Master’s Programme in Mathematics and Operations Research: Study Guide 2015-2016

Degree structure

Director of degree programme: Professor Nuutti Hyvönen
Degree: Master of Science (Technology), 120 ECTS

Description of the programme

The objective of the Master's Programme in Mathematics and Operations Research is to train experts who have broad knowledge of mathematical methods and tools as well as strong problem solving skills so that they can successfully tackle challenging scientific, industrial, economic, and environmental problems.

The students learn to think mathematically. They also learn to build mathematical models and to analyze them by developing and deploying state-of-the-art methods and algorithms. Through their choice of major, the students can focus on mathematical theory, computational methods, or modelling and problem solving skills that are needed in practice.

Graduates from the Master's Programme in Mathematics and Operations Research are in growing demand in many industries and in the public sector. This growth is partly driven by the ability to collect more data about a great variety of phenomena, which together with advances in mathematical methods and greater computational power makes it possible to apply mathematical skills ever more extensively.

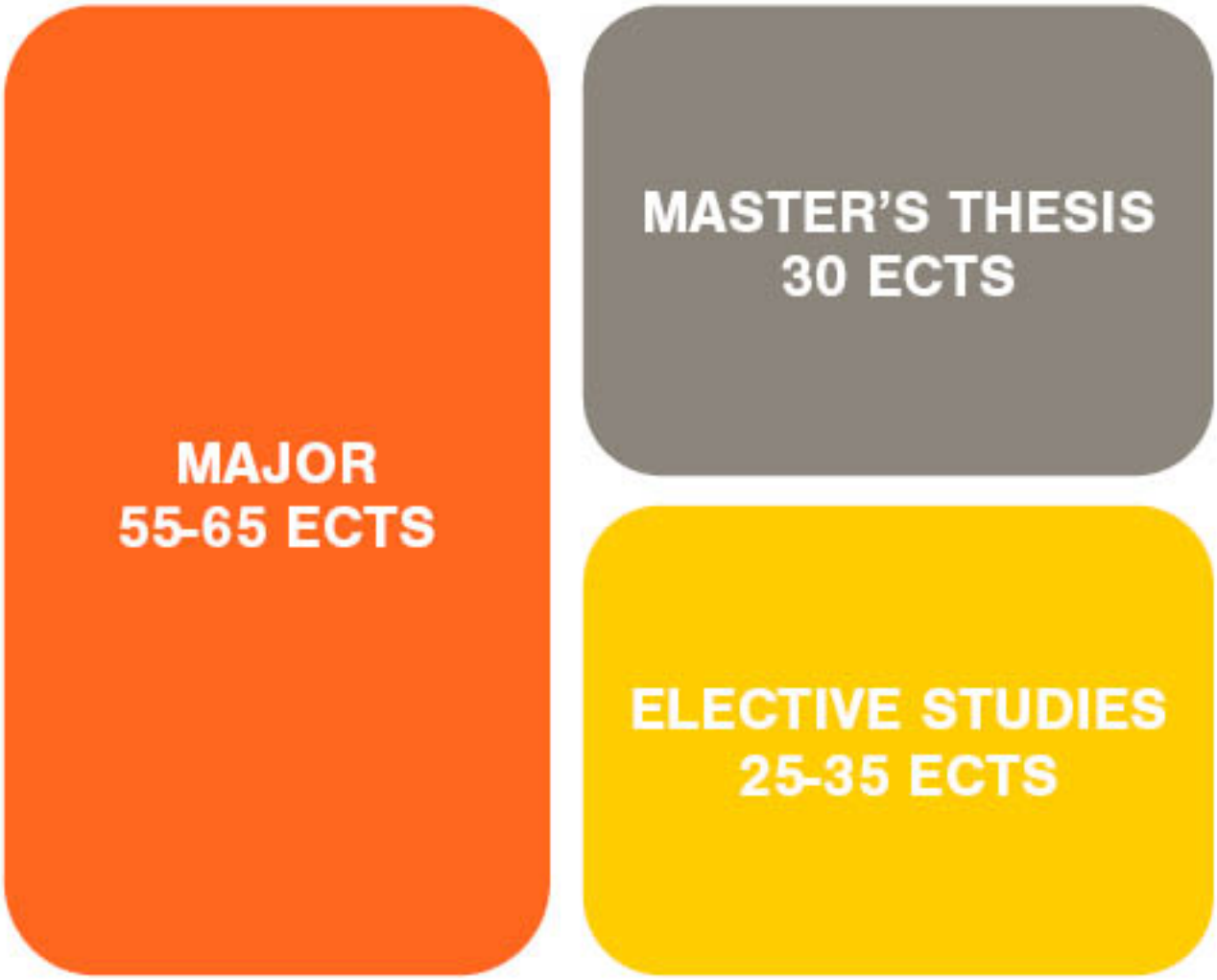
All three majors provide an excellent basis for building a career in scientific research. Thus, a large share of the students will continue their studies and obtain a doctoral degree.

Degree structure

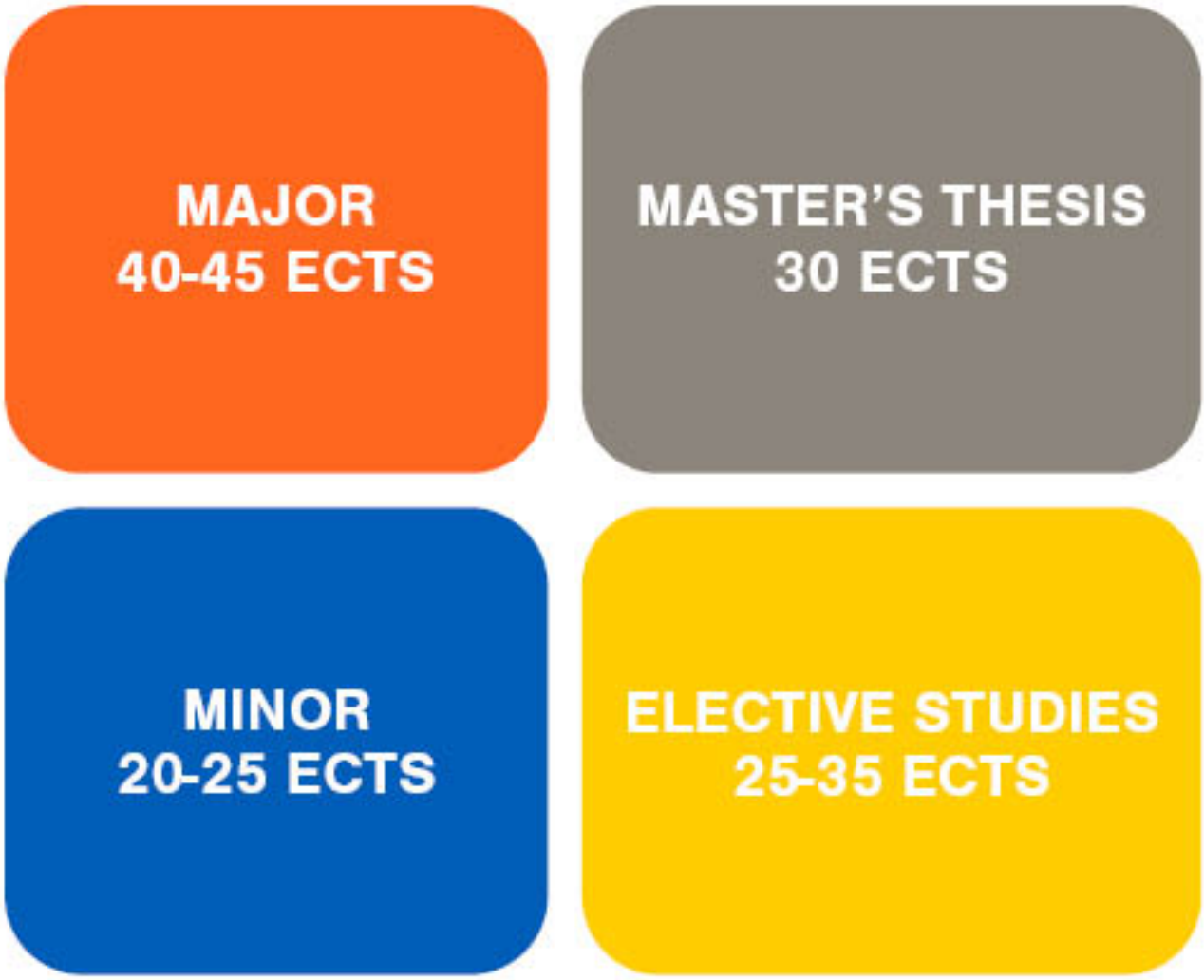
The student’s curriculum consists of a major (40-65 ECTS), an option for a minor (20-25 ECTS), elective studies (25-30 ECTS) and a Master’s thesis (30 ECTS), 120 ECTS as total.

Following the degree requirements the Master’s student has two possibilities to structure his/her studies:

1) Long major (55-65 ECTS) plus elective studies (25-35 ECTS) and Master's Thesis (30 ECTS) (not possible in Systems and Operations Research major)



2) Compact major (40-45 ECTS), minor (20-25 ECTS) plus elective studies (25-35 ECTS) and Master's Thesis (30 ECTS)



The extent of a major may not exceed 65 ECTS. Thus, the students will always have a choice of completely elective studies at minimum 25 ECTS.

Minor

All students in the Master's Programme in Mathematics and Operations Research are recommended to include a minor as a part of their studies. For the students having Systems and Operations Research as their major, including a minor is compulsory. There are no restrictions on the content of

the minor. For instance, all minors in Aalto University are admissible. The minor is confirmed in the Personal Study Plan.

More information on Aalto University's minor subjects:

- Aalto University Minors Guide 2015-2016

Elective studies

Students are required to select 25-35 credits of elective studies. The student can complete a minor and/or take individual courses lectured at Aalto University or the other universities in Finland. The student can also participate in an international student exchange programme or do an internship (max. 5 credits) in Finland or abroad.

For more information on internationalisation or Aalto University's minor subjects:

- Aalto University Minors Guide 2015-2016
- Internationalisation and studies abroad

Language studies

In Aalto School of Science, students have compulsory language studies as a part of the bachelor's degree. If these language studies have not been completed before entering the master's programme, they must be included in the master's degree as explained in the following:

A student whose language of school education is Finnish or Swedish must take 2 credits in the other national language. In addition, all students must demonstrate both oral (o) and written (w) proficiency in one foreign language (3 credits).

Students with excellent command of English (e.g. English as a first language) may apply for the exemption from the compulsory foreign language requirement and take 3 ECTS of Finnish courses instead. In this case, according to the Degree Regulations, the student has not demonstrated the requisite written and oral language requirement in a foreign language, which is reflected in the appendix of the degree certificate. Students may apply for an exemption in the beginning of each term (deadlines 15 September and 15 January) with an application form available in Into at https://into.aalto.fi/display/enmastersci/Forms.

The language studies are included in the elective studies.

More information about language courses can be found on the Language Centre's website into.aalto.fi/display/enlc/.

Master's thesis

All students are required to write a master's thesis, which is an individual research project with a workload of 30 credits. The topic of the thesis is usually related to the student's major, or in some special cases to the minor. The details of the thesis project are agreed upon with the supervisor who

must be a professor in the Aalto University. The advisor(s) of the thesis must have at least a master's degree.

Master's thesis work includes a seminar presentation or equivalent presentation. The student is also required to write a maturity essay related to the master's thesis.

The master's thesis is a public document and cannot be concealed.

Graduation

Students can apply for the master's degree after completing the bachelor's degree, when all courses required for the master's degree have been completed and the master's thesis is evaluated and approved by the Degree Programme Committee. The Dean grants the degrees.

Master's degree awarded with distinction

Students who have demonstrated excellent knowledge of their field in their studies, and particular maturity and sense of judgment in the master's thesis may be awarded a diploma for the degree of Master of Science (Technology) with distinction. The decision on awarding a degree with distinction rests with the Dean of the School of Science.

A degree may be awarded with distinction if the weighted grade average of the courses included in the degree, excluding the master's thesis and the grade of the master's thesis are at least 4.0. Courses graded 'pass' or 'fail' shall not be included in the calculation.

Majors

Master's Programme in Mathematics and Operations Research offers three majors from which students can choose from: Applied Mathematics, Mathematics, and Systems and Operations Research.

The extent of the major is 40-65 ECTS depending on the major. In Applied Mathematics and Mathematics majors the student can choose to complete the major either as a compact major (40-45 ECTS) or as a long major (55-65 ECTS). If the student chooses to complete Systems and Operations major, the extent of the major is always 40 ECTS.

The major is confirmed in the Personal Study Plan in the beginning of studies.

In addition to these three majors, the programme offers also a possibility to do a double degree in the Master's Programme in Applied and Engineering Mathematics (N5TeAM).

Applied Mathematics

Professors in charge: Nuutti Hyvönen, Timo Eirola, Antti Hannukainen, Camilla Hollanti, Pauliina Ilmonen, Lasse Leskelä, Rolf Stenberg
Credits: 40-65

Abbreviation: AM
Code: SCI3053

Objectives

The major in Applied Mathematics is designed for students interested in mathematical sciences and their application to other disciplines. It is based on a solid mathematical core that gives the student a broad set of skills for working on diverse mathematical problems. The major also includes an elective part that provides flexibility to orientate toward a master's thesis project in a chosen application area. A high proportion of students majoring in applied mathematics will continue their studies to a doctoral degree.

The importance of mathematical techniques is increasing in science and engineering as new fields employing sophisticated mathematical models are constantly emerging. The driving forces for such development are the ever-increasing computational resources, which should be used wisely and to their full power. This requires education of mathematicians who are able to interact and collaborate with experts in application areas. The major in Applied Mathematics responds to this need.

Each student choosing Applied Mathematics as major is assigned a mentor among the faculty of the Department of Mathematics and Systems Analysis.

Content and structure

(i) *Mathematical core (35 cr):* The student learns core skills in applied mathematics by taking seven courses in the following key areas: numerical analysis and computational methods, probability and statistics, discrete mathematics, and optimization.

The student must choose seven of the following ten courses:

Mathematical core (35 cr)

CODE	NAME	CREDITS	PERIOD	YEAR
MS-E1050	Graph theory	5	I	1.
MS-E1110	Number theory	5	II	1.
MS-E1460	Functional analysis	5	I	1.
MS-E1600	Probability theory	5	III	1.
MS-E1651	Numerical matrix computations	5	I	1.
MS-E1652	Computational methods for differential equations	5	II	1.
MS-E1653	Finite element method	5	III-IV	1.
MS-E1654	Computational inverse problems	5	IV	1.
MS-E2112	Multivariate statistical analysis	5	III-IV	1.
MS-E2139	Nonlinear programming	5	II	1.

(ii) *A specialization area (30 cr):* A personalized collection of mathematical courses and studies in a selected application area. The student is required to include some courses from an applied discipline, for example one related to engineering, computer science, or natural sciences. This part

of the studies is designed under the guidance of the mentor. All specialization area studies can be chosen on an individual basis, or they can be composed of a minor and 5-10 credits of supporting mathematical courses.

Examples of possible course contents

I Mathematical core ("Numerical analysis")

MS-E1050 Graph theory, MS-E1460 Functional analysis, MS-E1651 Numerical matrix computations, MS-E1652 Computational methods for differential equations, MS-E1653 Finite element method, MS-E1654 Computational inverse problems, MS-E2139 Nonlinear programming.

Possible specialization areas:

1. MS-E1740 Continuum mechanics 1, MS-E1741 Continuum mechanics 2, MS-E1742 Computational mechanics 1, MS-E1743 Computational mechanics 2, two courses in Structural Mechanics.

2. MS-E1740 Continuum mechanics 1, PHYS-E0413 Theoretical mechanics, a minor or a selection of courses in Applied Physics and/or Structural Mechanics.

3. MS-E1600 Probability theory, MS-E1602 Large random systems, a minor or a selection of courses in Applied Physics and/or Computer Science.

II Mathematical core ("Discrete mathematics and probability")

MS-E1050 Graph theory, MS-E1110 Number theory, MS-E1600 Probability theory, MS-E1651 Matrix computations, MS-E1654 Computational inverse problems, MS-E2112 Multivariate statistical analysis, MS-E2139 Nonlinear programming.

Possible specialization areas:

1. MS-E1111 Galois theory, MS-E2146 Integer programming, a minor or a selection of courses in Computer Science.

2. MS-E1051 Combinatorics, MS-E1602 Large random systems, a minor or a selection of courses in Computer Science and/or Applied Physics.

3. MS-E1601 Brownian motion and stochastic analysis, MS-E1602 Large random systems, a selection of courses in Systems and Operations Research and/or Computer Science.

Mathematics

Professors in charge: Juha Kinnunen, Alexander Engström, Gustaf Gripenberg, Kalle Kytölä, Olavi Nevanlinna
Credits: 40-65
Abbreviation: MA
Code: SCI3054

Objectives

The major in Mathematics helps students develop their mathematical thinking so that they understand how mathematical theories are constructed and how mathematical problems are formulated and solved. The education is research-based with all courses taught by mathematicians who lead active research projects related to the course topics. This major is partly intended as a preparation for students who plan to become researchers or university teachers in mathematics or related sciences. A master's degree in mathematics also provides the student with a broad range of skills in problem solving, logical reasoning, and flexible thinking, which are attributes valued throughout the society. The covered mathematical areas include abstract and commutative algebra, algebraic geometry, complex analysis, differential geometry, graph theory, mathematical physics, partial differential equations, probability theory, and real analysis.

Each student choosing Mathematics as major is assigned a mentor among the faculty of the Department of Mathematics and Systems Analysis.

Content and structure

Mathematics is a versatile major: the student has the opportunity to choose her/his field of mathematics with no pre-assigned restrictions. The course content of the major is planned under the supervision of the mentor, with emphasis on the mathematics courses lectured at the Department of Mathematics and Systems Analysis. The student has the opportunity to include a minor in the studies. Depending on whether a minor is included or not, the extent of the major is 40-45 credits or 55-65 credits.

The recommended courses include:

CODE	NAME	CREDITS	PERIOD	YEAR
MS-E1050	Graph theory	5	I	1.
MS-E1051	Combinatorics	5	II	1.
MS-E1110	Number theory	5	II	1.
MS-E1111	Galois theory	5	IV (every other year)	1. or 2.
MS-E1280	Measure and integral	5	II	1.
MS-E1281	Real analysis	5	IV (every other year)	1. or 2.
MS-E1460	Functional analysis	5	I	1.
MS-E1531	Differential geometry	5	III (every other year)	1. or 2.
MS-E1600	Probability theory	5	III	1.
MS-E1601	Brownian motion and stochastic analysis	5	II (every other year)	1. or 2.
MS-E1602	Large random systems	5	IV (every other year)	1. or 2.

In addition, the student can take courses in applied mathematics, operations research, or other mathematical sciences.

Examples of possible orientations

I Analysis:

MS-E1280 Measure and integral, MS-E1281 Real analysis, MS-E1460 Functional analysis, MS-E1531 Differential geometry, other courses and a minor chosen under the guidance of the mentor.

II Discrete Mathematics:

MS-E1050 Graph theory, MS-E1051 Combinatorics, MS-E1110 Number theory, MS-E1111 Galois theory, other courses and a minor chosen under the guidance of the mentor.

III Stochastics and Statistics:

MS-E1600 Probability theory, MS-E1601 Brownian motion and stochastic analysis, MS-E1602 Large random systems, MS-E2112 Multivariate statistical analysis, other courses and a minor chosen under the guidance of the mentor.

Systems and Operations Research

Professors in charge: Raimo Hämäläinen, Enrico Bartolini, Harri Ehtamo, Ahti Salo, Kai Virtanen
Credits: 40
Abbreviation: OR
Code: SCI3055

Objectives

The goal of the major in Systems and Operations Research is to teach the students modelling methods and practical skills for problem solving and decision making in complex industrial, managerial, economic, and environmental problems. The core is an engineering-economic systems approach, which is based on systems thinking and mathematical modelling. The field of Operations Research (OR) is generally called “the Science of Better”. OR people can work to improve the efficiency of processes or logistics, to optimize the use of limited resources, or to make better decisions under multiple criteria and risks. An important sub-area of OR called Analytics uses OR methods on large data sets to make better data-based decisions. Systems analysis and OR are needed everywhere in the modern society. Modelling and decision support are essential in energy markets and environmental management as well as in understanding the complex dynamics of climate change.

The core topics in the major include optimization, simulation, dynamic systems, decision modelling, statistics, forecasting, risk analysis, as well as hands on laboratory modelling and project case studies on real industrial problems. The major also provides an excellent basis for doctoral studies and many students do continue their studies to a doctoral degree. The graduates in Systems and Operations Research are in high demand in many areas ranging from the financial sector to industry, energy, and environment.

Content and structure

Courses marked with an asterisk (*) are given in Finnish but they can also be taken in English via special arrangements with the instructor. All courses can be taken in the first or second year of studies. The recommended years for the core courses are shown below.

CODE	NAME	CREDITS	PERIOD	YEAR

Mandatory courses (30 cr)

MS-E2112	Multivariate statistical analysis	5	III-IV	1./ 2.
MS-E2133	Systems analysis laboratory II	5	I-II	1.
MS-E2134	Decision making and problem solving	5	I	1.
MS-E2148	Dynamic optimization	5	III	1.
MS-E2139	Nonlinear programming	5	II	1./ 2.
or				
MS-E2140	Linear programming	5	I	1.
TU-91.1001	Kansantaloustieteen perusteet	5	I-II	1./ 2.
or				
TU-E1150	Managerial economics	5	III	1./ 2.

Select one seminar:

MS-E2142	Optimointiopin seminaari	5	I-IV	1./ 2.
MS-E2177*	Operaatiotutkimuksen projektityöseminaari (Seminar on case studies in operations research)	5	III-IV	1./ 2.
MS-E2191	Graduate seminar on operations research	5		1./ 2.
MS-E2198	Luovan ongelmanratkaisun seminaari	5	I-II	1./ 2.

Select one additional MS-E2-course (5 cr). Recommended courses:

MS-E2114	Investment science	5	IV
MS-E2117*	Riskianalyysi (Risk analysis)	5	III-IV
MS-E2129*	Systeemien identifiointi (System identification)	5	I-II
MS-E2130*	Matemaattinen malliajattelu (Mathematical modelling)	5	I-II
MS-E2136	Special topics in decision making	5	
MS-E2139	Nonlinear programming	5	II
MS-	Linear programming	5	I

E2140			
MS-E2146	Integer programming	5	IV
MS-E2152*	Peliteoria (Game theory)	5	I-II
MS-E2170	Simulation	5	IV

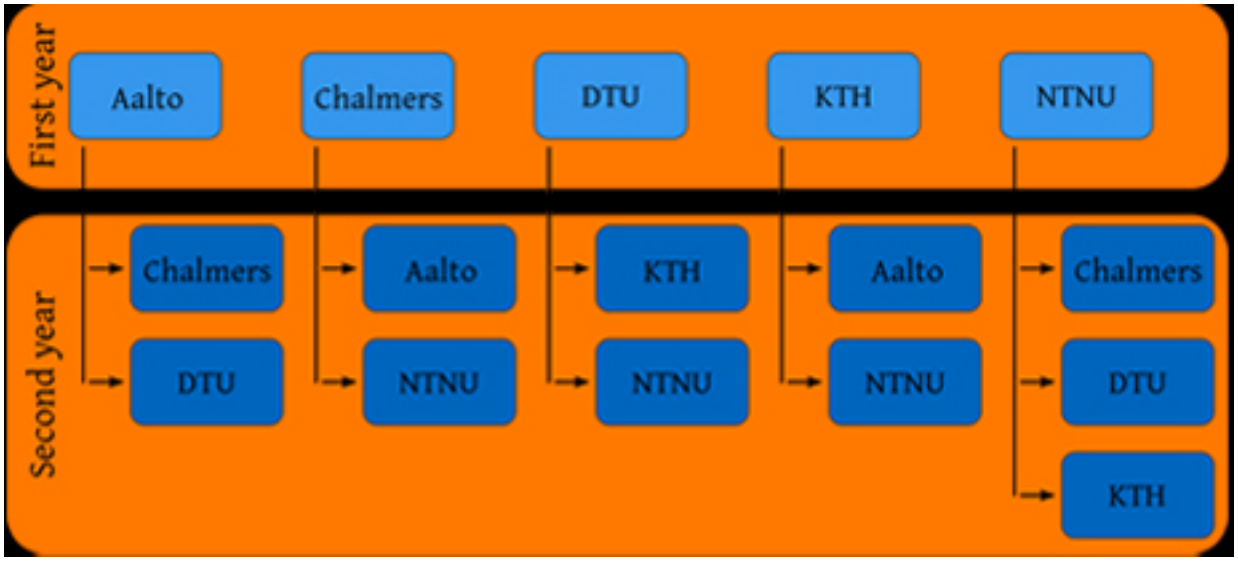
Master's Programme in Applied and Engineering Mathematics (N5TeAM)

Director of the Programme: Professor Camilla Hollanti
Degree: Master of Science (Technology) (double-degree)
Major: Applied and Engineering Mathematics (SCI3016)
Department in charge at Aalto University: Department of Mathematics and Systems Analysis (T3020)
Aalto Professors: Camilla Hollanti, Nuutti Hyvönen

N5TeAM is a two-year Master of Science programme (120 ECTS credits). During the programme the students study at two of the five Nordic partner universities: Aalto University in Finland, Chalmers University of Technology in Sweden, Technical University of Denmark (DTU), KTH Royal Institute of Technology in Sweden, and Norwegian University of Science and Technology (NTNU).

Each partner acting as a home university (= starting point, University 1) will provide 60 ECTS as first year study package and for the second year students, the host university (University 2) provides a 30 ECTS package of courses and provides the MSc thesis supervision jointly with the student's home university. The programme offers five specialization lines and eleven study tracks.

Student mobility and study tracks:



In this Study Guide, there are only Aalto courses (tracks: Aalto-Chalmers, Aalto-DTU, Chalmers-Aalto, KTH-Aalto). Information on the whole programme curriculum is on the programme website at http://n5team.aalto.fi/en/

Objectives of the Programme

The core skills of the graduated students are mathematical modelling of challenging, often multiphysical, problems in engineering and applied science, and the ability to choose suitable solution methods and critically evaluate the obtained solutions. To this end the students will be furnished with solid education in mathematics including the theory of ordinary and partial differential equations, probability and statistics, numerical linear algebra, optimization, and discrete mathematics. The students will also achieve qualified knowledge in an area of applied mathematics with active research such as biocomputing, cryptology, stochastics, and computational mechanics and geosciences. Special assignments and thesis work will give experience in research associated with the N5T math departments, their collaborating institutes, and partners in industry. The degree will also give a solid backround for PhD studies in applied math and many application fields.

Learning outcomes

Knowledge and understanding

A master's student with a degree from the N5TeAM programme has:

- qualified and broad knowledge in the field of Applied and Engineering Mathematics including techniques for mathematical modeling, analysis of mathematical models, and simulation,
- profound competencies in mathematical and computational disciplines which are applicable in industry, business world, and public administration,
- qualified knowledge in a certain area of applied mathematics which comes close to active areas of research and allows for actively taking part in research.

Skills and abilities

A master's student with a degree from the N5TeAM programme has the ability to:

- formulate mathematical models, choose suitable methods to investigate these models including the efficient use of computer tools,
- analyze different mathematical models within science and technology and work creatively, systematically, and critically
- find strategies for the solution of different types of mathematical models using knowledge about the possibilities and limitations of the different methods and tools,
- communicate effectively with professionals within applied and engineering mathematics as well as with persons working with different scientific-technological applications in an interdisciplinary context,
- communicate effectively with management as well as society at large using written and oral presentations,
- cooperate effectively with colleagues with different cultural backgrounds.

Ability to make judgements and adopt a standpoint

A master's student with a degree from the N5TeAM programme can:

- critically judge the validity and limitations of results obtained from different types of mathematical models,
- Identify the need for further knowledge in the field and take responsibility for keeping his/her personal knowledge up to date.

Degree Structure at Aalto University

Major studies 87-90 credits

- Studies completed in another partner university are included in the student´s major studies.

Elective Studies (0-3 credits)

- Compulsory studies in English (3 credits, both written and oral skills) are included in Elective Studies, if not already completed in Bachelor´s degree done in Finland.

Master´s Thesis (30 credits)

- Theses is jointly supervised by and accepted in both of the student´s universities.

Track: Computational Mechanics

Track: Aalto – Chalmers

In this specialization the students learn to develop, analyse and use computational methods for relevant applications in the natural sciences and engineering.

Computational mechanics is an interdisciplinary topic which applies mathematics and computing to solve real-world challenges. Important components are the formulation of a mathematical model for a given mechanical phenomenon, making useful approximations suitable for computers, efficient implementation of the resulting methods, and presentation and evaluation of the results. Finite difference and finite element methods are commonly used to bridge the mathematical world with computing.

First autumn courses

Code	Course	Credits	Period
MS-E2139	Nonlinear Programming	5	II
MS-E1651	Numerical Matrix Computations	5	I
MS-E1652	Computational Methods for Differential Equations	5	II
MS-E1460	Functional Analysis	5	I
	Other MS-EXXXX courses to be agreed with the professor of major	10	I/II
	TOTAL	30	

First spring courses

CODE	COURSE	CREDITS	PERIOD
Kie-98.xxxx	English course: compulsory degree requirement, both oral and written requirements	3	I-V
MS-E1653	Finite Element Method	5	III-IV
MS-E1600	Probability Theory	5	III
MS-E1654	Computational Inverse Problems	5	IV
	Other MS-EXXXX courses to be agreed with the professor of major	12	III/IV/V
	TOTAL	30	

Second autumn courses at Chalmers

CODE	COURSE	CREDITS
Choose four of the following courses:		
TMA401	Functional Analysis	7,5
TMA265	Numerical Linear algebra A	7,5
TMA632	Partial Differential Equations, project course	7,5
MVE080	Scientific Visualization	7,5
TMA462	Wavelet Analysis	7,5
KMG060	Systems Biology	7,5
FFR110	Computational Biology 1	7,5
TME225	Mechanics of Fluids	7,5
TME235	Mechanics of Solids	7,5
	TOTAL	30

Track: Cryptology and Coding Theory

Track: Aalto – DTU

Cryptology and coding theory is about secure and reliable communication. Coding theory is the study of how to transmit information efficiently and robustly in the presence of noise. It is the mathematics that allows data to be sent via satellites and scratched CD's to be read without errors. Cryptology protects information against malicious third parties. It is the science of protecting transmitted information from prying by an attacker, as well as integrity checking and autentification. Traditionally cryptography has been implemented only on fairly powerful computing devices but this has changed and today more and more smaller devices are in use, ranging from (still quite powerful) mobile telephones and PDAs to contactless smart cards and RFID tags.

In the specialization of cryptology and coding theory there will be a focus on lightweight systems and the students will learn how to design state-of-the-art cryptosystems for confidentiality and authentication.

First autumn courses

Code	Course	Credits	Period
MS-E2139	Nonlinear Programming	5	II
T-79.4502	Cryptography and Data Security	5	I-II
MS-E1051	Combinatorics	5	II
MS-E1651	Numerical Matrix Computations	5	I
MS-E1110	Number Theory	5	II
MS-E1993	Introduction to Abstract Algebra II	5	I
	TOTAL	30	

First spring courses

CODE	COURSE	CREDITS	PERIOD
Kie-98.xxxx	English course: compulsory degree requirement, both oral and written requirements	3	III-IV
MS-E1600	Probability Theory	5	III
T-79.5501	Cryptology P	5	III-IV
MS-E1995	Mathematical Tools for Coding Theory and Data Storage	5	III
MS-E1111	Galois Theory	5	IV
	Other MS-EXXXX courses to be agreed with the professor of major	7	III,IV,V
	TOTAL	30	

Second autumn courses at DTU

CODE	COURSE	CREDITS
	N5TeAM Summer School in Applied and Engineering Mathematics with follow-up	5
42490	Technology, Economy, Management and Organization E5	10
Three of the following courses:		
01235	Manifolds and Tensor Analysis E1A	5
01617	Dynamical Systems 1 E4A	5
01257	Advance Modelling	5
xxxxx	Light Weight Cryptology	5
	TOTAL	30

Track: High Performance and Scientific Computing

Tracks: KTH – Aalto, Chalmers – Aalto

This specialization aims to the use of high quality models of phenomena in science and engineering. Very often such models contain partial differential equations and multiphysics, for example, structures and flows, or mechanical vibrations and electromagnetic fields. Efficient and accurate numerical simulation and optimisation of such models is an essential part of this specialization. Specialists with this education are highly wanted in research and development projects.

Second autumn courses at Aalto

Code	Course	Credits	Period
Kie-98.xxxx	English course: compulsory degree requirement, both oral and written requirements	3	I-II
MS-E1981	Individual Studies in mathematics (N5TeAM Summer School)	3	I-II
24 cr of the following			
MS-E1659	Seminar on applied mathematics	0-5	I-V
MS-E1740	Continuum mechanics 1	5	I
MS-E1741	Continuum mechanics 2	5	II
	Other MS-EXXXX courses to be agreed with the professor of major	9-14	I/II
	TOTAL	30	