LECTURE

1

Systems engineering

Organization of the course, background knowledge – Systems analysis introduction

Ing. Zuzana Bělinová, Ph.D.

LECTURE 1 - OVERVIEW

Organizational Issues

Background knowledge - Systems analysis introduction

SCHEDULE

Lecturer: Ing. Zuzana Bělinová, Ph.D.

- Email contact: belinova@k620.fd.cvut.cz
- Consultation upon request

Time schedule:

Lectures even Tuesdays, 15.00-18.15, K404

Trainings even Tuesdays, 18.30-20.00, K404

Due to the individual character of lectures in 2019/2020 exact schedule may slightly differ.

BASIC INFORMATION

Web pages of the course

- its.fd.cvut.cz →Courses→Systems engineering
- Slides from presentation will be placed there

Study materials

- Slides from the presentations
- Indicated papers for reading

Motto of the course

- “Thinking is more important than learning by heart“

ASSESSMENT

Work during the semester

- For the trainings preparation of asigned tasks
  typically review of assigned paper on particular topic or author
- Presentation of the review in the trainings
- Reading of a chosen article, discussion during trainings

Project – will be specified

- Describe the system you are working on in your master‘s thesis following the rules of Systems engineering, systems analysis
- The work must follow the basic formal requirements (references, chapters, abstract, etc.)
- It is recommended to use your knowledge of system design from the Telematic systems and their design course

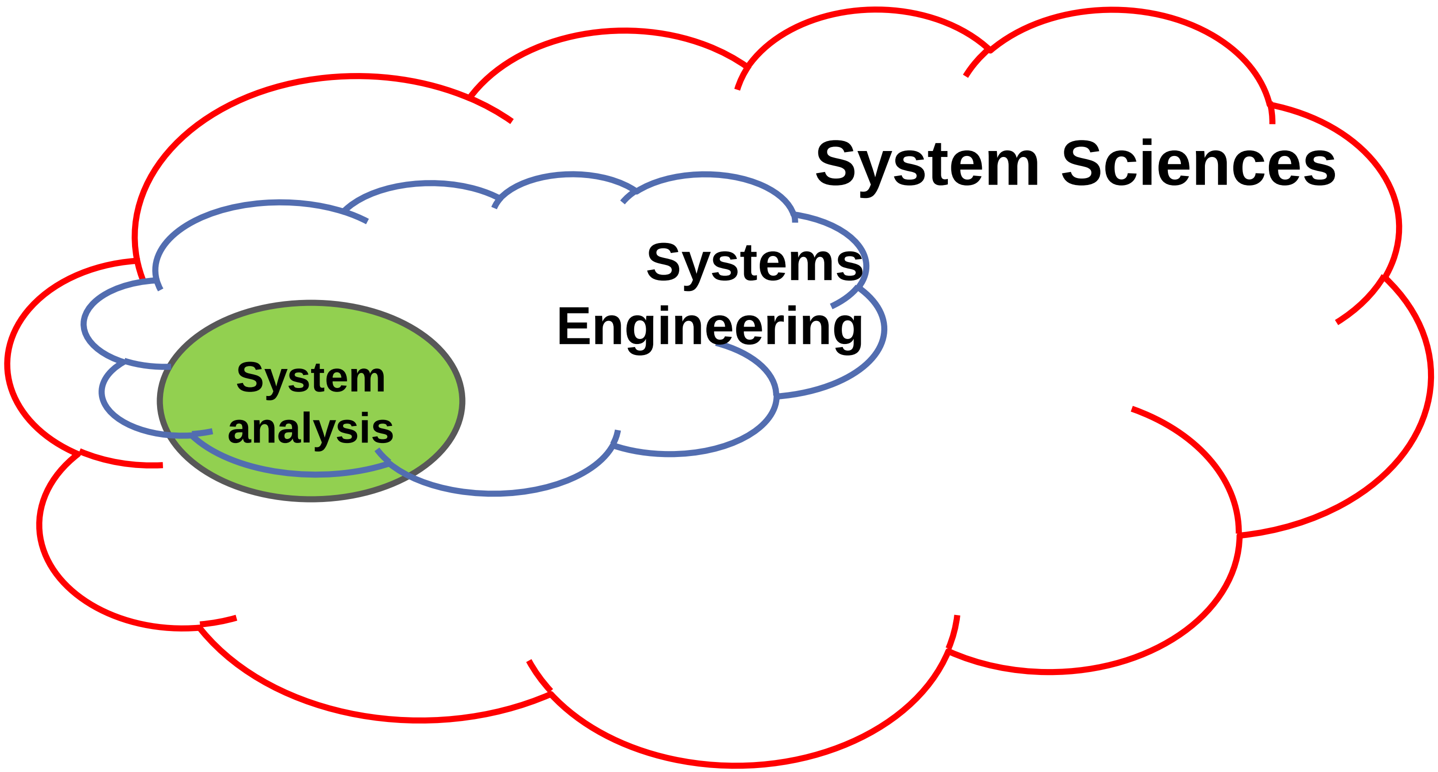
RECOMMENDATIONS FOR THE RESEARCH WORK DURING THE SEMESTER

Use databases accessible from the university

- http://knihovna.cvut.cz/home/ → EIR Gateway → e.g. 360Search
  - Wiley online library
  - E.g. IEEE Xplore
  - The ACM Digital library
  - and many others....

SYSTEMS SCIENCES

SYSTEMS SCIENCES



SYSTEMS ANALYSIS

Background for all tasks related to systems

- Part of Systems Sciences

- Part of Systems engineering

- It is necessary to know, what you are working with

SYSTEMS ANALYSIS

System science

Origin - the second quarter of 20. century

- Reasons:
    - Over-specialization
    - Lack of mutual correspondence and understanding
    - Rediscovering basically the same

HOLISTIC APPROACH

- Before – (e.g. 19th century – reductionism)

SYSTEMS ANALYSIS

Serves for identification and description of real world objects using tools and methods applicable in different areas to be able to work with them in the form of a model. This description is further used for. e. g. control, evaluation, etc. to be able to improve the performance, …

IS SYSTEMS ANALYSIS A SCIENCE?

Systems Sciences have their unique

- Subjects of study
- Data and knowledge
- Meta-level

→ fulfill all the requirements of the full-fledged Science

Fulfill requirements relating to:

- Practical purposes
- Measurability
- Ability to be algorithmized
- Ability to be standardized
- Ability to be proved by evidence
- Efficiency

→ they have also all the characteristics of the engineering branches of science

SYSTEMS SCIENCES EVOLUTION

Catalyzed by the significant advances in

Systems Thinking

Mathematics

Computer Science

SYSTEMS ANALYSIS - HISTORY

SystemsThinking could be documented since ancient era

Aristotle: **„The whole is more then a set of parts“**

Today‘s attitude – since 20th century

SYSTEMS ANALYSIS SUITABLE TASKS

organized complexity

heterogeneity

Openness

e.g. transport and telecommunication

Usage for different system types –from mathematical, technical up to sociological, biological,…

APPROACHES

Inductive Approach - **General Theory of Systems (GTS)**

Deductive Approach - **Mathematic Theory of Systems (MTS)**

WHAT IS A SYSTEM?

The role of a subject (investigator) is a key one

Gaines ´s definition: **“System is any entity an investigator recognizes as the System“.**
(a bit provoking manner)

Basic understanding
Set of things and their mutual relations

- not sufficient – missing behaviour, external evaluation, etc.

WHAT IS A SYSTEM?

Besides elements and their relations we need to know what the systém

- Is doing
- For whom,
- …

→ Behavior, external viewpoint (identity),…

IDENTIFICATION OF A SYSTEM ON AN OBJECT – STARTING POINTS I.

- There exists **subject** (observer)
- There exists something of his interest – **object**
- On the object the subject recognizes **variables**
- Independet variables – so call **base (**Subject – Object / variables /base (specific role of time) → **Source System)**
- Separation of variables on input and output ones – specification of neighborhood – placement of subject (as a rule to the neighborhood) → **Ordered / Neutral System** Evaluation of variables (continuous / crisp / fuzzy...

IDENTIFICATION OF A SYSTEM ON AN OBJECT – STARTING POINTS II.

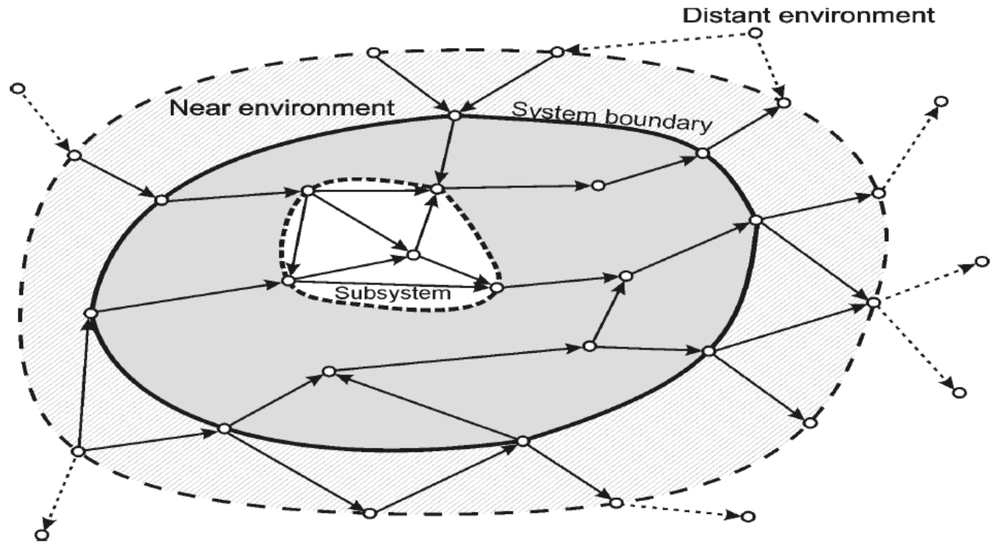
- Finding specific relations within the system which are **invariant against transforms of base**
- **Finding rules – Generative System**
- Subject eaims to describe the behaviour (processes)
- Finding the structure

LEVELS OF DISTINGUISH

Important input

Means level of detail

Can be done before the identification, during it, or iterative



SENTENCES

Knowledge of the behaviour is not sufficient for finding the system structure

- E.g. $y = 1$; $y = x / x$, (for $x \neq 0$).

Structure, state of the system and state of the neighbourhood define the behaviour

DEFINITIONS – SYSTEM'S ELEMENT

Elements of the System can be expressed as **Finite deterministic Automata**:

$A = (X, Z, Z0, Y, \alpha, \beta)$

- X,Z,Y are finite non-empty sets of inputs, internal states and outputs respectively; Z0 (subset of Z) is the initial state of automaton
- $\alpha := Z \times X \rightarrow Z$ transmission function
- $\beta := Z \times X \rightarrow Y$ output function

Both (mapping) functions (α, β) generate the dynamics of element / automaton

DEFINITIONS

Element state – inputs, outputs, internal states, states of elements functions

Transition – change of state (value or function of the system)

System state: „picture“ of the object in base variables

- L – set of system variables
- V – set of their values
- State space S=LxV

Event - change of state or time step
The change of the state of element ai can initiate the transition of (at least one) successive element aj

- An event occurred OUTi,t → INj,t or t → t + 1;

DEFINITIONS

Process - chain of events

- Serial (a single succession of events)
- Parallel (two or more events take part in the same step of time)
- Mixed
- Alternative (an event uj is followed either by the event uk_a, or the event uk_b. The choice of the alternative is a result of certain condition testing

DEFINITIONS

Magnitude M – set of all possible processes

Behavior of the System – set of processes activated for inputs in a specified time interval and in a given state of the neighborhood (Set of Trajectories in State Space)

Important subsets of behaviour:

- γ - **goal oriented** (goal seeking) behaviour
- δ - **species** / type focused **behavior** (**genetic code**)

Identity – relation with the Neighbourhood

DEFINITIONS

Structure is the set of elements and doubles of elements from the same set,

- St = (A, (ai, aj)); i ,j = 1,2,......n; A∈(a1, a2,…ai…aj…an); while doubles of elements express the existence of relations

Causality: State of the System is independent on the future states

Note: Relations are not holders of function! Elements carry the Functions. Relations, i.e. connections are specified by the set of parameters and by the set of domains of these parameters respectively

FORMAL SYSTEM NOTATION

System $\rightarrow$ evaluated structure

S = (A/F, R/P); where

- A is a set of elements / automata A = (ak); k = 1.......n;
- F is a set of functions α, β of elements; F = (αk, βk) defines the ability of system
- R/P is a set of relations among elements Y$\rightarrow$ X and their parameters

EXTENDED INDUCTIVE DEFINITION OF SYSTEM

$$S = (A/F, R/P, M, \gamma, \delta, I)$$

EXTENDED INDUCTIVE DEFINITION OF SYSTEM

S = (A/F, R/P, M,γ, δ, I)

- A/F is a set of elements and their functions
- R/P is a set of relations and their parameters
- M – magnitude = all processes
- γ – goal behaviour,
- δ – typical behaviour (genetic) code
- I – identity (how the system expresses itself towards the neighbourhood)

IDENTIFICATION OF STRUCTURED SYSTEM

1. Choice of the level of distinguish
2. Choice / generation of the elements
3. Allocation of the functions to the elements, parameters of the elements
4. Definition of joined doubles of elements, chaining, introduction of the Structure, Metrics, parameters of the relations
5. Identification of the conditions for activation of processes
6. Identifications of processes, finding alternate processes
7. Stating the rules for identification of strong functions / processes and compactness, genetic code
8. Identification of the system‘s identity

INTRODUCTION OF METRICS

The distance (d) has to fulfil these conditions:

- $d(ai, aj) = 0 \Leftrightarrow i = j$
- $d(ai, aj) = d(aj, ai)$ symmetry
- $d(ai, ak) \leq d(ai, aj) + d(aj, ak)$ „triangle inequality”
    - (i, j, k are natural numbers).

The distance of Systems Elements has to be defined for all identified parameters of respective Systems relations.

TYPES OF BEHAVIOUR

Equilibrium

- With Attractor

Stable

Divergent – regenerative / degenerative…

Goal oriented – with attractor / homeostasis…

Response to the inputs / activated from interior…

Species oriented (With genetic code) – ideal / standard / adaptive / mutation - failure / catastrophe / self-correction / self-learning

NEIGHBOURHOOD

Near

Far

MODEL

Based on object – original

Model – another object, of different nature, charactristics similar to the original

Homomorphism

- reflexive (xRx)
- transitive ($xRy \cap yRz \Rightarrow xRz$)

Isomorphism

- *Also symetrical ($xRy \Leftrightarrow yRx$)*

Model is simplification of the object (original)

MEANS OF SIMPLIFICATION

Elimination of variables

States aggregation

Division to parts

WAYS HOW TO RECORD A SYSTEM

Natural language

Tables (of elements, relations, architecture, etc.)

Figures and schemata (including time diagrams, flowcharts, etc.)

Logical schemata

Mathematical methods of description (graphs, functions, matrixes, equations, etc.)

Use of analogon (similar, equivalent system)

TYPICAL TABLES TO DESCRIBE A SYSTEM

- Table of elements, e.g.

Name	Complexity	Previous element	Following element	Required parameter	Offered parameter	Timing	Function	Other

- **Complexity of elements based on the input and output relations**
  - **Non-agressive (IN>>OUT)**
  - **Important, complex (IN≈OUT, high amount)**
  - **Simple (IN≈OUT, low amount)**
  - **Controlling, agressive (IN<<OUT)**

TYPICAL TABLES TO DESCRIBE A SYSTEM

- Table of relations, e.g.

Parameter	From element	To element	Timing	Carrier	Frequency	Format	Other

- Table of architecture

Subsystem	Contains elements	Superior systém (or systems works with…)	Subordinated systems	Capacity	Other

RECORDING STRUCTURE OF A SYSTEM

Adjacency matrix

	A	B	C	D
A	0	0	0	0
B	1	0	0	0
C	1	0	0	0
D	0	1	1	0

- Square matrix
- Elements in rows and also in columns
- Values – 1 – there exist the relation
  0 – there is no relation

HOW TO CHOOSE THE WAY OF SYSTEM RECORDING

According the object

According the subject

According the customer

SYSTEM ANALYSIS METHODS

Method from other science branches

- E.g. From operational research, graph theory, mathematics, linear programming, …

Authentic methods

- Soft systems
- Computer experimenting
- General attitude

Combination of methods

TYPICAL SYSTEMS ANALYSIS TASKS

Based on level of distinguish

- In the system – partial characteristics, not subject of systems analysis
- On the system – as a whole, typical system analysis task
- About the system – as part of higher system

BLACKBOX

System with known imputs and outputs

Unknown structure

CLASSES OF SYSTEMS ANALYSIS TASKS

Establishment of system‘s coherence

- Ensuring cooperation
- Solving conflicts – regularization
- System‘s evolvement or degeneration

Path problems

- Finding shortest path, trajectory of certain length, system’s magnitude (as set of all paths),
- Finding antecedent and precedent (subsequent) elements in system,

Capacity tasks

Structural tasks

- System’s decomposition and integration
- Feedbacks and their identification

CLASSES OF SYSTEMS ANALYSIS TASKS

System‘s goal

- Sources of goals
- Optimization of goals

System‘s behaviour

- Efficiency of system
- Alternative behaviour
- Typical behaviour

Tasks on identity

Other tasks – e.g. on contamination and imunity, ethics, …

ENSURING SYSTEMS EXISTENCE

Generalized Kirchhoff laws:

- Σ∀i (INi+OUTi) = 0
  - *Nothing neither disappears nor emerges per se in any Systems element or subsystems (with input IN and output OUT).*
- Σ for every closed path inside the System (INi - OUTj) = 0
  - *Nothing can be gained or lost moving on circular path inside the System.*

REGULARITY OF INTERFACES

REGULARITY OF INTERFACES – IMPORTANCE OF THE TOPIC

Mars Climate Orbiter

- Program Mars Surveyor 98 Orbiter
- Second probe Mars Polar Lander
- Mission goal – observing Martian climate
    - Observe the Martian climate from a 400 km near circular, near polar mapping orbit
    - Examine general atmospheric circulation patterns and how they affect atmospheric transport and climate change.
    - Derive information about atmospheric winds from global temperature observations.
    - Observe atmospheric dust to better understand the seasonal dust cycle, including initiation, spreading, and dissipation of global-scale dust storms.
    - Examine features on the Martian surface that can provide information about climatic evolution
- Value 125 mil. USD

REGULARITY OF INTERFACES – IMPORTANCE OF THE TOPIC

Mars Climate Orbiter

- Launched 11 December 1998 from the Eastern Test Range cosmodrome
- More than 9 months of journey to the Mars planet
- 23.9.1999 entering planet orbit
- Engine burst for reaching the planned altitude
- At that time probe hidden behind the planet
- It never appeared again

- English control center – using data on engine power in pounds
- Probed designed for data in newtons
- result – altitude 57 kilometers above surface (instead of 150 km – burning in the dense planet atmosphere)

REGULARITY OF INTERFACES – IMPORTANCE OF THE TOPIC

Vraňany accident - 19.3.2007

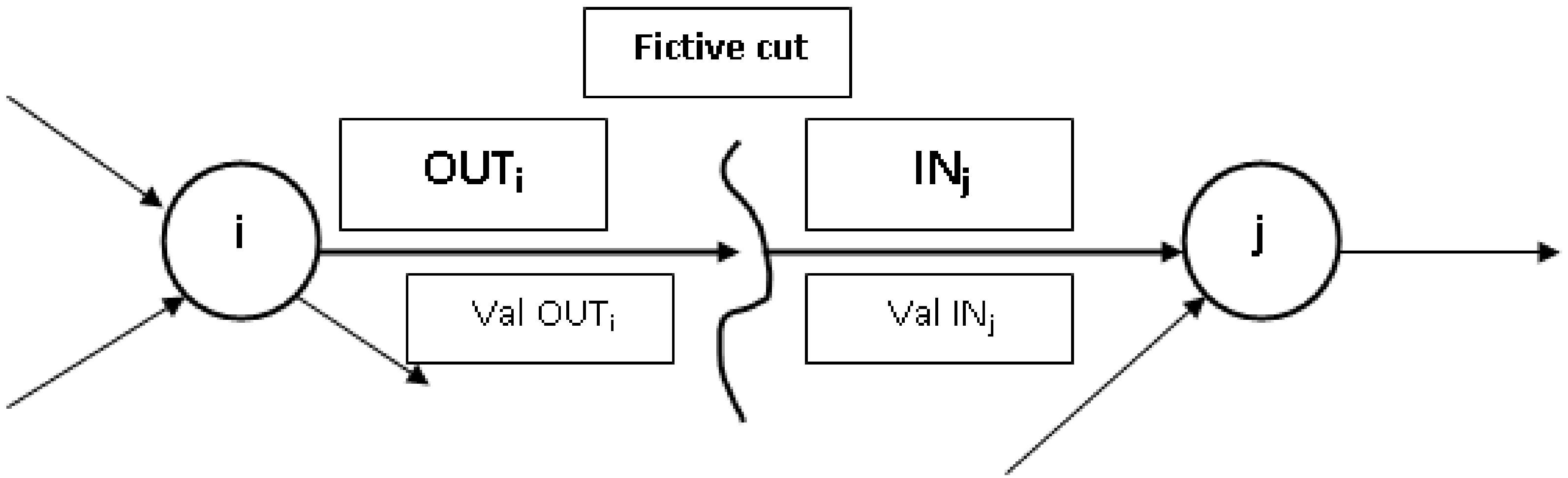
Source:Záznam telefonátů rozkrývá, proč musel vlak vykolejit . iDNES.cz. 5.4.2007. dostupné online: http://zpravy.idnes.cz/zaznam-telefonatu-rozkryva-proc-musel-vlak-vykolejit-p1c-/krimi.aspx?c=A070405_120207_krimi_cen (10.10.2015)

- Car on the crossing
- Misunderstanding in communication
- Engine and 3 carriages derailed
- Damage dosens of millions CZK

INTERFACE

Fictive cut among two parts of the system

Defined by set of parameters and their values on output and consequent input



REGULARITY

Regularity of system interface is condition for system existence (in longer term)

For keeping regularity there is need for:

- The same parameters in the interface
- Corresponding parameters‘ values

  {val pkO} ≈ {val pkI}

  ≈ stands for <=, >= or = depending on the meaning

EXAMPLES

Great Britain
240 V, 50 Hz

Czech republic
230 V, 50 Hz

ENSURING REGULARITY

Procedure:

- Finding out irregular relations on interfaces
- Regularization of these relations
- Projections of implemented actions into the coherence requirements (new control of system‘s regularity)

PROCEDURE

Finding of relations in the adjacency matrix

- Adjacency matrix
  - Standard two dimensional square matrix
  - Dimension n equal to the number of elements in the system
  - Displays the existence of relation between particular elements (0 – no relation, 1 – existing relation)

Creation of input (I) and output (O) matrix containing parameters and their values for particular relations

Comparing O and I

Result in regularity matrix or table

Regularizing the interface

Re-checking the regularity

HOW TO REGULARIZE THE INTERFACE

1. Changing function of the input or output element of the irregular relation (in this case there is big risk or irregularity spreading
2. Inserting conversion element (usually expensive solution)
3. Using substitutability of parameters (e.g. one currency)
4. Finding such elements in the system that can either supply the missing demand or consume surpluses
5. Reconstruction of the whole system

Thank you for your attention