Ministry of Science and Higher Education of the Republic of Kazakhstan

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APPROVED:
Dean of SIT&IS:
Kumargazhanova S.K.
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EXPERIMENTAL AND STATISTICAL METHODS FOR THE DEVELOPMENT OF MATHEMATICAL MODELS

Syllabus

Programme of Study: 8D07101 Automation and Control
Course code: ESMPMM7203
Number of credits: 5
Cycle: BD
Component: CS

Ust-Kamenogorsk, 2022

The syllabus was developed at «SIT&IS» School on the basis of the State General Educational Standard for Higher Education approved by the Minister for Education and Science of the Republic of Kazakhstan (Order No. 604 dated 10.31.2018), Rules for organizing educational process based on academic credit system approved by the Minister for Education and Science of the Republic of Kazakhstan (Order No. 563 dated 12.10.2018), Education Program, Work Curriculum, and the Catalog of Elective Courses.

Approved by the Quality Assurance Commission

Chairperson — Zhomartkyzy G.
Date 29.08.2022 y. minutes №1

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8D07101

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1 COURSE DESCRIPTION. ITS PLACE IN THE ACADEMIC PROCESS

1.1 Course Overview

This course provides the basics knowledge about experimental and statistical methods for obtaining mathematical models. Automation of technological processes is the most important production task, which can be solved using models and modeling. The course "Experimental and statistical methods for the development of mathematical models" allows students to gain knowledge and ideas about the basics and methodology of modeling, about obtaining and applying models to control of technological processes. The result of studying the course "Experimental and statistical methods for the development of mathematical models" should be the assimilation by doctoral students of the basic concepts and definitions of the theory of modeling, classifications of models and types of modeling and the acquisition of skills in statistical processing of experimental results and the establishment of functional dependencies of measured values, as well as analysis of the reliability and optimality of the applied models

1.2 Goals and Objectives of the Course

Goals of the course: the formation of students' basic ideas and knowledge about experimental-statistical methods for the development of mathematical models and the skills of statistical processing of the experimental results and the establishment of functional dependencies of the measured quantities, as well as the analysis of the reliability and optimality of the models used.

Objectives of studying the discipline:

As a result of studying the discipline, the student must:

- to gain knowledge about the basics and methodology of modeling, about the use of experimental and statistical methods for the development of mathematical models for the control of technological processes;
- to acquire the skills and abilities of statistical processing of the results of the experiment and the establishment of functional dependencies of the measured values, as well as the analysis of the reliability and optimality of the models used;
- be able to work with technical documentation and necessary software.

The knowledge provided by the course "Experimental and statistical methods for the development of mathematical models" is not only the basis, but also the key knowledge for independent research in the field of automation and control of technological processes.

1.3 Learning Outcomes

Learning outcomes are determined based on Dublin Descriptors for the appropriate educational level and are expressed through competencies

Core competencies to be formed	Learning outcomes (units of core competencies)	
	Programme of study	Course
	PO1 - Demonstrate an understanding of the nature and meaning of information, possession of the main methods, methods and means of obtaining, storing, processing information	Students should know: - basic concepts and principles of developing mathematical models of stochastic processes using experimental and statistical methods. Skills: - Working with specialized software; Competencies: Key competencies are:

Core competencies to be formed	Learning outcomes (units of core competencies)	
	Programme of study	Course
KK5 - Ability to work on innovative projects using research methods based on the study of scientific and technical information	PO5 - Perform calculations related to the choice of element parameter values, optimization of these parameters and operating modes using computer equipment	- knowledge of the basic concepts and principles of modeling, the main areas of application of experimental and statistical methods for the development of mathematical models; - the ability to work with specialized software used for mathematical modeling and analysis of the reliability and optimality of models; - practical skills in the application of experimental statistical methods for the development of mathematical models.
KK6 - The ability to perform work on standardization, technical preparation for the certification of technical equipment, equipment, metrological support	PO6 - apply modern metrological knowledge in the operation of equipment and instruments	

1.4 Educational Technologies Used in the Course

1.4.1 Key Educational Technologies

The following educational technologies are used during the Course:
- technology of research activities;
- technologies of educational and research activities;
- project-based learning;
- communication technologies (discussion, press conference, brainstorming, educational debate and other active forms and methods);
- information and communication (including distance educational) technologies.

1.4.2 Adaptive Learning Technologies (Inclusive Education)

The following learner-adaptive educational technologies can be used in education for persons with special needs:
- access to electronic teaching aids and the links to Internet resources;
- possibility to submit assignments through the LMS portal.

1.4.3 Innovative

It is planned to use the following innovative educational technologies (forms of training) during the lessons:

Traditional teaching

The traditional form of education provides:
- the systematic nature of training;
- orderly, logically correct presentation of educational material;
- organizational clarity;
- constant emotional impact of the teacher's personality;
- optimal resource consumption for mass training.

Distance learning

Distance learning provides:
- the systematic nature of training;

- orderly, logically correct presentation of educational material;
- organizational clarity;
- feedback from student and teacher;
- optimal resource consumption for mass training

Forms of organizing distance learning:
1. Lectures (video lectures, multimedia lectures, visualization lectures) using such basic programs as BBB and ZOOM;
2. Practical exercises (practical exercises on solving problems, laboratory work) are also carried out using the BBB and ZOOM platforms, as well as using the distance learning system (LMS);
3. Consultations with a teacher (in real time and in distributed time mode);
4. Quality control of knowledge (midterm and final control, test control, self-control, mutual control).

1.5 Prerequisites

Higher mathematics
Automatic control theory

1.6 Postrequisites

Knowledge in this discipline is necessary for the performance of qualifying work (doctoral thesis) and for research internship.

1.7 Course Workload

Types of classes	hours
Lectures	30
Laboratory works	15
SAWTG (Student Autonomous Work under Teacher Guidance)	75
SAW (Student autonomous work)	30
Final assessment method	Exam

2 COURSE CONTENT

2.1 Course Topics

№	Topic, content	Workload (hours)	Reading
Lectures			
1	Modeling: basic concepts and definitions. Goals and principles of modeling. Axioms of the theory of modeling.	2	[1-16]
2	Types of models and modeling. Functions of models. Factors affecting the object model.	2	[1-16]
3	Mathematical modeling: basic concepts and definitions. Requirements for the mathematical model. The structure of the mathematical model.	2	[1-16]

№	Topic, content	Workload (hours)	Reading
4	Classification of mathematical models. The goals of mathematical modeling for technical objects and technological processes. Examples.	2	[1-16]
5	Modeling technologies. Algorithm for constructing an analytical model. Examples.	2	[1-16]
6	Algorithm for constructing an empirical model. Examples. Brief description of the main stages of algorithms for constructing analytical and empirical models.	2	[1-16]
7	Development of empirical regression models: basic concepts, experiment planning, choice of factor levels, full factorial experiment, experiment.	2	[1-16]
8	Regression models with one input variable: basic concepts. Adequacy and Accuracy of Regression Models. Types of regression models with one input variable.	2	[1-16]
9	Regression models with multiple input variables. Multivariate (multiple) linear regression. Matrix Approach to Determining Regression Coefficients	2	[1-16]
10	Assessment of the adequacy and accuracy of a multivariate linear model. Linear regression models with multiple input variables.	2	[1-16]
11	Nonlinear regression models with multiple input variables. Step methods for building regression models	2	[1-16]
12	Interpretation and optimization of regression models.	2	[1-16]
13	Statistical modeling and its techniques. Statistical modeling versus mathematical modeling.	2	[1-16]
14	Statistical modeling software. Static modeling versus machine learning.	2	[1-16]
15	Mathematical models of stochastic processes obtained by experimental and statistical methods. Description of the investigated object in the local area of the space of variables.	2	[1-16]
TOTAL		**30**	
Laboratory works			
1	Measurement of physical (experimental) quantities and measurement errors. Determination of functional dependencies of experimental values using regression analysis in Excel.	2	[1, 3]
2	Algebraic operations on matrices and determinants.	1	[1, 17, 18]
3	Basic concepts and definitions of theory of automatic control (TAC). Determination of the optimal control law according to the Pontryagin maximum principle.	2	[17, 18]
4	Determination of the stability region of the automatic control system by the method of D-partitioning. Repetition of the basic concepts and definitions of TAC.	2	[17, 18]

№	Topic, content	Workload (hours)	Reading
5	Analysis of a dynamic system by the method of state variables. Analysis of the models of typical dynamic elements in a program-simulation VisSim	2	[17, 18]
6	Analysis of the optimal solution to a linear model using the Excel Solution Finder	2	[1-4]
7	Analysis of the optimal solution to an integer linear model using the "Excel Solution Finder"	2	[1-4]
8	Analysis of a nonlinear model solution using the Excel Solution Finder.	2	[1-4]
TOTAL		**15**	
Student Autonomous Work under Teacher Guidance (SAWTG)			
1	What is Mathematical Modeling? Steps of the Modeling Process.	5	[19-22]
2	Data Fitting. Definition: Descriptively realistic. Plotting data, including scatterplots, proportionality. Fitting linear data visually. Functions you should know on sight. Group discussion of fitting y=Cxk.	5	[19-22]
3	Why plot data visually? Exponential growth. Definitions: birth rate, death rate, growth rate, Mathusian model, Regression, Method of Least Squares. Regression and the method of least squares.	5	[19-22]
4	Examples Using Least Squares. Interpolation vs. Extrapolation.	5	[19-22]
5	Introduction to vectors and matrices. Matrix Multiplication. Transition matrix interpretation. Leslie matrices for modeling population change. Introduction to probability.	5	[19-22]
6	Errors inherent to the modeling process. Definition: Error, Fractional Error, Percentage Error.	5	[19-22]
7	Evaluation of Mathematical Models. How can a mathematical model be good? Definitions: Accuracy, Descriptive Realism, Precision, Robustness, General, Fruitfulness. College enrollment examples. The advantages of inaccuracy: Traveling Salesman Problem.	5	[19-22]
8	Positive and Negative Correlation. Types of Causality: Simple, Reverse, Mutual Causality, Confounding Variable, Coincidence. Correlation is not causation. Calculations.	5	[19-22]
9	Linear Optimization. Linear Programs. Graphical interpretation. Solving graphically. Using Excel to optimize.	5	[19-22]
10	Resource Allocation. Additional examples of linear programming. Integer programming	5	[19-22]
11	Sensitivity analysis in linear optimization. Group work on sensitivity analysis. Question and Answer Session.	5	[19-22]
12	Simulation modeling. Simulation models. Monte Carlo simulation. Using Excel to run simulations. Monte Carlo simulations to calculate area. Queuing simulations. Collecting, plotting, and visualizing data.	5	[19-22]

№	Topic, content	Workload (hours)	Reading
13	Queuing Simulation. Examples. Gathering data. Running many trials. Gathering and plotting time-dependent data.	5	[19-22]
14	Basic Probability. Deterministic versus Probabilistic. Independent events. Determining probability of events. Component Reliability.	5	[19-22]
15	Determining Probabilities. Markov Chains. Sources of Error. Project Presentations.	5	[19-22]
TOTAL		**75**	

2.2 Tasks for Student Autonomous Work (SAW)

Topic	Content	Assessment method	Submission date, week	Workload (hours)	Reading
State-of-the-art software for process modeling and control	Based on a review of relevant (over the past 7 years) research papers in the field of your research (with the provision of your review and references), highlight the main software used to solve modeling problems and give a brief description of it (name, manufacturer, tasks to be solved, main advantages) ...	Essay	7	15	required to provide
The use of experimental and statistical methods to develop a model in your research.	Describe the main idea (hypothesis), object and subject of the dissertation research. Analyze how you can apply experimental statistical methods to develop a model in your research, describe briefly the type of model and the processes simulated, indicate which	Essay	14	15	required to provide

Topic	Content	Assessment method	Submission date, week	Workload (hours)	Reading
	software can be used for this and why.				
TOTAL				**30**	

2.3 Schedule of Course Assignment Submission

Types of tasks	Academic period, week									
	1	2	3	4	5	6	7	8	9	10
Knowledge										
Essay					+				+	
Comprehension										
Laboratory work report				+				+		
Application										
Laboratory work report				+				+		
Analysis										
Essay					+				+	

3 ASSESSMENT OF STUDENT KNOWLEDGE

The teacher performs all types of current control and puts an appropriate assessment of the current progress of students twice in the academic period (semester, quarter). According to the results of the current control, a rating of 1 and 2 is formed. At the same time, the student's educational achievements are evaluated by accumulating points for certain types of tasks from 0 to 100. The assessment of the student's work in the academic period is carried out by the teacher in accordance with the schedule of assignments for the discipline. The control system can combine written and oral forms, group and individual forms.

Period	Type of task	Number of points (max)	Total
1st midpoint control (rating)	State-of-the-art software for process modeling and control (Essay). Laboratory work report.	100	0-100
2nd midpoint control (rating)	The use of experimental and statistical methods to develop a model in your research (Essay) Laboratory work report.	100	0-100
Final control	Exam		0-100

The student’s final grade in the course is calculated on a 100 point grading scale, it includes:
- 40% of the examination result;

- 60% of current control result.

The final grade is calculated by the formula:

$$И = 0.6\frac{P_1+P_2}{2} + 0{,}4Э \quad (1)$$

where P1, P2 are numerical values of Rating 1 and Rating 2 correspondingly;
Э is the numerical value of the examination grade.

Final alphabetical grade and its equivalent in points:

Point and alphabetical grading system of student achievements and its transfer to the traditional grading scale and ECTS.

Alphabetical grade	Numerical value	Points (%)	Traditional grade	Criterion
A	4.0	95-100	Excellent	The theoretical content of the course has been fully mastered, without gaps, the necessary practical skills of working with the mastered material have been formed, all the learning tasks provided for in the learning program have been completed, the quality of their performance is estimated by the number of points close to the maximum.
A-	3.67	90-94		
B+	3.33	85-89	Good	The theoretical content of the course has been fully mastered, without gaps, some practical skills of working with the mastered material have not been formed sufficiently, all the learning tasks provided for in the learning program have been completed, the quality of none of them has been evaluated with a minimum number of points, some types of tasks have been completed with errors.
B	3.0	80-84		
B-	2.67	75-79		
C+	2.33	70-74		
C	2.0	65-69	Satisfactory	The theoretical content of the course has been partially mastered, but the gaps are not significant, the necessary practical skills of working with the mastered material have been mainly formed, most of the learning tasks provided for in the learning program have been completed, some of the completed tasks may contain errors.
C-	1.67	60-64		
D+	1.33	55-59		
D	1.0	50-54		
FX	0.5	25-49	Unsatisfactory	

Alphabetical grade	Numerical value	Points (%)	Traditional grade	Criterion
F	0	0-24		The theoretical content of the course has not been mastered, the necessary practical work skills have not been formed, the completed learning tasks contain gross errors, additional independent work on the course material will not lead to a significant improvement in the quality of the learning tasks.

Exam questions

1. Modeling: basic concepts and definitions.
2. Goals and principles of modeling.
3. Axioms of the theory of modeling. Types of models and modeling.
4. Different types of models and simulations. Functions of models.
5. Object modelling. Factors affecting the object model.
6. Mathematical modeling: basic concepts and definitions.
7. Requirements for the mathematical model. The structure of the mathematical model.
8. Classification of mathematical models.
9. The goals of mathematical modeling for technical objects and technological processes.
10. Modeling technologies and software.
11. Algorithm for constructing an analytical model.
12. Algorithm for constructing an empirical model.
13. Brief description of the main stages of algorithms for constructing analytical and empirical models.
14. Development of empirical regression models: basic concepts, experiment planning.
15. Full factorial experiment, the choice of factor levels, experiment.
16. Regression models with one input variable: basic concepts.
17. Adequacy and Accuracy of Regression Models.
18. Types of regression models with one input variable.
19. Regression models with multiple input variables. Multivariate (multiple) linear regression.
20. Matrix approach to determining regression coefficients
21. Assessment of the adequacy and accuracy of a multivariate linear model.
22. Linear regression models with multiple input variables.
23. Nonlinear regression models with multiple input variables.
24. Step methods for building regression models
25. Interpretation and optimization of regression models.
26. Statistical modeling and its techniques.
27. Statistical modeling versus mathematical modeling. Statistical modeling software.
28. Statistical modeling versus machine learning.
29. Mathematical models of stochastic processes obtained by experimental and statistical methods.
30. Description of the investigated object in the local area of the space of variables.

4 COURSE POLICY

The student is obliged:
- comply with the mandatory requirements of the relevant educational program, individual plan, attend training sessions and complete all types of assignments provided for by the curriculum and academic discipline programs in a timely manner;
- to comply with the requirements of regulatory enactments in the field of education that regulate educational, scientific processes, their organization and conduct, the Charter of the University, these Rules, other local regulatory acts of the University;
- pass the intermediate and final attestation of knowledge within the prescribed period in accordance with the curricula and programs, the University Charter and other normative acts of the University;
- effectively use the technical means provided by the University, economically and rationally use materials, energy and other material resources of the University, take measures to ensure the safety of this property. In the event of material damage to the University, students are obliged to compensate it in accordance with civil law;
- be disciplined, maintain cleanliness and order at the University;
- observe the generally accepted ethics of behavior, communication;
- comply with safety regulations, fire safety.

For violation by a student of the obligations stipulated by the legislation of the Republic of Kazakhstan, these Rules and other local regulations of the University, the following disciplinary sanctions may be applied to the student: rebuke; expulsion from the University.

It is prohibited on the territory of the University:
- behavior that hinders the normal work of the relevant unit;
- smoking tobacco outside of places specially designated and equipped for this;
- the use of alcoholic beverages, including low alcohol;
- storage, use and distribution of drugs of toxic and narcotic intoxication, as well as their precursors (the list of which is determined by the legislation of the Republic of Kazakhstan);
- gambling;
- drunkenness, drug or toxic intoxication;
- appearance with animals;
- storage, distribution and use of explosives and pyrotechnics;
- stay in outerwear and headdresses, as well as eating in classrooms during classes.

5 RECOMMENDED READING

5.1 Key reading

1. D. C. Montgomery, G. C. Runger and N. R. Hubele, “Engineering Statistics”, 2nd Edn., John Wiley and Sons Inc, Hoboken, USA, 2001-342 p. (In English).
2. Ayupov, V.V. Mathematical modeling of technical systems: textbook / V.V. Ayupov; M-in s.-kh. RF, federal state budgetary images. institution of higher education "Perm state. s.-kh. acad. them. acad. D.N. Pryanishnikov ". - Perm: IPC "Prokrost", 2017. - 242 p. (In Russian)
3. Shterenzon V. A. Modeling of technological processes: lecture notes / V.A. Shterenzon. Yekaterinburg: Publishing house Ros. state prof.-ped. University, 2010.66 p. (In Russian)
4. Alontseva D.L. Organization and planning of scientific research: Methodological guidelines for practical training for undergraduates specializing in "Automation and

Control" and "Instrument Engineering" / D.L. Alontseva, V.A. Plotnikov - EKSTU, Ust-Kamenogorsk, 2012.- 36 p. (In Russian)
4. Ponomarev VB Mathematical modeling of technological processes: a course of lectures/ V.B. Ponomarev, A.B. Loshkarev. Ekaterinburg: GOU VPO USTU-UPI, 2006. 129 p. (In Russian)
5. Kostin V.N., Tishina N.A. Statistical Methods and Models: A Tutorial. - Orenburg: GOU OSU, 2004 .-- 138 p. (In Russian)
6. Draper N. Applied regression analysis: translation from English / N. Draper, G. Smith. 3rd ed. Moscow: Williams, 2007.912 p. (In English and in Russian)
7. Kuzmin V.V. Mathematical modeling of technological processes of assembly and mechanical processing of mechanical engineering products: a textbook for universities / V.V. Kuzmin et al.. Moscow: Higher school, 2008.279 p. (In Russian)
8. Ashikhmin VN Introduction to mathematical modeling: textbook / VN Ashikhmin et al.; ed. P.V. Trusova. Moscow: LOGOS, 2005.440 p. (In Russian)
9. Councils B. Ya. Modeling of systems: a textbook for universities / B. Ya. Soviets, S.A. Yakovlev. 3rd ed., Revised and enlarged. Moscow: Higher School, 2001.343 p. (In Russian)
10. Dyakonov V.P. New information technologies: textbook / VP Dyakonov et al.; ed. V.P.Dyakonov. Moscow: SOLON Press, 2005.640 p. (In Russian)
12. Sablina N. G. Information technologies: lecture notes: in 2 parts / N. G. Sablina, G. M. Chernogorodova. Yekaterinburg: USTU-UPI Publishing House, 2001. Part 2. 119 p. (In Russian)
13. Dulov V. G. Mathematical modeling in modern natural science: textbook / V. G. Dulov, V. A. Tsibarov; ed. V.G. Dulova. St. Petersburg: Publishing house of St. Petersburg. University, 2001.244 p. (In Russian)
14. Zarubin VS Mathematical modeling in technology: a textbook for universities / VS Zarubin et al.; ed. V.S. Zarubina. Moscow: Publishing house of MSTU im. N.E.Bauman, 2001.496 p. (In Russian)
15. Spirin N. A. Methods of planning and processing the results of an engineering experiment: textbook / N. A. Spirin [and others]; ed. N. A. Spirina; GOU VPO USTU - UPI. Ekaterinburg, 2003.260 p. (In Russian)
16. Rogov V. A. Technique and practice of technical experiments: a tutorial / V. A. Rogov. Moscow: Academy, 2005.288 p. (In Russian)

5.2 Further reading

17. Alontseva D.L. Theory of linear systems of automatic control: textbook / D.L. Alontseva, A.L. Krasavin, A.T. Kussayin-Murat. Ust-Kamenogorsk: D. Serikbayev EKTU, 2020.-136 p. (In Russian)
18. Alontseva D.L. Automatic control theory. Linear automatic control systems: a tutorial / D.L. Alontseva, A.L. Krasavin, A.T. Kussayin-Murat. Ust-Kamenogorsk: D. Serikbayev EKTU, 2021.-112 p. (In Russian)
19. Bellomo N., De Angelis E.,. Delitala M Lecture Notes on Mathematical Modelling from Applied Sciences to Complex Systems. Vol. 8 – 2010, Published by: SIMAI Politecnico Torino, Roma, Italy,171 p.

20. Barbarossa M. Basics of Mathematical Modeling from the Lecture Notes of Prof. C. Kuttler, May 11, 2010, 20 p.
21. Rumbos A. J. Mathematical Modeling. Preliminary Lecture Notes, Draft date March 23, 2012, 67 p.
22.Hanusa Ch. Mathematical Models. Lecture notes, Spring 2010 http://people.qc.cuny.edu/faculty/christopher.hanusa/courses/Pages/245sp10/notes.html