Wojskowa Akademia Techniczna

**Resolution**
**of the Senate of the Military University of Technology**

**No. 9/WAT/2025 of 27 February 2025**

**on the establishment of the "Curriculum" at the Doctoral School Military University of Technology - 2025 edition"**

Pursuant to Article 201(4) of the Act of 20 July 2018 – Law on Higher Education and Science (i.e. Journal of Laws of 2024, item 1571, as amended), in connection with § 21(1)(21) of the Statute of the Military University of Technology constituting an attachment to the Resolution of the Senate of the Military University of Technology No. 16/WAT/2019 of 25 April 2019 on the adoption of the Statute of the Military University of Technology (i.e. Announcement of the Rector of the Military University of Technology No. 2/WAT/2024 of 27 March 2024), the following is resolved:

§ 1

The "Curriculum" **(**Education program} at the Doctoral School of the Military University of Technology - 2025 edition" *is hereby established,* constituting an attachment to the resolution.

§ 2

The curriculum referred to in § 1 is in force from the academic year 2025/2026.

§ 3

Doctoral students of the Doctoral School of the Military University of Technology who started their education before the academic year 2025/2026 may update their Individual Education Programmes on the basis of this program.

§ 4

The resolution shall enter into force on the date of its adoption.

President of the Senate

Gen. bryg. prof. dr hab. inż. Przemysław WACHULAK

Attachment to the resolution of the Senate of the Military
University of Technology No.9/WAT/2025 of 27 February 2025

# CURRICULUM

## DOCTORAL SCHOOL

## MILITARY UNIVERSITY OF TECHNOLOGY

## - edition 2025

## I. General principles

1. The curriculum (education program) at the Doctoral School of the Military University of Technology is carried out for doctoral students of the following scientific disciplines:
    1) **automation, electronics, electrical engineering and space technologies** - a field of engineering and technical sciences;
    2) **information and communication technology** - a field of engineering and technical sciences;
    3) **civil engineering, geodesy and transport** - a field of engineering and technical sciences;
    4) **materials engineering** - a field of engineering and technical sciences;
    5) **mechanical engineering** - a field of engineering and technical sciences;
    6) **security studies** - a field of social sciences;
    7) **chemical sciences** - a field of exact and natural sciences.
2. The learning outcomes take into account the requirements specified for the 8th level of the Polish Qualifications Framework.
3. Number of semesters: **8**
4. Number of ECTS credits – min. **30 points**
5. The number of compulsory courses is 100 hours and 20 hours of practical training carried out in the form of conducting classes or participating in them and corresponds to a total of 10 ECTS credits, and the number of optional courses is at least 200 hours and corresponds to at least 20 ECTS credits**.** Optional courses may include classes in optional modules of subjects carried out at MUT for at least 100 hours and 10 ECTS credits, courses taught at another university or scientific institution in Poland or abroad, and other forms of education, e.g. apprenticeships, internships at and outside the MUT in particular at another university or institution in Poland or abroad.
6. Language of conducting:
    a. **Polish or English –** only in the case of subjects, internships or other forms of education indicated in the Individual Education Programme (IPK),
    b. **English –** in the case of education in a scientific discipline in English.
7. The program is valid from **the academic year 2025/2026.**
8. Indication of the relationship between the concept of education and the development strategy and mission of the Military University of Technology:
   Education at the Doctoral School of the Military University of Technology, hereinafter referred to as the "Doctoral School", is part of the development strategy and mission of the Academy, the essence of which is the professional preparation of future staff in the fields of engineering and technology, exact and natural sciences and social sciences, in particular in the field of military technology and security technology. The task of the Doctoral School is to ensure the transfer of the latest knowledge to doctoral students, the development of skills and improvement of competences at the highest level, as well as the cultivation of patriotic traditions and responsibility for the Homeland in broadly understood aspects, both military and civilian, in accordance with the principle "Omnia Pro

Patria" – "Everything for the Homeland". The activities of the Doctoral School correlate with the strategic objectives of the Academy's development in terms of strengthening the position of the Military University of Technology in the system of Polish and European higher education, including as the leading educational pillar of higher military education and the expert and research base of the Ministry of National Defense, as well as other ministries. In addition, it emphasizes the elite nature of the Academy as a university conducting innovative didactic and scientific activities, also developing international cooperation in this field.

9. Prerequisites for the candidate for the Doctoral School

   The candidate should have a Level 7 qualification. Polish Qualifications Framework (Master's degree, or equivalent) and complete a Master's degree in a field related to the scientific discipline conducted at the Doctoral School or have scientific achievements in this discipline. In exceptional cases, justified by the highest quality of scientific achievements, the Doctoral School may admit a person who is a graduate of first-cycle studies or a student who has completed the third year of uniform master's degree studies. Detailed requirements are set out in the rules of recruitment to the Doctoral School established annually by the Senate of the Military University of Technology.

## II. Description of the expected learning outcomes

The description of the expected learning outcomes includes:

- universal first-level characteristics specified in the Annex to the Act of 22 December 2015 on the Integrated Qualifications System;
- second-cycle characteristics set out in the Annex to the Regulation of the Minister of Science and Higher Education of 14 November 2018 on second-cycle learning outcomes for qualifications at levels 6-8 of the Polish Qualifications Framework (PQF).

Explanation of the markings:

1) in the column symbol *and effect number*:
   a) D - doctoral learning outcomes,
   b) W, U, K (after the underline) - category: knowledge, skills, social competences,
   c) 01, 02, 03, .... - number of the learning outcome,
   d) WAT01, ... - number of the learning outcome for subjects for which the university learning outcomes are required;
2) in the description *component code* column - reference of the assumed learning outcome to the appropriate code of the description component of the first- and second-cycle learning outcomes at level 8 of the Polish Qualifications Framework (PQF 8).

The description of the following expected learning outcomes will be achieved as a result of the implementation of the education programme, including the Individual Learning Programme (IPK) and the Individual Research Plan (IPB)

| Effect number symbols | Expected learning outcomes | code description component |
|---|---|---|
| **Knowledge: the graduate knows and understands** | | |
| *D_W WAT01* | *methods and techniques of conducting classes.* | *P8S_WG* |
| *D_W01* | *the global scientific and technological achievements in a given scientific discipline and the resulting implications for practice* | *P8U_W P8U_WG* |
| *D_W02* | *global scientific and technological achievements including theoretical foundations as well as general issues and selected specific issues – specific to a given scientific discipline* | *P8S_WG* |
| *D_W03* | *development trends in the scientific discipline* | *P8S_WG* |
| *D_W04* | *research methodology* | *P8S_WG* |
| *D_W05* | *rules for the dissemination of the results of scientific activity, also in the open access mode* | *P8S_WG* |
| *D_W06* | *fundamental dilemmas of modern civilization; economic, legal, ethical and other important determinants of scientific activity; basic principles of knowledge transfer to the economic and social sphere and commercialization of the results of scientific activity and know-how related to these results* | *P8S_WK* |
| **Skills: the graduate is able to** | | |
| *D_U WAT01* | *prepare and conduct classes related to the scientific discipline in a modern way* | *P8S_UK P8S_UU* |
| *D_U WAT02* | *obtain the necessary information related to the conducted research, using sources, including English-language* | *P8S_UKP8S_UO* |
| *D_U01* | *analyse and creatively synthesize scientific and creative achievements in order to identify and solve research problems and problems related to innovation and creative activities;* | *P8U_U P8S_UW* |
| *D_U02* | *create new elements of scientific and creative achievements* | *P8U_U P8S_UW* |
| *D_U03* | *independently plan and act for their own development and inspire and organize the development of others,* | *P8U_U P8S_UU* |
| *D_U04* | *use knowledge to creatively identify, formulate and innovatively solve complex problems or perform research tasks , in particular:*<br>*− define the purpose and object of scientific research, formulate a research hypothesis,*<br>*− develop research methods, techniques and tools and apply them creatively,*<br>*− draw conclusions on the basis of scientific research* | *P8S_UW* |
| *D_U05* | *critically analyse and evaluate the results of scientific research, expert activity and other creative work and their contribution to the development of knowledge* | *P8S_UW* |
| *D_U06* | *transfer the results of scientific activity to the economic and social sphere* | *P8S_UW* |
| *D_U07* | *communicate on specialist topics to the extent that allows active participation in the national and international scientific community* | *P8U_U P8S_UK* |
| *D_U08* | *disseminate the results of scientific activity, also in popular forms* | *P8S_UK* |
| *D_U09* | *initiate debate* | *P8U_U P8S_UK* |
| *D_U10* | *participate in scientific discourse, exchange of experiences and ideas, also in the international environment* | *P8U_U P8S_UK* |
| *D_U11* | *use a foreign language at the B2 level of the Common European Framework of Reference for Languages to a degree that allows participation in the international scientific and professional environment;* | *P8S_UK* |
| *D_U12* | *plan and implement individual and team research or creative projects, also in an international environment* | *P8S_UO* |
| *D_U13* | *plan classes or groups of classes and carry them out using modern methods and tools* | *P8S_UU* |

| | Social competences: the graduate is ready to | |
|---|---|---|
| *D_K01* | *independent research to increase existing scientific and creative output* | *P8U_K P8U_KK* |
| *D_K02* | *taking into account the challenges in the professional and public sphere, taking into account:<br>– their ethical dimension,<br>– responsibility for their consequences and shaping models of appropriate conduct in such situations* | *P8U_K P8U_KK* |
| *D_K03* | *critical evaluation of achievements within a given scientific discipline* | *P8U_K P8S_KK* |
| *D_K04* | *critically evaluate one's own contribution to the development of a given scientific discipline* | *P8U_U P8S_KK* |
| *D_K05* | *recognition of the importance of knowledge in solving cognitive and practical problems* | *P8U_U P8S_KK* |
| *D_K06* | *fulfilling the social obligations of researchers and creators* | *P8U_U P8S_KO* |
| *D_K07* | *initiating activities in the public interest* | *P8U_U P8S_KO* |
| *D_K08* | *thinking and acting in an entrepreneurial way* | *P8U_U P8S_KO* |
| *D_K09* | *maintaining and developing the ethos of research and creative communities, including:<br>− conducting scientific activity in an independent manner,<br>− respecting the principle of public ownership of the results of scientific activity, taking into account the principles of intellectual property protection* | *P8U_U P8S_KR* |

## III. Method of verification of the assumed learning outcomes

Verification of the assumed learning outcomes, to the extent resulting from the implementation of the education programme, including an individualised learning programme, is carried out by checking the acquired knowledge, skills and social competences by the doctoral student on the basis of:

- completion of courses included in the Basic Module, including a doctoral seminar in the subject Analysis of the research area,
- credit for courses from the Optional Module of a discipline or scientific disciplines, professional practice and subjects carried out outside the Military University of Technology and other forms of education[1] included in the Individual Education Program (IPK).

## IV. Implementation of the education program

1. Education at the Doctoral School lasts 8 semesters.
2. There is one curriculum for all scientific disciplines conducted at the Doctoral School.
3. The curriculum includes at least 300 hours of classes[2] and at least 20 hours of professional internships in the form of conducting classes or participating in them - at least 30 ECTS credits in total.
4. The doctoral student's education program consists of:
   1) the basic module for doctoral students of all scientific disciplines conducted at the Doctoral School, 100 hours with a total of 9 ECTS credits;
   2) optional modules related to the scientific disciplines conducted at the Doctoral School, at least 200 hours each, to which at least 20 ECTS credits have been assigned, subject to sections 6, 7 and 8;

[1] if they appear in IPK

[2] classes may include courses taught outside the Military University of Technology and other forms of education

3) 20 to 180 hours of professional internships in the form of classes or participation in them from the third to the seventh semester of education, – max. 60 hours per year (in accordance with the individual curriculum), which are assigned 1 ECTS credit, regardless of the number of hours of practice.
4) optionally, courses taught outside the Military University of Technology and other forms of education on an hourly basis and the number of ECTS credits specified in an individual curriculum.

5. A doctoral student is required to complete the basic module and 20 hours of professional practice in the form of conducting classes or participating in them. A doctoral student, in consultation with the supervisor from the optional module for the scientific discipline, selects the courses to be carried out so that the total number of ECTS credits corresponds to at least 20 credits. It is allowed for courses to come from different scientific disciplines and to be taught at another university or research institution.
6. In the case of planned completion of courses outside MUT and other forms of education (e.g. internship, internship at and outside MUT), the supervisor determines the number of ECTS credits and the learning outcomes to be achieved, provided that the number of hours of courses taught at MUT from the optional module cannot be less than 100 hours and 10 ECTS credits.
7. In the case of education for foreigners in English, the subjects included in the basic module referred to in Chapter V, concerning the issues of Polish regulations, may be replaced by other subjects. Decisions on the introduction of new subjects are made by the Director of the Doctoral School in consultation with the Chairman of the Scientific Discipline Council, within which the education of foreigners is conducted.
8. The implementation of the education programme, considering the provisions of sections 5-7, should ensure that the candidate achieves the assumed learning outcomes specified in Chapter II.
9. By the end of the first semester of education, the doctoral student submits an individual education program to the director of the Doctoral School, approved by the supervisor or supervisors.
10. Classes in the subjects of the basic module are planned centrally for all doctoral students of the first year, subject to paragraph 11
11. Classes for foreigners providing education in English may be planned centrally or as part of a scientific discipline, considering the subjects referred to in paragraph 7.
12. Classes in the subjects of the optional modules are planned according to individual curricula.
13. Classes in the subjects of the basic module or optional modules can be carried out in a stationary or remote or hybrid form.
14. The decision on the form of conducting classes in the subjects of the basic module is made by the director of the Doctoral School, and in the case of subjects of optional modules, by the lecturer.

## V. Modules of the curriculum

| Lp. | Course/Module Name | number of hours | number of ECTS credits | Reference to learning outcomes/Annex |
|---|---|---|---|---|
| **Basic module, obligatory for doctoral students of all disciplines[3] (I-II sem.)** | | | | |
| 1. | Higher education | 20 | 1 | *D_WWAT01, D_W05, D_W06, D_UWAT01, D_U03, D_K01, D_K02* |
| 2. | Rules for conducting classes | 10 | 1 | *D_WWAT01, D_UWAT01, D_U03, D_U13, D_K01, D_K06* |
| 3. | The process of applying for research funding | 10 | 1 | *D_W05, D_U7, D_K01, D_K03, D_K04* |
| 4. | Plan your experiment | 14 | 1 | *D_W04, D_U04, D_K04* |
| 5. | Methodology of conducting scientific research | 10 | 1 | *D_WAT02, D_U01-U05* |
| 6. | Ownership and commercialisation of research | 10 | 1 | *D_W05, D_W06, D_U06* |
| 7. | Scientometrics and bibliometrics in scientific activity | 6 | 1 | *D_W05, D_U08, D_K03, D_K04* |
| 8. | Analysis of the research area[4] | 20 | 2 | *D_W01, D_W02, D_W03, D_W4, D_U08* |
| **Optional modules related to the scientific discipline of a doctoral student (III-VII sem.)** | | | | |
| 1 | Automation, electronics, electrical engineering and space technology | min. 200 hrs[5] | min. 20 points | *List of items attachment V.1 - page 11* |
| 2 | Informatics and Telecommunications | | | *List of items attachment V.2 - p. 14* |
| 3 | Civil Engineering, Surveying & Transportation | | | *List of items attachment V.3 - p. 17* |
| 4 | Materials Science | | | *List of items attachment V.4 - p. 19* |
| 5 | Mechanical Engineering | | | *List of items attachment V.5 - p. 22* |
| 6 | Chemical Sciences | | | *List of items attachment V.6 - page 25* |
| 7 | Security Sciences | | | *List of items attachment V.7 - p. 26* |
| **Internship (III-VII sem.) -** in accordance with the individual education program | | | | |
| 1 | Professional practice in the form of conducting classes or participating in them | 20-180 hours | 1 | *D_WWAT01, D_UWAT01, D_K01* |
| **Subjects taught outside the Military University of Technology and Other forms of education (III-VII sem.)** **-** Optionally according to the individual training program | | | | |

[3] in the case of education for foreigners in English, the subjects included in the basic module, concerning the issues of Polish regulations, may be replaced by other subjects determined by the Director of the Doctoral School.

[4] course carried out on an individual basis with a supervisor or supervisors or a supervisor and an assistant supervisor completed with a doctoral seminar

[5] the minimum number of hours of classes in the Optional Module may be reduced by the implementation of other forms of education, the sum of ECTS credits for the Optional Module and other forms of education may not be less than 20 points, while maintaining at least 100 hours of classes at MUT in the Optional Module

| Lp. | Course/Module Name | number of hours | number of ECTS credits | Reference to learning outcomes/Annex |
|---|---|---|---|---|
| 1 | Subjects outside MUT and, for example, internships, internships carried out at and outside MUT at another university or scientific institution in Poland or abroad | *The number of hours, ECTS credits and reference to learning outcomes is determined by the supervisor in an individualised learning programme* | | |

## VI. Framework Program

The framework program includes the characteristics - curricular content of all subjects in the compulsory module and optional modules.

| Lp. | Name Item | Curriculum content |
|---|---|---|
| **Basic module, obligatory for doctoral students of all scientific disciplines** | | |
| 1. | Higher education | Basic concepts of contemporary general didactics. Functions of academic education, contemporary models of higher education, principles of functioning of higher education. Psychological foundations of the learning process. Principles of curriculum design. Taxonomies of learning objectives. Learning styles vs. teaching styles. Modern methods and techniques of education. Designing didactic classes. Developing the ability to formulate and creatively solve problems; shaping creative attitudes. Evaluation of learning outcomes; assessment methods. Methodology of interpersonal communication; student-teacher relations, moderating the work of student teams; modern methods of supporting students in the learning process. Social competences of an academic teacher. The ethos of a researcher - an academic teacher. History and evolution of the Military University of Technology. |
| 2. | Policy conducting classes | Methodology of conducting classes; basic forms of classes; problem-based education, project education. Principles of planning classes – constructing detailed outlines using modern teaching methods and techniques. Creating teaching materials. Methods of assessing learning outcomes. IT systems supporting the work of an academic teacher. Practical exercises preparing for the implementation of apprenticeships. |
| 3. | Process Inference for financing Research | The process of applying for funding for basic scientific research. Statutory activities, financing of domestic and foreign scientific internships for young scientists starting their scientific careers. General characteristics of the rules for applying for funding in domestic institutions (Ministry of Science and Higher Education, National Centre for Research and Development, NCN, FNP) and foreign institutions (European Union and others). |
| 4. | Plan your experiment | Determined and randomized experiment plans. Measures of position and dispersion of measurement results. Assessment of the significance of the impact of input quantities on the output quantity. Specify a function that approximates the function of an object. Assessment of the adequacy of the function of the facility and the significance of its coefficients. Experiential optimization. |
| 5. | Methodology Conduct research | Analysis of the state of knowledge based on a literature review – creating a synthetic summary of what has been done and what needs to be solved. Creating your own literature databases in accordance with the citation systems used (American and English). Posing a scientific problem that needs to be solved – assumptions (limitations), required theoretical/technological/experimental apparatus, expected time and money outlays, method of verification of the results obtained. Conducting scientific research and its documentation (scientific article as the main element of research documentation). Dissemination of research results: principles of correct oral and poster presentation, conference presentations and scientific publication, principles of citing literature sources, method of self-citation. Rules for determining the contribution to a given study and to whom you should give thanks. Polemics with reviewers – improvement of submitted scientific papers. |
| 6. | Proprietary Rights and commercializatio n Research | Basic information on the methods of intellectual property protection, in particular: copyrights, inventions, utility models, industrial designs, trademarks in the field of intellectual property protection. Issues of commercialization of the results of scientific research and development works. |
| 7. | Scientometrics l Bibliometrics in the activity | Scientometric and bibliometric indicators used in international bibliographic databases (Scopus, WoS), as well as national requirements related to the evaluation of researchers. Dissemination of scientific activities and research results, with particular emphasis on the requirements of the Open Access Policy at MUT regarding the provision of open access |

| | | |
|---|---|---|
| | Scientific | to publications and management of research data. The use of bibliographic databases and e-sources in scientific research. Tools supporting the collection of materials supporting the writing of scientific papers. |
| 8. | Area Analysis Research | Seminar classes supervisor – PhD student. Analysis of the state of knowledge in the field of research issues selected by the doctoral student. Literature review. Definition of the research problem (objective, research questions, subject, hypotheses) and initial definition of the methodology. Preparation of a report and presentation for the first doctoral seminar. Preparation of the draft Individual Research Plan. |

| **Lp.** | **Discipline name Scientific** | **Curriculum content** |
|---|---|---|
| **Optional modules related to the scientific discipline of the doctoral student** | | |
| 1 | Automation, electronics, electrical engineering and space technology | *Annex VI.1 – page 28* |
| 2 | Informatics and Telecommunications | *Annex VI.2 – page 35* |
| 3 | Civil Engineering, Surveying & Transportation | *Annex VI.3 – page 46* |
| 4 | Materials Science | *Annex VI.4 – page 50* |
| 5 | Mechanical Engineering | *Annex VI.5 – page 56* |
| 6 | Chemical Sciences | *Annex VI.6 – page 65* |
| 7 | Security Sciences | *Annex VI.7 – page 69* |

## VII. Organisation of apprenticeships and other forms of education

Apprenticeships are carried out in the form of teaching classes or participation in conducting them

Detailed rules for the implementation and completion of professional practice and other forms of education by doctoral students of the Doctoral School of the Military University of Technology are specified in the following regulations established by the Director of the Doctoral School of the Military University of Technology:

1. *Regulations of professional practice of doctoral students of the Doctoral School of the Military University of Technology".*
2. *"Regulations for the implementation of other forms of education by doctoral students of the Doctoral School of the Military University of Technology."*

## VIII. Educational plan

The education plan consists of a general part for all doctoral students of the year and an individual education plan for each doctoral student. The general part of the plan includes a schedule for the implementation of the basic module.

The Individual Education Plan for Doctoral Student Semesters III to VIII is created based on the Individual Education Programme.

Wojskowa Akademia Techniczna

**PLAN OF EDUCATION AT THE DOCTORAL SCHOOL FROM THE ACADEMIC YEAR 2025/2026**
**ALL SCIENTIFIC DISCIPLINES CONDUCTED AT THE DOCTORAL SCHOOL**

| | Modules/Subjects | total hours/ ECTS point | | liczba godzin/pkt ECTS w semestrze: | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | I | | II | | III | | IV | | V | | VI | | VII | | VIII | |
| | | Hours. | ECTS | Hours. | ECTS | Hours. | ECTS | Hours. | ECTS | Hours. | ECTS | Hours. | ECTS | Hours. | ECTS | Hours. | ECTS | Hours. | ECTS |
| **Basic module, compulsory for all disciplines** | | | | | | | | | | | | | | | | | | | |
| | **Total** | **100** | **9** | **50** | **4** | **50** | **5** | | | | | | | | | | | | |
| 1 | **Didactic of Higher education** | **20** | **1** | **20** | **1** | | | | | | | | | | | | | | |
| 2 | **Rules for conducting classes** | **10** | **1** | **10** | **1** | | | | | | | | | | | | | | |
| 3 | **The process of applying for research funding** | **10** | **1** | | | **10** | **1** | | | | | | | | | | | | |
| 4 | **Design of experiment** | **14** | **1** | **14** | **1** | | | | | | | | | | | | | | |
| 5 | **Research methodology** | **10** | **1** | | | **10** | **1** | | | | | | | | | | | | |
| 6 | **Property rights commercialization of scientific research** | **10** | **1** | | | **10** | **1** | | | | | | | | | | | | |
| 7 | **Scientometrics and bibliometrics in scientific activity** | **6** | **1** | **6** | **1** | | | | | | | | | | | | | | |
| 8 | **Analysis of the research area** | **20** | **2** | | | **20** | **2** | | | | | | | | | | | | |
| **Optional modules related to the scientific discipline - 315 subjects** | | | | | | | | | | | | | | | | | | | |
| 1 | **Automation, electronics, electrical engineering and space technologies - 56 subjects** | **min. 200 hours*** | **min. 20 pkt ECTS*** | | | | | | | | | | | | | | | | |
| 2 | **Information and communication technology - 59 subjects** | | | | | | | | | | | | | | | | | | |
| 3 | **Civil engineering, geodesy and transport - 30 subjects** | | | | | | | | | | | | | | | | | | |
| 4 | **Materials engineering - 40 subjects** | | | | | | | | | | | | | | | | | | |
| 5 | **Mechanical engineering - 78 subjects** | | | | | | | | | | | | | | | | | | |
| 6 | **Security studies- 30 subjects** | | | | | | | | | | | | | | | | | | |
| 7 | **Chemical sciences - 22 subjects** | | | | | | | | | | | | | | | | | | |
| **Apprenticeships** | | | | | | | | | | | | | | | | | | | |
| 1 | *Internships in the form of conducting classes or participation in conducting them* | **20-180** | **1** | | | | | | | | | | | | | | | | |
| **Subjects carried out at another university or scientific institution, domestic or foreign - optionally in accordance with the IPK** | | | | | | | | | | | | | | | | | | | |
| 1 | *Subjects carried out in direct and remote form* | ***according to IPK*** | | | | | | | | | | | | | | | | | |
| **Inne formy kształcenia - opcjonalnie zgodnie z IPK** | | | | | | | | | | | | | | | | | | | |
| 1 | *e.g. internships, internships carried out in and outside the Military University of Technology, at another university or domestic or* | ***according to IPK*** | | | | | | | | | | | | | | | | | |

**According to the Individual Education Program (IPK)**

** The total number of ECTS credits under the IPK must be min. 21 points, min. the number of hours in the Optional Module may be reduced to 100 hours and 10 points by completing courses outside the Military University of Technology and other forms of education to which the number of hours and ECTS credits has been assigned*

## IX. The system of ensuring the quality of education at the Doctoral School

The Education Quality Assurance System at the Doctoral School of the Military University of Technology (QMS SDR WAT) is a set of consciously planned activities providing opinions, analyses and conclusions on the functioning of individual elements of the doctoral education process and indicating the directions of corrective and corrective actions. It is a system subject to constant evaluation and changes, constantly adapted to the needs resulting from internal and external conditions.

The JJK SDR WAT is based on a number of projects and activities aimed at ensuring high quality education and research conducted by doctoral students. Quality assurance is carried out through the implementation of processes in the Education Quality Assurance System at the Military University of Technology and the JCS SDR WAT. The functioning of the system is continuous and systematic, through the continuous involvement of the Academy's organizational units responsible for the process of educating doctoral students, internal and external stakeholders. The activities of the SDR QMS are primarily covered by doctoral students and academic teachers who provide scientific supervision to doctoral students and conduct classes with them.

Supervision over the implementation, functioning and improvement of the SDR QMS is exercised by the Director of the Doctoral School.

Annex V.1
to the Education Program at the Doctoral School of the Military University of Technology

## Optional subjects

### Scientific discipline: automation, electronics, electrical engineering and space technologies

| No. | Item Name | number of hours | number of ECTS credits | reference to learning outcomes | Implementation semester academic year |
|---|---|---|---|---|---|
| 1. | **Computer Network Administration** | **20** | **3** | *D_W03* | *winter* |
| 2. | **Acoustic Electronics** | **30** | **3** | *D_W04, D_W05* | *winter* |
| 3. | **Computer-aided analysis of experimental data** | **30** | **3** | *D_W03, D_U06* | *winter* |
| 4. | **Smart Antennas** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *winter* |
| 5. | **Digital Image Processing** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *winter* |
| 6. | **Optical Radiation Detectors** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *winter* |
| 7. | **Electromechanical energy and signal converters** | **30** | **3** | *D_W01, D_U05* | *winter* |
| 8. | **Laser Physics** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *winter* |
| 9. | **Physics of laser media** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |
| 10. | **Photovoltaics** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |
| 11. | **Supercontinuum Radiation Generation** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |
| 12. | **Imaging Information Engineering** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |
| 13. | **Encoding and recognition of radio transmissions** | **30** | **3** | *D_U05* | *winter* |
| 14. | **Crystallography** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |
| 15. | **Laser absorption spectroscopy in gas sensors** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |
| 16. | **Laser-plasma X-ray and extreme ultraviolet (EUV) sources** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |
| 17. | **Lasers for medical applications** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *winter* |
| 18. | **Pico- and femtosecond lasers** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |
| 19. | **Fiber lasers** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |
| 20. | **Mathematical models of the electromagnetic field** | **30** | **2** | *D_W02, D_W03* | *winter* |
| 21. | **Finite Element Method** | **30** | **3** | *D_W02, D_W03* | *spring* |
| 22. | **Methods of analysis and measurement of random signals** | **30** | **3** | *D_W02, D_U05* | *spring* |
| 23. | **Data mining methods and tools** | **30** | **3** | *D_W02, D_W04* | *winter* |
| 24. | **Methods of logical synthesis** | **30** | **3** | *D_W02, D_W03* | *winter* |
| 25. | **Minimizing the electromagnetic susceptibility of infiltration of IT devices** | **30** | **3** | *D_U05* | *winter* |

| No. | Item Name | number of hours | number of ECTS credits | reference to learning outcomes | Implementation semester academic year |
|---|---|---|---|---|---|
| 26. | **Nonlinear Laser Conversion** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |
| 27. | **Scientific and engineering calculations** | **30** | **3** | *D_W04* | *winter* |
| 28. | **Optoelectronics in safety systems** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |
| 29. | **Coherent Light Optics** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *winter* |
| 30. | **Plasma in science and technology** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *winter* |
| 31. | **Remote Sensing Basics** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *winter* |
| 32. | **Basics of knowledge about viruses and other pathogens for engineers** | **30** | **3** | *D_W01, D_W02, D_U01, D_U07, D_K01* | *winter* |
| 33. | **Measurements of basic parameters of laser radiation** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *winter* |
| 34. | **Designing safety systems** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |
| 35. | **Programmable and Purpose-Built Circuits** | **30** | **3** | *D_W01, D_U05* | *spring* |
| 36. | **Acoustic sensors** | **20** | **2** | *D_W04, D_W05* | *winter* |
| 37. | **Microwave sensors in radiolocation** | **20** | **2** | *D_W02, D_U04* | *spring* |
| 38. | **Smart radio networks** | **30** | **3** | *D_W01, D_W03* | *winter* |
| 39. | **Optical Spectroscopy for Life Sciences** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |
| 40. | **Digital systems in optoelectronic devices** | **30** | **2** | *D_W01, D_W02, D_W03 D_U07, D_U010, D_K03, D_K05* | *winter* |
| 41. | **Test and measurement systems in the test laboratory** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |
| 42. | **Fiber optic technology** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *winter* |
| 43. | **Terahertz technique** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |
| 44. | **Information concealment technique (steganography)** | **30** | **3** | *D_W01, D_W02, D_U05* | *spring* |
| 45. | **Techniques in Biomedical Engineering** | **30** | **3** | *D_W01, D_W02, D_U01, D_U07, D_K01* | *winter* |
| 46. | **Field theory** | **30** | **3** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *winter* |
| 47. | **Thermal imaging and infrared technology** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |
| 48. | **Optical Radiation Detection Systems** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *winter* |
| 49. | **Laser beams** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |
| 50. | **Modern transducers measuring physical quantities** | **30** | **3** | *D_W01, D_U05* | *winter* |
| 51. | **Selected issues of the operation of anthropotechnical systems** | **30** | **3** | *D_W08, D_U05 i 06* | *spring* |
| 52. | **Advanced microelectronics technologies** | **30** | **3** | *D_W01, D_U05* | *spring* |
| 53. | **Applications of lasers in technology** | **30** | **2** | *D_W01, D_W02, D_W03 D_U010, D_K03, D_K05* | *spring* |

| No. | Item Name | number of hours | number of ECTS credits | reference to learning outcomes | Implementation semester academic year |
|---|---|---|---|---|---|
| 54. | **Advanced techniques for digital system design in FPGAs** | **30** | **3** | *D_W02, D_W03, D_U07, D_U09, D_K05* | *spring* |
| 55. | **Selected problems of the statistical theory of radiolocation** | **30** | **3** | *D_W01, D_W02, D_W03 D_U WAT02, D_U05, D_U010, D_K03, D_K05* | *winter* |
| 56. | **Signal processing in radars** | **40** | **3** | *D_W01, D_W02, D_W03 D_U WAT02, D_U05, D_U010, D_K03, D_K05* | *winter* |

Annex V.2
to the Education Program at the Doctoral School of the Military University of Technology

## Optional subjects

## Scientific discipline: information and communication technology

| No. | Item Name | number of hours | number of ECTS credits | reference to learning outcomes | Implementation semester per year Academic |
|---|---|---|---|---|---|
| 1. | **Quantum Algorithms III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *winter* |
| 2. | **Algorithm Analysis III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *winter* |
| 3. | **Analysis and synthesis of visual information III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *winter* |
| 4. | **Next-generation wireless systems (NG)** | **20** | **2** | *D_W01, D-W02,D_W03, D_U01,D_U02, D_K03, D_K05* | *spring* |
| 5. | **ICT Systems Diagnostics III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 6. | **Efficiency of ICT systems III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 7. | **Elements of forecast theory III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 8. | **Software Evaluation III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 9. | **Physical Foundations of Quantum Information III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *winter* |
| 10. | **Computer Graphics III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *winter* |
| 11. | **Software Quality Engineering III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01,D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 12. | **Cryptology III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 13. | **Mathematical Methods of Decision Support III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 14. | **Discrete Mathematics III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 15. | **Generative and Aspective Methods in Software Development III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *winter* |
| 16. | **Numerical methods III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *winter* |
| 17. | **Multi-Criteria Optimization Methods III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01,D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 18. | **Mathematical Modelling III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 19. | **Modeling and verification of ICT networks III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 20. | **Modeling Conflict Situations III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |

| No. | Item Name | number of hours | number of ECTS credits | reference to learning outcomes | Implementation semester per year Academic |
|---|---|---|---|---|---|
| 21. | **Business Process Modeling, Simulation and Analysis III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 22. | **Reliability of Systems III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 23. | **Optimization III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *winter* |
| 24. | **Probabilistic III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *winter* |
| 25. | **Stochastic Processes III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 26. | **Image Recognition and Processing III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 27. | **Neural networks and fuzzy logic III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *winter* |
| 28. | **Smart radio networks** | **20** | **2** | *D_W01, D_W03,D_U010, D_K03, D_K05* | *winter* |
| 29. | **Stochastic Exploitation Models III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 30. | **Computer Simulation III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *winter* |
| 31. | **Database Systems III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *winter* |
| 32. | **ICT systems III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 33. | **Decision support systems III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *winter* |
| 34. | **Artificial Intelligence III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 35. | **Theoretical foundations of computer science III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *winter* |
| 36. | **Graph and Network Theory III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *winter* |
| 37. | **Project and Process Management III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *winter* |
| 38. | **Complex Data Structures III** | **20** | **2** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05, D_U07,D_K01,D_K03* | *spring* |
| 39. | **5G network application for military** | **30** | **3** | *D_W01,D_W02,D_W03,D_U01D_U02,D_U04,D_U05* | *spring* |
| 40. | **Advanced cryptanalysis tools** | **20** | **2** | *D_W01, D_W02, D_W03, D_U01, D_U02, D_U04, D_U05, D_U07, D_K01, D_K03, D_K05* | *winter* |
| 41. | **Probabilistic graph models: representation** | **20** | **2** | *D_W01, D_W02, D_W03, D_U01, D_U02, D_U04, D_U05, D_U07, D_K01,D_K03* | *winter* |
| 42. | **Probabilistic graph models: the basics of inference** | **20** | **2** | *D_W01,D_W02, D_W03, D_U01, D_U02, D_U04, D_U05, D_U07, D_K01,D_K03* | *winter* |

| No. | Item Name | number of hours | number of ECTS credits | reference to learning outcomes | Implementation semester per year Academic |
|---|---|---|---|---|---|
| 43. | **Probabilistic Graph Models: Inference Methods** | **20** | **2** | *D_W01,D_W02, D_W03, D_U01, D_U02, D_U04, D_U05, D_U07, D_K01,D_K03* | *winter* |
| 44. | **Probabilistic graph models: parameter estimation** | **20** | **2** | *D_W01,D_W02, D_W03, D_U01, D_U02, D_U04, D_U05, D_U07, D_K01,D_K03* | *winter* |
| 45. | **Probabilistic graph models and hybrid models** | **20** | **2** | *D_W01,D_W02, D_W03, D_U01, D_U02, D_U04, D_U05, D_U07, D_K01,D_K03* | *winter* |
| 46. | **GNSS – Systems and signals" (GNSS)** | **20** | **2** | *D_W01, D-W02,D_W03, D_U01,D_U02, D_K03, D_K05* | *winter* |
| 47. | **Multidimensional Data Processing (WDP)** | **20** | **2** | *D_W01; D_W02; D_W03; D_U10; DU_04; D_K03; D_K05* | *winter* |
| 48. | **Automated Battlefield Database Systems (SBD-ZPW)** | **20** | **2** | *D_W01; D_W02; D_W03; D_U10; DU_04, D_K03; D_K05* | *Winter* |
| 49. | **Hiding data in telecommunications** | **20** | **2** | *D_W01, D-W02, D_W03, D_U01, D_U02, D_K03, D_K05* | *winter* |
| 50. | **AI in spectral processing and analysis** | **20** | **2** | *D_W01, D-W02, D_W03, D_U01, D_U02, D_K03, D_K05* | *winter* |
| 51. | **Special numbers in cryptology** | **20** | **2** | *D_W01, D_W02, D_W03, D_U01, D_U02, D_U04, D_U05, D_U07, D_K01, D_K03* | *winter* |
| 52. | **Elliptic curves in cryptanalysis of asymmetric ciphers** | **20** | **2** | *D_W01, D_W02, D_W03, D_U01, D_U02, D_U04, D_U05, D_U07, D_K01, D_K03* | *winter* |
| 53. | **Selected elements of the lattice theory** | **30** | **3** | *D_W01, D_W02, D_W03, D_U01, D_U02, D_U04, D_U05, D_U07, D_K01, D_K03* | *winter* |
| 54. | **Application of modular lattices in post-kwan cryptography** | **30** | **3** | *D_W01, D_W02, D_W03, D_U01, D_U02, D_U04, D_U05, D_U07, D_K01, D_K03* | *winter* |
| 55. | **Fundamentals of Measurement of Disclosing Emissions** | **20** | **2** | *D_W01, D_W02, D_W03, D_U01, D_U02, D_U04, D_U05, D_U07, D_K01, D_K03* | *winter* |
| 56. | **Digital data processing techniques** | **20** | **2** | *D_W01, D_W02, D_W03, D_U01, D_U02, D_U04, D_U05, D_U07, D_K01, D_K03* | *spring* |
| 57. | **Advanced technologies for next generation mobile networks** | **30** | **3** | *D_W01; D_W02; D_W03; D_U10; DU_04, D_K03; D_K05* | *winter* |
| 58. | **Machine learning for telecommunications** | **30** | **3** | *D_W01; D_W02; D_W03; D_U10; DU_04, D_K03; D_K05* | *spring* |
| 59. | **Quantum Communications** | **30** | **3** | *D_W01; D_W02; D_W03; D_U10; DU_04, D_K03; D_K05* | *winter* |

Annex V.3
to the Education Program at the Doctoral School of the Military University of Technology

## Optional subjects
## Scientific discipline: civil engineering, geodesy and transport

| No. | Item Name | number of hours | number of ECTS credits | reference to learning outcomes | Implementation semester per year Academic |
|---|---|---|---|---|---|
| 1. | **Safety and reliability of building structures** | **20** | **3** | *D_W03; D_W05; D_U02; D_K02* | *winter* |
| 2. | **Dynamic interaction of building structures with the soil medium** | **20** | **2** | *D_W02; D_U01; D_K05* | *spring* |
| 3. | **Environmental physics** | **20** | **2** | *D_W03; D_U04; D_K02* | *spring* |
| 4. | **Modeling of thermal and humidity processes** | **20** | **2** | *D_W03; D_U04; D_K03* | *spring* |
| 5. | **Identification of loads and structural systems** | **20** | **2** | *D_W02; D_U02; D_K02* | *winter* |
| 6. | **Investment process in the construction industry** | **20** | **2** | *D_W01; D_U04; D_K05* | *spring* |
| 7. | **Mechanics of road and airport runway soil foundations** | **20** | **3** | *D_W03; D_U02; D_U04; D_K03* | *winter* |
| 8. | **Test Methods for Stiffness and Load-Bearing Capacity of Road and Airport Pavements** | **20** | **2** | *D_W03; D_U07; D_K07* | *lukewarm* |
| 9. | **Design methods for folding bridge structures** | **20** | **2** | *D_W03; D_U01; D_U03; D_K01* | *winter* |
| 10. | **Design methods of the experiment** | **20** | **3** | *D_W02; D_U01; D_K01* | *spring* |
| 11. | **Modeling the Behavior of Reinforced Concrete Elements and Structures** | **20** | **2** | *D_W02; D_U01; D_K01* | *winter* |
| 12. | **Geometric and Physical Nonlinearities in Structural Mechanics** | **20** | **2** | *D_W03; D_U04; D_K05* | *spring* |
| 13. | **Explosive effects on defensive structures** | **20** | **2** | *D_W02; D_U01; D_K05* | *winter* |
| 14. | **Scheduling and costing systems for construction works** | **20** | **2** | *D_W06; D_U06; D_K08* | *spring* |
| 15. | **Engineering of building materials** | **20** | **3** | *D_W04, D_U04, D_K05* | *winter* |
| 16. | **Cartographic methods of research** | **20** | **2** | *D_W02, D_U05, D_U07, D_K03, D_K05* | *spring* |
| 17. | **Spatial data exploration** | **20** | **2** | *D_W02, D_W04, D_UWAT02, D_U01, D_U05, D_K03, D_K05* | *winter* |
| 18. | **Methods and technologies in Geospatial Data Science** | **20** | **2** | *D_W02, D_W03,D_UWAT02, D_U01, D_U05, D_K03, D_K04* | *spring* |
| 19. | **Advanced methods of photogrammetric studies** | **20** | **2** | *D_W02, D_W03, D_UWAT02, D_U05, D_K05* | *winter* |
| 20. | **Programming in spatial information systems** | **20** | **2** | *D_W02, D_W05, D_U06, D_U10, D_K03, D_K06* | *winter* |
| 21. | **Reference systems in geosciences** | **20** | **3** | *D_W02, D_W03, D_W04, D_UWAT02, D_U05, D_U07, D_K01, D_K03, D_K05* | *spring* |
| 22. | **Global Geodetic Observing System** | **20** | **3** | *D_W01, D_W03, D_W04, D_UWAT02, D_U05, D_U07, D_K01, D_K03, D_K05* | *spring* |
| 23. | **Modern photogrammetric techniques** | **20** | **2** | *D_W02, D_W03, D_UWAT02, D_U05, D_K05* | *spring* |

| No. | Item Name | number of hours | number of ECTS credits | reference to learning outcomes | Implementation semester per year Academic |
|---|---|---|---|---|---|
| 24. | **Selected numerical methods in geodesy** | **20** | **2** | *D_W02, D_W03, D_UWAT02, D_U05, D_K05* | *winter* |
| 25. | **Methods of parallel data processing** | **20** | **2** | *D_W02, D_W03, D_UWAT02, D_U05, D_K05* | *spring* |
| 26. | **Mathematical foundations of digital image processing** | **20** | **2** | *D_W02, D_W03, D_W05, D_U01, D_U02, D_U04, D_U05, D_U07, D_K01, D_K03, D_K04, D_K05* | *winter* |
| 27. | **Numerical methods with linear algebra** | **20** | **2** | *D_W02, D_W03, D_W05, D_U01, D_U02, D_U04, D_U05, D_U07, D_K01, D_K03, D_K04, D_K05* | *spring* |
| 28. | **Finite element methods in Hermit spaces (polynomials of degree 2 and 3). Nonlinear problems.** | **20** | **2** | D_W02, D_W03, D_W05, D_U01, D_U02, D_U04, D_U05, D_U07, D_K01, D_K03 | *winter* |
| 29. | **Finite element methods in Hermit spaces (polynomials of degree 2, 3 and 5). Linear problems.** | **20** | **2** | *D_W02, D_W03, D_W05, D_U01, D_U02, D_U04, D_U05, D_U07, D_K01, D_K03* | *spring* |
| 30. | **GNSS Environmental Research Methods** | **20** | **2** | *D_W01, D_W04, D_U WAT02, D_U01, D_U07, D_K03, D_K05* | winter |

Annex V.4
to the Education Program at the Doctoral School of the Military University of Technology

## Optional subjects

## Scientific discipline: materials engineering

| No. | Item Name | number of hours | number of ECTS credits | reference to learning outcomes | Implementation semester per year Academic |
|---|---|---|---|---|---|
| 1. | **Structural studies by X-ray diffraction** | **20** | **2** | *D_W02, D_W05, D_U WAT02, D_U04, D_U05, D_U10, D_U03, D_K01, D_K04, D_K09* | *winter* |
| 2. | **Structural studies by scanning microscopy** | **20** | **2** | *D_W01, D_W02, D_W04, D_UWAT02, D_U05, D_U06, D_K03, D_K03* | *winter* |
| 3. | **Mechanical Properties Testing of Engineering Plastics** | **20** | **2** | *D_W02, D_W05, D_U WAT02, D_U04, D_U05, D_U10, D_U03, D_K01, D_K04, D_K09* | *winter* |
| 4. | **Physical Basis of Electro-Optical Effects in Liquid Crystals** | **20** | **2** | *D_W01, D_W02, D_UWAT01, D_UWAT02, D_U06, D_U07, D_U10, D_K04, D_K05* | *winter* |
| 5. | **Calorimetric, thermogravimetric and volumetric methods for testing material properties** | **20** | **2** | *D_W01, D_W04, D_U05, D_K03* | *winter* |
| 6. | **Semiconductor materials for optoelectronic applications** | **20** | **2** | *D_W01, D_W02, D_W03, D_U WAT02, D_U02, D_U03, D_U05, D_K01, D_K03, D_K05* | *spring* |
| 7. | **Nano and ultracrystalline engineering materials** | **20** | **2** | *D_W WAT01, D_W02, D_W03, D_W04, D_U WAT01, D_U WAT02, D_U03, D_U05, D_U09, D_K01, D_K05, D_K08* | *winter* |
| 8. | **Nanoporous anodic aluminum oxide: synthesis, design and applications** | **20** | **2** | *D_W02, D_W03, D_U WAT02, D_U01, D_U07, D_U03, D_K01, D_K03, D_K05* | *spring* |
| 9. | **Non-telecommunications applications of fiber optics** | **20** | **2** | *D_W01, D_W03, D_W04, D_U01, D_U05, D_U07, D_K01, D_K03, D_K05* | *winter* |
| 10. | **Measurement of machine and device parts using coordinate measuring techniques** | **20** | **2** | *D_W01, D_W04, D_U05, D_U06, D_U07, D_K05, D_K08* | *spring* |
| 11. | **Experiment planning and data analysis using Origin and Statistica** | **20** | **2** | *D_W04, D_U01, D_U05, D_U12, D_K01, D_K03* | *winter* |
| 12. | **Basic properties of liquid crystals** | **20** | **2** | *D_W01, D_W02, D_W04, D_W05, D_W06, D_UWAT02, D_U01, DU_02, DU_03, DU_05, DU_06, D_K01, D_K04, D_K05, D_K08* | *winter* |
| 13. | **Keysight Vee and Lab View for Data Control and Processing** | **20** | **2** | *D_W02, D_W03, D_W04, D_UWAT02, D_U04, D_K05, D_K08* | *winter* |
| 14. | **Designing technological processes for incremental Direct Deposition methods** | **20** | **2** | *D_W01, D_W02, D_W03, D_U WAT02, D_U05, D_U07, D_K01, D_K03, D_K04, D_K05* | *winter* |
| 15. | **Dielectric spectroscopy** | **20** | **2** | *D_W02, D_W03, D_W04, D_UWAT02, D_U01, D_U05, D_U10, D_U11, D_K01, D_K03, D_K05* | *spring* |
| 16. | **Structural Determinants of Material Properties** | **20** | **2** | *D_W01, D_W03-06, D_UWAT02, D_U01 D_U04, D_U05, D_U07, D_U10, D_U11, D_K03-05, D_K09* | *winter* |

| No. | Item Name | number of hours | number of ECTS credits | reference to learning outcomes | Implementation semester per year Academic |
|---|---|---|---|---|---|
| 17. | **Modern methods of material characterization** | **20** | **2** | *D_UWAT01, D_UWAT02, D_U01, DU_02, DU_03, D_U04, DU_5, D_U07. D_K01, D_K02, D_K03, D_K05, D_K06* | *winter* |
| 18. | **High-energy ball milling and mechanical synthesis** | **20** | **2** | *D_W01, D_W01, D_U05, D_K03* | *winter* |
| 19. | **Advanced materials for hydrogen storage** | **20** | **2** | *D_W01, D_W03, D_U01, D_K04* | *spring* |
| 20. | **Basics of plasmonics and metamaterials** | **20** | **2** | *D_W01, D_W02, D_W03, D_U01, D_U04, D_U07, D_K03, D_K05, D_K05, D_K09* | *winter* |
| 21. | **Selected Materials and Functional Structures for Photonic Applications** | **20** | **2** | *D_W01, D_W02, D_W03, D_U01, D_U04, D_U07, D_K03, D_K05, D_K05, D_K09* | *spring* |
| 22. | **Computer Image Analysis in Materials Science** | **20** | **2** | *D_UWAT01, D_UWAT02, D_U01, DU_02, DU_03, D_U04, DU_5, D_U07. D_K01, D_K02, D_K03, D_K05, D_K06* | *spring* |
| 23. | **Additive manufacturing of functional materials** | **20** | **2** | *D_W WAT01, D_W02, D_W03, D_W04, D_U WAT01, D_U WAT02, D_U03, D_U05, D_U09, D_K01, D_K05, D_K08* | *winter* |
| 24. | **Methods for amplifying light emission from broadband semiconductor nanostructures** | **20** | **2** | *D_W01, D_W03, D_UWAT02, D_U04, D_U05, D_U07, D_U10, D_K01, D_K03, D_K04, D_K09* | *winter* |
| 25. | **Electrochemical synthesis of anti-reflective, super-hydrophobic coatings and photonic crystals** | **20** | **2** | *D_W01, D_W03, D_UWAT02, D_U04, D_U05, D_U10, D_K03, D_K04, D_K05, D_K09* | *winter* |
| 26. | **Modeling of semiconductor devices.** | **20** | **2** | *D_W01, D_W02, D_W03, D_U WAT02, D_U02, D_U03, D_U05, D_K01, D_K03, D_K05* | *winter* |
| 27. | **High-entropy alloys – synthesis, structure, research and properties** | **20** | **2** | *D_W01, D_W01, D_U05, D_K03* | *winter* |
| 28. | **Additive manufacturing of alloys based on intermetallic phases** | **20** | **2** | *D_W01, D_W02, D_W03, D_U WAT02, D_U05, D_U07, D_K01, D_K03, D_K04, D_K05* | *winter* |
| 29. | **Combinatorial Materials Manufacturing and Testing Engineering** | **20** | **2** | *D_W01, D_W02, D_W03, D_U WAT02, D_U05, D_U07, D_K01, D_K03, D_K04, D_K05* | *winter* |
| 30. | **Reactive mechanical grinding as a method of synthesis of modern materials for storing hydrogen in the solid phase.** | **20** | **2** | *D_W01, D_W01, D_U05, D_K03* | *winter* |
| 31. | **Additive techniques with elements of reverse engineering** | **20** | **2** | *D_W02, D_W04, D_UWAT02, D_U03, D_U07, D_K03, D_K05* | *winter* |
| 32. | **Overview of additive techniques used in modern technology** | **20** | **2** | *D_W01, D_W03, D_UWAT02, D_D_U10, D_K03* | *winter* |
| 33. | **Selected issues in 3D printing** | **20** | **2** | *D_W01, D_UWAT02, D_U01, D_U08,D_K04, D_K05* | *winter* |
| 34. | **Researcher's workshop 1 – tools for writing scientific texts** | **20** | **2** | *D_W04, D_U01, D_U05, D_U12, D_K01, D_K03* | *winter* |
| 35. | **Researcher's workshop 2 – writing scientific articles** | **20** | **2** | *D_W04, D_U01, D_U05, D_U12, D_K01, D_K03* | *winter* |

| No. | Item Name | number of hours | number of ECTS credits | reference to learning outcomes | Implementation semester per year Academic |
|---|---|---|---|---|---|
| 36. | **Researcher's Workshop 3 – Writing Scientific Articles** | **20** | **2** | *D_W04, D_U01, D_U05, D_U12, D_K01, D_K03* | *winter* |
| 37. | **Quantum mechanics in examples** | **20** | **2** | *D_W02, D_W03, D_W04, D_UWAT02, D_U01, D_U05, D_U10, D_U11, D_K01, D_K03, D_K05* | *winter* |
| 38. | **Corrosion testing in materials science** | **20** | **2** | *D_W01, D_W02, D_W03, D_W04, D_U01, D_K05* | *winter* |
| 39. | **Anodic oxides of copper and its alloys – production, characteristics and applications** | **20** | **2** | *D_W01, D_W02, D_W03, D_UWAT02. D_U01, D_U04, D_K03, D_K04, D_K06* | *winter* |
| 40. | **Anodizing of aluminum alloys** | **20** | **2** | *D_W01, D_W02, D_W03, D_UWAT02, D_U01, D_U04, D_K03, D_K04, D_K06* | *winter* |

Annex V.5
to the Education Program at the Doctoral School of the Military University of Technology

## Optional subjects
## Scientific discipline: mechanical engineering

| No. | Item Name | number of hours | number of ECTS credits | reference to learning outcomes | Implementation semester per year Academic |
|---|---|---|---|---|---|
| 1. | **Numerical Analyses in Load-Bearing Structures** | **40** | **4** | *D_W01, D_W02, D_W03, D_U05, D_K01, D_K03, D_K05* | *spring* |
| 2. | **Autonomy of mobile robots** | **30** | **3** | *D_U04, D_W03, D_K01* | *winter* |
| 3. | **Non-destructive testing of aircraft** | **30** | **3** | *D_W02; D_W05; D_U01; D_K05* | *winter* |
| 4. | **Biomechanics of human body movement during a road accident** | **20** | **2** | *D_W03, D_W05, D_U02 D_U05, D_K04* | *spring* |
| 5. | **Construction and operation of industrial robots** | **30** | **3** | *D_W01, D_W02, D_U04 D_U06, D_K01, D_K03* | *winter* |
| 6. | **Digital signal processing** | **30** | **3** | *D_W01, D_W02, D_U04 D_U06, D_K01, D_K03* | *winter* |
| 7. | **Dynamics of mechatronic system design** | **30** | **3** | *D_W03,D_W05, D_U02, D_U05, D_K04* | *spring* |
| 8. | **Dynamics of car movement** | **30** | **3** | *D_W03,D_W05, D_U02, D_U05, D_K04* | *spring* |
| 9. | **Dynamics and modeling of hydrostatic systems** | **30** | **3** | *D_U04, D_W04, D_K01* | *winter* |
| 10. | **Dynamics of multi-member systems** | **30** | **3** | *D_W01, D_W02, D_W03, D_U05, D_K01, D_K03, D_K05* | *winter* |
| 11. | **Impulse loads of motor vehicles – selected issues** | **20** | **2** | *D_W04, D_U04, D_K09* | *winter* |
| 12. | **Computer-aided operation of machines** | **20** | **2** | *D_W02, D_U05, D_K05* | *spring* |
| 13. | **Shaping a safe car body** | **20** | **2** | *D_W01, D_U04, D_K01, D_K05* | *spring* |
| 14. | **Composite materials in mechanical engineering** | **30** | **3** | *D_W01, D_W01, D_U04, D_K01, D_K05* | *spring* |
| 15. | **Finite Element Method** | **30** | **3** | *D_W01, D_W02, D_W03, D_U05, D_K01, D_K03, D_K05* | *winter* |
| 16. | **Methods of analysis of numerical experimental research results** | **30** | **3** | *D_W01, D_W02, D_W03, D_U05, D_K01, D_K03, D_K05* | *spring* |
| 17. | **Methods of testing the condition of machines** | **30** | **3** | *D_W03, D_U05, D_K01, D_K03* | *winter* |
| 18. | **Experimental methods for investigating the thermophysical properties of solids** | **30** | **3** | *D_W03, D_W04, D_U04, D_U05, D_K01, D_K03* | *spring* |
| 19. | **Methods and techniques for testing the mechanical properties of materials** | **30** | **3** | *D_W03, D_W04, D_U04, D_U05, D_K01, D_K03* | *winter* |
| 20. | **Numerical Methods in Engineering Applications** | **30** | **3** | *D_W01, D_W02, D_W03, D_U05, D_K01, D_K03, D_K05* | *winter* |
| 21. | **Numerical Methods in Mechanical Engineering** | **30** | **3** | *D_W01, D_W02, D_W03, D_U05, D_K01, D_K03, D_K05* | *winter* |
| 22. | **Methods for designing and optimizing aircraft structures** | **30** | **3** | *D_W01, D_W03, D_U04, D_U05, D_K01, D_K03* | *spring* |
| 23. | **Constitutive Models of Materials in FEM Analysis** | **30** | **3** | *D_W01, D_W02, D_W03, D_U05, D_K01, D_K03, D_K05* | *winter* |
| 24. | **Modelling of heat transfer processes** | **30** | **3** | *D_W01, D_W03, D_U01, D_U05, D_K01, D_K03, D_K05* | *winter* |

| No. | Item Name | number of hours | number of ECTS credits | reference to learning outcomes | Implementation semester per year Academic |
|---|---|---|---|---|---|
| 25. | **Modeling and simulation of mechatronics issues** | **30** | **3** | *D_W04, D_U04, D_K01* | *spring* |
| 26. | **Modeling and simulation of nonlinear mechanical problems** | **40** | **4** | *D_W01, D_W02, D_W03, D_U05, D_K01, D_K03, D_K05* | *spring* |
| 27. | **Parametric modeling and structural optimization with FEM** | **30** | **3** | *D_W01, D_W02, D_W03, D_U05, D_K01, D_K03, D_K05* | *spring* |
| 28. | **Flow modeling** | **30** | **3** | *D_W01, D_W02, D_W04, D_U05, D_K01, D_K03, D_K05* | *winter* |
| 29. | **Modeling machine motion** | **20** | **2** | *D_U04, D_W04, D_K01* | *spring* |
| 30. | **Modeling composite structures** | **30** | **3** | *D_W01, D_W02, D_W03, D_U05, D_K01, D_K03, D_K05* | *winter* |
| 31. | **Modeling of the Contact Phenomenon in Structural Mechanics** | **30** | **3** | *D_W01, D_W02, D_W03, D_U05, D_K01, D_K03, D_K05* | *winter* |
| 32. | **Modeling and research of the processes of cooperation between the wheel and the road** | **30** | **3** | *D_W01, D_W02, D_W03, D_U04, D_U05, D_K01, D_K03, D_K05* | *winter* |
| 33. | **Modeling of car traffic and controls** | **30** | **3** | *D_W01, D_W02, D_W03, D_U04, D_U05, D_K01, D_K03, D_K05* | *winter* |
| 34. | **Modern technologies for bonding structural materials** | **30** | **3** | *D_W01, D_W02, D_U05, D_K01, D_K05* | *spring* |
| 35. | **Modern CAD\CAM\Additive Manufacturing Design & Manufacturing Systems** | **20** | **2** | *D_U04, D_W03, D_K01* | *winter* |
| 36. | **Renewable energy sources** | **30** | **3** | *D_W06, D_U WAT02, D_K07* | *winter* |
| 37. | **CAE Engineering Software** | **30** | **3** | *D_W01, D_W02, D_W03, D_U05, D_K01, D_K03, D_K05* | *winter* |
| 38. | **Experiment planning and optimization of mechanical objects** | **30** | **3** | *D_W04, D_U04, D_K05* | *winter* |
| 39. | **Basics of road safety** | **20** | **2** | *D_W03, D_W05, D_U02 D_U05, D_K04* | *winter* |
| 40. | **Basics of Internal Combustion Engine Inlet Air Filtration in Baffle Filters** | **30** | **3** | *D_W04, D_U WAT02, D_U07, D_K02, D_K03* | *spring* |
| 41. | **Basics of Internal Combustion Engine Inlet Air Filtration in Inertia Filters** | **30** | **3** | *D_W04, D_U WAT02, D_U07, D_K02, D_K03* | *winter* |
| 42. | **Fundamentals of Mechanics of Continuous Media** | **30** | **3** | *D_W01, D_W02, D_W03, D_U05, D_K01, D_K03, D_K05* | *spring* |
| 43. | **LabVIEW environment in experimental research** | **30** | **3** | *D_W01, D_W02, D_W03, D_W04, D_U05, D_K01, D_K03, D_K05* | *spring* |
| 44. | **Starting processes of internal combustion engines** | **30** | **3** | *D_W04, D_U04, D_K01* | *spring* |
| 45. | **Programming control systems for unmanned working machines and robots** | **30** | **3** | *D_U04, D_W03, D_K01* | *winter* |
| 46. | **Mechatronic sensors** | **30** | **3** | *D_W03, D_W04, D_U06, D_K01, D_K04* | *winter* |
| 47. | **Condition monitoring systems** | **30** | **3** | *D_W02, D_W03, D_U02, D_U05, D_U07, D_K01, D_K03, D_K05* | *spring* |
| 48. | **Aircraft Operation Systems** | **30** | **3** | *D_W03; D_U01; D_K03* | *winter* |
| 49. | **Control systems in mechanical engineering** | **30** | **3** | *D_U04, D_W03, D_K01* | *spring* |
| 50. | **Technologies for the production and processing of composite materials** | **30** | **3** | *D_W01, D_W02, D_U04, D_K01, D_K05* | *spring* |
| 51. | **Selected solutions in the field of automotive technology and car motion** | **20** | **2** | *D_W01, D_W03, D_U04 D_K01, D_K05* | *spring* |

| No. | Item Name | number of hours | number of ECTS credits | reference to learning outcomes | Implementation semester per year Academic |
|---|---|---|---|---|---|
| 52. | **Theory and organization of machine operation** | **30** | **3** | *D_W04, D_U06, D_K03* | *winter* |
| 53. | **Thermomechanics of materials and studies of thermophysical properties** | **30** | **3** | *D_W03, D_W04, D_U01, D_K03* | *winter* |
| 54. | **Tribology** | **30** | **3** | *D_W03, D_U04, D_K05* | *winter* |
| 55. | **Durability of aircraft structures** | **30** | **3** | *D_W02, D_W03, D_U02, D_U05, D_U07, D_K01, D_K03, D_K05* | *spring* |
| 56. | **Introduction to the equations of mathematical physics** | **30** | **3** | *D_W01, D_W02, D_W03, D_U01, D_U04, D_K01, D_K03* | *spring* |
| 57. | **Modern machine and vehicle drive systems** | **30** | **3** | *D_W03, D_U04, D_K05* | *winter* |
| 58. | **Modern test methods for internal combustion engines and vehicles** | **30** | **3** | *D_W04; D_U01; D_U02; D_U03; D_U04; D_U05; D_UWAT01;* | *winter* |
| 59. | **Selected methods and techniques of temperature measurement** | **30** | **3** | *D_W03, D_W04, D_U04, D_K05* | *spring* |
| 60. | **Selected problems of rocket technology** | **30** | **3** | *D_W03, D_U04, D_K05* | *winter* |
| 61. | **Selected issues of waste gas treatment from motor vehicles** | **30** | **3** | *D_W01; D_W02; D_W03; D_K03; D_K05; D_U010;* | *spring* |
| 62. | **Selected issues of simulation of combustion processes and working processes of internal combustion engines.** | **30** | **3** | *D_W01; D_W02; D_W03; D_U05; D_K01; D_K03; D_K05;* | *winter* |
| 63. | **Selected issues of modern programming - introduction to modern programming languages.** | **30** | **3** | *D_W01, D_W02, D_W03, D_U05, D_K01, D_K03, D_K05* | *spring* |
| 64. | **Fatigue strength and fracture mechanics of materials and structures** | **30** | **3** | *D_W01, D_U04, D_K01* | *spring* |
| 65. | **Advanced methods of manufacturing products from sintered powders** | **30** | **3** | *D_W04, D_U04, D_K01* | *spring* |
| 66. | **Advanced ballistics, modeling, and simulation** | **30** | **3** | *D_W01, D_U04, D_K01* | *spring* |
| 67. | **Advanced Mathematics** | **40** | **4** | *D_W01, D_W02, D_W03, D_U05, D_K01, D_K03, D_K05* | *winter* |
| 68. | **Advanced modeling in structural dynamics** | **30** | **3** | *D_W01, D_W02, D_W03, D_U05, D_K01, D_K03, D_K05* | *winter* |
| 69. | **Advanced measurement systems** | **30** | **3** | *D_W04, D_U04, D_K01* | *winter* |
| 70. | **Advanced Materials Testing Methods** | **30** | **3** | *D_W01, D_W02, D_W04, D_U02, D_U04, D_U05, D_K01, D_K05* | *spring* |
| 71. | **Application of experimental mechanics in scientific research 1** | **30** | **3** | *D_W01, D_W02, D_W03, D_W04, D_U05, D_K01, D_K03, D_K05* | *winter* |
| 72. | **Application of experimental mechanics in scientific research 2** | **40** | **4** | *D_W01, D_W02, D_W03, D_W04, D_U05, D_K01, D_K03, D_K05* | *spring* |
| 73. | **Application of Finite Element Method in Mechanical Wave Propagation Analysis** | **30** | **3** | *D_W01, D_W02, D_W03 D_U05, D_K01, D_K03, D_K05* | *spring* |
| 74. | **Selected issues of vibration theory** | **20** | **2** | *D_W02, D_W03, D_U04, D_K01, D_K03, D_K05* | *winter* |
| 75. | **Selected issues in acoustoelectronics** | **30** | **3** | *D_W02, D_W03, D_U04, D_K01, D_K03, D_K05* | *spring* |
| 76. | **Numerical methods** | **30** | **3** | *D_W01, D_W03, D_U04, D_K01, D_K03, D_K05* | *winter* |
| 77. | **Electromagnetic field theory** | **30** | **3** | *D_W01, D_W03, D_U04, D_K01, D_K03, D_K05* | *winter* |
| 78. | **Quantum mechanics** | **30** | **3** | *D_W01, D_W02, D_W03, D_U04, D_K01, D_K03, D_K05* | *winter* |

Annex V.6
to the Education Program at the Doctoral School of the Military University of Technology

## Optional subjects

### Scientific discipline: chemical sciences

| No. | Item Name | number of hours | number of ECTS credits | reference to learning outcomes | Implementation semester per year Academic |
|---|---|---|---|---|---|
| 1. | **Analysis of Chemical Warfare Agents** | 20 | 2 | *D_W03, D_W04, D_UWAT02, D_K02, D_K03* | *winter* |
| 2. | **Chemistry and technology of liquid crystal materials** | 20 | 2 | *D_W01, D_W03, D_U06, D_U02, D_K01* | *spring* |
| 3. | **Chemistry and technology of high-energy materials** | 20 | 2 | *D_W 01, D_W 03, D_U01, D_U04, D_K01, D_K02* | *spring* |
| 4. | **Polymer chemistry** | 20 | 2 | *D_W02, D_W03, D_UWAT02, D_K01* | *spring* |
| 5. | **Chemistry of heterocyclic compounds** | 20 | 2 | *D_W01, D_W03, D_W04, D_UWAT02, D_U01, D_U04, D_K01, D_K05* | *spring* |
| 6. | **Chemical Foundations of Environmental Pollution** | 20 | 2 | *D_W02, D_W03, D_UWAT02, D_K01, D_K03* | *spring* |
| 7. | **Chiral and polar liquid crystal functional materials** | 20 | 2 | *D_W01, D_W02, D_W03, D_UWAT02, D_U02, D_K01* | *spring* |
| 8. | **Physicochemical Properties of Carbon Materials** | 20 | 2 | *D_W01, D_W02, D_W03, DW_04, D_UWAT02, D_U01, D_K03, D_K05* | *spring* |
| 9. | **Physicochemical aspects of the explosion** | 20 | 2 | *D_W01, D_W02, D_W03, D_U04, D_U06, D_K01, D_K05* | *spring* |
| 10. | **History of chemistry** | 20 | 2 | *D_W02, D_W03, D_UWAT02, D_K01* | *winter* |
| 11. | **Ionization methods in analytics** | 20 | 2 | *D_W03, D_W04, D_UWAT02, D_K01* | *winter* |
| 12. | **Methods for preparing samples for analysis** | 20 | 2 | *D_W02, D_W03, D_UWAT02, D_K01* | *spring* |
| 13. | **Spectroscopic methods** | 20 | 2 | *D_W02, D_W03, D_UWAT02, D_K01* | *winter* |
| 14. | **Modeling and simulation computer programs in chemistry** | 40 | 4 | *D_W01, D_W02, D_W03, D_W04, D_U04, D_U05, D_K01, D-K03, D_K04* | *winter* |
| 15. | **Modern nanoporous materials** | 20 | 2 | *D_W02, D_W03, D_U WAT02, D_U01, D_K01, D_K03* | *winter* |
| 16. | **Modern methods of synthesis of functional organic compounds** | 20 | 2 | *D_W01, D_W02, D_W03, D_UWAT02, D_U02, D_K01* | *spring* |
| 17. | **Biomedical polymers and biomaterials** | 20 | 2 | *D_W02, D_W03, D_UWAT02, D_U09, D_K01* | *winter* |
| 18. | **Practical Tools and Concepts for Modern Organic Synthesis** | 20 | 2 | *D_W01, D_W03, D_W04, D_UWAT02, D_U01, D_U04, D_K01, D_K05* | *winter* |
| 19. | **Synthesis of liquid crystals** | 20 | 2 | *D_W01, D_W02, D_W03, D_UWAT02, D_U02, D_K01* | *winter* |
| 20. | **Modern analytical chemistry** | 20 | 2 | *D_W02, D_W03, D_UWAT02, D_K01* | *winter* |
| 21. | **Advanced pyrotechnics** | 20 | 2 | *D_W02, D_W03, D_UWAT02, D_K01* | *spring* |
| 22. | **Advanced spectroscopic methods** | 20 | 2 | *D_W02, D_W03, D_UWAT02, D_K01* | *spring* |

Annex V.7
to the Education Program at the Doctoral School of the Military University of Technology

## Optional subjects

### Scientific discipline: security studies

| No. | Item Name | number of hours | number of ECTS credits | reference to learning outcomes | Implementation semester per year Academic |
|---|---|---|---|---|---|
| 1. | **Social research in security sciences** | **40** | **4** | *D_W WAT01; D_W01; D_W06; D_UO3; D_K03;* | *winter* |
| 2. | **Statistical methods in social research** | **40** | **4** | *D_WO4; D_U O3; D_U04; D_KO1; D K03;* | *spring* |
| 3. | **Security risk management** | **30** | **3** | *D_WO1; D_W03; D_UO3;* | *spring* |
| 4. | **Security Systems Project Management** | **30** | **3** | *D_W03; D_U04; D_K05;* | *spring* |
| 5. | **Safety Systems Engineering** | **30** | **3** | *D_W03; D_W02; D_UO6; D_U10; D_KO5;* | *winter* |
| 6. | **Safety propaedeutics** | **30** | **3** | *D_W02; D W05; D_U01; D_K05;* | *winter* |
| 7. | **Strategies and concepts of state security management** | **30** | **3** | *D_W02; D_U04; D_KO5;* | *winter* |
| 8. | **Crisis management in public administration** | **30** | **3** | *D_WO1; D_W03; D_UO3; D_U12;* | *spring* |
| 9. | **Universal safety** | **30** | **3** | *D_W02; D_W03; D_U01; D_K07;* | *spring* |
| 10. | **Internal security** | **30** | **3** | *D_W02; D_W03; D_KO5; D_KO7;* | *spring* |
| 11. | **Threat intelligence** | **30** | **3** | *D_W03; D_W06; D_U05; D_U07; D_U10; D_K04; D_K05;* | *spring* |
| 12. | **Survey data analysis** | **20** | **2** | *D_WO4; D_U04; D_KO1;* | *winter* |
| 13. | **Multivariate analyses** | **20** | **2** | *D_WO4; D_U04; D_U05; D_KO1; D_K03; D_K04;* | *winter* |
| 14. | **Evaluation research procedures** | **20** | **2** | *D_WO4; D_U04; D_U05; D_KO1; D K03* | *spring* |
| 15. | **Logic and theory of argumentation** | **20** | **2** | *D_WO4; D_U01; D_U04; D_U05; D_KO1; D_K03; D_K04;* | *winter* |
| 16. | **Forecasting and simulations in security** | **20** | **2** | *D_W03; D_W04; D_U WAT01; D_U05; D U13; D_K03; D K04; D K05;* | *spring* |
| 17. | **Modern technologies in security** | **20** | **2** | *D_WO1; D_WO2; D_U; WATO1; D_UO6; D K03;* | *spring* |
| 18. | **Philosophy of security sciences** | **20** | **2** | *D_W02; D_W03; D_U01; D_U05; D_KO1; D_K03;* | *winter* |
| 19. | **Modern terrorism** | **20** | **2** | *D_W03; D_W06; D_U05; D_UO8; D_U09; D_KO1; D_KO6;* | *winter* |
| 20. | **Morale and Security Culture in National and International Relations** | **20** | **2** | *D_U WAT01; D_U WAT02; D_U05; D_U13; D K03; D_K04; D_K05;* | *spring* |
| 21. | **Safety history** | **20** | **2** | *D_W02; D_W03; D_U; WATO2; D_U05; D_K03; D_KO9;* | *winter* |
| 22. | **Strategic communication** | **20** | **2** | *D_WO1; D_WO3; D_UO6; D_U10; D_KO1; D_KO5* | *spring* |

| No. | Item Name | number of hours | number of ECTS credits | reference to learning outcomes | Implementation semester per year Academic |
|---|---|---|---|---|---|
| 23. | **Political security sector** | **20** | **2** | *D_WO2; D_WO3; D_UO8D_U12; D_K02;* | *winter* |
| 24. | **Shaping military security in the 21st century** | **20** | **2** | *D_W04; D_U WAT01; D_U WAT02; D_U05; D_U13; D K03; D_K04; D_K05;* | *winter* |
| 25. | **Information security** | **20** | **2** | *D_W06; D_U01; D_K05;* | *winter* |
| 26. | **The economic dimension of safety** | **20** | **2** | *D_W03; D_U WAT02; D_U05; D_K03; D_K04; D_K05;* | *winter* |
| 27. | **Energy security in the face of socio-economic transformation** | **20** | **2** | *D_W04; D_U WAT01; D_U WAT02; D U05; D_U13; D_K03; D_K04; D_K05;* | *spring* |
| 28. | **Social Determinants of the Security of Modern States** | **20** | **2** | *D_W03; D_W06; D_U04; D_U05; D_KO5; D_K07;* | *winter* |
| 29. | **Environmental security on a global, regional and national scale** | **20** | **2** | *D _W03; D_W04; D_U WAT01; D_U WAT02; D_U05; D 1,113; D_K03; D_K04; D_K05;* | *winter* |
| 30. | **Cultural security factors** | **20** | **2** | *D_W03; D_W06; D_U04; D_U07; D_U10; D_K04; D_K05;* | *spring* |

**Annex VI.1**
**to the Education Program (curriculum) at the Doctoral School of the Military University of Technology**

## Curriculum content for optional subjects
## Scientific discipline: automation, electronics, electrical engineering and space technologies

| No. | Item Name | Curriculum content |
|---|---|---|
| 1. | **Computer Network Administration** | Human-machine relations. Socio-technical system. Communication of network devices. Fundamentals of Windows and Linux administration. Configuration of network devices and multimedia services in wired (Ethernet) and radio (5G) networks. Security, reliability and quality of ICT networks. |
| 2. | **Acoustic Electronics** | Technical applications of elastic waves. Elastic waves in solids and their types. Elastic waves in confined media. Ferroelectric materials. Piezoelectricity. Electrostriction. Excitation and detection of acoustic volume waves. Acoustic volume wave filters and resonators. Construction and properties of interdigital transducers. Filters and dispersion lines with acoustic surface wave. Acoustic convolutors and Fourier processors.<br>Acoustoelectronic sensors of mechanical quantities. Acoustoelectronic activators. Remote identification systems. Basics of synthesis of acoustic surface wave systems. Matching acoustoelectronic circuits to external circuits |
| 3. | **Computer-aided analysis of experimental data** | Selected problems in the field of confirmatory and exploratory data analysis including estimation of parameters of various data models, problems of graphical representation of uni- and multivariate data, processing of multivariate experimental results by means of linear transformations, problems of discrimination including methods of minimal-distance classification, nearest proximity, k-means and hierarchical grouping. |
| 4. | **Smart Antennas** | Basic properties of smart antennas. Construction of antenna arrays. Applied solutions for shaping the characteristics of smart antennas. An overview of algorithms used in smart antennas. The principle of operation of adaptive patterns, the properties of their components and the configurations in which they are used in practice. Simulation models of the adaptation process. |
| 5. | **Digital Image Processing** | Digital representation of images. Intensity transformations and spatial filtration. Spatial frequency processing. Image correction. Wavelet analysis. Morphological image processing. Image segmentation. |
| 6. | **Optical Radiation Detectors** | Physical basics of optical radiation detection. Thermal detectors: thermocouples, bolometers, pyroelectric detectors, thermal detector arrays. Photon detectors: photoresistors, p-n, pin, APD photodiodes, with Schottky barrier, UV, VIS, IR detectors, THz detectors, photomultipliers, MCP microchannel plates. CCD and CMOS sensors. Hybrid matrices. Signal reading systems. Architecture of reading chips for CCD and CMOS sensors. Direct detection systems. Noise models of photoreceiver input stages. Detectors from type II superlattices. QWIP detectors. Barrier detectors. |
| 7. | **Electromechanical energy and signal converters** | Electromechanical systems with rotary motion - mathematical description. Generalized theory of electromechanical energy conversion in relation to Euler Lagrange's formalism. State functions, magnetic coenergy function, and generalized external forces. Dissipative elements. |
| 8. | **Laser Physics** | Heisenberg's uncertainty principle, operator operators and equations, Schrodinger's equation. Harmonic oscillator, electromagnetic field quantization. Blackbody radiation. Interaction of radiation with the medium: probabilities of forced transitions, form of spectral line. Laser medium, three-level and four-level and quasi-three-level systems, laser material equations. Gain saturation effect, the condition of stationary laser generation. Laser output power. Laser resonators. Laser beam parameters. Types of non-stationary generation of lasers. Structure of energy levels of active ions in solid media, levels of ions of rare earth elements, ions of transition group metals. |
| 9. | **Physics of laser media** | Interaction of an electromagnetic field with a medium (quantum description). Action of a harmonic perturbation on a quantum object. Electron energy levels of free ions. Therms and multiplets of ions of rare earth elements and transition group metal elements Elements of group theory and their matrix representations. Splitting the energy levels of ions in a crystal field. Electron-phonon interaction. Energy levels of transition group metal ions. Phenomena of energy transfer between ions in active media. |

| No. | Item Name | Curriculum content |
|---|---|---|
| 10. | **Photovoltaics** | Quantitative and qualitative characteristics of solar energy. Semiconductor theory in the aspect of photovoltaics. Structures of modern photovoltaic cells. Technology for the production of photovoltaic cells, modules and panels. Photovoltaic modules. Photovoltaic installations. |
| 11. | **Supercontinuum Radiation Generation** | The idea behind the supercontinuum (SC) generation process. Characteristics of tertiary-order nonlinear phenomena (phase self-modulation, cross-phase modulation, self-focusing, four-wave mixing, forced Raman scattering). General characteristics of optical pumps used for SC generation, characteristics of nonlinear media used for SC generation in the visible, near and mid-infrared ranges. Structure and properties of optical fibers with a step change in the refractive index and optical fibers with a photonic crystal structure. Dispersion and methods of shaping dispersion characteristics. Nonlinear Schrodinger equation. Description of the dynamics of SC radiation generation using pulses with duration fs. Description of the dynamics of SC radiation generation using pulses of duration ps, ns and continuous beams. Solitons. Design solutions of supercontinuum radiation sources with high output average power. Applications of supercontinuum sources. |
| 12. | **Imaging Information Engineering** | Machine vision systems, analysis of fast-changing phenomena and processes, interpretation of 2D and 3D scenes, recognition and identification of objects. Fusion of images and data in information systems: analysis and fusion of images in the spectral bands UV, VIS, NIR, IR, THz, analysis of image material based on metadata. Imaging technology in virtual and augmented reality systems: imaging technology in Virtual Reality (synthesis of 3D models, capturing the movement of objects), Mixed Reality – key system components, application solutions. |
| 13. | **Encoding and recognition of radio transmissions** | Error-proofing of data transmission in the SERIAL TONE (MIL-STD-188-110A) system operating in the shortwave range. Error-proof data transmission during automatic ALE (Automatic Link Establishment) connection in a shortwave channel. Analysis of selected radio communication protocols and corresponding algorithms for encoding binary information sequences. Algorithms for generating transmission errors for binary strings corresponding to selected radio communication protocols. Determination of distinctive features enabling automatic recognition of transmission protocols. Algorithm for recognition of selected transmission protocols. Block and convolution code recognition algorithm. |
| 14. | **Crystallography** | Geometric crystallography. Straight and reverse network. Transformations in crystallography. Symmetry in crystallography. Operations and symmetry elements. Matrix representations of symmetry operations. Definition of symmetry group. Characteristics of point and spatial symmetry groups. The symbolism of Hermann-Mauguin and Schoenflies. Classification and characterization of crystal structures. Defects in crystals. Basics of diffractive methods for studying the structure of crystals. Systematic extinctions. Phase problem and ways to solve it. Basic methods of diffractive studies of crystal structure. Studies of defects in the crystal structure and microstructure of polycrystals. Diffraction in the language of Fourier transforms. Tensor description of anisotropic physical properties of crystals. |
| 15. | **Laser absorption spectroscopy in gas sensors** | Gas detection methods and defining gas sensor parameters. Laser absorption spectroscopy. Optical spectra of gas molecules. Basics of optoelectronic gas sensors. Methods to improve the detection limit. Measurements of concentrations in samples of gas mixtures using optoelectronic sensors. |
| 16. | **Laser-plasma radiation sources X-ray and extreme ultraviolet (EUV)** | Methods of producing X-rays and extreme ultraviolet radiation (EUV), basics of laser-generated plasma physics and X-ray and EUV optics, principles of operation and construction of laser-plasma sources of X-ray radiation and extreme ultraviolet radiation (EUV), examples of the use of these sources in science and modern technology. |
| 17. | **Lasers for medical applications** | Description of optical properties occurring in biological media. Physical phenomena and their application in optical therapy and diagnostics. Selected methods of forming radiation distributions in laser systems for medical applications. Laser systems for biostimulation, selected optical diagnostic systems, therapeutic kits – planned effects of laser beam interaction with tissues and selected methods of implementation. Medical applications sources with pico- and femto-second pulse durations. Examples of design solutions for laser sets for medical applications and the therapeutic and diagnostic effects obtained. |
| 18. | **Pico- and femtosecond lasers** | Characteristics of supershort laser pulses and their propagation. Femtosecond optics, dispersion and its compensation. Selected problems of the interaction of supershort pulses with matter. Mode synchronization as a method of generating ps and fs pulses, description in the time and frequency domain. Active and passive mode |

| No. | Item Name | Curriculum content |
|---|---|---|
| | | synchronization, realization of passive mode synchronization. Modern solutions of fs lasers. In the direction of atto-seconds. |
| 19. | **Fiber lasers** | Optical fibers, selected geometries, eigenproblem for the fiber, propagation of E-M radiation in optical fibers. Double-walled fibers and photonic fibers. Design solutions for laser pumping systems and fiber amplifiers. Semiconductor pumping lasers used. Fiber laser resonators – structure and properties. Selected methods of shaping the radiation spectrum – doped media. Structure of energy levels of active ions in solid media, levels of ions of rare earth elements, ions of transition group metals - selected issues. |
| 20. | **Mathematical models of the electromagnetic field** | Analytical and numerical methods of calculating the electromagnetic field. Differential relationships. Distribution. Orthogonal functions in wireless communication (LTE and 5G) and radiolocation. Wave propagation in materials and metamaterials. Simplified analytical models for calculating the radiation field. Techniques of calculation using potentials. Radiation field analysis. Field of the elementary Hertz dipole. Morphology of the electromagnetic field. Mathematical and physical conditions of the distant zone criterion. Computational numerical electromagnetism - differential methods. |
| 21. | **Finite Element Method** | Mathematical foundations of FEM. Generation of 2D and 3D meshes. Implementation rules. Libraries supporting FEM programming. Commercial simulation tools. |
| 22. | **Methods of analysis and measurement of random signals** | Generalized structure of random signal analysis procedures. Methods of parametric and non-parametric estimation of signals. Conditions for the implementation of measurements minimizing errors in the estimation of parameters and characteristics. Stationarity, periodicity and normality tests. Assessment of the degree of correlation of signals. Methods of analysis of correlation and mutual spectrum of signals. Estimation of transmittance of the transmission channel. |
| 23. | **Data mining methods and tools** | Basic concepts of "data mining", optimization methods and algorithms used in data mining. Linear and logistic regression methods. Bayes classifiers. Decision trees. MLP and RBF artificial neural networks. Generalization abilities of neural networks. SVM support vector network and its applications in data mining. Classifier and predictor teams. Methods for assessing the quality of classifiers and predictors. Deep neural networks and methods of their learning Transformations and methods of reducing the dimension of data. Selected methods of generation and selection of diagnostic features. Sharp and fuzzy methods of grouping data. Multidimensional data visualization Examples of data mining methods. |
| 24. | **Methods of logical synthesis** | Tasks of logical synthesis. Two- and multi-level synthesis. Algorithms of the ESPRESSO method. Selected procedures of the SIS and Demain programmes. Principles of multi-valued and symbolic minimization. Functional decomposition of combinational systems and its models. Decomposition of sequential circuits: ROM address modification chips and ROM content modification chips. The issues discussed during the lectures will be practiced practically as part of calculation and laboratory exercises, and the main effect of the education will be the acquisition of the ability to consciously use logical synthesis methods in the design of digital devices. |
| 25. | **Minimizing the electromagnetic susceptibility of infiltration of IT devices** | Electromagnetic disturbances as revealing emission. Measurement of the level of electromagnetic disturbance emissions. Uncertainty of measuring the level of electromagnetic disturbance emissions. Assessment of the quality of the results of measurements of the level of emission of disturbances. Protection of IT devices against electromagnetic penetration of information in the form of shielding and filtration. Factors affecting the required shielding efficiency and insertion loss of power supply filters. Methodologies for measuring parameters affecting the level of electromagnetic safety (shielding efficiency, insertion loss of power supply filters and signal filters, absorption and dispersion losses of materials). Examples of applications for the protection of IT devices against electromagnetic penetration of information. |
| 26. | **Nonlinear Laser Conversion** | Elements of crystallography and crystal optics. Properties of uniaxial and biaxial crystals (KDP, LiNbO3, KTP, BBO, LBO, etc.). Electromagnetic wave in a crystal. Frequency mixing in a three-wave approach. Phase matching, scalar and vector synchronizm. Generation II of the harmonic of light and the summation and differential frequencies in uniaxial and biaxial crystals. Parametric light generators and amplifiers, tuning methods. Generation threshold and conversion efficiency. Quasi-phase matching. Nonlinear crystals with a periodic domain structure. Design and application of Optical Parametric Chirped Pulse Amplification circuits |

| No. | Item Name | Curriculum content |
|---|---|---|
| 27. | **Scientific and engineering calculations** | Overview of basic numerical methods in the context of implementation. Tools for engineering calculations. Parallel programming. Processing and presentation of calculation results. |
| 28. | **Optoelectronics in safety systems** | Propagation of optical radiation in the atmosphere, reflectance, safety of vision. Laser Rangefinder, Basics of Operation, Flow Chart, Range Equation Improvement of the Noise Signal Ratio, Timing, Probability of Detection, and Probability of False Alarm. Discussion of the principle of operation of lidars: scattering, DIAL, fluorescent, Raman, Doppler. Flame detector, laser scanner. |
| 29. | **Coherent Light Optics** | Preliminaries of stochastic processes. 1st order thermal and laser light statistics. Partially polarized radiation, coherence matrix, degree of polarization. 2nd order statistics, spatiotemporal coherence function. Propagation of the spatiotemporal coherence function, boundary forms of the spatiotemporal function, Van Cittert-Zernike tw. Radial temporal coherence, measurement of the coherence path in the Michelson interferometer, Spatial coherence of radiation, measurement of the coherence radius in the Young interferometer. Measurements of radiation coherence parameters. |
| 30. | **Plasma in science and technology** | Introduction to plasma physics, basic concepts. Movements of charged particles in electric and magnetic fields. Plasma in terms of fluid mechanics. Atomic processes in plasma. Magnetic and inertial maintenance of plasma. Plasma diagnostics. Applications of plasma in technology. |
| 31. | **Remote Sensing Basics** | Interaction of electromagnetic radiation (from microwaves to cosmic rays) and corpuscular radiation and acoustic fields with matter. Physical basis of spectroscopic methods – absorption, scattering, radiation emission. Forms of energy of an atom and a molecule. Nuclear magnetic resonance imaging (NMR) (radiospectroscopy). Electron paramagnetic resonance (EPR) (microwave spectroscopy). Rotational and oscillatory spectra (infrared spectroscopy). Electron spectra (VIS-UV spectroscopy). Active and passive methods of electromagnetic radiation detection as well as image recording and analysis. Spatial, temporal, radiometric and spectral resolution. Multispectral remote sensing. Laser remote sensing systems. Application of laser spectroscopy methods in lidar systems. Spectroscopic methods in the analysis of environmental contamination and pollution. Sensors for security systems and for military applications. |
| 32. | **Basics of knowledge about viruses and other pathogens for engineers** | Presentation of selected issues of microbiology, epidemiology and public health in the light of the latest scientific discoveries. Using the achievements of bioinformatics to describe the world of microorganisms. Discussion of contemporary threats to human and animal health, basic groups of pathogens and ways to prevent infections and infestations. Zoonotic diseases. Gene and genome engineering, biotechnology, threats to ecosystems. The concept of One Health. Basics of immunoprophylaxis and hygiene. Pathogens are particularly dangerous in states of war and natural disasters. |
| 33. | **Measurements of basic parameters of laser radiation** | Measurement methods of radiation spectrum, radiation power and energy, pulse duration and pulse repetition frequency, radiation beam divergence angle. Familiarizing yourself with the basics of laser safety |
| 34. | **Designing safety systems** | Security strategy and principles for creating technical protections. Normative principles and a set of good industry practices. The range of technical protection measures that can be applied. Specificity of protective devices designed for outdoor and indoor applications. A general overview of the solutions used. Characteristics of a set of security devices for indoor and outdoor applications. Working conditions and restrictions on this account. Structure of the technical and detailed design. The scope of the technical executive design in the security industry. Characteristics of the hazard analysis and the concept of the technical design. Rules for detailed design and cost estimation. Design study in the field of technical and detailed design. Required resources to lay the groundwork for the project. Threat analysis. The concept of technical protection of the security system. Rules for conducting a hazard analysis for sample objects. Characteristics of the numerical determination of the scale of the object's hazard. Rules for describing the site area. Attack scenarios and verification of the possibility of technical protection against them. Technical description of the detailed design. Characteristics of the principles of designing alarm systems. Methods of description and graphical representation of the technical design. The way documentation is organized. Examples of technical executive designs of critical infrastructure facilities. Documents related to the technical detailed design. Rules for the development of an investor's and "blind" cost estimate. The need to compile technical catalogues and technical data sheets of devices. |

| No. | Item Name | Curriculum content |
|---|---|---|
| 35. | **Programmable and Purpose-Built Circuits** | Technology and methods of designing specialized digital integrated circuits (ASICs) and programmable digital circuits (FPGAs). Principles of digital circuit topography design, power distribution and clock distribution, I/O buffers, IP blocks, and design tools. |
| 36. | **Acoustic sensors** | Features and parameters of modern acoustic sensors. Mechanical structures. Piezoresistive sensors. Magnetoelectric and electromagnetic transducers. Condenser drivers. Acousto-optical transducers. Magnetostrictive transducers. Piezoelectric transducers. Systems with acoustic surface waves. |
| 37. | **Microwave sensors in radiolocation** | Microwave sensors in radiolocation. Broadband microwave sensors with noise signals. Sensors in medical diagnostics. Anti-collision sensors. |
| 38. | **Smart radio networks** | Smart radio network concept. CR architectures. Semantic context of CR. Problems of teaching in the CR system. Dynamic spectrum management. Problems of reception in CR. Ad-hoc CR networks, collaborative MIMO. Standards for CR networks. Security problems in CR. Current research programs in the area of CR. |
| 39. | **Optical Spectroscopy for Life Sciences** | The laws of absorption, dispersion and emission. Excited states of molecules. Orbitals. Photophysical and photochemical phenomena. Jabłoński's diagram Spectroscopic apparatus – light sources, detectors, monochromators, methodologies. Biomaterials and Studied Objects in Biomedical Engineering. Fourier and photoacoustic spectroscopy. Molecular spectroscopy (UV-VIS, fluorescence, Ramana, FTIR). Atomic spectroscopy (ICP, ASA, flame photometry). Spectroscopy in other radiation ranges (NMR, EPR, microwaves, X) |
| 40. | **Digital systems in optoelectronic devices** | Digital system architecture. Digital system design principles. Basic control and digital signal processing. Design of digital modules for signal control and processing. Design of microprocessor systems. Embedded systems design. Exchange of information between digital system modules and with external systems |
| 41. | **Test and measurement systems in the test laboratory** | Signal conditioning systems. Control and measurement systems. Measurement signals and their processing. Measuring instruments and platforms. Interfaces of measuring systems. Automated control and measurement systems in practice. |
| 42. | **Fiber optic technology** | Optical fibres and optics components. Testing of optical fibers and optics components. Lasers and optical transmitters. Photodetectors and optical receivers. Optical signal modulators. Optical signal amplifiers. Digital optical links. Measurements of characteristics and parameters of fiber optic links. Multiplexing and demultiplexing. Coherent transmission. Studies of the characteristics of fiber optic interferometers. Optical analogue links. Radio and fiber optic systems. Optical links in free space. |
| 43. | **Terahertz technique** | Introduction to THz radiation. THz radiation sources – semiconductor and photonic. THz radiation detectors. Photoconductive switches. Time domain spectrometry. Imaging and tomography. Sensors, waveguides, metamaterials THz. Applications THz. |
| 44. | **Information concealment technique (steganography)** | Glossary of data hiding techniques. An overview of practical applications for data hiding in multimedia, speech, radio and network protocols. Differentiation of basic types of algorithms: watermarking and steganography. Classification of data hiding methods. Basic algorithms for embedding and data extraction and their properties. Development of assumptions for the designed system. Selection of the method of embedding and extraction of hidden data. Perceptual models for the Human Auditory and Visual Model. Correction of the additional signal. Methods of evaluating perceptual transparency. Methods of evaluation of resistance and steganoanalytical susceptibility. Examples of software and hardware implementations of data hiding systems. New methods of hiding data – cases and scenarios of action. |
| 45. | **Techniques in Biomedical Engineering** | Fundamental issues and research techniques in biology and biomedicine will be discussed, including the main points of bioengineering and biotechnology. Thus, the skills necessary to undertake interdisciplinary research in these areas of science will be developed. The principles of construction of essential research equipment will be presented, including measurements based on fluorescence excitation. The possibilities of bioinformatics analysis and international databases will be discussed. In addition, the principles of good laboratory practice and safe work in biomedical laboratories will be presented. Requirements for conducting reliable measurements and elaborating results in biomedical research and medical bioengineering will also be discussed. |

| No. | Item Name | Curriculum content |
|---|---|---|
| 46. | **Field theory** | Basic concepts and equations of the theory of the electromagnetic field. Maxwell's equations, Properties of mediums and boundary conditions. Fields at the boundary of medium separation, Electromagnetic field energy. Types of electromagnetic phenomena, Electrostatics and magnetostatics. Stationary and quasistationary electromagnetic fields, Maxwell's equations in complex form for harmonic waveforms, Electromagnetic waves. Wave equation for the area without sources, Uniform plane wave. Propagation parameters of a homogeneous plane wave, Propagation of a homogeneous planar wave in a lossless dielectric, Propagation of a homogeneous planar wave in lossy dielectrics, Propagation of a homogeneous planar wave in a good conductor, Structure of a homogeneous planar wave, Reflection and refraction of a homogeneous planar wave at a planar boundary of two different mediums. Reflection and refraction of a homogeneous plane wave at the boundary of two different dielectrics, Reflection of a homogeneous plane wave propagating in a dielectric from the plane surface of a conductive medium Electromagnetic potentials and radiation, Potentials of alternating fields, delayed potentials. Hertz vector potential, Field of elementary oscillator, Electromagnetic field at short distances from the oscillator, Electromagnetic field at long distances from the elementary oscillator, Wave phase, wave type, phase velocity, Propagation of waves in parallel systems of conductors and in waveguides, Transverse electromagnetic wave TEM, Transverse magnetic wave TM in a rectangular waveguide, Transverse electric wave TE in a rectangular waveguide, Base Type, Cuboid Cavity Resonator |
| 47. | **Thermal imaging and infrared technology** | Methods of correction of heterogeneity of matrix detector characteristics in thermal imaging devices. Radiometric calibration of a thermal imaging camera and its impact on the accuracy of remote measurement of temperature and radiation power. Thermal imaging methods for the recognition of chemicals and minerals are based on spectral emissivity analysis. Multi and hyperspectral infrared systems. Active thermal imaging, measurement capabilities and prospects for its application. Infrared imaging polarimetry. |
| 48. | **Optical Radiation Detection Systems** | Signal processing systems for detectors and arrays. Phase-sensitive detection (Lock-In). Detection circuits with synchronous signal integration. Signal averaging detection systems. Coherent detection (heterodyne, homodyne). Advanced methods of optical signal processing in practice. |
| 49. | **Laser beams** | Modeling of laser beams, Measurements of laser beam parameters. Design of optical paths of laser beams. Selected systems and systems of laser beam generation, shaping of laser beam transverse profiles, Folding of laser beams, propagation of laser beams in the atmosphere. Selected applications of laser beams in military science, technology and technology. |
| 50. | **Modern transducers measuring physical quantities** | The concept of a measuring transducer and their classifications. Static and dynamic properties of transducers. Resistance strain gauges. Capacitive, piezoelectric, inductive, magnetoelastic, thermoelectric and pehametric transducers. Conductivity transducers. Flow meters. Fiber optic transducers, their specifics and classifications. Optoelectronic and acoustic transducers. Photoacoustic and photonic transducers. Integrated transducers. |
| 51. | **Selected issues of the operation of anthropotechnical systems** | Interpretation of the concept of operational diagnostics. Methods and ways of diagnosing. A model of the operation process in terms of safety. Uncertainty in the processes of diagnosis and surveillance. Interpretation of the concept of operational reliability. Indicators of operational and maintenance reliability basic reliability structures. Proactively improve reliability. Selected timetables of the facility's runtime. |
| 52. | **Advanced microelectronics technologies** | Modern technologies for the growth of single crystals and the formation of single crystal layers. Technology and the problems of miniaturization. Ultra-fast nanometer electronics. Graphene in modern semiconductor technology. Selected problems of spintronics. Engineering of the energy structure of semiconductors. |
| 53. | **Applications of lasers in technology** | Types of lasers, optical components and systems used in material processing – an overview. Examples of lasers in macro and micro machining. Interaction of radiation with materials, Lorentz-Drude model, optical and thermal parameters of materials, reflection, absorption, energy transport, phase changes, plasma shielding, interaction ranges, thermal conductivity equation. Lasers in surface engineering – polishing, engraving, texturing, hardfacing, impact hardening, cleaning, direct interference lithography in micro- and nanotechnology. Application examples. Lasers in volumetric processing of materials – hardening, welding, cutting, drilling and other applications of lasers in industry. Application examples. |

| No. | Item Name | Curriculum content |
|---|---|---|
| 54. | **Advanced techniques for digital system design in FPGAs** | The Advanced FPGA Digital Systems Design Techniques course discusses issues related to, m.in others, the development of integrated digital systems in FPGAs, topographic design, effective use of design constraint attributes, preparation of functional tests, and good design practices. The course is divided into a theoretical part (lectures) and a practical part (laboratories and a project), and the results of the project work carried out are discussed at the seminar. Before taking the course, it is advisable to know the Hardware Description Languages (HDL) and the architecture of FPGAs. |
| 55. | **Selected problems of the statistical theory of radiolocation** | Signal detection and mathematical statistics, optimization criteria (Bayes criterion, Neyman-Pearson criterion, criterion for maximizing SNR values, min-max criterion). Signal detection rule, relationship of the likelihood ratio (decision statistics) for basic signal models with the receiver structure. Bayesian synthesis of TES systems. Bayesian estimation of signal parameters – radar echoes. Relation of the radar uncertainty function (Woodward function) with the problems of synthesis of complex signals. Distinguishability and accuracy of measurements in time and frequency. Cognitive radar vs "silent" radar. |
| 56. | **Signal processing in radars** | Presentation of basic and advanced techniques of radar signal processing. Types of probing signals. Filtration matched. Doppler filtration. Eliminate interference. Radar echo detection. |

**Annex VI.2**
**to the Education Program at the Doctoral School of the Military University of Technology**

## Curriculum content for optional subjects
## Scientific discipline: information and communication technology

| No. | Item Name | Curriculum content |
|---|---|---|
| 1. | **Quantum Algorithms III** | Mathematical foundations of quantum computing: operators in Hilbert spaces, tensor product of Hilbert space and vectors in this space, Hermitian and unitary operators. Description of a quantum system and its states. Description and properties of measurement in quantum systems. Forms of recording information. Information processing. Quantum gates. A generic form of a quantum algorithm. Deutsch-Jozs problem, Grover's algorithm, Shor's algorithm. Quantum optimization algorithms. Quality of quantum computing. |
| 2. | **Algorithm Analysis III** | Algorithms and algorithmic problems. Introductory concepts. Definition of an algorithm, criteria for the quality of algorithms, complexity of the algorithm and complexity of the task, numerical stability of algorithms, principles of designing effective algorithms. Computational complexity of combinatorial algorithms. Types of tasks, sequential models of computation (DTM and NDTM), problem transformations, computational complexity classes, NP-completeness, temporal and memory complexity of algorithms (pessimistic and expected), sensitivity of algorithms (pessimistic and expected), examples of complexity estimation. Approximate algorithms Methods for estimating the accuracy of algorithms. Polynomial approximation schemes (PTAS), fully polynomial approximation schemes (FPTAS), examples of approximation algorithms for computationally difficult problems. Heuristic search methods. Techniques for designing effective algorithms Recursion vs. iteration, divide-and-conquer techniques, parallelization techniques, advanced data structures and algorithm complexity. Advanced models and methods of graph and network theory. Examples of the use of methods for designing effective algorithms. |
| 3. | **Analysis and synthesis of visual information III** | Weierstrass theorem and orthogonal spanning of signal state space. Basics of the theory of function approximation. Transforms with orthogonal span with unlimited carrier. Laplace's and Fourier's Transform. Orthogonal bases with limited carrier. Wigner, Wannier, and wavelet functions. Wavelet transform – definitions and examples. Applications of the wavelet transform. Process singularities as extreme and/or singularity points of the signal. Searching for extreme and singular points of the signal in wavelet spaces. |
| 4. | **Next-generation wireless systems (NG)** | Development trends. Networking. Radio interface techniques. Development of services and applications. Organization and management in NG systems. Applications of artificial intelligence (AI) and machine learning (ML). Bulk systems, D2D (Device-to-Device) systems, transport systems. Cognitive NG networks. Green communication. |
| 5. | **ICT Systems Diagnostics III** | General theory of functional testing. Types and properties of tests. Error and control effectiveness of the test. Methods of determining tests. The use of tests in recognition (of the condition of the object), in technical diagnostics and in data processing. Test Methods for Digital Devices and Logic Networks. Ways of propagation of unfitness. Conditions for the transfer of the consequences of unsuitability. Masking unsuitability. Roth's algebra. Random testing methods for digital devices. Methods for compressing test results. Compression spectrum. Signature analysis and its application. Diagnostic procedures. Thorough diagnosis. Methods of determining optimal procedures. Models and methods of system diagnostics. Self-diagnosing systems. Diagnosing the system by means of diagnostic dialogue between its elements. Structures of diagnostic dialogue and their properties. Diagnosing the system by means of diagnostic opinions on its elements. Structures of diagnostic opinions and their properties. Determination of diagnostic structures with specific properties. Software Diagnostics. Properties of the program control transfer network. |
| 6. | **Efficiency of ICT systems III** | ICT network efficiency indicators. Stochastic models of event streams. Models of local and wide area computer networks. Wireless and cellular network models. Stochastic and deterministic problems of task scheduling. |
| 7. | **Elements of forecast theory III** | Basic concepts of forecast theory. Linear and nonlinear trend models. Naïve models, moving average and exponential smoothing models. Forecasting based on econometric models. Forecasting qualitative phenomena. |

| No. | Item Name | Curriculum content |
|---|---|---|
| 8. | **Software Evaluation III** | The essence of software evaluation. The concept of software quality. Factors shaping the quality of software: quality of the project, quality of implementation. Software quality assessment criteria: computational complexity, reliability. Methods for assessing the computational complexity of algorithms. Computational complexity of algorithms: time complexity, memory complexity. Methods for assessing the time complexity of algorithms. Asymptotic complexity of recursive iterative algorithms. Methods for assessing software reliability. Software reliability models: time domain models, data domain models, phenomenological models. Methods of practical use of software reliability models. Software quality assurance methods. Reviews and inspections. Principles of conducting inspections and reviews in the software development process. Testing. Types and methods of software testing. Design test datasets. Criteria for completing the testing process. Formal methods of constructing and verifying the correctness of programs. Hoare's logic. Inference rules. A description of the program through states and operations. The concept of implicit specification of operations. Proving the correctness of operations. Proving the correctness of programs. The role and importance of standards in the process of ensuring the required quality of software. Characteristics of standards in the field of software engineering. Software quality standards. Use of standards. |
| 9. | **Physical Foundations of Quantum Information III** | Introduction to quantum mechanics. Introduction to quantum electrodynamics. Hilbert space and L2 space. Q-bit and its physical implementations. Mathematical representations of q-bit. The uncertainty principle and its consequences. Mixed states and convoluted states. The Stern-Gerlach experience. Schrodinger's cat and the superposition of states, Bell's inequality. Superposition and entanglement of states. Open layout and closed layout. The holism of EPR states. Space Seal. Fermions and bosons and entanglement. Physical realizations of entangled states in optics – examples. Teleportation of states. |
| 10. | **Computer Graphics III** | Introduction to computer graphics, basic applications - computer animation, visual simulation, AR and VR systems. Vector graphics, raster graphics - representation of image data. Basic graphics standards - GKS, PHIGS, OpenGL. Raster algorithms - Bresenham, anti-aliasing, HLHSR. Geometric modeling - curves and surfaces, 3D objects. Geometric transformations - translations, rotations, scaling, projection. Color modeling - color perception, CIE, RGB, HLS, HSV(B) color models, color space transformations. Lighting modeling - lighting models, shading algorithms, raytracing, radiosity. Texture Modeling - Defining, mapping, and filtering textures. |
| 11. | **Software Quality Engineering III** | Reliability as a measure of software quality. Software quality metrics. The concept and indicators of software reliability. Organizational and software methods of shaping the reliability of software in the process of its development. Software reliability models. Classification and general characteristics of software reliability models. Time-domain models: reliability rates, finite error models, infinite error models. Models with the data domain: reliability indicators, the concept of the operational profile of the program, the Nelson model. Phenomenological models: complexity measures based on the number of lines of source code, Halstead measures, McCabe cyclomatic measures, object-oriented measures. Model evaluation criteria. Methods for determining the parameter values of software reliability models. Maximum probability method. The method of least squares. Examples of estimation of parameter values of selected software reliability models. Modeling the reliability of the program in the testing process. A mathematical model of the program testing process. Program testing strategy. Program reliability indicators. The cost of the testing process. Use optimization methods to determine the program testing strategy. Methods of computer-aided assessment of software reliability. Assessment of the possibility of computer-aided software reliability assessment. SMERFS software package^3. CASRE software package. Software quality engineering. Quality management system. ISO 9001:2000 standard. CMMI Maturity Model. Use of standards related to software reliability assessment: IEEE/ANSI Std 982.1- 1988, IEEE/ANSI Std 982.2-1988. |
| 12. | **Cryptology III** | Basic concepts and history of cryptology. Modular arithmetic. Classic cryptosystems. Cryptanalysis of ciphers. Stream ciphers. Block ciphers. AES and NESSIE competition. Asymmetric cryptosystems. Hash functions. Cipher security. Cryptographic protocols. Applications of cryptography |
| 13. | **Mathematical Methods of Decision Support III** | Decision-making process and cycle. Mathematical modeling of decision-making processes. Optimal and approximate decisions. Modeling the preferences of the Decider. Sensitivity analysis of optimal solutions. Usability features. Decision- |

| No. | Item Name | Curriculum content |
|---|---|---|
| | | making under uncertainty. Methods of determining the representation of sets of irreparable decisions. Methods for determining "approximate sets of optimal solutions". Examples of modeling decision support processes. |
| 14. | **Discrete Mathematics III** | Relationships and functions. A relationship of equivalence, order, good order. The principle of abstraction. Maximum, minimum, largest, smallest, majoranta, minoranta. Surjections, injections and beatings. Permutations. Generalized operations on sets. Recursions. Counting sets and functions. Counting techniques. Binomial and multinomial coefficients. Stirling numbers. Surjection, injection and bijection counting. Bell numbers. Euler numbers. Catalan's numbers. Break down the number into its components. Asymptotics. Creating functions. Asymptotic notations. Universal recursion. Asymptotic approximations. Operations on creating functions. Generating functions for selected strings. Determining the number of solutions to Diophantine equations. Recursion Solution. Sets with repetitions. Divisibility of integers. Modulo operation. Division algorithm. Euclid's algorithm. The basic theorem of arithmetic. Congruences. Fermat's small theorem. Solving congruences and congruence systems. Chinese residual theorem. Euler's Functions and Theorem. Elements of graph theory. Graph counting. Coloring vertices and graph branches. Associations in graphs. Transversals and matroids. Capacitive networks. |
| 15. | **Generative and aspective methods in manufacturing software III** | Advanced modeling in UML: diagrams of classes, use cases, sequences, states, activities. UML methodology: application field and consistency rules. Metaprogramming and metamodeling. Generative techniques: Generation of state and test machines. Contract specification on the example of OCL. Elements of AspectJ-oriented programming: junction points, intersection points, Councils, AOP applications |
| 16. | **Numerical methods III** | Basic concepts of numerical analysis: vectors, matrices and norms; rounding errors in computer calculations; conditioning of the calculation task; numerically correct and numerically stable algorithms. Solving linear systems of algebraic equations: conditioning the problem; Gaussian method with full and partial selection of the main element; the Cholesky-Banachiewicz method; the Householder method; the impact of rounding errors on the result; poorly conditioned tasks. Linear least squares problem: distribution of matrices by special values; a generalized inverse matrix and a generalized solution of a system of linear equations; algorithm with a normal equation; algorithm with Householder transformation; the conditioning of the task; regularization. Finding the roots of nonlinear equations: the secant method and its properties; tangent method, sphere and convergence exponent; fishing method. |
| 17. | **Multi-Criteria Optimization Methods III** | Mathematical basis of optimization. Formulation of a multi-criteria optimization task. Dominant and non-dominated solutions. Pareto optimization. Ideal and anti-ideal point. A compromise solution. Methods of objectivizing rankings. Hierarchical optimization. Optimization for multiple goals. Examples of formulating multi-criteria optimization tasks. |
| 18. | **Mathematical Modelling III** | Principles of mathematical modeling. Mathematical model. Data, decision variables and indicators. Analysis of the information level. Correct data. Acceptable decisions. Possible KPI values. Goal Achievement Evaluation Features. Optimization task. The task of extremization. Multi-criteria and game models. Criterion space. A relationship of domination in the Pareto sense. Lexicographic order. The method of compromise. Ideal point and nadir point method. Satisfactory solutions. Methods of analyzing game situations. Extensive form of the game. Normal character of the game. Dominated strategies. Iterated elimination of pure strategies. The best answer. The point of equilibrium in the sense of Nash. Backward induction method. Coalition games. Multiple games. Probabilistic models Risk-based decision-making. Replacing a random variable with its characteristics: expected value, quantile, probability of favorable and unfavorable events, variance. The principle of not taking small probabilities into account. Application of multi-criteria methods. Dominance of the efficiency of the indicator. Decision trees. Lotteries. Usability feature. Fuzzy models Fuzzy sets. Optimal decisions in fuzzy conditions. The goal, limitations and decision are blurred. Operations on fuzzy sets. Cartesian product. Fuzzy numbers. Relationships blurred. Elements of fuzzy logic. Fuzzy: negation, conjunction, alternative, implication, and equivalence. Models with uncertainty Maximin , maximax, Hurwitz, Laplace, Savage criteria. Confidence indicator. Uncertain variables. Decision making with uncertain data. A relationship of indistinguishability. Lower and upper approximation of the set. Approximation |

| No. | Item Name | Curriculum content |
|---|---|---|
| | | accuracy. Optimal decisions with approximate data knowledge. Decision boards. Deterministic and non-deterministic rules. Uncertain variables. |
| 19. | **Modeling and verification of ICT networks III** | Basics of verification of ICT systems (ST) based on formal models: model verification, models of parallel systems, linear-time properties, safety and service life. Elements of Petri Net Theory (SP): model properties, problems of marking reachability and network lifetime, constructing an achievability tree and a state diagram. Basic types of Petri nets: time, stochastic, coloured (CPN). Time-based ST modeling: analysis of simple and interval time SP, analysis of temporal stochastic networks. Elements of the theory of time automata. ST modeling with time automatons. Examples of tasks of modeling and verification of ICT systems: testing the properties of the system based on the model using the following tools: PIPE-2, CPN Tools, UPPAAL. |
| 20. | **Modeling Conflict Situations III** | Modeling conflict situations. Quality criteria in conflict situations. Game models. Strategy games. Balance points. Balance in Nash's sense. Cooperative games. Modeling group decision-making processes. Optimization task with multiple goals. Trade-offs in game models. |
| 21. | **Business Process Modeling, Simulation and Analysis III** | Modeling of functions and business processes. Principles of designing the processes of the organization's functioning. Models and methods of business process design. Function hierarchy diagrams. Business process diagrams. Service process diagrams. WorkFlow systems. BPMN notation. BPMN Notation Properties. Objects in BPMN notation. Events, simple and complex activities, logic gates, and control flows in BPMN notation. Describe roles in BPMN notation. Process patterns in BPMN notation. WorkFlow systems modeling and analysis environments. Review of WorkFlow modeling and analysis environments compatible with BPMN notation. ARIS environment from Software AG. WebSphere Business Modeler Advanced from IBM. Sybase's Power Designer environment with Simul 8. Testing the effectiveness of WorkFlow systems. Methods of examining the properties of WorkFlow systems composed of business process diagrams. Time and cost characteristics of business processes. WorkFlow system performance indicators. Use of WorkFlow class system modeling and analysis environments. |
| 22. | **Reliability of Systems III** | Basic concepts of reliability theory. The generalized state of the object. Assessment of the condition of the facility. Structural function. Reliability states. Reliability of the technical facility. Reliability model. Reliability indicators. Classification of objects from the point of view of reliability tests. Reliability of non-renewable facilities Reliability model of a non-renewable facility. Definitions of reliability indicators of a non-renewable facility. Basic properties of reliability indicators of a non-renewable facility. Methods for determining the values of reliability indicators for non-renewable facilities. Selected timetables. Reliability of renewable facilities with zero renewal. Reliability model of a renewable facility with zero renewal. Definitions of reliability indicators for renewable facilities with zero renewal. Basic properties of reliability indicators of renewable facilities with zero renewal. Methods for determining the values of reliability indicators for renewable facilities with zero renewal. Reliability of renewable facilities with non-zero renewal. Reliability model of a renewable facility with non-zero renewal. Definitions of renewable facility reliability indicators with non-zero renewal. Basic properties of the reliability indicators of a renewable facility with non-zero renewal. Methods for determining the values of reliability indicators for renewable facilities with non-zero renewal. Reliability of systems. System reliability model. Reliability structure. Structural reliability function of the system. Examples of reliability structures. Probabilistic reliability model of the system. The process of changing the reliability states of the system. Redundancy in the system. |
| 23. | **Optimization III** | Overall optimization task. Classification of optimization tasks. Convex tasks. Methods of solving linear problems. Discrete tasks. Relaxation, restrictions. Algorithms for solving PCL, PCLM, PLB problems. Evolutionary algorithms for discrete optimization. Nonlinear tasks without limitations. Methods for solving nonlinear problems with constraints. Parallel computations in optimization. Probabilistic algorithms. Evaluation of the quality of optimization algorithms. |
| 24. | **Probabilistic III** | Multivariate random variables. Parameters of multivariate random variables. Examples of univariate and multivariate distributions. Random Variable Functions. Application of characteristic and creative functions. Limit theorems. Asymptotic properties of distributions. Parametric and non-parametric estimation. Parametric tests. Nonparametric tests. Randomness study. Analysis of partial and multiple correlations. Multivariate regression analysis. |

| No. | Item Name | Curriculum content |
|---|---|---|
| 25. | **Stochastic Processes III** | Random sequences and their properties. A probabilistic description of the stochastic process. Process examples. Markov trials. Ergodicity. Counting processes. Queuing systems and characteristics. The Semi-Markov Trials. |
| 26. | **Image Recognition and Processing III** | Introduction to the issues of digital recognition and image processing. Frequency methods in digital image processing. Image acquisition, spatial methods in image processing. Improving image quality with filtering. Frequency methods in digital image processing, basics of the use of transforms in digital image processing and analysis.<br>Introduction to image recognition methods. Segmentation algorithms using the following methods: thresholding, edge separation, area growth, divisions and merges, point classification. Application of the Hough transform for analytical curves and irregular objects. Application of neural networks, including deep learning methods, for image recognition (models, applications). |
| 27. | **Neural networks and fuzzy logic III** | Multi-layered neural networks and algorithms for their training. Neural network as an approximator of functions. Fuzzy sets and approximate inference. Fuzzy-neural control and approximation. Fuzzy controls with rule learning. Fuzzy Logic Toolbox in Matlab. |
| 28. | **Smart radio networks** | Smart radio network concept. CRAHN ad-hoc networks. CR hardware and software architectures. Semantic context of CR. Problems of teaching in the CR system. Policies in the CR network. Dynamic spectrum management. Sensing and spectrum sharing. Collaboration and competition in CR networks. Security problems in CR. Standards for CR networks and CR solutions in NG (New Generations) networks |
| 29. | **Stochastic Exploitation Models III** | Introduction to stochastic modeling of systems. Complex technical systems. Operating conditions. Modelling objectives. Uniformity and stationarity of the functioning and operation of technical systems. Efficiency of technical systems. Models of Markowa operation of technical systems. The use of DD class Markow models for modeling the functioning and operation of systems. The use of DC-class Markov models for modeling the operation and operation of systems. Instantaneous and borderline probabilities of the system staying in states. Limiting probabilities of the system residing in subsets of states. Estimating dwell times in subsets of states. Presentation of the functioning of a selected computer system in the form of a Markov model. Semi-Marko models of the operation of technical systems. Application of Semi-Marko models to model the functioning and operation of systems. Instantaneous and borderline probabilities of the system staying in states. Limiting probabilities of the system residing in subsets of states. Estimating dwell times in subsets of states. Presentation of the functioning of a selected computer system in the form of a semi-Markovsky model. Queuing models of technical system operation. Simple queuing systems. Open systems. Closed systems. Markowo queuing systems. Niemarkowo queuing systems. Queue networks. Modeling systems using queuing systems. Queuing models of basic computer system structures. Computer network models. An example of the operation of a technical system. Presentation from assumptions to the implementation of a stochastic model of the functioning or operation of a computer system. The impact of the development of design assumptions on the form of the stochastic model of operation and operation. Study of the properties of a computer system based on the study of its stochastic model. |
| 30. | **Computer Simulation III** | Models and methods of formal description of complex processes subject to experimental study. Determination of the simulation model, advantages and disadvantages of simulation methods, types of research problems. Basic laws and theorems used in computer simulation. Methods of generating numbers and random processes, testing random generators. Continuous and discrete simulation systems, the issue of time lapse in computer simulation, basic principles of designing simulation experiments, statistical analysis of simulation results. Methods for testing the adequacy of simulation models. Parallel and distributed simulation, general characteristics of simulation languages. Presentation of simulation systems and environments. Computer simulation trends. |
| 31. | **Database Systems III** | Basic concepts, database systems and information systems. Data models: hierarchical, network, relational, object-oriented. Database system architecture, data description levels, the essence of central data management and independence, defining and processing languages, database management system tools. Data modeling and normalization, practical data modeling. Security and data protection in classic and statistical databases. Methodological basics of database design. Application of databases: databases vs. application systems, commercial |

| No. | Item Name | Curriculum content |
|---|---|---|
| | | database systems, warehouses and data mining. Formulation and discussion of selected research tasks in the field of databases. |
| 32. | **ICT systems III** | Route and link availability control in the LAN environment: LAN availability control using the STP protocol, HSRP protocol and default gateway availability control, link load control using access control lists. High-performance routing protocols for LANs: VLSM technique, route aggregation using VLSM, default routes – broadcast, classless routing problems, characteristics of link state routing protocols, characteristics of EIGRP and OSPF protocols. NAT and PAT address translation. DHCP protocol: the principle of operation of the address translator, forms of NAT and PAT implementation.<br>Technologies and protocols in WANs: characteristics of selected protocols used in WANs, packet switching networks and channel switching.<br>Basic concepts related to QoS systems: architecture of quality assurance systems, DiffServ model, IntServ model. Packet classification: IP Precedence and DSCP – structure and interpretation of IP header field values, marking and classifying packets by switching devices in layers 2 and 3 of the reference model. Methods of managing bandwidth, congestion and queuing of packets: characteristics of queuing methods – FIFO, WFQ, PQ, CQ, LLQ, congestion avoidance using the RED and WRED gate algorithm. MPLS protocol – integrating MPLS with the QoS system: characteristics of the MPLS protocol, principles of operation of border and internal routers of the MPLS domain, traffic management and congestion avoidance in MPLS VPNs, configuration of switching devices using labels. Private VPN networks: the concept of VPN, methods and protocols for VPN implementation, examples of VPN implementation using GRE tunneling and IPSec protocol, MPLS-based VPNs. |
| 33. | **Decision support systems III** | Methods of identifying decision-making processes in management and management systems. Basic concepts of decision analysis. Models of decision-making processes in a selected class of systems, formulation of decision-making tasks based on adopted models using optimization methods and artificial intelligence. Predictive models. Introduction to the design of decision support systems. Principles of designing a decision support system for a specific management or management system, development of a language system, knowledge system and task processing system, formulation of project tasks for SWD. The use of IT tools to construct algorithms and decision support systems for specified decision-making tasks. Principles of using simulation games in the process of evaluation and decision support. Methods of verification of decision support algorithms. Presentations of decision support environments and tools. |
| 34. | **Artificial Intelligence III** | Paradigms of artificial intelligence and areas of its applications, limitations of artificial intelligence – Gödel's theorem and Church-Turing's thesis. Formal systems – alphabet, formulas, axioms and rules. Propositional and predicate calculus. Herbrand and Skolem's theorem, Introduction to Artificial Intelligence Languages. Space search techniques (classical, evolutionary, taboo search, simulated annealing). Machine learning, approximate sets, elements of neural networks. Knowledge bases and knowledge representation – ontologies and semantic networks. Inference methods (classical, fuzzy). Algorithms for recognizing patterns in data mining. |
| 35. | **Theoretical foundations of computer science III** | Algorithmic theory of information. Accuracy and correctness of algorithms. Computation models, deterministic and non-deterministic Turing machines, probabilistic machines, non-uniform computations. Turing-sense complexity of algorithms. Types of complexity. Decision and optimization problems. Polynomial transformations of problems. The complexity of the problems. Classification of problems: classes P, NP, NP -complete and strongly NP -complete, Co-NP, PSPACE. Complexity hierarchies. Models for defining and recognizing character patterns. Language, grammar, languages designated by grammars. Deterministic and non-deterministic finite automata. Finite languages accepted by automata. Regular expressions. Regular expression generated languages. Context-free grammars. Normal forms grammar. Contextual grammars. The generational power of grammars, regular expressions, and finite automata. Parallel computing models. |
| 36. | **Graph and Network Theory III** | Graph definition. Graph as a model of the system. Characteristics of the graph and elements of its structure, measures of vertex centrality. Types of graphs. Graph parts, subgraphs, and partial graphs. A complex graph as a special type of graph. Graph coloring. Stable subsets of graph vertices. Graph databases. Graph chromatics. Graph coloring models. Algorithms accurate and approximate graph coloring, on-line graph coloring. Computational complexity of coloring algorithms. |

| No. | Item Name | Curriculum content |
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| | | Routes, chains and roads in graphs. Definitions of route, chain, road. Graph consistency and strong consistency. Cyclomatics and graph carcasses. Computational complexity of the algorithms discussed. Berge Graphs. Definition and types of Berge graphs. Components of strong digraph cohesion. Leifman algorithm. Roads in digraphs. Layered representation of the digraph. Euler's and Hamilton's paths in the graph. Computational complexity of the algorithms discussed. Graph similarity. Measures of exact graph similarity: graph isomorphism, graph homomorphism, largest common subgraph, smallest common overgraph. Measures of approximate similarity of graphs: editing distance of graphs, iterative measures. Methods of pattern recognition using measures of graph similarity. Network. Network definition. Economic carcasses. Extreme roads in cyclic and acyclic networks in the sense of roads. Network methods of analysis of complex projects (CPM, PERT, GERT). Stochastic networks and the fundamental problems defined in them. Computational complexity of the algorithms discussed. Flows in networks. Flow on a standard network. Separating cross-section and its throughput. Algorithm for determining the maximum flow. Edge and vertex consistency. Roads are disjoint apical and edge-wide. Menger's theorem. A satisfying flow with a minimum cost. Computational complexity of the algorithms discussed. Optimal Quotas Specify the allocation as a bipartite network association. Hall theorem. Algorithm for determining the most abundant quota, the most numerous allocation with the minimum cost. Computational complexity of the algorithms discussed. |
| 37. | **Project and Process Management III** | Functional and process concepts of management: definitions and classes of operating systems, place and classes of processes, identification of system features, organizational structures, the essence of process management, management strategies.<br>The essence and role of projects in organization management: definitions and classes of projects, management functions and project management cycle, systemic aspects of the subject of design, formal project structures, basic design cycle, identification of project needs, areas of project management, complexity of processes and projects. Identification of the life cycle of projects and products: product life cycle and project life cycle, needs analysis and definition of requirements, definition of project assumptions and constraints, artifact models according to systems engineering, construction and prototyping, verification, documentation and closure of the project, implementation and implementation, improvement, annihilation of the project, process and product. Planning of project processes: planning the scope and effects of the project, analysis and planning of project and process costs, evaluation of projects and processes, analysis of the value of projects and processes, planning the usability and functionality of project processes, planning the reliability of project activities, planning of control and verification of results, project risk management.<br>Quantitative and qualitative analysis of design processes: analysis and evaluation of the effectiveness of project processes, defining project quality, measures and methods of estimating project quality, quality management of processes and projects, project logistics management. Time-cost validation of design processes: project process budgeting, activity-task structures of processes, project time evaluation, project scheduling, project improvement and development processes, change management, project integration management. Innovation process management: the concept of innovation, classification of innovation processes, organization of requirements and planning of innovative processes, evaluation of innovation processes and systems, product design, design of technological processes, principles and methods of innovation management. Organization of the design entity: the place of the entity in the organizational structure of the company, organization and planning of the structure of project teams, hierarchical and flat organizations, network and virtual models, hybrid models, tasks and selection of project teams, institutional forms of project management, control and evaluation of project teams, communication management in the project, methods and techniques of process improvement, models of management development Process. Project and process management using benchmarking: methods, techniques and tools of design support, CAD/CAISE computer aided design systems, management of the design process through the project repository, X-engineering strategy in design processes based on utility models, functionality of packages supporting the management of design processes, spatio-temporal and cost conditions. Development tendencies in project management: the essence of the rhomboid |

| No. | Item Name | Curriculum content |
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| | | model of project management, principles and foundations of good projects, innovation, technology, complexity and pace of project implementation, implementation of the rhomboid model in project organizations, conditions for the implementation of process models in project organizations, implementation costs and limitations. |
| 38. | **Complex Data Structures III** | List structures. One-way and two-way lists. Implementation of lists. Basic operations. Applications of letter structures. Binary trees. BST trees: properties, implementation, basic operations, and their time complexity. Methods for balancing BST trees. An overview of the applications of BST trees. AVL trees: properties, implementation, basic operations, uses. Red and black trees: properties, implementation, basic operations, uses. RST trees: properties, implementation, basic operations, uses. Trees partially ordered. Properties of partially ordered trees. Binary mounds: properties, types, basic operations. An overview of the uses of semi-ordered trees. Jointable mounds. Binomial trees and mounds: properties, basic operations, applications. Fibonacci mounds: properties, structure, basic operations, applications. Multidirectional trees. B-trees: properties, implementation, basic operations, and their time complexity. Types of B-trees. Applications. Data structures for disjoint sets. Representation of disjoint sets. Basic operations on disjoint sets. Applications. |
| 39. | **5G network application for military** | 5G network technologies. 5G use cases and system concept. 5G Network Architecture. 5G architecture elements and functionalities/roles. Millimeter wave communications. Device-to-device (D2D) communications. The 5G radio-access technologies. Machine-type communications. Massive multiple-input multiple-output (MIMO) systems. 5G Network Miltary Gaps. Sensors and effectors. Military scenarios (use cases). 5G network Military Application and use cases: 5G network in Spectrum Situation Awareness application (workshop). 5G network Military Application and use cases: (own work/seminar/workshop with teacher support). |
| 40. | **Advanced cryptanalysis tools** | Elliptic curves, hyperelliptic curves and the concept of a diviser. Attacks on elliptic curves using transfer methods. Improper and degenerate curve attacks: An example of a practical attack on TLS-ECDH. Index method on elliptic curves over extended and straight bodies. Quantum attacks: Shor's and Grover's algorithm. Algebraic attacks. Transformation of factorization, discrete logarithm, and algebraic attacks into the QUBO problem. Application of quantum annealing in cryptanalysis. Isogeny-based cryptography. Practical attacks on the post-quantum scheme of SIDH. Cryptanalysis of selected cryptological problems. |
| 41. | **Probabilistic graph models: representation** | Basics – probabilistics, graphs, information theory, optimization; Bayesian lattices and directed graphs; Markow's networks and undirected graphs; local probabilistic models. |
| 42. | **Probabilistic graph models: the basics of inference** | Strict inference, elimination of variables; approximate inference: approximation with probability propagation, progressive sampling, Markov chains and Monte Carlo methods; inference algorithms, inference in state space models. |
| 43. | **Probabilistic Graph Models: Inference Methods** | Information entropy; Transmitting confidence-rated messages; inference: variational, using Monte Carlo methods, using Markov chains. |
| 44. | **Probabilistic graph models: parameter estimation** | Machine learning of graphical models; linear models; estimation of model parameters; models with incomplete data; Teach undirected models predictive models; Deep neural networks, Bayesian neural networks. |
| 45. | **Probabilistic graph models and hybrid models** | Causality, complex decision-making model; models with hidden variables; statespace models; deep machine learning with graph models; decisions under uncertainty – selected algorithms for approximate inference and learning. |
| 46. | **GNSS – Systems and signals" (GNSS)** | The state of the art of GNSS - the introduction to GNSS, the classification of systems, and areas of implementation of GNSS. The architecture of systems and elements – structures, description & characterization of physical processes, technical parameters, and areas of application. Signals in GNSS – classification, mathematical models of signals, propagation of signals, interferences of signals, methods of protection of signals. Modeling and simulation of systems and signals. Modeling and simulation of jamming and spoofing. |
| 47. | **Multidimensional Data Processing (WDP)** | Basics of the theory of pattern recognition in data. Pattern definition, pattern classes, and the process of recognizing patterns in data. Pattern recognition techniques used. Division of data classification and grouping methods. Grouping |

| No. | Item Name | Curriculum content |
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| | | criteria and methods. Threshold criteria (nearest and most distant neighbor). The distance of Euclid, Sebestyen, Mahalanobis, Hamming, Cannber and selected similarity functions. Grouping methods based on hierarchical grouping algorithms. Construction of dendrograms. Extraction of distinctive features using polynomial interpolation (Lagrange analysis). |
| 48. | **Automated Battlefield Database Systems (SBD-ZPW)** | Basic terminology and characteristics of databases. Requirements for databases. Database technology, data models, data structures, data model operators, integrity constraints. Developer tools. Database management system (software, functionality). Database System Architecture (ANSI/SPARC). Database system users. Implementation technologies. Communication architecture. Division of database systems. Entity relationship model, relationship modeling, entity hierarchy. Transformation, entity transformation rules, relationship transformation rules. Standardization and its process and basic concepts. The first (1NF), second (2NF), third (3NF) and fourth (4NF) normal form. Concurrent data access, data loss after failure. ACID transaction properties, transaction state diagram, logical vs. physical transaction, transaction model and classification, transaction executions. Operational data structures in the MIP model JC3IEDM database. Replication, transformation and data exchange based on the DEM protocol. Databases in battlefield analytics |
| 49. | **Hiding data in telecommunications** | Data formation in the process of mapping and shaping, modern methods of marking and steganography, detection of hidden information channels, paradigms of data hiding, study of selected cases, perception and steganoanalysis of hidden communication channels. Development of marking methods for telecommunications systems and their qualitative analysis. |
| 50. | **AI in spectral processing and analysis** | Analysis of signals in the radio spectrum. Basic characteristics and imagery for the spatial domain and the transform domain. Detection and extraction of events on the radio scene. Forming, detecting and classifying radio signals using Deep Learning methods. Short- and long-term prediction using LSTM networks. Identification of the friend-alien in the radio spectrum. |
| 51. | **Special numbers in cryptology** | The aim of the lecture is to familiarize the audience with numbers (mainly natural numbers) of particular importance in cryptology.<br>Examples of numbers used in cryptography are RSA numbers and their extensions. On the other hand, in cryptanalysis, smooth and partially smooth numbers, but also generic and balanced natural numbers play a special role. Their meanings are revealed, for example, when studying the distribution of divisors of prime typical natural numbers, as well as their numbers - described by the classical "omega" functions. Applications will include the complexity of algorithms used in the cryptanalysis of asymmetric ciphers. |
| 52. | **Elliptic curves in cryptanalysis of asymmetric ciphers** | The aim of the lecture will be to study asymmetric ciphers, selected attacks on such cryptosystems and computational problems related to their security. The main emphasis will be on the importance of special numbers in cryptanalysis of ciphers using the difficulty of the problem of factorization of natural numbers and the problem of discrete logarithm, with particular emphasis on the problems of DLPC, ECDLP, CDH, DDH and their applications in cryptosystems with bilinear operation. Reductions between special computational problems will be shown, including the reduction of the natural number factorization problem for the calculation of Fourier coefficients of the L-Hecke function. |
| 53. | **Selected elements of the lattice theory** | The aim of the lecture is to familiarize the student with advanced concepts in the field of number geometry and lattice theory, which are used in modern asymmetric cryptography. We will analyze in detail the problems computationally on the grids, their difficulty, complexity and appropriate reductions. We will discuss the meaning of dual lattices, their properties and the relationships between the grating and dual lattice. We will explain in detail the concept of smoothing factor and its impact on the quality of lattice solutions in the context of cryptographic security. |
| 54. | **Application of modular lattices in post-kwan cryptography** | As part of the lecture, we will discuss the origin and construction of selected cryptographic schemes based on MLWE, MLWR modular problems. We will analyze in detail the special importance of modular lattices for postquantum cryptography and discuss the reasons for the advantage of modular lattices and |

| No. | Item Name | Curriculum content |
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| | | MLWE/MLWR over RLWE. We will analyze the schemes (KEM, DSS) from the CRYSTALS family and the Smaug, Haetae schemes, we will perform a comparative analysis in order to indicate the global tendencies of their construction from the perspective of achieving safety. We will discuss ROM and QROM along with the differences, and conduct formal proofs of safety of IND-CCA2 AND UF-CPA, for KEM and DSS, respectively. |
| 55. | **Fundamentals of Measurement of Disclosing Emissions** | Revealing emission – myths and reality (not every emission is a revealing emission). Sources of disclosing emissions and methods of reception. Electromagnetic compatibility issues, equivalent diagrams of emission sources. Issues of conducted emission measurement, construction of emission measurement stations for 230V power supply and low voltage power supply (maximum 5V). Measuring stations for emission measurement at communication and management interfaces. |
| 56. | **Digital data processing techniques** | Functions and functional spaces; Banach and Hilbert spaces. Interpolation and mid-squared approximation with polynomials. Interpolation, Mean Square Approximation, and Plywood Smoothing. Smoothing discrete data. Numerical integration, simple and complex interpolation quadratures. Numerical differentiation. |
| 57. | **Advanced technologies for next generation mobile networks** | The aim of the course is to deepen knowledge of mechanisms and algorithms implemented in the latest generation of cellular networks (5G and 6G) used for network management and traffic management based on the division of traffic (slicing). Since the fifth generation of mobile networks, traffic management has been based on Slices and Network Function Virtualization. Lectures provide knowledge about operating mechanisms and knowledge about research on new management mechanisms. The projects convey the ability to propose other mechanisms and algorithms along with their implementation in mobile networks. |
| 58. | **Machine learning for telecommunications** | The first part of the course will reveal statistical data learning theories, which are a toolkit for understanding data. These tools essentially cover two classes: supervised learning and unsupervised learning. Basically, supervised learning refers to the prediction of outcomes based on one or more inputs. One or more estimators make such a forecast. The estimator(s) choice is closely related to the nature of the data. On the other hand, unsupervised learning provides a relationship or pattern in data with no supervised outcome.<br>The second part of the theory described in the course presents the AI decision-making theory. This theory discusses how to represent knowledge, including incomplete and uncertain knowledge about the data (measurements, estimations, etc.); how to use these models and inference methods to decide what to do, especially by making plans (Constraint Satisfaction Problems, CSP); and how to reason and make decisions (Multi-criteria decision making) in the face of uncertainty about the world.<br>The final part deals with Machine Learning, which describes both symbolic and statistical learning methods and reinforcement learning, deep learning, and multi-agent learning (game theory) to generate the knowledge required by the reasoning and/or decision components of intelligent agents or systems. Here, the methods and algorithms for providing machine learning will be analysed, and the theory of artificial intelligence will be revealed and analysed. |
| 59. | **Quantum Communications** | The main objective of the course is to explore the fundamentals of quantum communications technology. The first part ofthe course introduces basic concepts of quantum electrodynamics like field quantisation, coherent states, entanglement, anihilation and creation operators. Based on this knowledge main quantum key exchange algorithms are consistently introduced, i.e. BB84 and E91. In the second part, the basics of bit error analysis, quantum information theory and vulnerabilities of quantum key distribution algorithms are discussed. In the last part, selected implementation aspects of quantum key distribution in modern telecom networks are explored. |

**Annex VI.3**
**to the Education Program at the Doctoral School of the Military University of Technology**

## Curriculum content for optional subjects
## Scientific discipline: civil engineering, geodesy and transport

| No. | Item Name | Curriculum content |
|---|---|---|
| 1. | **Safety and reliability of building structures** | Knowledge in the field of safety and reliability of building structures. Classifications and rules for shaping the load-bearing structures of buildings and the conditions for assessing their safety. Methods of description and distribution of random variables. Functions of reliability and damage intensity. Methodology for conducting reliability tests, risk assessment, the safety of building maintenance and their effectiveness. |
| 2. | **Dynamic interaction of building structures with the soil medium** | Methods of formulating computational models of the dynamics of structural elements and systems as well as the soil foundation medium of the building. Determination of the physical characteristics of the soil medium under static and dynamic loads. Influence of the content of the phases on the parameters of the substrate. |
| 3. | **Environmental physics** | The laws of the black body. The atmosphere as an ideal gas. Thermodynamic processes in the Earth's atmosphere. The greenhouse effect and ozone holes. Greenhouse gases – a reminder. Natural disasters (earthquakes, volcanic eruptions, tsunamis). Pollution of the atmosphere, hydrosphere and lithosphere, Noise and civilization diseases. Renewable energy sources – Polish's attitude to the protocols of the Climate Summits. Types of light sources for lighting. Indoor and outdoor illumination, luminous flux, illuminance, luminous efficacy, light source spectrum, standard observer, objective determination of the source color. |
| 4. | **Modeling of thermal and humidity processes** | Modeling of thermal and humidity processes. Energy balances of heat demand and air conditioning of the building. Conduction of heat and moisture through the layered partitions of the building – walls, ceilings and floors on the ground, in the conditions of various centres adjacent to the partitions. Conduction equations and methods of solving them. Application of the method of initial functions in the interpretation of heat and moisture fluxes in the modeling of thermal and humidity processes in building elements. Solutions to the Laplace equation using field theory concepts. (gradient, divergence, rotation). Description of solutions to the Laplace-Poisson equation by the method of separating variables. Major potentials in the theory of moisture diffusion and heat conduction in a porous medium. Equations for moisture diffusion and heat conduction in a porous medium. Determination of potential and flux functions in fluid and in porous medium Flux and potential functions, Problems of their determination. |
| 5. | **Identification of loads and structural systems** | Identification of load intensity, weight and stiffness. Gravitational and dynamic loading of structural systems together with the analysis of their reasonable static schematization or determination of the dynamic model. The basis for identification are the results of the initiating reactions of the supporting systems of objects, which are revealed by static or dynamic displacements or vibration frequencies. |
| 6. | **Investment process in the construction industry** | Organization of construction investments, in particular methods of analysis, research and design of construction, assembly, reconstruction, renovation and operation of buildings in a specific place, time, system environment and natural environment. Principles of testing the effectiveness, technology and organization of construction works, preparation and implementation of construction projects, structure and operation process of construction facilities. |
| 7. | **Mechanics of road and airport runway soil foundations** | Modeling of the soil as a single-phase or three-phase continuum depending on the type of soil (cohesive or no-cohesive). Stiffness and load carrying capacity of the ground as the problem of an elastic half-space. Dynamic effects generated by moving loads. |
| 8. | **Test Methods for Stiffness and Load-Bearing Capacity of Road and Airport Pavements** | Testing the stiffness and load-bearing capacity of road and airport surfaces allows to verify the performance and approval for safe use, The testing techniques are based on the use of the wave theory of elastic half-space, which is equipped with layers of the substructure and the surface itself. Half-space reaction is forced by means of impacts with a dynamic plate and registration of surface deflections under moving loads. Factors influencing the results of the research - soil, material and climatic parameters. |
| 9. | **Design methods for folding bridge structures** | Construction of folding bridges with determination of their technical and operational parameters. Theory of Calculation of Folding Bridges Taking into Account Mounting Clearances for Objects in Static and Dynamic Systems. |

| No. | Item Name | Curriculum content |
|---|---|---|
| 10. | **Design methods of the experiment** | The essence of experimental research. Resistance extensometry. Measurements and analysis of measurement errors. Organization of the measurement line. Experimental methods of testing materials in simple stress conditions - tensile, compression, shear, bend, torsion tests. Materials testing in complex stress states. Assessment of rheological properties of materials - creep and relaxation. Optical research methods in mechanics – elastooptics, optical, mesh and holographic interferometry. |
| 11. | **Modeling the behavior of elements and structures reinforced concrete** | Reinforced concrete structures as material compositions of concrete and reinforcing materials. Modeling of static and dynamic behavior of structural materials: concrete and reinforcing steel. Modeling the cooperation of component structural materials in elements. Reinforced concrete homogenization method: models of a substitute, homogeneous structural material taking into account the properties of the components of structural materials. Modeling of the mechanisms of destruction of reinforced concrete elements and structures: cracking and crushing of concrete. Application of FEM in modeling the behavior of reinforced concrete structures. |
| 12. | **Geometric and physical nonlinearities in mechanics Design** | Deformations of flaccid structures and bodies with low rigidity, the use of geometric relationships with linear and nonlinear terms. Consequences of deformation in equilibrium equations written in the deformed configuration. The full spectrum of nonlinearities of the physical compounds of the material is considered along with the associative and non-associated laws of strain. |
| 13. | **Explosive effects on defensive structures** | Physics of phenomena generated by explosion of explosive charges and fuel-air mixtures. Methods of determining the parameters of explosion loads. Types of mechanisms destroying elements and load-bearing structures of buildings. |
| 14. | **Scheduling and costing systems for construction works** | Principles of scheduling and cost estimation with the use of currently available specialized IT techniques and software. The idea of BIM technology and its possibilities at all stages of the construction project and the operation of the facility. Optimization formulas and methods of solving multi-criteria decision-making problems in construction. |
| 15. | **Engineering of building materials** | Contemporary trends in the modification of building, construction and finishing materials. Technologies of preparation, implementation and optimal procedures for incorporating materials and products under building conditions. Structure and material considerations of composites used in construction. The role of additives and admixtures in buildings technologies. |
| 16. | **Cartographic methods of research** | The use of maps to describe, analyze and scientifically learn phenomena, including cartometric research, mathematical and statistical analysis and methods of mathematical theory of information. Issues related to, among others, distribution analyses (potential maps, concentration analyses), dynamics of phenomena, as well as correlation methods and trend methods. |
| 17. | **Spatial data exploration** | Review of exploratory data analysis methods with particular emphasis on geospatial data, including classification and grouping, reduction of the number of variables, and spatial pattern discovery. Classification using decision trees and the Byesian classifier, hierarchical grouping, and quality evaluation of classifiers and model validation. |
| 18. | **Methods and technologies in Geospatial Data Science** | Advanced geospatial data processing, analysis, and modeling. Searching for trends and dependencies using exploratory data analysis techniques, machine learning and artificial intelligence, m.in.: real estate market, land cover changes, population distribution. The quality of the data and its impact on the effect of forecasting and modeling, as well as effective reporting and visualization of results. |
| 19. | **Advanced methods of implementation of studies photogrammetric** | Problems of filtering radar images. Use wavelet analysis in image filtration. Morphological operations on digital images. Determination of MTF. Fundamental problems of contemporary digital photogrammetry. Digital image acquisition systems – photogrammetric digital cameras and VHRS and Nano satellite systems. Remote sensing and photogrammetric methods of data acquisition. Modern photogrammetric technologies – their applications in the development of site and elevation maps, digital terrain model and orthophotomaps, as well as 3D spatial maps. Application of Computational Intelligence Algorithms in contemporary photogrammetric studies. Characteristics of new multi-image fitting methods. Methodology for developing dense point clouds from images. |
| 20. | **Programming in spatial information systems** | The use of the programming environment, the concept of procedure, function and instructions for data processing. A way of accessing and processing spatial data directly using programming code. Libraries that enable spatial data processing in the .NET environment, the ability to automate the ArcGIS environment using Python. |

| No. | Item Name | Curriculum content |
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| 21. | **Reference systems in geosciences** | We live on a dynamic planet in constant motion that requires long-term continuous quantification of its changes in a truly stable frame of reference. To be understood in context, when the motion of the Earth's crust is observed, it must be referenced. The global geodetic frame of reference is the fundamental basis for measuring worldwide processes and is crucial for its proper interpretation especially for climatic studies. A terrestrial reference frame provides a set of coordinates of some points located on the Earth's surface. It can be used to measure plate tectonics, regional subsidence or loading and/or used to represent the Earth when measuring its rotation in space. This rotation is assessed with respect to a frame tied to stellar objects, called a celestial reference frame. The Earth Orientation Parameters (EOPs) connect these two frames together. Nowadays, four main geodetic techniques are used to compute accurate coordinates: the GPS (Global Positioning System), VLBI (Very Long Baseline Interferometry), SLR (Satellite Laser Ranging), and DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite). They all use networks of stations located on sites covering the whole Earth. Modern realizations are of kinematic type, which means that they include station positions and velocities. They model secular Earth's crust changes that is why they can be used to compare observations from different epochs. The Ph.D. students will learn about advancements of the International Terrestrial Reference System (ITRS) which is a World spatial reference system co-rotating with the Earth in its diurnal motion in space for the geodetic, but also astronomical, and geophysical communities. |
| 22. | **Global Geodetic Observing System** | Global Geodetic Observing System (GGOS) is the Observing System of the International Association of Geodesy (IAG). GGOS and its related research and services address the relevant science issues related to geodesy, geodynamics and geophysics in the 21st century, but also issues relevant to society, like global risk management, geo-hazards, natural resources, climate change, severe storm forecasting, sea level estimations and ocean forecasting, or the space weather. The Global Geodetic Observing System works with the IAG components to provide the geodetic infrastructure necessary for monitoring the Earth system and global change research. GGOS mission is to: (i) provide the observations needed to monitor, map, and understand changes in the Earth's shape, rotation, and mass distribution, (ii) provide the global geodetic frame of reference that is the fundamental backbone for measuring and consistently interpreting key global change processes and for many other scientific and societal applications, and (iii) benefit science and society by providing the foundation upon which advances in Earth and planetary system science and applications are built. Within this subject Ph.D. students will advance their understanding of the dynamic Earth system by quantifying our planet's changes in space and time and learn about the integration within the geodetic, geodynamic and geophysical communities at the highest level, in service to the technical community and society as a whole. |
| 23. | **Modern photogrammetric techniques** | A modern approach to photogrammetric studies based on the use of the latest techniques of processing imagery obtained from various altitudes and the use of their geometric relationships in the field of situational and elevation measurement in areas including: development and updating of maps, feeding topographic databases, supporting the construction of 3D cadastre, as well as cooperation with mobile systems in the field of building virtual reality at various levels of detail. |
| 24. | **Selected numerical methods in geodesy** | Practical use of numerical methods to solve scientific and technical problems (geodesy), ideas and concepts of numerical methods, numerical algorithms, programming elements - computational scripts. Use of selected tool libraries of scripting languages such as Matlab, Octave and Scilab. |
| 25. | **Methods of parallel data processing** | Methods of parallel data processing for solving scientific and technical problems in geodesy. Ideas and concepts of parallel data processing methods. Selected parallel processing algorithms. Examples of programs that parallelize numerical calculations. Parallel processing methods of scripting languages: Octave, Scilab. Methods and functions of the Parallel Computing and MATLAB Distributed Computing Server Toolbox modules. |

| No. | Item Name | Curriculum content |
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| 26. | **Mathematical foundations of digital image processing** | Creating gradient and edge filter masks based on differential diagrams constructed using the finite difference method (FDM) and the finite element method (FEM) (convergence, agreement, order of precision, π- as the first form of differential approximation). Spectral properties of masks (matrices of the third and fifth order), including the spectral transfer function and its graphical presentation. The goodness of the mask is defined as the quotient of the spectral transfer function of the filter under study and the spectral transfer function of the differential transfer of the Laplace operator. Operations on masks (addition, subtraction, 45° rotation), determining the form of the differential operator related to the results of these transformations (Laplacian, bi-Laplacian, etc.). Filters that identify only corners (vertices). Bi-Laplacian mask vs. Harris corner detector. |
| 27. | **Numerical methods with linear algebra** | Vector norm, matrix norm, induced norm. Norm 1, 2 and maximum. Matrix conditioning indicator. The use of linear algebra methods in numerical (differential) solving of mathematical physics problems (advection equation, diffusion, diffusion problem with advection). Convergence and stability of the differential method. Spectral transfer operator. π- a form of the first differential approximation. Numerical diffusion, creation. Analysis of selected differential schemes in terms of spectral properties – explicit, implicit, semi-implicit scheme, Crakn-Nicholson, Crank-Nicholson-Galerkin. Dissipation and dispersion in Lax-Wendroff and Beam-Warming schemes used in civil engineering and trance-sport. |
| 28. | **Finite element methods in Hermit spaces (polynomials of degree 2 and 3). Nonlinear problems.** | The scope of the course in the winter semester includes the presentation of the form of differential schemes for the problems of nonlinear advection, nonlinear diffusion and the BKdV equation – soliton in shallow and deep water. Fortran program + presentation and discussion of results. |
| 29. | **Finite element methods in Hermit spaces (polynomials of degree 2, 3 and 5). Linear problems.** | The finite element method has been known for many years (at the Military University of Technology it was created and developed by Prof. Szmelter, Dacko, Dobrociński, Wieczorek, Niezgoda, and now Winnicki). It is an engineering method (light, heavy, aircraft, medical - stents) and a method of solving equations and systems of equations (linear and nonlinear) of partial differentials. These issues have been dealt with for years by the team of the Department of Military Hydrometeorology. The scope of the course in the summer semester includes the presentation of the forms of polynomials of degree 2-5 forming the basis of functions approximating the solution of the differential problem with the initial condition and examples of forms of differential schemes for the problem of linear advection and linear diffusion. Fortran program + presentation of results. |
| 30. | **GNSS Environmental Research Methods** | Issues related to the use of satellite navigation systems in geodynamic, tectonic and atmospheric monitoring. The basics of GNSS systems, such as GPS, GLONASS, Galileo or BeiDou, as well as various types of GNSS receivers and their application in the scientific and technical environment. GNSS data processing and interpretation of results in environmental studies. Application of GNSS data in modeling of atmospheric processes. Analysis of ionospheric parameters based on GNSS signals. Determination of tropospheric water vapour (PWV) content from GNSS data. Monitoring of tectonic plate movements. Analysis of crustal deformations: landslides, subsidence, vertical and horizontal movements. |

**Annex VI.4**
**to the Education Program at the Doctoral School of the Military University of Technology**

## Curriculum content for optional subjects
## Scientific discipline: materials engineering

| No. | Item Name | Curriculum content |
|---|---|---|
| 1. | **Structural studies by X-ray diffraction** | Basic concepts and laws of crystallography. Translation, spatial lattice vs. crystalline lattice. Crystal lattice theory, Interplanar distances. Reverse network. Stereographic projection. Wulf grid. Classification of crystalline bodies. Types of structures. X-ray diffraction on a crystal lattice. Design, principle of operation and analytical capabilities of the X-ray diffractometer. X-ray qualitative and quantitative analysis. Stress and texture measurements. |
| 2. | **Structural studies by scanning microscopy** | Terms used in electron microscopy. Principles of operation of electron microscopes (scanning and transmission). Basic research methods used in electron microscopy. Preparation used in reflection and transmission electron microscopy. Selected by advanced microscopic methods (microanalysis of chemical composition, diffractive orientation of crystallites, quantitative analysis of images and breakthroughs). |
| 3. | **Mechanical Properties Testing of Engineering Plastics** | General characteristics of technological and endurance tests. Stress-strain relationship in a structural material. Hook's Law, material constants. Division of strength test methods depending on the nature of the load. Characteristics of strength indicators determined in laboratory tests. Static methods for measuring hardness and microhardness. Static endurance tests. Tests carried out at elevated temperatures. Fatigue and impact tests. Basics of fracture mechanics. |
| 4. | **Physical Basis of Electro-Optical Effects in Liquid Crystals** | Physical basis of electro-optical effects in Liquid Crystals (CK). Selected optical, dielectric, flexoelectric, elastic and viscous properties of CK, interactions of the ordered CK layer with the external electric field. Basic electro-optical effects in CK such as: dynamic scattering effect, Freedericks effect, TN (Twisted Nematic) effect, STN (Super Twisted Nematic) effect. Bistable switches in Ferroelectric Liquid Crystals and tristable switches in AntiFerroelectric Liquid Crystals. |
| 5. | **Calorimetric, thermogravimetric and volumetric methods for testing material properties** | Study of materials, in particular materials for storing hydrogen in the solid phase, using: differential calorimetry, thermogravimetry and volumetric analyses. Types of equipment, principles of operation, calibration methods, good practices of use, advantages, disadvantages, possibilities and limitations. Basics of analysis of test results, correction of results and selection of test parameters to obtain the best results. |
| 6. | **Semiconductor materials for optoelectronic applications** | Basic properties of semiconductor materials used in the construction of optoelectronic devices: band structures, absorption coefficient, mechanisms of carrier generation and recombination, carrier mobility. Semiconductor compounds of group III-V materials used in semiconductor lasers. Group III-V nitrides used in blue optoelectronics. Solid solutions II-VI in the detection of infrared radiation. Low-dimensional quantum structures (superlattices, quantum wells, quantum dots) in the detection and generation of electromagnetic radiation. Materials for I, II and III generation photovoltaics (silicon, CdTe, CIS, CIGS, organic semiconductors). |
| 7. | **Nano and ultracrystalline engineering materials** | Nano and ultracrystalline engineering materials – definitions and basic terms. Structural determinants of the properties of nano- and ultracrystalline materials. Methods of obtaining materials with an extremely fragmented structure. Methods of studying the structure of nano- and ultracrystalline materials. Characteristics of selected groups of materials with nano and ultracrystalline structure. |
| 8. | **Nanoporous anodic aluminum oxide: synthesis, design and applications** | Mechanism of anodic aluminum oxide growth (ionic conductivity, basic chemical reactions, lattice stress-induced ion transport, etc.). Geometrical parameters of the anodic aluminum oxide matrix (pore diameter, pore spacing, etc.) and their relationship with the applied parameters of electrochemical synthesis (temperature, voltage, time). The process of self-organization of the matrix pores into a hexagonal system. Soft anodization. Hard anodization. Pulsed anodization. Synthesis of nanostructures using matrix-assisted methods of anodic aluminum oxide (electrochemical deposition, sol-gel, CVD, ALD methods). Applications of anodic aluminum oxide matrix (biosensors, filters, optoelectronic components, tissue engineering, etc.). New perspectives and development trends related to the production and application of anodic aluminum oxide. |
| 9. | **Non-telecommunications applications of fiber optics** | Interference (phase) fiber optic sensor technology. Terminology used in the description of sensors, the ideology of the mathematical formalism of the sensor description along with the definition of the role of the transducer as well as optical and electronic signal processing. Methods of building sensors with a point and a distributed detection field. Multiplication of point sensors. |

| No. | Item Name | Curriculum content |
|---|---|---|
| 10. | **Measurement of machine and device parts using coordinate measuring techniques** | Use coordinate measuring techniques and tactile profilometry at various stages of the production process. Metrological properties of coordinate measuring machines and tactile profilometers Programming of a multi-sensor measuring machine to carry out measurements as part of the final acceptance of machine parts and equipment manufactured in mass production conditions. |
| 11. | **Experiment planning and data analysis using Origin and Statistica** | The use of computer programs to plan an experiment. Statistical methods. Origin and Statistica's capabilities for experiment planning and data analysis. |
| 12. | **Basic properties of liquid crystals** | Liquid crystals as a separate state of matter. Classification of liquid crystals. Chemical structure of mesosogens. Description of the liquid crystal phase, the concept of director and the ordering parameter. Liquid crystals as a viscoelastic medium. Free energy deformation of liquid crystal. Arrangement of liquid crystals. Anisotropy of physicochemical properties of liquid crystals. Electro-optics and magneto-optics of liquid crystals. Nonlinear optics and liquid crystal acoustooptics. Applications. |
| 13. | **Keysight Vee and Lab View for Data Control and Processing** | Basics of programming in LabView, including the logic of the so-called graphic language. Basic programming structures - sequential blocks, loops (for loop, while), selection structures, feedback, etc. How to use objects of various types (numeric, string, bool), including in the form of matrices and clusters. Methods of data processing and transfer. Creating a program algorithm to control a given device according to specific assumptions. Execution of a program that controls the device in the form of a "virtual device". Expansion of the program with preset elements such as menu buttons. Basics of programming in Keysight Vee, including the logic of the so-called graphic language. Basic programming structures - sequential blocks, loops, selection structures, conditional statements, etc. A way of using objects of various types, including matrices and complex variables. Basic methods of data processing and transfer. Cooperation Keysight Vee – MS Excel. Development of own program algorithm for controlling a given device according to specific assumptions. Expansion of the program with preset elements such as a panel. |
| 14. | **Designing technological processes for incremental Direct Deposition methods** | Design of elements of machine and equipment parts using solid and surface modeling. Rules for creating and editing and the possibility of repairing data exchange files dedicated to incremental techniques. Initial assessment of the functionality of products in the concurrent production process - defining the material, process window and generating source files for Rapid Prototyping techniques. Direct Deposition technological process design - production of the target production series |
| 15. | **Dielectric spectroscopy** | Dielectric spectroscopy (impedance spectroscopy/radio range spectroscopy) as an experimental method in materials science and chemistry, as well as in electronics for the analysis of the properties of materials used in electronics. Electrical phenomena at the atomic, molecular, and macroscopic (medium) levels. Theoretical foundations (mathematical apparatus) of relaxation phenomena in condensed matter. Parasitic effects in impedance measurements. Research equipment (impedance analyzers), experiment and analysis of experimental data in the context of the properties of various materials. |
| 16. | **Structural Determinants of Material Properties** | Terminology, methodology, critical reception of external data, critical evaluation of the results of solving scientific problems in the area of materials and technology. Improvement in the formulation of research assumptions, scientific goals, analysis of results and conclusions. |
| 17. | **Modern methods of material characterization** | Basics of material characterization methods. Cleaning of materials. Densitometry. Methods for testing thermal, electrical, magnetic and optical properties. UV, IR, Raman and Mossbauer spectroscopy. Selected specialized spectroscopic methods. TEM and SEM electron microscopy. Atomic force microscopy and scanning tunneling microscopy. X-rays, electronography and neutronography. Methods for the study of photonic materials, nanomaterials and metamaterials. Material characterization track. |
| 18. | **High-energy ball milling and mechanical synthesis** | Issues related to high-energy grinding of materials in ball mills as well as mechanical alloying. Types of ball mills, the principle of their operation, capabilities and the effects of grinding.<br>As part of the course, tests of mechanical synthesis of alloys of selected metals and high-energy grinding of pure metals and their alloys, as well as selected ceramic materials will be carried out. |

| No. | Item Name | Curriculum content |
|---|---|---|
| 19. | **Advanced materials for hydrogen storage** | Assumptions of the idea of hydrogen economy and its limitations. Characteristics of hydrogen storage methods including solid storage materials. Hydrogen storage materials based on adsorption. Low-capacity materials for storing hydrogen at room temperature. Magnesium-based hydrogen storage materials. Complex hydrides as high-capacity materials for hydrogen storage. Methods to improve the hydrogenation ability of materials. Methods for testing hydrogen storage materials. |
| 20. | **Basics of plasmonics and metamaterials** | Basic definitions of plasmonics and metamaterials. Physical basics, interaction of electromagnetic waves of different frequencies with metamaterials in different wavelength ranges, surface plasmons, metasurfaces. Technological conditions for the implementation of metamaterial one-, two- and three-dimensional structures. Physical and technological requirements and limitations for different types of metamaterials, as well as the use of classical technologies for the production of nano- and metamaterials. Methods for simulation of the properties of selected metamaterial and plasmonic structures and methods for characterization of metamaterials and nanometre-sized structures using AFM, STM microscopy, etc. to assess the properties and shape of the SRR. Application of metamaterial structures in photonic devices and prospects for the development of nano- and metamaterials with particular emphasis on military applications. |
| 21. | **Selected Materials and Functional Structures for Photonic Applications** | Properties and applications of such materials and structures as: optical glass and polymer substrates for the construction of electro-optical transducers, oxide and organic functional layers used as anti-reflective layers, bandstop and edge filters, transparent conductive organic and inorganic layers, nanomaterials for organic applications, photonic polymers and liquid crystals, including composite structures. Construction, construction and operation of selected photonic elements, made on the basis of, among others. the above-mentioned functional materials; spatial light modulator, dynamic wave plates, dynamic elements of diffraction optics (diffraction gratings), optical vortices, microlasers based on self-organizing structures, Kerr and Pockels cells, optical materials and elements for spatial imaging and others. |
| 22. | **Computer Image Analysis in Materials Science** | Basics of stereology, including basic assumptions and stereological implementations. Detection methods and binarization procedures necessary for quantitative image analysis. Fundamentals of image acquisition and processing (m.in. morphological transformations, logical and arithmetic operations). Procedures carried out during computer image analysis in the study of real engineering materials. |
| 23. | **Additive manufacturing of functional materials** | Practical aspects of additive manufacturing of functional metallic materials using LMD/LENS laser technology. Influence of manufacturing parameters on the ability to shape the microstructure, structure and properties of functional materials. |
| 24. | **Methods for amplifying light emission from broadband semiconductor nanostructures** | Basic types of broadband semiconductors. Properties of luminescent broadband semiconductors on specific examples (e.g. GaN, ZnO, $SnO_2$). Methods of synthesis of nanostructures. Modulation of optical properties of nanostructures at the synthesis stage. Post-synthetic methods of luminescence enhancement. Intentional doping of broadband semiconductors. The phenomenon of charge and energy transfer. The phenomenon of surface plasmon resonance (SPR) and localized surface plasmon resonance (LSPR). Plasmonic light gain from semiconductor nanostructures – basic criteria for coupling SPR or LSPR to the frequency of optical transitions in semiconductors at the metal/semiconductor interface. |
| 25. | **Electrochemical synthesis of anti-reflective, super-hydrophobic coatings and photonic crystals** | Basic knowledge of the production of porous anodic aluminum oxide (AAO). Parameters of electrochemical synthesis. The phenomenon of constructive and destructive interference. Single-layer and multi-layer interference. Features of an ideal anti-reflection coating. Anti-reflective coatings with gradient refractive index. Microstructure of the moth eye. Surface wettability. High-energy vs. low-energy surfaces. Hysteresis of the contact angle. Wetting textured surfaces: Wenzel model vs. Cassie-Baxter model. General characteristics of 1D, 2D and 3D photonic crystals. Structural coloration. Inspirations drawn from nature, or what is biomimetics. Multi-step electrochemical synthesis of AAO with conical pore shapes. Electrochemical production of 1D crystals by pulsed method. Design of voltage or current pulse sequences, taking into account processes limited by diffusion and the speed of ion transport through the barrier layer. Control of electrochemical synthesis parameters to obtain the desired photonic properties of AAO-based photonic crystals. |

| No. | Item Name | Curriculum content |
|---|---|---|
| 26. | **Modeling of semiconductor devices.** | The genesis of transport equations derived on the basis of the principles of behavior and postulates of thermodynamics of irreversible processes. Generation-recombination mechanisms responsible for the magnitude of charge carrier concentration. Contribution of cross-band processes and SHR mechanisms involving point defects, dislocations and surface states. Process modeling and determination of cross-sections. Mechanism of interband absorption of radiation. Construction of iterative diagrams enabling numerical solving of a system of transport equations. Record on the numeric grid. Problems related to numerical solving of nonlinear equations. He will be able to write a fragment of the program as a task to pass the subject. This fragment can be implemented into my program in order to design a specific device or to study the physical parameters of the structure. |
| 27. | **High-entropy alloys – synthesis, structure, research and properties** | The latest group of materials – the so-called high-entropy alloys. Theoretical aspects of their formation and stability, properties, structure, synthesis methods and heat treatment. Practical attempts to synthesize and study the properties of alloys from this group. |
| 28. | **Additive manufacturing of alloys based on intermetallic phases** | Specific aspects related to the additive manufacturing of alloys based on intermetallic phases (in particular FeAl). The influence of manufacturing parameters on the ability to shape the microstructure, structure and properties of these materials. |
| 29. | **Combinatorial Materials Manufacturing and Testing Engineering** | Possibilities of using DED laser additive techniques for combinatorial search for new engineering materials. As part of the course, attempts will be made to synthesize both continuous and discrete alloy libraries and the possibility of their rapid study. |
| 30. | **Reactive mechanical grinding as a method of synthesis of modern materials for storing hydrogen in the solid phase.** | Synthesis of solid-phase hydrogen storage materials using reactive hydrogen grinding in ball mills. Attempts at the synthesis of selected metal hydrides and complex hydrides and studies of the influence of synthesis conditions on its result and the properties of the produced material. |
| 31. | **Additive techniques with elements of reverse engineering** | Devices used in reverse engineering. Editing and processing of point clouds and generation of STL files, taking into account technological specifics. Preparation for 3D printing (model positioning, material selection, degree of infill, division into layers, source code generation). Multi-variant production of models with complex geometry using FDM and SLA techniques. "Post-processing" and assessment of the quality of the obtained printouts using a 3D scanner and a micro-computed tomography. |
| 32. | **Overview of additive techniques used in modern technology** | The idea, technical solutions and development trends of 3D printing. Overview of additive methods used in strategic industries – material, technological and economic conditions. Specifics of the processing of high-strength thermoplastics used in aviation and medicine – devices, technological parameters of 3D printing. Evaluation of the geometric and metallurgical quality of sample parts of printed machines using various additive techniques. Additive technologies and Industry 4.0. |
| 33. | **Selected issues in 3D printing** | Analysis of the possibility of manufacturing structural elements using Rapid Manufacturing techniques. Specificity of processing advanced construction materials using laser additive forming methods. Material tests and assessment of geometric quality of printouts. Traditional vs. laser methods of regeneration of machine and equipment parts. Analysis of the possibility of reconstructing the operating indicators of machine and equipment parts using the semi-industrial LENS system – multi-criteria quality assessment. |
| 34. | **Researcher's workshop 1 – tools for writing scientific texts** | The course introduces the student to issues related to the basic methods of creating texts describing the results of research work, including advanced use of the functions of the following programs: MS Word, LATEX, ENDNOTE, MENDELEY and practical ways of creating drawings, tables and citations. In addition, students are familiarized with the methodology of selecting the right journal and practical tips when sending manuscripts for publication in prestigious journals. |
| 35. | **Researcher's workshop 2 – writing scientific articles** | The course introduces the student to issues related to the basic methods of designing the content of scientific articles, the vocabulary used, methods of graphic processing of results and the use of software helpful in the creation of scientific |

| No. | Item Name | Curriculum content |
|---|---|---|
| | | texts. In addition, the methods of literature analysis, the ethics of creating scientific texts and the selection of author's typesetting, the basis of the methodology for processing results, as well as the possibilities of using software and services for linguistically correcting scientific texts will be presented. |
| 36. | **Researcher's Workshop 3 – Writing Scientific Articles** | The course introduces the student to the issues related to the estimation of measurement uncertainty in scientific papers. The issues raised during the classes are focused on learning practical methods of determining uncertainty in real measurements. Theoretical aspects, i.e. the mathematical apparatus used in estimating uncertainty, is reduced to the necessary minimum. Part of the classes is intended to solve the issues reported by the students. |
| 37. | **Quantum mechanics in examples** | The course aims to solve in detail and analyze the most important examples describing the behavior of particles in the microworld in the language of quantum mechanics. After the introduction to wave mechanics, the following examples will be analyzed:<br>free particle; transmission (reflection) through the potential threshold; transmission (reflection) through the potential barrier (tunnel effect);<br>an infinite pit of potential; a finite pit of potential; harmonic oscillator; the Krönig-Penney model; solving the problem of the Coulomb potential. |
| 38. | **Corrosion testing in materials science** | Corrosion phenomenon and mechanisms of various types of electrochemical and chemical corrosion, thermodynamic determinants of corrosion phenomena: corrosion vs. passivity – Pourbaix diagrams, qualitative and quantitative methods in corrosion tests – review, polarization and polarization curve with its characteristic points and ranges, determination of corrosion current potential and density from extrapolation by the Tafel equation, chronoamperometry and determination of the initiation and propagation time of pitting in corrosion Basics of electrochemical impedance spectroscopy: equivalent circuits and real elements of materials and coatings, salt chambers, immersion tests. |
| 39. | **Anodic oxides of copper and its alloys – production, characteristics and applications** | Synthesis and mechanism of growth of passive layers on copper, review of the methods and experimental conditions used for the production of copper oxides and hydroxides by electrochemical means, thermodynamic conditions allowing the growth of oxides and hydroxides, redeposition and growth of layers, modifications of copper oxides and hydroxides, applications of nanostructured copper oxides and hydroxides: corrosion protection, photocatalysis, electrochemical reduction of carbon dioxide to alcohols and Hydrocarbons. |
| 40. | **Anodizing of aluminum alloys** | Structure and mechanical properties of alloys vs. corrosion resistance, corrosion failure mechanisms of common aluminum alloys, overview of industrial anodizing methods, conversion coatings vs. anodic coatings, soft, hard and plasma anodizing (PEO/MAO), hexavalent chromium problem, chromium-free alternatives used in anodizing aluminum alloys, nanoporous oxide and corrosion protection, pore closure, REACH convention vs. anodizing and pore closure, durability of anodic aluminum oxide on technical alloys, methods of quantitative treatment of corrosion of aluminum alloys after anodizing. |

**Annex VI.5**
**to the Education Program at the Doctoral School of the Military University of Technology**

## Curriculum content for optional subjects
## Scientific discipline: mechanical engineering

| No. | Item Name | Curriculum content |
|---|---|---|
| 1. | Numerical Analyses in Load-Bearing Structures | Theoretical foundations of numerical methods of analysis of load-bearing structures including multi-stage analyses, strategy of computer FEM simulation of two- and three-dimensional problems in the field of mechanics and strength of materials and methodology of simplification (reduction of static diagrams) of real structures enabling the creation of a correct and effective numerical model. Methods of modeling mechanical structures with particular emphasis on supporting structures using graphics preprocessors. Construction of 2D and 3D models for analysis in the field of selected engineering issues, performance of calculations with attention to the selection of optimal analysis parameters and assessment of the correctness of calculation results using analytical methods and available results of experimental tests, on the example of elements and components of vehicles, special and load-bearing structures. |
| 2. | Autonomy of mobile robots | Introduction, definitions, components of the construction of mobile robots. Wheeled robot drive systems. Navigation and self-location of robots. Navigation with the use of markers. Odometry, methods to improve self-localization results. Determining the position of the robot based on the map. Methods of planning the path of a mobile robot. Local planning, probabilistic methods. Tasks, construction, architecture of control systems Vision systems in mobile robotics. Walking robots. Applications of autonomous mobile robots. |
| 3. | Non-destructive testing of aircraft | Types of defects, defects and damage that threaten the safety of operation of technical facilities. Non-destructive testing methods – physical basis. Visual and penetrative methods. Ultrasound method. Acoustic methods. Eddy current method. Thermographic method. X-ray method. Shearograps and DSight. Non-destructive testing methods – advantages, disadvantages and limitations in use. Non-destructive testing certification. |
| 4. | Biomechanics of human body movement during a road accident | Biomechanics of the human body. Human anthropometric analysis. Dynamic loads and the process of injury. Basics of building measuring dummies. Basics of human body modeling. Computer simulation of the movement of a human body model and experimental research. Calculating the risk of injury to the head, torso and thighs. Injury risk prediction models. |
| 5. | Construction and operation of industrial robots | Construction and operation principle of industrial robots. Principles of robotization of production lines. Environments and languages for programming industrial robots |
| 6. | Digital signal processing | Mathematical models of deterministic signals. Advanced signal sampling techniques. Selected problems of analysis of discrete signals in the time and frequency domain. Frequency resolution of digital spectral analysis algorithms. Fast weave algorithm. Selected specialized implementations of digital filters. Basics of digital filter design. Decimation and interpolation of digital signals. Digital signal spectrum conversion. Direct Digital Signal Generation Method (DDS). Program receiver. |
| 7. | Dynamics of mechatronic system design | Issues of modeling mechatronic systems. Elements of motion and vibration analysis of linear systems with single and multiple degrees of freedom. Elements of motion analysis of nonlinear mechatronic systems. Stability testing of linear and nonlinear mechatronic systems. Self-excited vibrations. Methods of measuring vibrations of mechatronic systems. |
| 8. | Dynamics of car movement | Modeling the movement of the car. Modeling of movement on hard, snowy and deformable surfaces. Analysis of the dynamics of rectilinear and curvilinear motion. Steerability and stability. Overcoming terrain obstacles. Wheeled and tracked chassis. Modeling the process of a car crashing into an obstacle. Analysis of vibrations and driving comfort. |
| 9. | Dynamics and modeling of hydrostatic systems | Principles of dynamics of hydrostatic systems. Description of the dynamics of drive units and systems. Steady and transient, boot processes. Dynamic analysis and its description. Modeling of hydrostatic drive assemblies, subassemblies, elements |

| No. | Item Name | Curriculum content |
|---|---|---|
| | | and systems. Open and closed systems. Modeling of hydrostatic systems in MATLAB-SIMULINK. |
| 10. | Dynamics of multi-member systems | Theoretical foundations of numerical methods of analysis with the use of rigid bodies and the strategy of computer simulation of multibodies with the use of various algorithms for the formulation of equations of motion and their integration. Overview of multibody analysis software environments and examples of mechanical engineering solutions. Methods of modeling mechanical structures with rigid solids in planar and spatial systems. Construction of planar and spatial models with the use of various applications for the analysis of kinematics and dynamics of multi-member systems in the field of selected issues of mechanical engineering. Multivariant numerical analyses with attention to the selection of optimal calculation parameters and the assessment of the correctness of the obtained results using analytical and experimental methods. |
| 11. | Impulse loads of motor vehicles – selected issues | Operating conditions of motor vehicles, dynamic loads – sources. Impulse loads – characteristics. Experimental and model studies of impulse loads acting on vehicles, methods and design solutions to reduce the effects of these impacts. |
| 12. | Computer-aided operation of machines | Information needs of the operating system. Information management – information system. Characteristics of computer software. Design and operation of management information systems. Features of IT systems supporting operation management. ICT services in management. |
| 13. | Shaping a safe car body | Body construction - shaping energy-consuming and survival zones; construction of the floor plate. Estimating the energy dissipated by the body during a crash. Materials used in body construction. Body equipment - passive and preventive safety elements. Paint coatings. Crash tests. |
| 14. | Composite materials in mechanical engineering | Definition and classification of composite materials. Strength and performance properties of composite materials. Technologies for the production of composite materials. Research used in the experimental analysis of mechanical properties of composites. Joining composite materials. Metal-composite joints. Exploitation of composite materials. Repairs of composite structures. |
| 15. | Finite Element Method | Selected examples of FEM applications. FEM in terms of displacement. Member structures. Triangular and quadrangular elements. Flat state of stress and strain. Axisymmetric issues. Plate and shell elements in terms of FEM. Three-dimensional elements. Selection parameters for creating an FEM mesh – criteria. Isoparametric formulation of finite elements. Shape features. Definition of start-boundary conditions. Material models in terms of FEM. Construction of the stiffness matrix. Aggregation of the global matrix. Transformations of quantities between coordinate systems. Matrix equilibrium equation. Methods of solving systems of equations. Analysis of the model and results. Basics of adaptation methods with criteria. Determination and measures of error. |
| 16. | Methods of analysis of numerical experimental research results | Selected deterministic and stochastic examples in the research methodology allowing the use of experimental research results both in the process of validation of numerical models and verification of the obtained results using the nonlinear method of least squares, verification of statistical hypotheses, or ANOVA analysis of variance. |
| 17. | Methods of testing the condition of machines | Basic terms and definitions. Object status. Object model. Methods of analysis and recognition of the state of the object. Classification and recognition of failure conditions of objects. Criteria and rules for the selection of decision variables. Procedures and methods of testing the condition of the machine. Selected aspects of the construction of measurement and diagnostic systems. Vibroacoustic systems for testing the condition of machines. Computed tomography of machines. The use of artificial intelligence in machine condition research. |
| 18. | Experimental methods for investigating the thermophysical properties of solids | Thermophysical properties of solids, thermal conductivity, specific heat, thermal diffusivity, thermal expansion. Mechanical properties of solids – dynamic mechanical analysis (DMA). |
| 19. | Methods and techniques for testing the mechanical properties of materials | Methods of testing mechanical properties under quasi-static loading. Impact tests. Methods for determining material constants. Methods of static strength tests of elastomeric and ceramic materials. Hardness and microhardness measurement methods. Methods of measuring deformations during strength tests. Methods of |

| No. | Item Name | Curriculum content |
|---|---|---|
| | | testing the mechanical properties of materials under shock loading conditions. (Hopkinson test, Taylor test, ring test). |
| 20. | Numerical Methods in Engineering Applications | Basic concepts related to numerical calculations, sources of errors. Interpolation and approximation. Differentiation and quadrature. Systems of linear equations. Algebraic eigenproblem. Methods of solving ordinary differential equations. The linear problem of least squares. Fourier analysis. Optimization elements. Information about other areas of numerical analysis (partial differential equations, stochastic methods, etc.). |
| 21. | Numerical Methods in Mechanical Engineering | Basics of numerical methods. Interpolation polynomials. Approximation methods. Integration methods. Methods of solving systems of equations. Methods of solving nonlinear equations. Methods of solving differential equations. Application of numerical methods in mechanical engineering, including CAD/CAE systems. |
| 22. | Methods for designing and optimizing aircraft structures | Parameterization of the geometry of aerodynamic structures, dimensionless shape coefficients. Optimization methods in application applications. Numerical optimization methods: structural modeling, shape and dimensional optimization. Stages of the optimization process. Aircraft quality indicators, task and mission modeling in the tasks of optimal aircraft design. Converging and divergent spiral design. Systems and systems that are subject to the optimization process: geometry, aerodynamics, powertrain, mission, performance, structure and mass characteristics. GRIP programming language for the Siemens NX system. The use of the GRIP language for the processes of searching for the optimal geometry of the designed optimization object using integrated design systems. |
| 23. | Constitutive Models of Materials in FEM Analysis | Mathematical description of constitutive models of materials such as steels, alloys, rubbers, elastomers, foams, ceramics, etc. Experimental studies to determine the parameters of models. Numerical analyses using learned material models. |
| 24. | Modelling of heat transfer processes | The subject prepares to formulate mathematical models of heat and mass transfer processes, which require solution of the boundary-value problems for systems of partial differential equations. Within the framework of lectures mechanisms of complex and coupled (conductive-radiative) heat and mass transfer, constitutive equations of Cattaneo-Vernotte and Tzou dual-phase lag models, selected analytical as well as numerical methods of solution both the direct (including phase transitions) and the inverse heat conduction problems are discussed. During tutorials and laboratory practices PhD students use practically knowledge gained in lectures to find analytical solution of simple radiative heat transfer problems and they are searching for numerical solutions of coupled heat and mass transfer problems by using their own numerical codes as well as commercial software |
| 25. | Modeling and simulation of mechatronics issues | Principles of physical and mathematical modeling, and parametric identification of the model. Application of the Matlab/Simulink environment in the simulation of mechatronics issues |
| 26. | Modeling and simulation of nonlinear mechanical problems | Description of the implementation of deformations of solids characterized by physical nonlinearity in the range of small and large deformations. Getting to know numerical methods for solving nonlinear problems and methods for refining the solution. |
| 27. | Parametric modeling and structural optimization with FEM | Theoretical basis of the optimization procedure. Optimization algorithms. Methods of Structural Optimization Using FEM Structural Analysis. Methods for creating parametric FEM models using preprocessor scripts. Analysis of optimization results. Topological optimization. |
| 28. | Flow modeling | Methods of computer modeling of flow processes in basic and applied problems of fluid motion dynamics. Simulation methods for researching streamlined issues. Basics of modeling flow processes. Conservative formulations of basic fluid dynamics equations, boundary conditions in computational problems, basic numerical schemes and the basic CFD - Fluent computational solver. Modeling of flow turbulence, including averaged Navier-Stokes equations, turbulent stress tensor, turbulence modeling capabilities and problems. Direct methods of solving turbulent movements (the so-called DNS method), the large vortex method (LES). Mapping of complex simulation study objects, construction and execution of basic operations on computational grids, analysis of the reliability and accuracy of numerical modeling results. |
| 29. | Modeling machine motion | General principles of modeling mechanical systems. hydrostatic, electromechanical. Deterministic and random processes. Construction of simulation models. Identification of model parameters and their validation. Characteristics of basic dynamic members. Basics of dynamics of systems with variable mass. |

| No. | Item Name | Curriculum content |
|---|---|---|
| 30. | Modeling composite structures | The use of laminates. Laminate configuration. Micromechanics and macromechanics of laminates. Modeling at the level of lamina and laminate. Determination of material parameters. Stiffness and strength of laminates. Strength hypotheses. Design elements and modeling of composite (laminate) structures. Strength Analysis of Composite Structure for Selected Load Conditions. |
| 31. | Modeling of the Contact Phenomenon in Structural Mechanics | General division of contact phenomena. Mathematical foundations of the description and solution of the problem of contact. Algorithms for defining and solving the problem of contact in the environment of computer-aided engineering calculations. Use of a large-scale approach. |
| 32. | Modeling and research of the processes of cooperation between the wheel and the road | Issues of modeling and testing the processes of cooperation between the wheel and the road to the extent necessary to model the dynamics of vehicle motion (selected mathematical models, methods and techniques of testing tire wheels on a drum stand and with the use of a test trailer). |
| 33. | Modeling of car traffic and controls | Review of vehicle motion dynamics models and models describing the driver-vehicle-road system (models of lateral dynamics of the car in various control configurations). |
| 34. | Modern technologies for bonding structural materials | Friction stir welding (FSW), laser beam welding (LBW), areas of application and strength properties of the cohesive joints obtained. Influence of bonding processes on the microstructure of selected construction materials. Heat and mechanical treatment of FSW and LBW cohesive joints. |
| 35. | Modern CAD\CAM\Additive Manufacturing Design & Manufacturing Systems | Systems for computer-aided CAx design, construction and manufacturing processes. CAM technological process support systems. Additive manufacturing technology – Rapid-protytyping, Rapid-manufacturing and reverse engineering techniques. |
| 36. | Renewable energy sources | The importance of energy in the development of modern civilization. Modern fossil-based energy sources and ecological factors. Renewable energy sources. Solar energy. Wind. Water power. Geothermal energy. Bioenergy. Energy from the use of hydrogen as the fuel of the future. Energy storage systems. |
| 37. | CAE Engineering Software | An overview of CAE engineering support systems with an indication of their purpose and the possibility of using them in structural analyses. Preparation of numerical models for calculations in the static and dynamic range. Running calculations and presenting and processing the results obtained. |
| 38. | Experiment planning and optimization of mechanical objects | Introduction to planning an experiment. Measurement errors and uncertainties. Characteristics of random variables. Statistical hypotheses and their verification. Correlation and regression analysis. Plan your experiment. Two-level plans. Three-level plans. Multi-level plans. Simplex plans for analysis composition – property. Criteria for the optimality of plans. Optimization of Extreme Machine Technology of Statistical Functions and Their Limitations. Methods of determining the extremum of statistical functions. Examples of experiment optimization in mechanical engineering. |
| 39. | Basics of road safety | Basics of road safety analysis. Modeling the course of a road accident. Models of driver operation. Methods of analysis of road accidents. Safety in the movement of autonomous vehicles. Statistics of road accidents and their interpretation. |
| 40. | Basics of Internal Combustion Engine Inlet Air Filtration in Baffle Filters | Classification of internal combustion engine intake air filters. Performance requirements for air filters. Porous filter media. Aerosol filtration mechanisms in the fibrous bed. Models of filtration efficiency and aerosol flow resistance in the pulp bed. Properties of papers and filter composite materials with the addition of nanofibers. Types and methods of shaping filtration partitions. Panel, cylindrical and core inserts. Criteria for selecting air filters for the vehicle engine. Rules for the use and operation of air filters. |
| 41. | Basics of Internal Combustion Engine Inlet Air Filtration in Inertia Filters | Classification and characteristic values of inertial filters. Types of cyclones. Characteristic dimensions of the cyclone. Geometric parameters of cyclones. Factors determining the effectiveness of cyclones and multicyclones. Aerosol filtration process in cyclones. Forces acting on a particle in a cyclone. Condition for separation of particle from gas. Formulas for determining the grain diameter of the limit. Models of filtration efficiency and gas flow resistance in a cyclone. The influence of dust extraction from the sedimentation tank on the efficiency of the multicyclone. Criteria for the selection of inertial filters for motor vehicle engines. The essence of filtration of engine inlet air in two-stage filters. |

| No. | Item Name | Curriculum content |
|---|---|---|
| 42. | Fundamentals of Mechanics of Continuous Media | Fluid mechanics in the field of statics and hydrodynamics, mechanics of a deformable solid in the field of the theory of elasticity and plasticity, modeling of materials. |
| 43. | LabVIEW environment in experimental research | The process of creating programs in the LABVIEW environment with the use of control and measurement equipment (myRIO, sbRIO, DAQmx). Data types in LABVIEW. Complex data types in LABVIEW, Communication with measuring devices in LABVIEW. Analysis of measurement results. |
| 44. | Starting processes of internal combustion engines | Engine starting characteristics. Characteristics of driving the crankshaft of engines. Ignition processes and fuel combustion under start-up conditions. Characteristics and models of start-up processes. Methods and devices of starting aids. Diagnostic aspects of the start-up process. |
| 45. | Programming of control systems for unmanned working machines and robots | Introduction to the UML standard. Build relational schemas and use case schemas. Creation of control algorithms. Introduction to programming, programming devices for hydrotronic applications. Design a feedback loop. Implementation of feedback loops in control systems. |
| 46. | Mechatronic sensors | Mathematical models of mechatronic sensors. General principles of mechatronic sensors. Methods of measurement, errors and methods of calibration of sensors. |
| 47. | Condition monitoring systems | Sensors used in condition monitoring. Resistance strain gauge. Fiber optic sensors. Crack sensors. Data transmission. Recording and analysis of measurement data. Inference. Coupling of condition monitoring systems with the operating system and the operation system. |
| 48. | Aircraft Operation Systems | Principles of operation and repair of military aircraft in the Republic of Poland. Harmonized European Military Airworthiness Regulations (EMAR). European Airworthiness Regulations (PART). The role of EASA and the Civil Aviation Authority in supervising the operation of aircraft. Bulletins and other documents regulating the operation. |
| 49. | Control systems in mechanical engineering | Advanced control systems for mobile machines. Machine control system functions. Types of control systems. Development trends of sensors used in mobile machines. Vision and lidar locating and navigation systems. Satellite systems in machine control Centralized and distributed control. Intelligent communication networks. PLC control. Fuzzy logic in machine control |
| 50. | Technologies for the production and processing of composite materials | Composites, ways of defining them, types of components that make them up, the most important methods of their production and processing, the importance of this class of materials in mechanical engineering. The structure of modern composite materials depending on the method of production and the treatment used, e.g. heat, thermo-plastic. Manufacture of ceramic matrix composites and multilayer metallic composites and achievements in the use of composites. |
| 51. | Selected solutions in the field of automotive technology and car motion | Problems of the development of automotive technology and road traffic. Concepts of intelligent transport systems. Selected issues of modern automotive technology (progress in engine construction, development of drive systems – solutions used in modern gearboxes, all-wheel drive, adjustable and active suspensions, wheel hubs, new tire designs, lighting systems). Driver assistance systems. Self-driving cars. |
| 52. | Theory and organization of machine operation | Processes and operation of machines. Measurement and analysis of diagnostic signals. Procedures for diagnosing machines. Features and measures of machine reliability. Reliability of repairable objects and systems. Planning the use and renewal of machines. Designing processes and operating systems. Principles of rational operation of machines. |
| 53. | Thermomechanics of materials and studies of thermophysical properties | Phenomenological description of processes related to the accumulation and transport of energy in the manner of heat in substances and presentation of selected issues of statistical description of these phenomena to explain the nature of thermo-physical properties. Heat transfer phenomena in materials and material structures. Material properties vs. resultant and apparent properties of material structures. Methodology of testing thermo-physical properties. Thermal Analysis Methods. Methods for determining specific heat, thermal conductivity, thermal diffusivity, thermal expansion of materials and material structures. |
| 54. | Tribology | Tribology – an interdisciplinary and multidisciplinary science. Tribological systems of machines and technical equipment. Solids and liquids as structural elements of tribological systems. Friction processes in tribological systems of machines. Processes of tribological wear of machine elements. Lubrication in tribological systems of machine components. Selected methods of friction and wear testing of machine elements. Contemporary tribological problems - from nano to tera tribology. Microsystems and nano tribological systems. Selected research |

| No. | Item Name | Curriculum content |
|---|---|---|
| | | techniques of tribological microsystems. Micro/nanomechanical testing. Micro/nanotribological studies. Application of micro/nanotribological test results. Selected problems of biotribology and ecotribology. |
| 55. | Durability of aircraft structures | Methods for determining and testing aircraft durability. Concepts of aircraft operation, factors limiting the durability of aircraft, the impact of operation on durability, measurement and monitoring of loads, methods of estimating the durability of aircraft, full-scale fatigue tests, non-destructive testing techniques in aircraft operation. Corrosion of aircraft. |
| 56. | Introduction to the equations of mathematical physics | Formulation of mathematical models of physical processes that require the solution of limit problems for systems of partial differential equations. General principles for formulating limit problems for partial differential equations. The method of deriving equations describing convection, diffusion and wave transport is discussed. A general approach to the construction of mathematical models based on the equations of mathematical physics. The method of reducing borderline issues to a dimensionless form is discussed. Formulation of mathematical models based on mathematical physics equations. |
| 57. | Modern machine and vehicle drive systems | Engines used to drive machines and vehicles. Piston internal combustion engines. Turbine internal combustion engines. Electric motors. Hybrid powertrains. Energy storage systems. Other energy sources for driving machines and vehicles. Ecological aspects of the use of various drive systems. Directions of development of drive systems of machines and vehicles. |
| 58. | Modern test methods for internal combustion engines and vehicles | Identification of the purpose of research. Selection of the test method. Validation of research methods and procedures. Approval test procedure. Selected methods of homologation tests, measuring equipment. Processing of measurement results. Analysis of outliers, estimation of measurement uncertainty Analysis and presentation of research results. Calibration of measurement systems. Practical implementation of selected research methods. |
| 59. | Selected methods and techniques of temperature measurement | Theoretical basics of temperature measurement, contact and non-contact temperature sensors (design, principle of operation), their dynamic properties and related measurement errors and calibration procedures. Types of thermometers: liquid, thermoelectric, resistive, thermistor, quartz, bimetallic, radiation, fiber optic and thermal imaging cameras. Statistical processing of measurement results |
| 60. | Selected problems of rocket technology | Mathematical models of physical processes related to the dynamics of rocket motion. General rules for building rockets. Construction of rocket compartments with mathematical models. Computer simulation and visualization of the rocket flight path. Overloading of rockets on the flight path. |
| 61. | Selected issues of waste gas treatment from motor vehicles | The impact of the automotive industry is influenced by the natural environment. Characterization of harmful substances. Systems and methods of motor vehicle waste gas treatment. Development tendencies in flue gas cleaning methods. Test methods and equipment for testing waste gases from internal combustion engines and vehicles. Studies on the influence of the operating condition of an internal combustion engine on the emissions of individual exhaust components and the granulometric composition of particulate matter. |
| 62. | Selected issues of simulation of combustion processes and working processes of internal combustion engines. | Simulation tasks. Selection of the simulation method. Selected models of the work cycle of an internal combustion engine. Workflow simulation software. Procedure for simulating selected routings. Analysis and presentation of simulation results. Evaluation of simulation results. Simulation of selected working processes of internal combustion engines. |
| 63. | Selected issues of modern programming - introduction to modern programming languages. | Introduction to programming using high-level languages. The issue of structural and object-oriented programming. Introduction to Python with basic libraries and the PyCharm environment. Creating console programs using Python. Introduction to creating GUI programs. |
| 64. | Fatigue strength and fracture mechanics of materials and structures | Material fatigue phenomena and quantities describing the fatigue process. Basics of design and strength calculations of structures in the field of unlimited and limited fatigue life. Application of the principles of fatigue strength of materials and fracture mechanics. Fatigue test methodologies and fatigue testing equipment. Crack |

| No. | Item Name | Curriculum content |
|---|---|---|
| | | development due to cyclic loads. Fatigue crack growth characteristics. Methods for evaluating the strength of cracked components |
| 65. | Advanced methods of manufacturing products from sintered powders | Manufacturing processes of machine parts using modern methods of manufacturing engineering, including powder metallurgy. |
| 66. | Advanced ballistics, modeling, and simulation | Development trends in the field of solid propellants and propellant systems (theoretical basis for modeling the operation of atypical propellant systems from the point of view of internal ballistics). Outflow of powder gases from the barrel during firing and their flow through the muzzle brake (description of the phenomena occurring during the outflow of gunpowder gases from the barrel during firing - transitional ballistics). Geometrical, mass-inertial and aerodynamic characteristics of missiles and rockets (theoretical basis for modeling the motion of flying objects from the point of view of external ballistics). Modeling of the impact impact of objects (theoretical foundations for analytical and numerical modeling of phenomena that are the domain of final ballistics). |
| 67. | Advanced Mathematics | Tensor calculus basics. Vector and Euclidean space. Activities in Euclidean space. Basis and determination of the rebase matrix. The concept of a tensor. Tensor space. Base and polybase. Basic tensor operations and operations. Euclidean tensors with valence 2. Types and properties of tensors, tensor distribution. Tensor invariants. Values and majors. Scalar, vector and tensor fields. Derivative of tensor function, tensor field gradient, divergence and rotation of vector field. Stress and strain tensors. Strain energy density. Constitutive equations. Basics of calculus of variations. Functional. A variation of a functionary. Conditions of the minimum of a functional – Euler's equations. Formulation of local and global equilibrium issues |
| 68. | Advanced modeling in structural dynamics | Methods of solving dynamic problems in computer terms. Constitutive modeling for impulse-loaded structure cases. Implementation of impulsive excitations – analytical and coupling approach. Testing the response of the structure. Description of the dynamic interaction of two bodies for the contact problem. |
| 69. | Advanced measurement systems | Structure and organization of computer-controlled measurement systems and with procedures and selected "tools" for programming system controller controllers. concepts and basic methods of numerical calculations. Programming basics and how to use virtual instruments to collect, collect and process measurement data. |
| 70. | Advanced Materials Testing Methods | Methods of testing materials, possibilities and limitations of various test methods based on the use of specialized equipment. Modern electron microscopy, confocal microscopy and X-ray microanalysis (qualitative and quantitative) and their practical application in mechanical engineering. Methods for investigating the macro- and microstructure of metals, their alloys and ceramic materials, and interpreting the test results obtained by various materials testing methods. Topographic contrast and its use for fractography studies, evaluation of changes in the microstructure of materials as a result of treatments, studies of powders and thin surface films. Microanalysis of phases and inclusions in materials research. Testing of material heterogeneity. Trace analysis of elements. Light microscopy in materials research. Metallography. Image analysis. Electron beam and its properties. Electron diffraction. Structure of a scanning and transmission electron microscope. |
| 71. | Application of experimental mechanics in scientific research 1 | Mechanical properties of engineering materials. Investigation of mechanical properties of materials in static tests. Elaboration of experimental research results. |
| 72. | Application of experimental mechanics in scientific research 2 | Rheological tests. Determination of material characteristics in cyclic load tests. Determination of material characteristics in shock load tests. Testing of materials at high and very high strain rates. Non-destructive testing. |
| 73. | Application of Finite Element Method in Mechanical Wave Propagation Analysis | Issues related to wave propagation (elastic, plastic). Mathematical description of the phenomenon of mechanical wave propagation. Boundary conditions. Methods to solve the presented issue. Numerical analysis of wave propagation. |
| 74. | Selected issues of vibration theory | Equations of motion of systems with one two degrees of freedom. Free vibrations of conservative systems. Free vibrations of non-conservative systems. Method of forces. Forced vibrations, resonance analysis. Vibrations forced by arbitrary force. |

| No. | Item Name | Curriculum content |
|---|---|---|
| | | Free vibrations of discrete systems with any finite number of degrees of freedom. Frequencies and forms of vibrations. Vibrations of continuous systems. |
| 75. | Selected issues in acoustoelectronics | Physical foundations of acoustoelectronics. Properties of volume and surface waves. Excitation and propagation of surface waves in piezoelectric materials. Analytical models of surface acoustic wave transducers. Classification of acoustic electronic components. Complex signal generation and processing technique. Selected methods of signal processing, compression receiver, generator. Sensors of physical quantities. Nonlinear Acoustic Surface Wave Components and Their Applications.<br>Components of acoustic surface wave component technology. |
| 76. | Numerical methods | Selected elements of linear algebra. Systems of linear equations, norms of vectors and matrices. Determining the solution of a system of linear equations - condition index. Gaussian method of numerical solving of a system of linear equations. Direct methods of numerical solving of a system of linear equations (LU distribution method, inverse matrix method). Iterative methods of numerical solving of a system of linear equations (Jacobi and Gauss-Seidler methods). A linear task of least squares. Methods for approximate solving of nonlinear algebraic equations. Interpolation with polynomials. Bonded functions. Function approximation. Integration and numerical differentiation of functions. Methods of numerical solving of ordinary differential equations. |
| 77. | Electromagnetic field theory | Maxwell's equations; Differential form of Maxwell's equations in material media; Maxwell's equations for harmonically variable fields; Integral form of Maxwell's equations. Electromagnetic waves in an ideal dielectric; TEM type flat wave; Wave impedance and specific impedance. Electromagnetic waves in a lossy medium. Boundary conditions and energy relationships in the electromagnetic field. Power balance in the electromagnetic field in real and complex description. A real, complex and time-average Poynting vector. Wave incident obliquely on the dielectric-dielectric interface; Fresnel formulas for a plane wave falling obliquely on the boundary of two dielectric media. Reflectivity and power transmission. A wave incident perpendicularly at the dielectric-dielectric interface. Determination of reflection coefficients and power transmission for a plane wave incident perpendicularly on the boundary of two dielectric media. Electromagnetic waves in waveguides. Wave Mods. Potentials in electrodynamics and radiation from current sources; Vector and scalar potential. Delayed electromagnetic potentials. Potentials generated by localized sources. Hertz's Dipole. |
| 78. | Quantum mechanics | Wave function and Schrödinger equation. Probabilistic interpretation of the wave function. Probability current density. Expected value. Separation of the wave equation. Quantum Mechanics Formalism; N-dimensional vector space; Space base; Scalar product; Hilbert space; Orthogonality of vectors and systems. Orthonormal bases; Linear operators; Operator equations; Matrix representation of an operator; Hermitian and unitary operators; Dirac notation.<br>Selected solutions of the Schrödinger equation in 1D; A quantum particle in an infinite potential well. A free quantum particle. Uncertainty of Observables - Heisenberg Uncertainty Principles. Eigenvalues and eigenfunctions of a quantum harmonic oscillator. Creation and annihilation operators. Separation of the Schrödinger equation in 3D. Quantum particle in a spherical potential well in 3D. Values and eigenfunctions of the angular momentum operator. The spin theory of the electron. - Pauli matrices. Mutual uncertainty of spin components. Entangled states and non-locality. - The concept of entangled states and qubit. Their role in new quantum technologies. |

**Annex VI.6**
**to the Education Program at the Doctoral School of the Military University of Technology**

## Curriculum content for optional subjects
## Scientific discipline: chemical sciences

| No. | Item Name | Curriculum content |
|---|---|---|
| 1. | Analysis of Chemical Warfare Agents | General characteristics and classification of chemical warfare agents. General physical and chemical properties of CWA. Toxicological, tactical, chemical classification. Basic concepts of toxicology. Possible hazards and required health and safety rules when working with chemical warfare agents. Organophosphorus poisonous agents. Toxic agents with necrotic effect. Methods for the preparation of samples containing CW and their degradation products for analysis. Analytical methods used in the analysis of CW, their precursors and their degradation products. Analytical methods used in the analysis of CW, their precursors and their degradation products. Modern instruments for the analysis of contamination in field conditions. Using chromatography for BST analysis. Determination of sulphur mustard and its decomposition products by gas chromatography (GC-MS/MS). Identification of FOST BST and their decomposition products by liquid chromatography (LC-MS/MS). |
| 2. | Chemistry and technology of liquid crystal materials | Molecular structure, structures and textures of CK. Elements of molecular structure and synthesis of CK compounds with thermotropic properties. Optical and dielectric properties, viscosity and elasticity constants CK. Electro-optical effects and principles of LCD operation. Chiral CK compounds, their properties and uses. |
| 3. | Chemistry and technology of high-energy materials | Current state of knowledge in the field of chemistry and technology of modern explosives, gunpowder and rocket fuels: structural determinants of the stability and sensitivity of explosive compounds; design, fabrication and characterization of nanostructured explosive mixtures; principles and methods of changing the shape, dimensions and morphology of the surface of particles of explosive compounds; New ways to craft explosive compositions and form them into charges. design, manufacture and characterization of thermobaric explosives; design, synthesis and explosive properties of complex compounds; design, synthesis and properties of high-energy and high-nitrogen salts and ionic liquids as well as new components of complex gunpowder and rocket fuels (polymers and oxidizers). |
| 4. | Polymer chemistry | Polymers obtained in the process of polychain reaction. Condensation polymers, polyadducts. Inorganic-organic polymers. Polymers of natural origin. Special-purpose polymers. |
| 5. | Chemistry of heterocyclic compounds | Organic chemistry course covering saturated and aromatic heterocyclic compounds, how they are obtained, reactivity, utilization and importance. The course emphasizes the ability to plan and predict the syntheses of organic compounds that have a ring structure, where one or several carbon atoms forming the ring are replaced by an atom or atoms of another element (so-called heteroatoms). Heteroatoms are most often atoms of nitrogen, oxygen, sulfur. |
| 6. | Chemical Foundations of Environmental Pollution | Basics of ecology. Man and the environment. Natural resources and ecological factors: temperature, radiation, air, water and soil. Humanity in the face of global challenges. The paradigm of sustainable development. Principles of green chemistry. Air pollution (acid jet, ozone depletion, greenhouse effect, London and Los Angeles smog). Sources of water pollution (municipal, industrial and agricultural pollution). The most important pollutants found in sewage. Pollution of seawater. Water treatment. Soil pollution. Types of harmful effects of human activity on soil: geomechanical, hydrological and chemical transformations, physical and biological degradation. Heavy metals, their characteristics, sources and impact on the environment and human health. Characteristics of cleaning and washing agents (soaps, detergents). Negative effects of using cleaning and washing agents. Organochlorine compounds in the environment (chlorophenols, polychlorinated biphenyls, dioxins). Pesticides. Classification of pesticides and their properties. Chemical structure of pesticides. Pesticide forms. Benefits and problems of pesticide use. Building materials (paints, adhesives, asbestos, products containing formaldehyde, oils) and their impact on the environment and human health. Volatile organic compounds (VOCs). VOC sources. Harmful effects of VOCs in the stratosphere. Pharmaceuticals and personal protective equipment in water. Classification, sources of origin, occurrence and environmental impact of drug residues. Food chemistry. Classification and characteristics of food additives (preservatives, improvers, antioxidants, flavor enhancers, sweeteners, dyes). Dietary supplements. |

| No. | Item Name | Curriculum content |
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| 7. | Chiral and polar liquid crystal functional materials | Basic concepts of functional and intelligent materials based on liquid crystal materials, both medium and high molecule, with particular emphasis on those with chiral and polar phases. Methods for the development of chiral liquid crystal materials (ChMCK) and polar liquid crystal materials (PMCK). Description of the basic methods confirming the structure/composition and physicochemical properties of MCC and PMCK (m.in. spontaneous polarization, tilt angle of the director, parameters of the helicoidal and helical structure, SHG, thermo-, chemo- and electro-optical response). Methods of measuring the described properties. Methods of modifying and optimizing the properties of the CMC and PMCK. Applications of the above as functional and/or intelligent materials. |
| 8. | Physicochemical Properties of Carbon Materials | Carbon - a chemical element and macromolecule - a material with unique physical, physicochemical and chemical properties. Structure and properties of carbon materials (MWeg): single crystal graphite, graphene, natural and industrial graphite, glass-like carbon, carbon black and activated carbons, carbon and graphite fibers, fullerenes, carbon nanotubes, diamonds and diamond layers. Carbon composites. Carbon quantum dots, their production and application. Obtaining MWeg, modifying their properties and test methods. Reactivity and bioactivity of carbon materials. Prospects for the development of new carbon structures and their applications. |
| 9. | Physicochemical aspects of the explosion | Explosion and detonation processes. Classical theory. Zeldowicz-von Neuman-Doring theory of detonation. Perfect and imperfect detonation. Detonation parameters in gases and solid explosives. Thermochemistry of explosives – codes for calculating detonation and explosion parameters. Initial parameters of shock waves at the boundary of the products of detonation and the external medium. Glaring factors of the explosion. Gust waves in the air. Impact of gust waves on people and objects – criteria, danger zones. Crushing and throwing effect of explosion. Assessment of the crushing capacity of explosives. To propel bodies with the products of detonation. The phenomenon of accumulation, designation of shrapnel hazard zones. Explosion hazard of gas mixtures. |
| 10. | History of chemistry | Synthesis of elements in the universe, first observations and chemical achievements of antiquity (alchemy). History of chemical discoveries in the world: physical chemistry, analytical, chemical analysis, organic synthesis, food chemistry. Achievements of chemistry after 1661 (R. Boyl). Development of separation techniques and analysis and their impact on the development of views on chemistry and the structure of chemical compounds. Evolution of nomenclature and symbols of elements and chemical compounds. History of the periodic table, kinetic and thermodynamic studies. The development of chemistry and organic synthesis in the twentieth century and its impact on the emergence of molecular biology. |
| 11. | Ionization methods in analytics | Classification of methods of ionization of chemical substances. Sources of ionization and methods of producing primary ions. Direct ionization of the analyte. Chemical ionization in positive and negative mode. Electron capture. Simple ionization detectors. Movement of ions in gases. Ion balance. Ion mobility spectrometry. Ionization of an analyte in mass spectrometry. Coupling of mass spectrometers with systems for chemical ionization – PTR-MS systems. Studies of the kinetics and thermodynamics of ionization processes. An overview of the applications of ionization methods in analytics. |
| 12. | Methods for preparing samples for analysis | Methods of preparing samples for gas chromatography – general classification and initial discussion. Traditional methods of sample preparation for analysis compared to modern separation techniques. Solid samples: Soxhlet extraction, ultrasonic, supercritical SFE, accelerated by ASE solvents. Liquid samples: liquid-liquid extraction, solid-phase extraction (SPE), SPME micro-extraction, elimination and capture method, above-surface analysis method. Gas samples: enrichment methods by sorption, freezing and desorption techniques. New aspects of environmental sample analysis. Calibration. Certified reference materials. Discussion of the sources of systematic and accidental errors, most often made during sampling and preparation. Ways to avoid their occurrence. |
| 13. | Spectroscopic methods | A subject for doctoral students of disciplines other than chemical sciences. Electron spectroscopy (UV-Vis), vibrational spectroscopy (IR), nuclear magnetic resonance (NMR) spectroscopy, mass spectrometry (MS). The doctoral student can additionally choose spectroscopic methods from the given group of methods: near-infrared spectroscopy (NIR), Raman spectroscopy, oscillation-rotational and rotational spectroscopy, two-dimensional nuclear magnetic resonance |

| No. | Item Name | Curriculum content |
|---|---|---|
| | | spectroscopy (2D NMR), circular dichroism spectroscopy (ECD and VCD), fluorescence spectroscopy. |
| 14. | Modeling and simulation computer programs in chemistry | Fundamentals of Computational Chemistry: Computational Assumptions and Methods. CHEMCAD program organization and basics of use. Application of CHEMCAD in chemical technology and materials engineering. Implementation of a project in the field of chemical technology using the CHEMCAD system. Organization of the SCIGRESS program and basics of use. Optimization of geometry and calculation of physicochemical properties of molecules. Modeling of chemical reactions in the gas phase and solution. Modeling of spectroscopic properties of molecules. |
| 15. | Modern nanoporous materials | Latest developments in the field of nanostructures. Review of techniques for studying the structure, morphology, chemical composition, surface and thermal properties of nanomaterials. Nitrogen and argon adsorption as a complete method for determining specific surface area, pore volume, pore volume distribution function and surface properties of nanoporous materials. The latest developments in the field of obtaining nanoporous silica materials. The latest developments in the field of obtaining nanoporous carbon materials. Properties and application of activated carbons obtained from polymers. Organometallic networks (MOFs). Preparation and investigation of adsorption properties of graphene composite materials. Investigation of the physicochemical properties of nanoporous materials obtained by mechanochemical method. Determination of the parameters of the porous structure of materials on the basis of adsorption isotherms. |
| 16. | Modern methods of synthesis of functional organic compounds | Introduction to functional materials – division, applications. Liquid crystals, properties, applications, liquid crystals – typical classes – correlation structure – properties. LC synthesis – synthesis of yesterday and today and synthesis of key intermediates. Synthesis of superfluorinated materials. Synthesis of positive nematics and s negative nematics. Synthesis of chiral liquid crystal compounds. OLED, OSC, OFET materials – structure, properties, applications. Organic Emission Materials – Types and Properties. Synthesis of p-type organic materials and n-type materials. Synthesis of semiconductor polymer materials and other organic functional materials |
| 17. | Biomedical polymers and biomaterials | Definition of biomaterials, classification, role of chemical composition, working environment, properties and uses of biomaterials. Metal biomaterials. Ceramic biomaterials. Polymer biomaterials. Carbon and composite biomaterials. Modern polymer and hybrid systems used in biomedicine for diagnostic purposes (e.g. contrasts for magnetic resonance imaging) and therapeutic purposes (e.g. drug carriers). |
| 18. | Practical Tools and Concepts for Modern Organic Synthesis | An advanced course in organic chemistry with an emphasis on acquiring the ability to plan the syntheses of complex organic compounds. The use of modern organic synthesis techniques. Chemistry of organofluorine compounds. Flow chemistry in organic synthesis. High-pressure organic reactions. |
| 19. | Synthesis of liquid crystals | Introduction to liquid crystals, structure and anisotropic properties. Applications of liquid crystal, display and photonic materials. Methods for determining liquid crystal phases. Two-component and multi-component liquid crystal mixtures, non-additive behaviors. Superfluorinated liquid crystal materials, synthesis of fluorinated materials - a review of synthesis methods. Design of liquid crystal materials synthesis, retrosynthetic analysis in LCs synthesis, review of transition metal-catalyzed coupling methods, typical LC synthesis pathways. Purification and planning processes of multi-stage syntheses. Synthesis of chiral liquid crystal materials. |
| 20. | Modern analytical chemistry | The importance of analytical chemistry. Application of analytical chemistry in environmental protection and in areas important for human life. Basic properties of analytical equipment. Miniaturization and mobility of analytical equipment – lab on chip. Hybrid devices. Analytical methods in Polish Standards. Trends in the development of techniques for preparing samples for analysis. Chromatography as a method of analysis of organic compounds. Chromatographic matrix columns. Biochromatography. Remote analysis methods. |
| 21. | Advanced pyrotechnics | The latest solutions used in military and civilian pyrotechnics. Currently used reducers, oxidants, binders and modifiers. Pyrotechnic applications of high-nitrogen compounds. Modern compositions of curtain smokes active in the infrared range. Modern multi-base solid rocket fuels. Solutions used in airbag inflators. Prospective applications of pyrotechnic mixtures in medicine. Basic algorithms used in modeling |

| No. | Item Name | Curriculum content |
|---|---|---|
| | | combustion processes and analytical optimization of the composition of pyrotechnic compositions. |
| 22. | Advanced spectroscopic methods | A subject for doctoral students of the discipline of chemical sciences. Expanding the knowledge about basic spectroscopic methods: electron spectroscopy (UV-Vis), vibrational spectroscopy (NIR, IR, Raman), nuclear magnetic resonance spectroscopy (NMR), mass spectrometry (MS). Advanced spectroscopic methods, including time-resolution, two-dimensional, combined techniques. |

**Annex VI.7**
**to the Education Program at the Doctoral School of the Military University of Technology**

## Curriculum content for optional subjects
## Scientific discipline: security studies

| No. | Item Name | Curriculum content |
|---|---|---|
| 1. | **Social research in security sciences** | Scientific approach in social research. Implications of the location of the discipline of security science in the field of social sciences. The logical-empirical nature of the social sciences. Basic research approaches in the field of theory construction, data collection and analysis. Basic concepts and elements of the research process. Theory and practice of operationalization of a research problem. Methods and techniques of quantitative and qualitative research. Non-reactive methods. Desk *research* |
| 2. | **Statistical methods in social research** | Population and sample. Statistical features. Measurement scales. Random variables. Normal distribution. Characteristics of qualitative and quantitative characteristics. Nonparametric estimation. Parametric estimation (point and interval). Verification of statistical hypotheses. Diagram of the materiality test. Testing the normality of the distribution. Problems of analysis of the interdependence of phenomena. The research process in the social sciences and the typical structure of scientific work. The course of data collection, analysis and evaluation. |
| 3. | **Security risk management** | Risk concept and risk management process. The concept of risk and risk management. Development of the risk management field. Risk management process. Risk measures. Types of risk in the security sector. Risk measurement in public sector entities. Risk measurement in the context of ensuring system continuity. |
| 4. | **Security Systems Project Management** | Identification of security systems. Identification of the essence, structures and attributes of the project. Complexity of projects and processes. Criteria for process analysis and evaluation. Creating process structures. Evaluation and validation of processes. Efficiency and quality of processes. Reliability of process structures. Risk in the evaluation of projects and processes. Holistic models of evaluation and validation of security system processes and designs. |
| 5. | **Safety Systems Engineering** | The place of systems security theory in the family of sciences. Basic concepts of system security (system status, description of system security-related states, system security indicators). Principles of mathematical modeling of system security. Component and subsystem safety. Systems security models. Systems security research. Analysis of system security. Control of safety, systems. |
| 6. | **Safety propaedeutics** | Characteristics of the three dimensions of modern security. Advancing Security Studies. Realism and neorealism. Comparative analysis of realist currents. The theory of liberalism in explaining security challenges and threats. The theory of constructivism. The main schools of security studies "Old" and "new" wars in the interpretations of realism and constructivism. |
| 7. | **Strategies and concepts of state security management** | The process of creating concepts and expressing the essence of safety. Ambiguity in the understanding of international security. Functional relativity of safety (awareness, relativity, environment). Verbal functional factors and ways of defining security in doctrines and strategies (comparative analysis). |
| 8. | **Crisis management in public administration** | Contemporary concepts of crisis management (the concept of vulnerability, the concept of resilience, the concept of adaptation). The subject of crisis management. Legal basis of crisis management in Poland. Crisis management process. Basic types of threats – sources of crisis situations. A crisis situation. Crisis management system in Poland. Effectiveness in crisis management. |
| 9. | **Universal safety** | The essence of public safety. General security and national security. Mechanisms shaping public safety. Rescue. Civil protection. Civil Defense. Fire protection. Critical infrastructure protection. Organization of the protection of human life and health, material and cultural goods and the natural environment Methods and tools used to ensure public security in Poland and the EU. |
| 10. | **Internal security** | Perception of security. Political determinants of internal security. Institutional system of internal security. Administrative police in the internal security system. Private entities in the organization of internal security. Organization of security in the region. Organization of security in the district. Organization of security in the district. |
| 11. | **Threat intelligence** | The importance of threat analysis for research and practical activities in the field of security. Basic concepts and definitions in the field of threats. Identification, |

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| | | typology, taxonomy of threats. Quantification and measurement of threats. Assess hazard probabilities, hazard impacts, and hazard risks. Threat management. |
| 12. | **Survey data analysis** | Creating measurement tools. Sampling. Preliminary analysis. Schedule analysis. Contingency tables, boundary and conditional distributions. Analysis of single-choice and multiple-choice questions. Significance and strength of the relationship between nominal and ordinal variables. Hypothesis testing. |
| 13. | **Multivariate analyses** | Methods of graphical presentation of multidimensional data. Multiple regression analysis. Analysis of canonical correlations. Principal components analysis. Exploratory Factor Analysis (EFA). Multidimensional scaling. Linear ordering. Cluster analysis. |
| 14. | **Evaluation research procedures** | The concept of evaluation research. History and institutionalization of evaluation research. Types of evaluation research – the concepts of "impact assessment", "action research". Differentiation of evaluation research in terms of their social functions. Experimental designs in evaluation studies. The Concept of Experimental Society by A. Etioni. Monitoring and evaluation. Elements of cost-benefit analysis in evaluation research. Measurement problems in evaluation research. |
| 15. | **Logic and theory of argumentation** | Logical argumentation. Deductive, reductive and inductive inferences. Diagrams and argumentation diagrams. Recognizing arguments. Diagram. Classified premises and conclusions. Elements of the evaluation of argumentation. Acceptability of premises. Reliability of sources. Relevance. |
| 16. | **Forecasting and simulations in security** | Forecasting and social practice. Social premises for predicting behavior. Forecast vs. decision-making. Model methods. Extrapolation of trends. Validity, admissibility and error of the forecast. Forecasting based on time series. Forecasting based on econometric models. Heuristic forecasting models. Social simulations. |
| 17. | **Modern technologies in security** | Know-how, modern technologies and their importance in ensuring safety. Modern technologies in the defense and protection system. Modern technologies in the economic security system of the state. Modern technologies in the social security system. The use of modern safety technologies in electricity generation, in the transport system, in the protection of critical infrastructure, in the protection of the natural environment. |
| 18. | **Philosophy of security sciences** | Origins, subject and branches of philosophy and philosophy of security as the most general knowledge about security. The genesis and types of human knowledge in philosophical discourse (sources: mystical, intuitive, philosophical and scientific; types: scientific, theoretical, practical and intuitive). The logic of scientific discovery, revolution in science and the progress of knowledge in the view of contemporary epistemology. Semantic analytics of the name security and types of its understanding – the essence of security in philosophical terms. A natural and conventional concept of security. Materialistic, idealistic and realistic concepts in the hermeneutic anchoring of security. The Praxeological Concept of the Four Simple Acts and Universal Methods of Shaping Security. Tendencies in Broadening, Deepening and Thickening Security Studies The Method of War, Peace, Non-Peace and Non-War in Praxeological Approach. Philosophical problems of security in contemporary societies of control and surveillance from the perspective of dataism and technohumanism. |
| 19. | **Modern terrorism** | Basic concepts and their meaning. The origins of terrorism. Causes of modern terrorism. The main factors generating and escalating terrorism. Systematization of the causes of terrorism. A triad of terrorist motivation. Key elements and types of terrorist threat. The scope and nature of terrorism at the beginning of the 21st century. Effects of terrorism. Preventing and combating terrorism. |
| 20. | **Morale and Security Culture in National and International Relations** | The essence and importance of the security culture (KB) and morale (M) of physical and legal entities in internal and international relations. Psychosocial and praxeological models and "mechanisms" of KB and M functioning – relations between them. Safety culture (KB) and morale as types of key resources and competitive advantage factors in "normal" and crisis situations. Security culture as an interface integrating the security areas in question and the national security system (SBN). Intuitive and scientific ways of diagnosing and improving KB and M. Security culture and morale in times of information warfare and asymmetric conflicts |

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| 21. | **Safety history** | Military, political and economic security of medieval Polish and the Polish-Lithuanian Commonwealth until its collapse. The main problems of European security in the nineteenth century. Polish national uprisings of the nineteenth century. World War I. Determinants of international security in the interwar period. Military, political, economic and social security of the Republic of Poland (1918–1939). World War II. International security in the second half of the twentieth century. U.S.-USSR relations and their impact on international security. Military, political and economic security of Poland after World War II. |
| 22. | **Strategic communication** | Characteristics of strategic communication (terminology, essence, responsibility in NATO). Public diplomacy (terminology, essence, structures). Informing the public (terminology, essence, structures). Information operations (methods, views of NATO, views and structures of the USA, Polish views). Psychological operations (methods and techniques of action, US structures, German structures, Polish structures, British structures). |
| 23. | **Political security sector** | Political security. Concepts. Political security in security sciences. Forms and types of political threats as well as determinants and research of political security. A model of institutionalization of political security. The need for citizen security and the tasks of a democratic state. The crisis of civic identity. Power as a factor of security. Security strategy as an instrument of political security. The influence of interest groups on political decisions. Media – shaping public opinion. The basic dilemma of political security. |
| 24. | **Shaping military security in the 21st century** | Characteristics of military security of selected states and associations of states in relation to the methodology of identification and description of challenges, and thus potential opportunities and threats to the existence and development of individual societies. The terminology of military security, the components of this security, the impact of these elements on the state and process of military security in the face of identified and described challenges (opportunities and threats) in the perspective of the current century. |
| 25. | **Information security** | Definitions and interpretation of the basic terms: threat, vulnerability, security, incident, information security. Basic processes of information asset protection: authentication, authorization, accounting. Formal models: Bella-LaPauduli, Biby, Shiver-Wilson, Brewer-Nash. Basic security claims. Security policy, main objectives and challenges. Risk management and assessment of the state of protection of information resources. |
| 26. | **The economic dimension of safety** | Defining economic security and its dimensions. Economization of state security. Typology of threats to economic security. The state and the national economy in the face of contemporary cultural and civilizational changes. Economic aggression in international relations. Financial crises. Activities of transnational corporations. Technological espionage as a threat to economic security. State activity to ensure economic security. |
| 27. | **Energy security in the face of socio-economic transformation** | The impact of socio-economic transformation on the functioning of the energy sector of developing and developed countries, and thus also on the energy security of these countries. A parallel process of influencing the way the energy industry operates, as well as the functioning of the energy security sector to protect the industry against threats (both old and new, generated by current socio-economic changes). |
| 28. | **Social Determinants of the Security of Modern States** | The essence of social security. Social security and the model of the state system. Mechanisms shaping social security. Concepts of social security. Models of social security in the EU. Problems of social security in Poland and ways to overcome them. EU activities for social security. |
| 29. | **Environmental security on a global, regional and national scale** | Types of challenges (opportunities and threats) generated by climate change in the area of environmental security. Identification of the impact of climate change on the national security of selected societies on a national, regional and global scale. |
| 30. | **Cultural security factors** | Culture: concept, categories, identity. Cultural security: conceptual aspects, cultural security in the area of spiritual culture, security in the area of material culture. Cultural threats to the security of the Republic of Poland. The cultural security system of the Republic of Poland. Cultural aspects of international relations. The Cultural Background of International Conflicts. Security Culture – National and International Aspects |