Syllabus

Applied System Analysis

(5 ECTS)

Программа учебной дисциплины «Прикладной системный анализ» *(на английском языке)*

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Meeting Minute # _____ dated _____ 2019

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Number of credits (ECTS)	5
Classroom work (h.)	64
Self-study (h.)	126
Year	1
Format of study	without using the online course(s)

1 Course Description

a) Pre-requisites

It is presupposed that all students enrolled on the course completed corresponding *full-time Bachelor degree training programs* and were selected (based on either portfolio tenders, or other core performance indices) to continue their MS studies in the educational program "System and Software Engineering" (SSE). Therefore, no other special requirements, apart from those that are mentioned above, are put forth.

b) Abstract

The course "Applied System Analysis" is offered to students of the Master Program "System and Software Engineering" (area code 09.04.04) in the School of Software Engineering, Faculty of Computer Science (FCS) of the National Research University Higher School of Economics (HSE). The course is a part of MS curriculum pool of compulsory courses (1st year, Base Clause – *General Scientific disciplines* of the academic year's curriculum, M.1 – *General Courses of Specialization*), and it is a four-module course (semester A quartile 1 thru semester B quartile 4).

2 General Information about the Course and Learning Objectives

The first mention of the term *"system analysis"* (SA) in the literature is often referred to the works of RAND corporation in the 40s of the last century and the development of new complex objects of the military purpose. At present, system analysis can be considered as a set of approaches, methods and techniques aimed at understanding peculiarities of the problem situation faced by its owner(s), and the development of improving interventions into the problem (its control) based on the options (alternatives) produced.

As a rule, the causes of the problem are subjective, and they are related to one person or group of persons, his/her (their) perception of reality, his/her (their) dissatisfaction with the observed state of affairs. Therefore, *Applied System Analysis* (ASA), i.e. the application of SA as universal approach to solving problems in different fields of human activity (engineering, management, economics, to name a few), is based on the concepts of the **problem** as a result of human's perception of reality; **system** and **model** that express the understanding and representation of the reality, creation of a "collective" image of the problematic situation of all parties involved;

alternatives of behavior (improving intervention in the situation or solving the problem depending on the goals) and **monitoring** (changes occurring as a consequence of the solution being implemented). Classification of problems as *well-defined* (not so often arising in practice), *weakly defined* and *ill-defined* ones (more realistic and often occurring) requires the use of different models (approaches) in a each particular situation. This fact has led to the formation of so-called *"hard"* and *"soft"* system methodologies based on formal and informal approaches within the framework of system analysis, respectively. All this leads to the realization of the "uniqueness" of the representation (modeling) approach used in ASA based on the fusion of science, intuition, sociability (discussion of different aspects of the problem with people involved in one way or another, i.e. stakeholders) and creativity.

The main objective of the course "Applied System Analysis" is to present, examine and discuss with students fundamentals and principles of both *System Analysis* and *Systems Thinking* that emerged in response to (1) steadily growing complexity of problems arising in various areas of day-to-day and professional human activity, (2) necessity to structure problems and to present (viz. to develop mental or formal model(s)) and to assess emerged situations complemented with a search for acceptable solutions (problem solving). In particular, the vast field of software engineering (SE) is concerned with such problems and their solutions that cannot always be fully understood and explained clearly, but nevertheless we can claim that software engineers deal with systems, real physical products. There is no common comprehension and general approach to present SA and its practical applicability from interdisciplinary viewpoint within the scope of university courses, text-books (or, manuals). As an integrate, the learning objectives of the course can be thought as a combination of the following constituents:

- discussion and comprehension of historical and methodological preconditions for the rise of system analysis (milestones of the 20th century),
- understanding of the notion of system and origin of system properties, classification of systems, structural aspects of systems, systems complexity, general-system regularities as well as the framework of system analysis as the most significant area of applied system studies, specificity of applied systems analysis and systems thinking,
- discussion of stages of system analysis, understanding of the role of models (modeling) in SA, selected "hard" and "soft" system approaches (e.g. optimization problems, systems thinking, systems thinking tools and problem solving (views and opinions of D.Meadows, P.Senge, J.O'Connor, I.McDermott, J.Gharajedaghi, A.Rutherford, R.Arnold, et al.), mental models and hypotheses in problem solving, use of heuristic methods in problem solving (viz. informal analysis),
- understanding of the difficulties with goal-setting, importance of goals analysis, classification of stakeholders (PI-matrix), proper accounting of stakeholder interests, understanding the importance of working closely with stakeholders,
- discussion of Q-analysis (structural analysis of systems), decision-making approaches, multi-criteria decision analysis (MCDA) methods – AHP, TOPSIS, et al., decision-making under uncertainty (fuzzy case), types of uncertainty, fuzzy versions of MCDA methods.

Seminar examples (case studies) stipulate thinking over certain problem's points, substantiation (defense) of answers (theoretical schemes), discussion of ASA techniques covering both "hard" and "soft" approaches.

3 Learning Outcomes

While mastering the course material, the student will

- understand historical and methodological preconditions for the rise of SA, peculiarities of both general system theory and cybernetics as applied disciplines related to general description of organization and control within systems,

- know what system, systems thinking, systems engineering are (definitions and views), what systems properties are, structure (framework) of system analysis as the area of applied systems studies, specificities of applied system analysis, system-wide regularities and technologies of ASA,
- understand stages of system analysis, the role of models (modeling) in SA, types (representation forms) of models, so-called «hard» и «soft» system methodologies (different cases are considered); perceive modeling objectives and its base role in studies and research, main aims of system analysis as a methodology of problem solving (step-by-step process that relates to establishing priorities of problem's constituents); assimilate system approach as a methodological base, in particular, for software design process, think in «big picture» terms while analyzing the problem,
- see both patterns and trends in a problem; gain insights about our role in problems we experience; discover (systemic) structure behind a pattern of behavior; defend their own elaborated approaches and ideas while working on problem's solution individually and/or in small groups (collaborative efforts),
- acquire skills of analyzing and solving weakly structured/unstructured problems, using heuristic methods of problem solving, decision-making approaches, decision-making under uncertainty (fuzzy case), multi-criteria decision analysis (MCDA) methods; gain experience in reading, understanding and presenting in their own words (ad-lib report in a condensed form, viz. summary) the main point(s) of selected research papers.

In short, the course contributes to the development of the following professional competencies related to (1) thinking and research activities, (2) project activities, and (3) technical activities.

4 Course Plan (Main Topics / Sections)

NOTE: Seminars are organized in groups. The discussion of lecture material and seminar topics can be arranged in more *flexible manner* allowing to alternate lectures and seminars as necessary.

Section_A. Introduction and overview of the course (in particular, comments and necessary explanations concerning grading policy applied). Origins of systems analysis (SA). Notions of system, systems thinking and systems engineering (definitions and comments). Problem and system – is there any relationship between them? Classification of systems, SPE-pyramid (grasping system's structure), causal schemes (CLD) – what can we "see" in them? Examples,

Section_B. Organizations and system approach. Systems and complexity. Stages of system analysis, the role of models (modeling) in SA. Models of systems. Hard and soft methodologies in the analysis of systems (discussed throughout the course; examples and comments). Main aims of SA as a methodology of problem solving, thinking in «big picture» terms while analyzing the problem, systems thinking and problem solving,

Section_C. Mental models, cognitive maps. Mental models and hypotheses in problem solving, use of heuristic methods in problem solving (viz. informal analysis); who are the stakeholders? Stakeholder analysis,

Section_D. Use of structural analysis in systems studying (on the example of Q-analysis – structural vector, structural complexity, simplex and complex, eccentricities of simplices); system analysis tools,

Section_E. Problem situation. Operations research, optimization problems (as examples of hard models in SA). Next Release Problem (NRP)/ILP problem,

Section_F. Work with experts, Delphi method. Multi-criteria decision analysis (MCDA). AHP, TOPSIS, et al. methods and their discussion. Decision-making under uncertainty (fuzzy case), types of uncertainty, fuzzy versions of MCDA methods; examples and discussion,

Section_G. System Analysis (SA) of goals. Discussion: What system analysis (SA) really is?

Selected Topics (*subject for changes*) to discuss at Seminars (in no particular order):

- Defining characteristics of systems. Events, Patterns, Structure. Problem analysis and structure

- Software engineering – is it really engineering field? Discussion of selected papers
- Typical question: 'We observe a problem, not system' – Is it the case? Representation of systems
- System thinking, principles of systems thinking[1] («big» picture), measurable and non-metering (non-measurable) data, rich picture presentation, causal loop diagrams. Comments related to causal loop diagram (CLD). Understanding of feedback (connections between system's components). Feedback loops; hidden troublemakers. Building CLD, discussion of approaches. Multiloop diagrams. Relationships between variables ('s' and 'o' notations). Distinguishing reinforcing and balancing processes
- Connections and interdependencies among components of a problem, intangible aspects of a problem, widening view of a problem; uncovering systemic structures: formulating the problem, identifying key variables in the situation (problem)/main actors, identification of main problem in complex situation, graph the behavior of key variables over time (BOT graph)
- System analysis and design. Are they really needed, or we can do without them?
- Discussion of the paper "Teaching systems analysis to software engineering students: experience with a structured methodology"
- Systems thinking and problem solving, models in problem solving, heuristic approaches in problem solving. Case study
- Archetypes in CLD. Information links and rate-to-level links in CLD (difference). Formal approaches in CLD analysis. Are there are applicable here or it all comes down to applying qualitative approaches? CLD and cognitive (mental) maps. Case study
- Stakeholder analysis – simple matrix-based models. What are they giving us?
- Topological features of CLD (qualitative assessment of strengths/works of B.Kosko and C.Eden)
- Case study (works of C.Eden). Pattern of behavior (structure behind a pattern of behavior)
- Q-analysis procedure. Formal description of system's structure. Local and global characteristics of connectivity. Simplices and simplicial complex, structural vector of simplicial complex, eccentricities. Discussion of selected papers (R.Atkin/J.Casti)
- 'Hard' and 'soft' methods in system analysis. Optimization tasks (e.g. Next Release Problem (NRP)). Multi-criteria decision-making (e.g. Yager's approach). Discussion of examples
- AHP method, its use in IT/CE and SE fields (following publications by T.L.Saaty and others), TOPSIS approach (examples), other MCDM models, decision-making under uncertainty (fuzzy case), fuzzy AHP (other methods can be considered either). What is the real need to fuzzify AHP (and other) method(s)? Representation of expert assessment. Case study.

5 Reading List

(IMPORTANT: mainly, the articles will be recommended for self-studying and analysis – all of them are available from the electronic resources of the HSE library e-resources (https://library.hse.ru/en/) | *HSE main page* → *HSE Library* → *Electronic Resources and Remote Access*.
Also, follow regular announcements at "Applied System Analysis" LMS pages)

a) Recommended Sources

- [in English] Guide to the Systems Engineering Body of Knowledge (SEBoK) – Foundations of Systems Engineering, Systems Engineering and Management, Applications of Systems Engineering, etc.; ver. 1.9.1 or ver. 2.0 (as of August 2019); https://www.sebokwiki.org
- [in English] The Guide to the Software Engineering Body of Knowledge (SWEBoK Guide, ver. 3.0) – https://www.computer.org/web/swebok
- [in Russian] Тарасенко Ф.П. Прикладной системный анализ : учеб. пособ., М.: КНОРУС, 2010 (**Tarasenko F.** Applied Systems Analysis (Teaching Aid), KNORUS Publ., Moscow, 2010) (available: HSE Library),
- [in English] Gorod A., et al. Case Studies in System of Systems, Enterprise Systems, and Complex Systems Engineering, CRC Press, 2015 (available: HSE Electronic Resources / Books 24x7),
- [in Russian] Ларичев О.И. Теория и методы принятия решений, а также Хроника Событий в Волшебных Странах (учебник), М.: Логос, 2000 (**Larichev O.** Theory and Methods of Decision Making, as well as the Chronicle of Events in the Magical Lands (Textbook), Logos Publ., Moscow, 2000) (available: HSE Library),
- [in Russian] Козлов В.Н. Системный анализ, оптимизация и принятие решений (уч. пособие), М.: Проспект, 2010 (**Kozlov V.** Systems Analysis, Optimization and Decision Making (Teaching Aid), Prospect Publ., Moscow, 2010) (available: HSE Library),
- [in Russian] Волкова В.Н., Денисов А.А. Теория систем и системный анализ : учебник для вузов, М.: ИД Юрайт, 2010 (**Volkova V., Denisov A.** System Theory and Systems Analysis (Textbook), URight Publ. House, 2010) – или более поздние издания (available: HSE Library),

- [in Russian] Антонов А.В. Системный анализ, М.: Высшая Школа, 2006 (**Antonov A.** Systems Analysis, Higher School ((Visshaya Shkola) Publ., Moscow, 2006) – или более поздние издания (available: HSE Library),
- [in English] Schaveling J., Bryan B. Making Better Decisions Using Systems Thinking: How to Stop Firefighting, Deal with Root Causes and Deliver Permanent Solutions, Palgrave Macmillan Publ., 2018 (available: HSE Electronic Resources / Books 24x7),
- [in English] Eisner H. Topics in Systems, Mercury Learning, 2013 (available: HSE Electronic Resources / Books 24x7),
- [in English] Crawford L., Pollack J. Hard and Soft Projects Framework for Analysis, Int. Journal Project Management, vol. 22, #8, 2004, pp. 645-653 (available: HSE Electronic Resources / ScienceDirect),
- [in English] Backlund A. The Definition of System, Kybernetes, vol. 29, #4, 2000, pp. 444-451 (available: HSE Electronic Resources / Emerald Insight),
- [in English] Arnold R.D., Wade J. A Definition of Systems Thinking: A Systems Approach, Procedia Computer Science, 44, 2015, pp. 669-678 (available: ScienceDirect / ResearchGate).

b) Additional (optional) Sources

- [in English] Principia Cybernetica Project (PCP), 2002, http://pespmc1.vub.ac.be/ (in particular, section on Systems Concepts) - http://pespmc1.vub.ac.be/SYSCONC.html),
- [in Russian] Ксенчук Е. Системное мышление. Границы ментальных моделей и системное видение мира, М.: ИД 'Дело' (РАНХиГС), 2011 (**Ksenchuk E.** Systemic Thinking. Boundaries of Mental Models and System Vision of the World, Delo Publishing House, Moscow, 2011) (available: HSE Library),
- [in English] Bagnall A.J., Rayward-Smith V.J., Whittley I.M. The Next Release Problem, Information and Software Technology, vol. 43, iss. 14, 2001, pp. 883-890 (available: HSE Electronic Resources)
- [in English] International Society for the Systems Sciences, http://www.isss.org/world/,
- [in English] Legrand J. How Far Can Q-analysis Go Into Social Systems Understanding? (Association Française de Science des Systèmes), 5th European Systems Science Congress, 2002,
- [in English] Gharajedaqhi J. Systems Thinking: Managing Chaos and Complexity. A Platform for Designing Business Architecture, 3rd ed., Morgan Kaufman Publ., 2011 (available: HSE Electronic Resources / Books 24x7 | HSE Library (Russ. translation)),
- [in English] Casti J.L. Connectivity, Complexity and Catastrophe in Large-Scale Systems (International Series on Applied Systems Analysis), John Wiley & Sons, 1979,
- [in English] Casti J.L. Polyhedral Dynamics: I. The relevance of Algebraic Topology to Human Affairs, IIASA (International Institute for Applied Systems Analysis) Working Paper WP-75-030, 1975,
- [in English] Casti J.L. Polyhedral Dynamics - II: Geometrical Structure as a Basis for Decision Making in Complex Systems, IIASA Research Memorandum RM-75-034, 1975,
- [in English] Atkin R., Casti J.L. Polyhedral Dynamics and the Geometry of Systems, IIASA Research Report RR-77-006, 1977,
- [in English] Sankaran S., Haslett T., Sheffield J. Systems Thinking Approaches to Address Complex Issues in Project Management, PMI Global Congress, 2010 - https://www.pmi.org/learning/library/systems-thinking-soft-methodology-issues-6912.

NOTE: A variety of both printed and electronic books that cover (from various perspectives and to different extent) aspects of system theory, Systems Analysis, complexity, etc., opens up possibilities to choose those particular books (documents, reports) that seem useful and convenient for perception from the standpoint of material's presentation and refinement.

6 Grading System (Comments and Explanations)

Type of control	Form of control	1st year				Extra information
		Module 1	*Module 2*	*Module 3*	*Module 4*	
Progress control (week)	3 written quizzes (WQ) – **WQ_1, WQ_2, WQ_3**	-	1 quiz (**WQ_1**) (November-December)	2 quizzes (**WQ_2,WQ_3**) (January-February)	-	Written tests (quizzes, 1-2 questions each) offered during regular class hours (duration – appr. 50 to 60 min. each)
	Course Examination (**CE**)	-	week 7 or 8 (end of December)	-	-	Computer-based test or written test (duration – 60 to 70 min.)
	Homework (**HW**)	-	appr. week 7 (*Module 2*) - week 9 or 10 (*Module 3*) (exact time periods will be specified further on)		-	Written report (paper) following IEEE, Elsevier or Springer LNCS publ. template
Resultant	Final Course Examination (**FE**)	-	-	-	(April - June 2020)	Oral presentation of the work (HW) done + questions/answers session…

Grading criteria – detailed outline

Progress (interim) and resultant grades are made up of the following components:

- Course Examination (CE) – end of Module 2 (Semester A Quartile 2), and calculation of the interim result

CE implies the arrangement of (option 1) computer-based testing + written test or (option 2) written test only for all students enrolled (the decision is made by the course instructor at a closer time to the exam's date; all students are informed about this decision in advance). Subject area covered by tests embraces those course' topics that are discussed during both lectures and seminars up to the date announced. The computer-based test (CT_{CMP}) may contain both single-choice and multiple-choice questions; in that case the grade for the test is specified by the test program automatically. As a second option, written test (CT_{WRT}) includes 1 to 2 questions (letter 'T' means *«test»*). If student misses ICE because of some *valid reason* (only this case is covered by the document!), situation has to be discussed with representatives (managers) of the Departmental (Program's) Office of Studies.

The course examination (**CE**) is assessed on the ten-point scale (usual rounding takes place after weighted sum's calculation is completed), and the grade is calculated as follows (depends on the option is use as mentioned earlier):

(option 1) $$O(\mathbf{CE}) = IE1 = 0.4 \cdot O(CT_{\mathbf{CMP}}) + 0.6 \cdot O(CT_{\mathbf{WRT}}),$$

(option 2) $$O(\mathbf{CE}) = IE1 = O(CT_{\mathbf{WRT}}).$$

The interim assessment (IA_{Module_2}) is cumulative, i.e. it takes into account all grades obtained by the end of Module 2 (examination week period). Please, pay attention to the fact that the missed quiz (**WQ_1**) is not eligible for retaking. Thus, the interim grade is calculated as a weighted sum of individual components, i.e. $O(IA_{Module\_2}) = 0.7 \cdot O(\mathbf{CE}) + 0.3 \cdot O(\mathbf{WQ_1})$, no blocking.

- Homework assignment (**HW**) – 2nd -3rd modules (Sem. A Quartile 2 – Sem. B Quartile 3)

is prepared by students individually (x1) or in groups by two (x2, at most), herewith each student (group) must prepare electronic (PDF format solely) report, which is of the form of a scientific paper (6 to 9 pages) in IEEE or other well-established formats (*following IEEE, Elsevier or Springer LNCS publ. format template – selected links will be provided at course' webpages in LMS; see also* https://www.overleaf.com/gallery/tagged/academic-journal). Students are free to choose a problem to consider based on their own interests and preferences – after approval by the instructor, the work can be started (appr. second part of December 2019). HW covers the task that is related to field of IT, Computer or Software Engineering – we should not deviate from the program's focus.

All reports must be submitted in the electronic form to the instructor through HSE *L*earning *M*anagement *S*ystem (LMS) for consideration *before* the date *day_x*, which is set (last decade of March 2020 as a rough estimate) and announced in the beginning of Module 3. All reports are checked and graded by the instructor on ten-point scale by the end of the 4th Module as the latest, and $\mathrm{O}(\mathrm{HW}_{\mathrm{REPORT}})$ gives the assessment for the 4th Module of the course.

Important NOTE: Please, be informed in advance that failure to comply with specified deadline *day_x* for submission of the report leads automatically to the reduction of $\mathrm{O}(\mathbf{HW}_{\mathbf{REPORT}})$ by *0.3 points* for each delayed day. The conditions for all students should be the same, regardless of the subsequent date of HW presentation.

Finally, the overall course grade on ten-point scale is obtained as

$$\mathrm{O}(\mathbf{Total}) = 0.15\cdot\mathrm{O}(\mathbf{WQ_2}) + 0.15\cdot\mathrm{O}(\mathbf{WQ}_3) + 0.15\cdot\mathrm{O}(\mathrm{IA}_{\mathrm{Module\_2}}) + 0.35\cdot\mathrm{O}(\mathbf{HW}_{\mathbf{REPORT}}) + 0.2\cdot\mathrm{O}(\mathbf{FE}_{\mathbf{Pres}})$$

(usual rounding takes place after calculations are done, no blocking), where $\mathrm{O}(\mathbf{HW}_{\mathbf{REPORT}})$ is a grade for a text (written presentation) of the HW report (paper) as such subject to reduction, if any – see Important NOTE above, $\mathrm{O}(\mathbf{WQ}_2)$ and $\mathrm{O}(\mathbf{WQ}_3)$ are grades for quizzes #2 and #3, correspondingly, whereas $\mathrm{O}(\mathbf{FE}_{\mathbf{Pres}})$ is a grade obtained for the presentation (of the HW) done – questions related to topics covered by the course and submitted HW report can be asked to students. The resultant grade $\mathrm{O}(\mathbf{Total}) \geq 4$ (after rounding) means successful completion of the course (grade "Pass"), while grade of 3 or lower means unsuccessful result (grade "Fail").

Student has a chance to obtain "automatic" O(**Total**) grade (final course grade that can be only at the "excellent" level, i.e. 8, 9 or 10) *without* passing through **FE** (presentation) provided that following is satisfied, i.e. (1) all written quizzes (**WQ1**, **WQ2** and **WQ3**) are graded as "very good", "almost excellent" or above (7 or above on ten-point scale), (2) the result of $\mathrm{O}(\mathrm{CT}_{\mathrm{CMP}})$ is 8 or above and $\mathrm{O}(\mathrm{CT}_{\mathrm{WRT}})$ is 8 or above (under option 1 – see page 6), or the result of $\mathrm{O}(\mathrm{CT}_{\mathrm{WRT}})$ is 8 or above (under option 2 – see page 6), and (3) homework assignment (HW report / $\mathrm{O}(\mathbf{HW}_{\mathbf{REPORT}})$) is graded at 8 or above (on ten-point scale). Even in these circumstances, it is strongly recommended to all students, without exceptions, to make presentations of their works (HW).

Conversion of the concluding rounded grade O(**Total**) to five-point scale grade is performed in accordance with the following table:

Summary Table: Correspondence of ten-point (10) to five-point (5) system's grades

Ten-point scale [10]	Five-point scale [5]
1 – unsatisfactory 2 – very bad 3 – bad	Unsatisfactory – **2**

4 – satisfactory **5** – quite satisfactory	Satisfactory – **3**
6 – good **7** – very good	Good – **4**
8 – almost excellent **9** – excellent **10** – brilliantly	Excellent – **5**

7 Educational Methods and Technologies

Class studies in the course are organized in the form of lectures and seminars; primordial (appr. 5-7%) part of the theoretical material is supported by slides that allow to cover corresponding material faster, without spending much time on writing (slides are left mainly for self-studying). Some topics are also accompanied by slides; discussion in the course stipulates active utilization of markers and whiteboard (writing + explanations) and case studies (formulation, discussion, etc.) that highlight vividly core ideas, their meaning, analysis/research approaches in use, regular and unusual situations, and so on.

According to late Prof. Paul Lawrence (Harvard Business School), a good case study is the *"vehicle by which a chunk of reality is brought into the classroom to be worked over by the class and instructor"*. As a result, the case study approach used in class makes the learning process more interactive. In addition, much attention is also paid to encourage students to approach responsibly to the preparation of the homework reports (papers) and their presentation in English.

To the extent possible, case studies deal with those topics that are related on the whole to fields of IT, engineering and management.

a) Recommendations for Course Instructors

It should be emphasized that the core problem for the instructor offering this course is the lack of ready-to-use sources of information (e.g. titles covering the full range of material to recommend students to follow straight on, slides that in-depth accomplish certain book's contents, detailed description of case studies that can be followed and analyzed in all minute aspects, etc.). This fact must be addressed responsibly while preparing materials.

8 Learning Resources (Software and Supplementary Ref. Materials)

As it was already mentioned above, it is strongly advised to use **Electronic Resources** of the **HSE library** (http://library.hse.ru/e-resources/e-resources.htm) that provide access to information sources related to foreign scientific and technical journals, full-text theses, electronic books, dictionaries and encyclopedias.

Besides, the following software titles (*Free Mind Mapping tools*) can be noted as potential candidates for use while preparing course homework:

- Edraw MindMap (a vector-based mind mapping software with rich examples and templates) – http://www.edrawsoft.com/freemind.php) – *free mind map software*,
- Freeplane (a free and open source software to support thinking, sharing information and getting things done – http://freeplane.sourceforge.net/wiki/index.php/Main_Page) – *free mind map software*,
- XMind is a popular mind mapping software - http://www.xmind.net/),
- FreeMind (a free mind mapping software – http://freemind.sourceforge.net/wiki/index.php/Main_Page) – *free mind map software*,

Additional information on FreeMind tool can be found at http://upgradeway.ru/articles/eshhe-odin-udobnyj-instrument-dlya-sozdaniya-intellekt-kart/)

- MAPMYself (инструмент для создания интеллект-карт онлайн –

http://www.mapmyself.com/) – *free mindmapping software*,
- VUE (The Visual Understanding Environment, Tufts University | is a tool for managing and integrating digital resources in support of teaching, learning and research; visual environment for structuring, presenting, and sharing digital information – http://vue.tufts.edu/) – *free tool*,
- TheBrain (a powerful brainstorming and knowledge management tool – http://www.thebrain.com/),
- mindmaps (online service to work with mind maps – http://ruseller.com/service.php?rub=22&id=2228) – *free online service (in Russian)*,
- IHMC Cmap Tools (a software that enpowers users to construct, navigate, share knowledge models represented as Concept Maps) – *free access* – https://cmap.ihmc.us.

a) Additional Reference Sources (Mind Mapping Tools)

- Main principles of mind maps processing (*in Russian* – http://www.cfin.ru/management/controlling/mind_map.shtml),
- What is Mind Map? – http://en.wikipedia.org/wiki/Mind_map,
- Mental Modeler (*modeling software*) – http://www.mentalmodeler.org/,
- 7 Ways to Use Mind Maps in Business (ThinkBuzan, 2010 – http://www.thinkbuzan.com/uk/articles/view/7-ways-to-use-mind-maps-in-business,
- The Theory Underlying Concept Maps and How to Construct and Use Them by Novak J.D. and Carias A.J. – http://cmap.ihmc.us/Publications/ResearchPapers/TheoryCmaps/TheoryUnderlyingConceptMaps.htm,
- Introduction to Concept Mapping – http://www.inspiration.com/visual-learning/concept-mapping.

b) Additional Sources Related to AHP, TOPSIS Approaches

- AHP Priority Calculator (works with up to 20 criteria – https://bpmsg.com/ahp/ahp-calc.php),
- Vargas R.V. Using the Analytic Hierarchy Process (AHP) to Select and Prioritize Projects in a Portfolio (conference paper, 2010 | PMI Library – https://www.pmi.org/learning/library/analytic-hierarchy-process-prioritize-projects-6608)
extra link: https://ricardo-vargas.com/articles/analytic-hierarchy-process/,
- Super Decisions (decision support software, AHP / ANP) – https://www.superdecisions.com/,
- Multi Criteria Decision Making Calculator – https://people.revoledu.com/kardi/tutorial/AHP/MCDM_Calculator.html,
- How to Do AHP Analysis in Excel (Bunruamkaew K., 2012 – http://giswin.geo.tsukuba.ac.jp/sis/gis_seminar/How%20to%20do%20AHP%20analysis%20in%20Excel.pdf),
- AHP Using Microsoft Excel (Pyzdek T., 2013 / YouTube – https://www.youtube.com/watch?v=aX8npmWWA_A),
- Fuzzy AHP Calculation / R package – https://www.rdocumentation.org/packages/FuzzyAHP/versions/0.9.1,
- Expert Choice Solutions – How AHP Works (The Analytic Hierarchy Process: Structured Decisions, 2019 – https://www.expertchoice.com/ahp-software),
- Decision Radar – Ez-TOPSIS Calculator, https://decision-radar.com/,
- Asahi T., Turo D., Shneiderman B. Visual decision-making: using treemaps for the analytic hierarchy process / Proc. CHI'95 Conference Companion on Human Factors in Computing Systems, ACM Digital Library | extra: Johnson B., Shneiderman B.Tree-Maps: A Space-Filling Approach to the Visualization of Hierarchical Information Structures (https://www.cs.umd.edu/hcil/trs/91-06/91-06.pdf).