972)

- Austrian-born biologist
- Main founder of the general systems theory
- Already in the 1930's Bertalanffy formulated the **organismic system theory** (assigns to the biological systems a self-organizational dynamics)
- For this theory developed the kinetic theory of open systems
- Later it became the kernel of the GST General systems theory - methodology that is valid for all sciences
- 1940's he conducted his **theory of open systems** from a thermodynamical point
- worked on metabolism, growth, biophysics, and cancer cytology

SYSTEMS THEORY FOUNDERS

Ludwig von Bertalanffy (1901-1972) – continuation

- from the 1950's onwards he shifted his research from the biological sciences to the methodology of science, the General System Theory (*GST*) - new paradigm which should control the model construction in all the sciences
  - Describes its models in a qualitative and non-formalized language
  - Deduce universal principles which are valid for systems in general
  - System as set of interrelated components, a complex entity in space-time which shows structural similarities
  - System constitutes itself in such a way that the systemic particles maintain their structure by an assemblage process and tend to restore themselves after disturbances-analogous to the features of a living organism

SYSTEMS THEORY FOUNDERS

Ludwig von Bertalanffy (1901-1972) – continuation

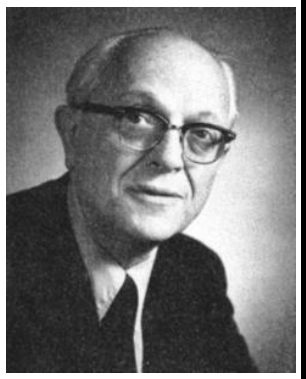
- Later his system theoretical approach focused on the modern world of technology
- emphasized in his later works the importance of the symbolic worlds of culture
- themes encompassed theoretical biology, experimental physiology, theoretical psychology, cancer research, and philosophy and history of science

SYSTEMS THEORY FOUNDERS

Ilya Prigogine (1917-2003)

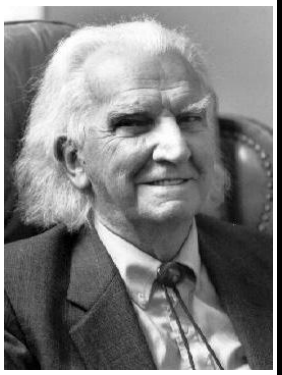
- awarded the Nobel Prize for Chemistry in 1977 for his contributions to non-equilibrium thermodynamics, particularly the theory of *dissipative structures*
- *dissipative structures* - systems existing and established only on the basis of a continuous dissipation of matter-energy
- provide a better understanding of the role of time in the Physical Sciences and in Biology
- understanding of irreversible processes, particularly in systems far from equilibrium

SYSTEM THEORY FOUNDERS



Anatol Rapoport (1901-2007)

- mathematical psychologist
- studies in conflict & cooperation, and peace research
- application of mathematical methods, first to biology and later to the social sciences



Kenneth Boulding (1910-1993)

- emphasized that human economic and other behaviour is embedded in a larger interconnected system
- emphasized research and development of scientific understanding of the ecodynamics of the general system to understand human behaviour and economics

SYSTEM THEORY FOUNDERS

Ralph Waldo Gerard (1900-1974)

- neurophysiologist and behavioral scientist
- work on the nervous system, nerve metabolism, psychopharmacology, and biological basis of schizophrenia
- referred to scientists as the brain of the social organism, depicting science as a kind of guidance system
- Obtained many honors, e.g. medal from Charles University in Prague, the Order of the White Lion (4th class) of Czechoslovakia in 1946

Systems engineering

Systems engineering definitions

SYSTEMS ENGINEERING ACCORDING HALL [1962]

Operates in the space **between research and business**, and assumes the attitudes of both.

considers the **needs of its customers** and determines how these can be best met

formulates the operational, performance and economic **objectives**, and the broad technical plan to be followed.

SYSTEMS ENGINEERING PROCESS ACCORDING HALL [1962]

Functions in five phases:

- system studies or program planning;
- exploratory planning, which includes problem definition, selecting objectives, systems synthesis, systems analysis, selecting the best system, and communicating the results;
- development planning, which repeats phase 2 in more detail;
- studies during development, which includes the development of parts of the system and the integration and testing of these parts;
- current engineering, which is what takes place while the system is operational and being refined.

SYSTEM ENGINEERING ACCORDING INCOSE (International Council on Systems Engineering)

interdisciplinary approach and means to enable the **realization** of successful systems.

focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:

- Operations
- Cost & Schedule
- Performance
- Training & Support
- Test
- Disposal
- Manufacturing

integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation.

considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

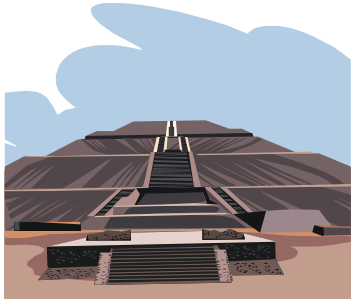
History of Systems engineering - projects

HISTORY OF SYSTEMS ENGINEERING

Traces of Systems engineering may be found in ancient era

Projects in ancient Egypt, Mezopotamia, Greece, Rome

- water distribution systems, irrigation systems
- pyramids
- roman road system



HISTORY OF SYSTEMS ENGINEERING

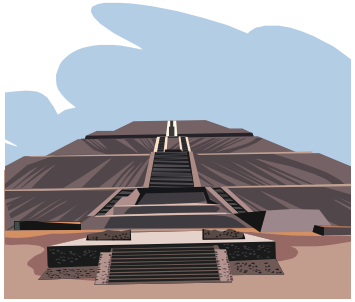
Pyramid building

Today‘s idea:

Tens of thousand craftsman (not slaves)

Foreigners

Worked for salaries



Moving stone blocks with weight of up to 70 tons, extreme accuracy in proportions

Method still unknown

Theory pyramids served as astronomic observatory

Number of wild theories, you can find the pi number, Eulers number, number of days, Earth radius, Earth-Sol distance, …

HISTORY OF SYSTEMS ENGINEERING

Roman Aquaducts

Status in the late 3rd century:

11 main aquaducts leading to Rome

Total lenght around 800 km, around 50 km od aquaducts (bridges)

Total supplay about 1 million cubic metres of water per day!

HISTORY OF SYSTEMS ENGINEERING

Roman road system

Build from 4th century BC

Around 80 000 km of hard surfaced roads

Irrigation systems in Mesopotamia

- Using flooding
- System of dikes, canals, dams,…
- Used for hundreds of years

RECENT HISTORY OF SYSTEMS ENGINEERING - PROJECTS

The concepts of systems engineering can be traced back within Bell Labs to early 1900s

The term systems engineering dates back to Bell Telephone Laboratories in the early 1940s [e.g. Hall, 1962].

British multi-disciplined team formed (1937) to analyze air defense system

The Department of Defense entered the world of systems engineering in the late 1940s with the initial development of missiles and missile-defense systems [Goode and Machol, 1957].

Systems engineering projects during World War II

Number of projects followed

HISTORY OF SYSTEMS ENGINEERING - PROJECTS

Bell Labs supported Nike development (1945-1953)
– Nike - line-of-sight anti-aircraft missile system


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

SAGE Air Defense system (SAGE - Semi Automatic Ground Environment (SAGE) air-defense system) defined and managed by MIT (1951 – 1980)

ATLAS Intercontinental Ballistic Missile Program managed by systems contractor Ramo-Wooldridge Corporation (1954 – 1964)

RECENT HISTORY OF SYSTEMS ENGINEERING - PROJECTS

http://www.nasa.gov/

the Apollo project (1961-1972)

- Complex engineering systems
- Technical and social processes
- Incorporating various elements:
  - launch vehicles, various upper stage modules to accomplish lunar orbit rendezvous, descent and return from the lunar surface, earth return, reentry, and recovery, mission and support crews, missile assembly and checkout equipment, crew training and many support organizations and their facilities, such as downrange tracking and communications relay stations, mission control
- Total costs as reported in 1973 app. 25 billions USD

RECENT HISTORY OF SYSTEMS ENGINEERING - FORMALIZING

The success of those millitary systems development programs proved the value of systems engineering

The United States government formalized systems engineering and documented it for use it in weapon systems development

The most notable document

- **U.S. Department of Defense's MIL-STD-499** (released in 1969)

Since 1970s boom of systems engineering applications

RECENT HISTORY OF SYSTEMS ENGINEERING - FORMALIZING

Other systems engineering standards and recommendations followed:

- European Cooperation for space standardization, ECSS-E-10A (April 1996) system Engineering
- Electronics Industry Association, EIA-632 (December 1998), Processes for Engineering a system
- IEEE std 1220-1998, standard for Application and Management of the systems engineering Process
- Information Technology Association of America EIA-731-1, systems engineering Capability Model (August 2002)

RECENT HISTORY OF SYSTEMS ENGINEERING – THEORETICAL ISSUES

First attempt to teach systems engineering as we know it today came in 1950 at MIT by Mr. Gilman, Director of Systems Engineering at Bell (according Hall [1962]).

The RAND Corporation (founded in 1946 by the United States Air Force) created *systems analysis*, important part of systems engineering.

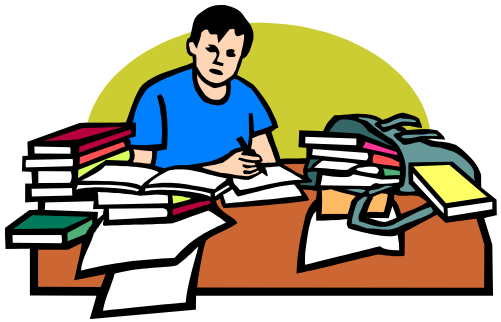
Allocation of the systems functions to the physical elements of the system addressed in the late 1940s and early 1950s [Fitts, 1951].

SYSTEMS ENGINEERING EDUCATION

Today there are many speciliazed study programs, courses, training for Systems Engineering, both at universities and private companies, presenting different attitudes to Systems Engineering.

E.g.

- Information systems enginering
- Process systems engineering
- Industrial systems engineering
- Space systems engineering
- Computer systems engineering
- Etc.



International organizations in the systems theory field

SYSTEMS THEORY BACKGROUND – SUPPORTING ORGANIZATIONS

In 1954 Society for the Advancement of General Systems Theory founded (in 1956 renamed to **Society for General Systems Research**) by the founders of systems theory

- biologist Ludwig von Bertalanffy
- the economist Kenneth Boulding
- the neuroscientist Ralph Gerard
- mathematician Anatol Rapoport

In 1988 it was renamed to "**International Society for the Systems Sciences**" (ISSS) in 1988 to "reflect its broadening scope“

INTERNATIONAL SOCIETY FOR THE SYSTEMS SCIENCES

Among the first and oldest organizations devoted to interdisciplinary inquiry into the nature of complex systems

Most broadly inclusive

The initial purpose of the society was "to encourage the development of theoretical systems which are applicable to more than one of the traditional departments of knowledge"

INTERNATIONAL SOCIETY FOR THE SYSTEMS SCIENCES - TODAY

Principal aims:

- to investigate the isomorphy of concepts, laws, and models in various fields, and to help in useful transfers from one field to another;
- to encourage the development of adequate theoretical models in areas which lack them;
- to eliminate the duplication of theoretical efforts in different fields; and
- to promote the unity of science through improving the communication among specialists.

ISSS has expanded its scope beyond purely theoretical and technical considerations to include the practical application of systems methodologies to problem solving.

INTERNATIONAL SOCIETY FOR THE SYSTEMS SCIENCES - TODAY

Provides forum where scholars and practitioners from across the disciplinary spectrum, representing academic, business, government, and non-profit communities, can come together to share ideas and learn from one another.

Long history of annual meetings

TOPICS OF SEVERAL LAST CONFERENCES

2019 Topic: Nature's Enduring Patterns: A Path to Systems Literacy

2018 Topic: Innovation and Optimization in Nature and Design

2017 Topic: From Science to Systemic Solutions – Systems Thinking for Everyone

2016: Topic: Leadership for Sustainability of Socio-Ecological Systems

2015: Topic: Governing the Anthropocene: the greatest challenge for systems thinking in practice?

2013: Topic: Curating the Conditions for a Thrivable Planet: Systemic Leverage Points for Emerging a Global Eco-Civilization

2012: Topic: Service Systems, Natural Systems

2011: Topic: All together now – working across disciplines: People, principles and practice

ISSS TODAY - SPECIAL INTEGRATION GROUPS

SIGs:

- Agent-based Social Simulation
- Balancing Individualism and Collectivism
- Critical Systems Theory & Practice
- Designing Educational Systems
- Evolutionary Development
- Health and Systems Thinking
- Hierarchy
- Human Systems Inquiry
- Information Systems Design & Information Technology
- ISSS Roundtable
- Living Systems Science
- Organisational Transformation & Social Change
- Research Towards General Theories of Systems
- Socio-Ecological Systems

ISSS TODAY - SPECIAL INTEGRATION GROUPS

SIGs:

- Spirituality and Systems
- Students SIG
- Systemic Approaches to Conflict and Crises
- Systemic Approaches to Persistent Poverty and Disadvantage
- Systems Applications in Business & Industry
- Systems Biology and Evolution
- Systems and Mental
- Systems Modeling & Simulation
- Systems Pathology
- Relational Science
- Service Systems Science
- Systems Engineering
- Foundations of Information Systems
- Monetary Systems

ORGANIZATIONS IN SYSTEMS ENGINEERING

International Council on Systems Engineering (INCOSE)

Founded in 1990 as the National Concil on Systems Engineering (NCOSE), renamed to International in 1995

- not-for-profit membership organization founded to develop and disseminate the interdisciplinary principles and practices that enable the realization of successful systems
- **Mission -** Share, promote and advance the best of systems engineering from across the globe for the benefit of humanity and the planet.
- **Vision -** The world's authority on Systems Engineering.

ORGANIZATIONS IN SYSTEMS ENGINEERING

INCOSE Goals

- To provide a focal point for dissemination of systems engineering knowledge.
- To promote international collaboration in systems engineering practice, education, and research.
- To assure the establishment of competitive, scaleable professional standards in the practice of systems engineering.
- To improve the professional status of all persons engaged in the practice of systems engineering.
- To encourage governmental and industrial support for research and educational programs that will improve the systems engineering process and its practice

Thank you for your attention

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