The Master’s program in Business Analytics is a multidisciplinary program aimed at improving business performance by applying a combination of methods that draw from mathematics, computer science and business management. Based on a good understanding of the field and making excessive use of data, you will learn to statistically analyze these data, develop and analyze predictive models, and optimize business processes. The emphasis is on the complete trajectory of decision making in practice; together with the combination of the three different fields of expertise, this makes the Business Analytics program unique.

The goal of the master program Business Analytics is to prepare students for a career in business, industry, or within governmental or research facilities, with (possibly only initially) a major quantitative aspect.

There are two variants of the program: The Professional Track and the Dual Master’s Program.
<table>
<thead>
<tr>
<th>Course Description</th>
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<tr>
<td>Master BA The Dual Master's Programme - Compulsory selection Mathematics and BA</td>
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<td>(18 EC)</td>
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<td>Vak: Continuous Optimization (Periode 1+2)</td>
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<tr>
<td>Vak: Project Optimization of Business Processes (Periode 3)</td>
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<tr>
<td>Vak: Stochastic Processes for Finance (Periode 1+2)</td>
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</table>
BA Dual Variant

The dual Master's program combines work and study. During this program the student is employed part time, and studies part time. The work has to be relevant for the study and the dual work period is granted with 18 EC. Moreover, it is possible to do the Research Paper BA (6 EC) on a case-study that is work related, provided the case-study is combined with a sound theoretical basis. Often, the external master project is carried out at the same organization as the dual work period. This makes the total of work related credit points 60 EC, being the equivalent of one year of study. The students can only start their internship or Master Project after having finished the compulsory Research Paper BA (6 EC) and having completed all but possibly one program components. Typically, a student participating in the dual master's program should expect to obtain the Master's diploma after two and a half years.

Admission to the dual Master's program is granted to those who have a Business Analytics Bachelor's degree. For those with another university Bachelor's degree, such as Mathematics, Econometrics, Computer Science, or a Bachelor's degree from an institute of higher education, admission may be granted on an individual basis. Those seeking admission to the dual Master's program should realize that admission also depends on obtaining suitable employment. The VU has contacts with a number of companies that are interested in participating in this program.

For more information concerning the dual master's program, contact the coordinator for the external master's project or the master coordinator.

The program consists of 120 European credit points (EC)
- compulsory courses 84 EC (including a Master Project of 36 EC)
- compulsory selection 18 EC
- optional courses 18 EC

Note: Every program, including the choice of optional courses, has to be discussed and agreed upon with the master coordinator and approved by the Examination Board.

Opleidingsdelen:

- Master BA The Dual Master's Programme - Compulsory selection Mathematics and BA (18 EC)
- Compulsory Courses

Master BA The Dual Master's Programme - Compulsory selection Mathematics and BA (18 EC)

There is a compulsory selection of at least three courses (18 EC) from this list below.

Note: Every programme, including the choice of optional courses, has to be discussed and agreed upon with the master coordinator and approved by the Examination Board.

Vakken:
Compulsory Courses

Both the Research Paper BA (6 EC) and the Master Project (36 EC) may be work-related. The work period consists of 18 EC. The total work related credit points has therefore a maximum of 60 EC.

Compulsory alongside the mentioned courses, are a compulsory choice (18 EC) and optional courses (15 EC) to complete 120 EC.

Note: Every programme, including the choice of optional courses, has to be discussed and agreed upon with the master coordinator and approved by the Examination Board.

Vakken:

<table>
<thead>
<tr>
<th>Naam</th>
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<th>Credits</th>
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<tr>
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<th>Periode</th>
<th>Credits</th>
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</table>
Professional track

The emphasis will be on a broad and multidisciplinary education, preparing the student for a role as an academically trained quantitative professional in a multidisciplinary organization. Even so, the possibility to continue after the Master in a PhD program exists also for these variants.

Business Analytics is a two-year program. The first six months are devoted to compulsory courses. Over the next twelve months, you will deepen your knowledge in the three fields of expertise after which you will have the opportunity to specialize in business process optimization, computational intelligence and financial risk management. Combining the knowledge you acquire and applying it to practical situations plays an essential role in the program. As such, the Master’s degree is concluded with a six-month individual internship at a company (the Master’s project). The students can only start their internship or Master Project after having finished the compulsory Research Paper BA (6 EC) and having completed all but possibly one program components.

The program consists of 120 European creditpoints (EC)
- compulsory courses 72 EC (including a Master Project of 36 EC)
- compulsory choice 24 EC
- optional courses 24 EC

Note: Every program, including the choice of optional courses, has to be discussed and agreed upon with the master coordinator and approved by the Examination Board.

Opleidingsdelen:
- Compulsory Selection
- Compulsory Courses

Compulsory Selection

There is a compulsory selection of at least four courses (24 EC) from this list below.

Note: Every program, including the choice of optional courses, has to be discussed and agreed upon with the master coordinator and approved by the Examination Board.

Vakken:

<table>
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<th>Periode</th>
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<tr>
<td>Advanced Linear Programming</td>
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### Compulsory Courses

The following list contains the compulsory courses (72 EC).

**Vakken:**

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<td>Evolutionary Computing</td>
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### Advanced Linear Programming

**Vakcode**

X_400326 (400326)
Inhoud vak
This course is part of the joint national master programme in mathematics. For schedules, course locations and course descriptions see http://www.mastermath.nl.

Doelgroep
mMath; mBA

Intekenprocedure
You have to register your participation in each Mastermath course via http://www.mastermath.nl/registration/
Registration is mandatory and absolutely necessary for transferring your grades from Mastermath to the administration of your university.

Advanced Selforganisation

<table>
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<td>Voertaal</td>
<td>Engels</td>
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<td>Faculteit</td>
<td>Faculteit der Exacte Wetenschappen</td>
</tr>
<tr>
<td>Coördinator</td>
<td>prof. dr. L. Stougie</td>
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<tr>
<td>Examinator</td>
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Vakcode         X 400434 (400434)
Periode         Periode 2
Credits         6.0
Voertaal        Engels
Faculteit       Faculteit der Exacte Wetenschappen
Coördinator     dr. M.C. Schut
Examinator      dr. M.C. Schut
Docent(en)      dr. M.C. Schut
Lesmethode(n)   Hoorcollege
Niveau          400

Doel vak
To understand, simulate and analyse the behaviour and self-organization of complex systems. The student is able to explain, implement and recognize basic principles and properties of such systems.

Inhoud vak
This course is about the understanding of the behavior and self-organization of complex systems: systems in which the interaction of the components is not simply reducible to the properties of the components. The general question the we address is: how should systems of very many independent computational (e.g. robotic or software) agents cooperate in order to process information and achieve their goals, in a way that is efficient, self-optimizing, adaptive, and robust in the face of damage or attack? We will look at natural systems that solve some of the same problems that we want to solve, e.g. adaptive path minimization by ants, wasp and termite nest building, army ant raiding, fish schooling and bird flocking, coordinated cooperation in slime molds, synchronized
firefly flashing, evolution by natural selection, game theory and the evolution of cooperation. The course includes a practical part in which students implement a simulation of a self-organizing complex system and conduct structured experimental analysis with this simulation.

**Onderwijsvorm**
Theory in lectures and practice in labs.

**Toetsvorm**
Report including description of simulation and experimental analysis.

**Literatuur**

**Doelgroep**
mAI, mBA, mCS, mPDCS

**Overige informatie**
More information available on BlackBoard. This is a project- oriented course and therefore students will be expected to have basic programming skills.

### Applied Analysis: Financial Mathematics

<table>
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<tr>
<td>Coördinator</td>
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<td>Hoorcollege</td>
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</tbody>
</table>

**Doel vak**
The course aims to introduce the student to several aspects of the mathematical theory of option pricing.

**Inhoud vak**
This course gives an introduction to financial mathematics. The following subjects will be treated:
- introduction in the theory of options;
- the binomial method;
- introduction to partial differential equations;
- the heat equation;
- the Black-Scholes formula and applications;
- introduction to numerical methods, approximating the price of an (American) option.

**Onderwijsvorm**
Lectures, exercises, discussion of exercises.
Toetsvorm
Homework exercises and oral examination

Literatuur

In addition, lecture notes will be made available for several topics which are not treated in the book.

Aanbevolen voorkennis
Calculus and Linear Algebra

Doelgroep
3W, mMath, mBA, 3Ect

Applied Stochastic Modeling

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<th>Vakcode</th>
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<td>dr. R. Bekker</td>
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<td>Lesmethode(n)</td>
<td>Hoorcollege, Werkcollege</td>
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<td>Niveau</td>
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</table>

Doel vak
To learn the most often used stochastic models and how they are applied in practice. During the course you learn to handle such practically motivated problems as an independent researcher. This means that you:
- learn to determine the appropriate model
- are able to formulate the problem mathematically correct
- are able to solve the stochastic model
- know how to interpret the outcome.

Inhoud vak
This course deals with a number of stochastic modeling techniques that are often used in practice. They are motivated by showing the business context in which they are used. Topics we deal with are: birth-death-processes, basic queueing models, inventory models, renewal theory and simulation. We also repeat and extend certain parts of probability theory.

Onderwijsvorm
Hoor- en werkcollege.

Toetsvorm
Written examination.

Literatuur
Lecture notes of Ger Koole (made available via blackboard). Additional material will be announced in due time.
Doelgroep
mBA, mMath

Business Intelligence

Vakcode | E_BK3_BI (61312020)
Periode | Periode 1
Credits | 6.0
Voertaal | Engels
Faculteit | Fac. der Economische Wet. en Bedrijfsk.
Coördinator | prof. dr. J.F.M. Feldberg
Examinator | prof. dr. J.F.M. Feldberg
Docent(en) | prof. dr. J.F.M. Feldberg
Lesmethode(n) | Hoorcollege, Practicum, Computerpracticum
Niveau | 300

Doel vak
Students that successfully finished this course must be able:
- To define, describe and recall the basic concepts, principles and theories underlying business intelligence solutions (decision support systems).
- To classify and compare business intelligence solutions as well as the constituent components of business intelligence solutions.
- To apply business intelligence concepts, principles and theories to business problems.
- To analyse a business intelligence case, and propose business intelligence solutions.
- To evaluate and discuss the organizational and social implications of business intelligence solutions.
- To design a schema representing managerial information needs (‘star schema’).
- To analyse data and decide which data to use given a problem to be solved.
- To create insights using an established business intelligence tool (Cognos Powerplay).

Inhoud vak
Modern organizations, in particular the management of these organizations, tend to suffer more from an overload of data than from a lack of data. To a great extent this overload is caused by the overwhelming growth of information systems in organizations. Enterprise Systems (ERP), Customer Relationship Systems (CRM) as well as the growing number of Internet-based applications (e. g. e-commerce) are all important sources for the explosion of financial, production, marketing and other business data. The challenge for most organizations is to develop and build systems that support the transformation of the collected data into knowledge. To be successful in this transformation processes organizations have to develop the capability to aggregate, analyze and use data to make informed decisions. This course deals with the theory concerning business intelligence as well as with the application of business intelligence solutions. To be able to successfully implement business intelligence solutions, one has to have knowledge about their functioning and proficiency in using them, as well as knowledge about their field of application, e. g., how to...
select, transform, integrate, condense, store and analyze relevant
data. This course uses the term 'business intelligence & analytics' in a
broad sense. A narrow interpretation would only deal with software
solutions ('data warehousing' and 'online analytical processing'). The
broad interpretation - to be used in this course - also includes:
theories concerning decision making, related decision support systems
and their application for management, i.e., data warehousing, online
analytical processing, big data and data mining.

**Onderwijsvorm**
lecture
tutorial

**Toetsvorm**
owned interim examination
(weekly) Business intelligence tutorial tests.
All tests and exams will be administered through a digital test system.

**Literatuur**
- To be announced.
- Various papers.

**Aanbevolen voorkennis**
- Basic course in Information Systems, f.e. on the level of Laudon &
  Laudon, Management Information Systems,

**Overige informatie**
Language: "Dutch & English"

**Business Process Analytics**

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<td>Coördinator</td>
<td>dr. H. Leopold MSc</td>
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**Doel vak**
After taking this course, the student will:

- be aware of the current possibilities to support BPM with information
technology.
- understand and be able to employ process mining techniques for the
  purpose of process discovery, compliance checking, and improvement.
- know key technologies for analyzing large process model repositories.
- know and be able to employ basic as well as advanced NLP techniques
  for the purpose of process analysis.
- know and be able to use process model simulation for testing and
  improving process design.
Inhoud vak

There is a steadily increasing interest of organizations to use Business Process Management (BPM) for documenting and improving their operations. However, the associated manual effort for thoroughly eliciting, documenting, and updating process knowledge in the form of process models is often considerable.

Within this course, we put an emphasis on the technological and analytical perspective and discuss how they can support organizations in effectively and efficiently implementing BPM. In fact, techniques from the fields of information retrieval, data mining as well as simulation provide valuable foundations to reduce the manual effort in the context of BPM. Hence, we introduce and discuss four different technological angles and demonstrate how each of these angles can strengthen the different phases of the BPM life cycle. In particular, we address the following technological areas:

1. Process Mining: The technology of process mining builds on the analysis of event logs that were generated by information or workflow systems. We discuss how process mining techniques can be used for process discovery, compliance checking, and improvement and elaborate on basic as well as advanced process mining algorithms. In addition, we introduce current process mining tools for the application of process mining in practice.

2. Process Model Collections: Many large organizations maintain process model repositories with several hundred process models. Hence, manual analysis efforts are time-consuming and cumbersome. Recognizing this, we introduce key concepts to automatically analyze process model collections. Among others, we discuss techniques for process model comparison, process model search, and behavioral analysis of process models.

3. Natural Language Analysis: The automated analysis of natural language, which is referred to as Natural Language Processing (NLP), has been applied in many contexts. As an example, consider Apple’s Siri or Google’s S Voice, which are capable of interpreting human speech. In fact, also organizations and their business processes may considerably benefit from natural language processing techniques. Hence, we introduce the key NLP techniques that are relevant in the context of BPM. Among others, we discuss techniques for process model content analysis, process model quality insurance, and identification of improvement potential in process models.

4. Simulation: The simulation of business processes is a tool that is used to predict performance and to understand the impact of change. It, for instance, allows organizations to test processes before they are actually technically implemented in a system. Due to its usefulness for organizations, we introduce the technological foundations for process simulation and give an overview of process simulation tools.

The various lectures and instructions will be devoted to these technological areas.

Onderwijsvorm

There will be lectures as well as work instructions.
**Toetsvorm**
The grading for students who follow this course in the scheduled period will be based on two grades:

1. The first grade is based on a number of home assignments. The goal of the assignments is to evaluate whether the students can successfully apply the content from the lecture. Among others, the students will be asked to mine a business process model from a given event log and to automatically infer relevant information using natural language processing tools from a given text.

2. The second grade is gained by participating in the regular exam during the exam week. The exam is a closed book exam, which consists of theoretical questions and small assignments. Selected chapters from the books "Fundamentals of Business Process Management", "Process Mining", and "Speech and Language Processing" will be the basis for this exam.

The overall result for this exam is the rounded, weighted average of the first grade (50%) and the second grade (50%) provided that both grades (unrounded) at least amount to a 5.00. If either of the grades is lower than a 5.00, the overall grade for this course is determined by the rounded, lowest grade of the two.

For all students who fail the course in the scheduled period or decide to follow the course outside this period, the course is graded solely by the grade for the re-exam. This is a full exam similar to the original exam and the assignments. The re-exam is a closed book exam, too.

**Literatuur**


**Aanbevolen voorkennis**
Students will, among others, benefit from the knowledge they acquired in the courses Information Management and Business Process Management. However, we aim at providing all necessary foundations within this course.

**Doelgroep**
This is an interdisciplinary course. Any student who is interested in learning how technology can be used to improve business processes in practice is invited to join this course.

**Continuous Optimization**
Inhoud vak
This course is part of the Joint National Master Programme in Mathematics. For schedules, course locations and course descriptions see http://www.mastermath.nl.

Doelgroep
mMath;mBA

Intekenprocedure
You have to register your participation in each Mastermath course via http://www.mastermath.nl/registration/. Registration is mandatory and absolutely necessary for transferring your grades from Mastermath to the administration of your university.

Corporate Financial Management

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Doel vak
This course expands on financial topics covered in the first and second year. The emphasis in this course is on the Optimal Capital Structure of a corporation. The aim is to prepare students for a (possible) career as (assistant) Financial Manager in Industry or in the FBI sector: Finance, Banking (commercial and investment) and Insurance, incl. pension funds, investments funds, stock markets, Euronext, DNB, ECB, AFM, Ministry of Finance etc.

Inhoud vak
The following topics, issues and concepts will be dealt with:
- Capital structure in perfect Markets
- Leverage and Debt
- Optimal Capital Structure with Taxes and Financial Distress
- Payout Policy, Dividends and Share Repurchases
- Capital budgeting and Valuation
- Financial Modeling
- Corporate Governance

Onderwijsvorm
Lecture. Students have to complete before each lecture quizzes (tests) on MyFinancLab.
**Toetsvorm**
written interim examination (80% 5, 0 min. ) cases / tutorials (20% of final grade based on average of scores of tests and quizzes on MyFinanceLab.

**Literatuur**

**Vereiste voorkennis**
This course is for Business Administration students and/or Pre- Master BK students specializing in Financial Management. Students must be familiar with Corporate Finance / Financial Management as covered in the 1st and 2nd year.

**Overige informatie**
ONLY FOR PREMASTER STUDENTS:
For this course you do not need to subscribe. You will be subscribed by the department.

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**Data Mining Techniques**

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**Doel vak**
The aim of the course is that students acquire data mining knowledge and skills that they can apply in a business environment. How the aims are to be achieved: Students will acquire knowledge and skills mainly through the following: an overview of the most common data mining algorithms and techniques (in lectures), a survey of typical and interesting data mining applications, and practical assignments to gain "hands on" experience. The application of skills in a business environment will be simulated through various assignments of the course.

**Inhoud vak**
The course will provide a survey of basic data mining techniques and their applications for solving real life problems. After a general introduction to Data Mining we will discuss some "classical" algorithms like Naive Bayes, Decision Trees, Association Rules, etc., and some recently discovered methods such as boosting, Support Vector Machines, and co-learning. A number of successful applications of data mining will also be discussed: marketing, fraud detection, text and Web mining, possibly bioinformatics. In addition to lectures, there will be an extensive practical part, where students will experiment with various data mining algorithms and data sets. The grade for the course will be
based on these practical assignments (i.e., there will be no final examination).

**Onderwijsvorm**

Lectures (h) and compulsory practical work (pra). Lectures are planned to be interactive: there will be small questions, one-minute discussions, etc.

**Toetsvorm**

Practical assignments (i.e. there is no exam). There will be two assignments done in groups of three. There is a possibility to get a grade without doing these assignments: to do a real research project instead (which will most likely to involve more work, but it can also be more rewarding). For the regular assignments the first assignment counts for 40% and the second for 60%. The grade of both assignments needs to be sufficient to pass the course.

**Literatuur**


ISBN 978-0-12-374856-0

**Aanbevolen voorkennis**

Kansrekening en Statistiek of Algemene Statistiek (knowledge of statistics and probabilities) or equivalent. Recommended: Machine Learning.

**Doelgroep**

mBA, mCS, mAI, mBio

**Dual Workperiod Master**

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<tr>
<td>Coördinator</td>
<td>drs. H.J.M. van Goor-Balk</td>
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**Doel vak**

During the dual work period the student gains experience and skills. The dual period allows the student to bring the learning into practice. So the student can apply his theoretical knowledge into practice. The student also brings practical work experience back to the university. In addition, the student will receive relevant work experience while studying. As a result the student is easier to deploy in the labor market after graduation.

**Inhoud vak**

During two years, students are required to divide their time equally between work and study. So study and work are fully integrated. The student is an employee and a student at the same time. The student is on
the payroll of the host organization for (at least) 20 hours a week
during 24 months. The student will conduct work which is of direct
relevance to the BA master study programme.

**Onderwijsvorm**
The student is an employee of the host organization.

**Toetsvorm**
Direct supervision of the students day-to-day activities is provided by
the host organization. There will be frequent contact and consultation
between the student, the university (by the coordinator of the BA
master's dual variant programme) and the host organization throughout
the programme. The student writes a report on his/her activities in the
organization. The performance of the student will be evaluated by the
organization, the coordinator of the BA master's dual variant programme,
and a member of the BA Internship Committee. The organization completes
an assessment form.

**Vereiste voorkennis**
The formal approval of the BA Internship Committee is required before
the student can actually take up employment.

**Doelgroep**
mBA-D

**Overige informatie**
For more information on the dual program:
- [http://tinyurl.com-duaal-ba-studeren](http://tinyurl.com-duaal-ba-studeren) (NL)
- [http://tinyurl.com/dual-programme](http://tinyurl.com/dual-programme) (EN)

**Entrepreneurship in Data Science and Analytics**

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**Doel vak**
The objective of this course is to learn about entrepreneurship, with a
focus on IT, and especially business ideas that involve Data Science
and/or Analytics.

**Inhoud vak**
This course consists of several elements:
- lectures about different aspects of entrepreneurship;
- guest lectures by for example successful entrepreneurs and investors
  in starting companies;
- writing a business plan for a real or imaginary company.
For students who have the intention to start their own company we will
make it possible to pitch their ideas for venture capitalists (like a Dragons's Den).
Presence during the lectures is compulsory.
The course will be given by Enno Masurel (specialized in Entrepreneurship, FEWEB), Frans Feldberg (Business Intelligence, FEWEB) and Ger Koole (Analytics, FEW), assuring that all aspects of entrepreneurship will be covered.

Onderwijsvorm
weekly lectures

Toetsvorm
The assessment consists of:
- a written exam
- the writing of a business plan

Literatuur
handouts to be distributed during the course

Doelgroep
mBA, mMath, mCS, mAI, mIS, mPDCS

Overige informatie
Register as usual and via Blackboard

Evolutionary Computing

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<td>prof. dr. A.E. Eiben</td>
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Doel vak
To learn about computational methods based on Darwinian principles of evolution. To illustrate the usage of such methods as problem solvers and as simulation, respectively modelling tools. To gain hands-on experience in performing experiments.

Inhoud vak
The course is treating various algorithms based on the Darwinian evolution theory. Driven by natural selection (survival of the fittest), an evolution process is being emulated and solutions for a given problem are being "bred". During this course all "dialects" within evolutionary computing are treated (genetic algorithms, evolutionstrategyën, evolutionary programming, genetic programming, and classifier systems). Applications in optimisation, constraint handling, machine learning, and robotics are discussed. Specific subjects handled include:
various genetic structures (representations), selection techniques,
sexual and asexual variation operators, (self-)adaptivity. Special
attention is paid to methodological aspects, such as algorithm design
and tuning. If time permits, subjects in Artificial Life will be
handled. Hands-on-experience is gained by a compulsory programming
assignment.

Onderwijsvorm
Oral lectures and compulsory programming assignment. Highly motivated
students can replace the programming assignment by a special research
track under the personal supervision of the lecturer(s).

Toetsvorm
Written exam and programming assignment (weighted average).

Literatuur
Eiben, A.E., Smith, J.E., Introduction to Evolutionary Computing.

Doelgroep
mBA, mAI, mCS, mPDCS

Heuristic Methods in Operations Research

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Inhoud vak
This course is part of the Joint National Master Programme in
Mathematics.
For schedules, course locations and course descriptions see
http://www.mastermath.nl.

Doelgroep
mMath, mBA

Inlezenproceder
You have to register your participation in each Mastermath course via
http://www.mastermath.nl/registration/
Registration is mandatory and absolutely necessary for transferring your
grades from Mastermath to the administration of your university.

Investments

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Doel vak
This course aims to make students familiar with the insights from investments and portfolio management theory. Students also have to be able to apply these insights in practical situations involving portfolio decisions and investment management for both individuals and institutions.

The course is divided in four parts – portfolio theory and asset pricing, security analysis and portfolio management, fixed income securities, and derivatives.

By the end of the course, students should be able to:

Part 1. Portfolio theory and asset pricing (Lecture 1-4)
- calculate statistical measures of risk and return, such as expected returns and standard deviations, ex post and ex-ante, perform a time series analysis of historical rates of return, understand stylized facts about asset returns in terms of their distributional characteristics;
- calculate and understand the implications of risk measures (Value-at-Risk and Conditional tail expectation) based on different distributional assumptions;
- understand and apply the concept of risk aversion in the utility function of an investor and its effect on asset allocation;
- compute and explain the concept of expected utility;
- optimally allocate a portfolio between risk-free and risky assets based on mean-variance preferences and understand the effect of leverage;
- obtain a mean-variance frontier from a universe of assets;
- define systematic and firm-specific risk and evaluate the effect of portfolio diversification on the firm-specific risk in a portfolio;
- interpret and estimate index models, explain the decomposition of risk that they imply and obtain optimal portfolios based on them;
- have a thorough understanding of the Capital Asset Pricing Model (CAPM), its assumptions and resulting equilibrium conditions; test empirically the validity of the CAPM implications and be able to review extensions of the CAPM that rely on relaxing one or more of its assumptions;
- have a thorough understanding of factor models and the Arbitrage Pricing Theory (APT) and its equilibrium implications;
- identify and discuss the forms or market efficiency and related empirical tests of the efficient market hypothesis;
- understand the premises of behavioral finance;
- master the methodology behind testing empirically the validity of the CAPM and the multifactor APT model;

Part 2. Security analysis and portfolio management (Lecture 5-6):
- have a thorough understanding of the business cycle and the macroeconomic factors that affect security prices;
- understand industry analysis and the sensitivity of different industries to the business cycle;
- value a firm using the appropriate dividend discount model and the price/earnings ratio derived from it; understand the limitations of each of these models;
- be able to analyze a firm using basic financial statements; analyze problems by using the ROE decomposition;
- carry out portfolio performance evaluation by calculating various risk-adjusted return measures;
- understand market timing and be able to test the market timing ability of a portfolio manager;
- decompose excess portfolio returns into components that can be attributed to different asset allocation choices;
- apply active portfolio management models;
- analyze hedge fund characteristics and strategies and be able to set up a statistical arbitrage strategy.

Part 3. Fixed-income securities (Lecture 7-9):
- have a thorough understanding of the characteristics and risk determinants of bonds;
- calculate yields and prices of different types of bonds;
- understand the key ratios used by rating agencies to determine bond ratings;
- understand the role of protective covenants against default risk;
- understand the principle of securitization for reallocation of credit risk;
- understand the concept of the yield curve and be able to describe the major term structure theories;
- calculate forward rates from the spot yield curve;
- construct the yield curve from observed coupon bond prices;
- fit the yield curve using the Nelson & Siegel model;
- have a thorough understanding of the concept of duration and be able to calculate it for individual bonds and for bond portfolios;
- calculate price approximations using duration and convexity;
- construct immunized bond portfolios and understand the limits to conventional immunization;
- understand active bond portfolio management.

Part 4. Options, futures and other derivatives (Lecture 10-12):
- calculate pay-offs of derivative contracts and trading strategies based on them;
- build option-based portfolio strategies that achieve a certain risk-return profile;
- identify the embedded options via the pay-off structure of different assets and identify the ways in which the option-like characteristics impact the prices of these assets;
- understand the put-call parity relationship;
- identify the determinants of option prices;
- apply a binomial option pricing model via a replicating portfolio or using risk-neutral valuation;
- compute the Black-Scholes value of an option;
- compute hedge ratios and construct portfolio insurance strategies using option hedge ratios;
- understand the trading mechanisms involving futures contracts, incl. margin trading arrangements, the trading strategies based on them and the risks involved.

Inhoud vak
Investment decisions take a prominent role in everyday life. We can think of investment decisions taken by institutional investors (banks, insurance companies, pension funds, mutual funds), but also financial
decisions taken by individual households (additional pension savings, saving for one's children's education (and how), buying a house, etc.) Investment theory is also strongly linked with risk management. The importance of sound decision making in this field has been underlined by recent experiences on financial markets, law suits involving complex financial products for retail clients, the debate about the (in)solidity of pensions, etc. The Investments course aims to provide an overview of the principles of investment analysis. A framework is developed that allows one to address a variety of (at first sight) completely different investment problems in a unified way. The course is divided in four parts – portfolio theory and asset pricing, security analysis and portfolio management, fixed income securities, and derivatives.

Onderwijsvorm
Lectures and tutorial sessions.

Toetsvorm
Written exam and Case work. Exam questions are meant to test the candidate's theoretical insight as well as analytical and computational skills. Case work is used to test students implementation skills in Excel of the material treated in the course. Correctly completing a minimum of case work is compulsory for obtaining a pass for this course. Guidelines are communicated via Blackboard at the start of the course.

Literatuur
The course literature consists of detailed lecture slides to be found under Course documents on Blackboard. These will be posted weekly before each set of lectures. In addition to them, the textbook below is a compulsory reading material:
- Zvi Bodie, Alex Kane and Alan J. Marcus: Investments, McGraw Hill (10th edition)
As optional supporting material for the applied Excel work, I suggest the following books:
- Adair, Excel Applications for Investments (introductory book to Excel and its applications for investment problems).
- Mary Jackson and Mike Staunton, Advanced Modeling in Finance using Excel and VBA, Wiley Finance (advanced VBA applications and programming).

Vereiste voorkennis
The course builds upon prior knowledge in the 1st and 2nd year Finance courses (Finance 1.4, 2.2 and 2.4 for Economics students and Finance and Financial modeling 1.5 and Financial Management 2.4 for Financial Management students). For students coming from different programs or having a different background, this should correspond to mastering the concepts in the book of Braeley and Myers, Principles of corporate finance, chapters 1-15, 20-23, 27-30.

Overige informatie
The course is taught in English.

ONLY FOR PREMASTER STUDENTS:
For this course you do not need to subscribe. You will be subscribed by the department.

Master Project Business Analytics
Doel vak
The objectives of the internship are:
- To research and analyse a specific issue or problem affecting the host organization, and to suggest (potential) solutions.
- To gain an understanding of the way in which the organization functions. The student will gain a general impression how the organization as a whole works, including its primary business processes and its support processes. The internship should be positioned within these processes.
- To practise and develop social and communication skills. The student is introduced to the standards and values in place within the host organization. He will develop communication skills through personal interaction with the staff of the organization, and through the written and verbal reports.
- To explore potential career options.

Inhoud vak
Each Master's programme is concluded by an external master project. This is in principle a project to be carried out within a business, industry or research facility other than the departments of Mathematics and Computer Science.

Onderwijsvorm
The student is an intern of the host organization. The student will be supervised by a staff member of the Faculty of Science.

Toetsvorm
A written report and a verbal presentation.

Vereiste voorkennis
At least 78 credits, and the Research Paper Business Analytics.

Aanbevolen voorkennis
At least 78 credits, and the Research Paper Business Analytics.

Doelgroep
mBA, mBA-D

Overige informatie
If you are planning to start your Master Project within four months, please make an appointment with Annemieke van Goor (H.J.M.van.Goor-Balk@vu.nl)

More information (NL):
- http://tinyurl.com/masterproject
- http://tinyurl.com/bedrijfscontacten
**Doel vak**
The course aims to introduce the student to the mathematical theory of control systems.

**Inhoud vak**
Many phenomena are characterized by dynamic behaviour where we are interested in a certain input/output behaviour. Examples are to be found in the exact and natural sciences (mechanics, biology, ecology), in engineering (air- and spacecraft design, mechanical engineering) as well as in economics and econometrics (macro- economical models, trend and seasonal influences in demand and supply, production systems). Systems theory is concerned with modeling, estimation and control of dynamical phenomena. During the course the following subjects will be treated: models and representations (linear systems, input-output, state space, transfer function, stochastic systems, spectrum), control (stabilisation, feedback, pole placement, dynamic programming, the LQ problem), and identification and prediction (parameter estimation, spectral analysis, Kalman- filter, model reduction). Applications are in the area of optimal control and prediction.

**Onderwijsvorm**
There is a lecture of two hours each week. In addition, there is another session which will be half lecture and half practicum, in which there is the possibility to ask questions about the compulsory computerpracticum. The practicum makes use of the Matlab package.

**Toetsvorm**
The computerpracticum counts for 70%, the oral examination concerns the theory and counts for 30%.

**Literatuur**
Aanbevolen voorkennis
Analysis, probability theory, statistics.
Complex analysis and Fourier theory would be useful, but are not absolutely necessary.

Doelgroep
3W, mBA, mMath

Neural Networks

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<tr>
<td>Coördinator</td>
<td>dr. M. Hoogendoorn</td>
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<tr>
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<td>dr. M. Hoogendoorn</td>
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Doel vak
The course provides an introduction to key concepts and algorithms for pattern recognition and neural networks. It strives towards providing insight both from a theoretical perspective as well as more practical settings. In the end, the student should be able to confidently apply the aforementioned techniques in real-life settings and understand their theoretical basis.

Inhoud vak
The course provides an introduction to key concepts and algorithms for pattern recognition and neural networks. It covers the following topics:

- classification, regression, and clustering problems,
- elements of statistical pattern recognition,
- methods for estimation of probability distributions,
- linear classifiers, including Support Vector Machines,
- single-layer and multi-layer networks,
- RBF-networks and kernel methods
- methods for dimensionality reduction
- methods for feature extraction and selection

Moreover, several real-life applications of pattern recognition, including recognition of speech, handwritten characters, images, etc., will be discussed in depth.

Onderwijsvorm
Lectures (h) and practical (pra).

Toetsvorm
Practical assignments and written examination. Both count for 50% of the final grade and both grades should be sufficient in order to pass the course.
Literatuur
Simon Haykin, Neural Networks and Learning Machines, Pearson Education, 3rd international edition, 2008

Doelgroep
mAI mBio, mBA, mCS

Overige informatie
More information will be available via Blackboard.

Numerical Methods

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<td>dr. R. Castelli</td>
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Doel vak
- Gain experience in numerically solving a variety of problems.
- Getting acquainted with methods from numerical analysis.
- Develop intuition for the reliability of numerical methods.
- Learn how to use matlab.

Inhoud vak
Numerical methods are used frequently in all areas of science, such as fluid dynamics, meteorology and financial risk management. Moreover, techniques from numerical analysis play an important role in mathematical research on differential equations, stochastics, optimization, etcetera.
We focus on the main numerical methods from modern-day analysis and scientific computing. The theory is implemented in hands-on practical assignments. Active participation is expected. The list of subjects includes: error analysis, systems of nonlinear equations, eigenvalue problems, least square methods, fast Fourier transform, ordinary and partial differential equations. Applications include phone number recognition, ranking algorithms, curve following and planet motions.

Onderwijsvorm
Lectures alternated with practical work in the computer rooms.
A number of matlab assignments form an integral part of the course.

Toetsvorm
Active participation is expected. The grade is determined on the basis of the assignment (matlab code and short reports).

Literatuur
Numerical Analysis by Richard Burden and J. Douglas Faires
ISBN: 978-0538735643
Vereiste voorkennis
A basic course in linear algebra (e.g. X_400041, X_400042, X_400638 or X_400639)

Aanbevolen voorkennis
A basic course in linear algebra.

Doelgroep
2W, 2W-B, mBA, mBA-D

Intekenprocedure
Enroll on blackboard

Optimization of Business Processes

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<td>prof. dr. G.M. Koole</td>
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Doel vak
To learn about applications of stochastic operations research in the context of a few application areas, especially in services.

Inhoud vak
We deal with a number of application areas of stochastic modeling: production logistics, call centers, health care and revenue management. For each area we present quantitative problems and discuss how they can be solved using mathematical models. We also discuss a number of new models. Several guest lectures are given by people from industry.

Onderwijsvorm
Lectures and practical work.

Toetsvorm
Written examination, individual assignments, and a book presentation.

Literatuur
Lecture notes.

Aanbevolen voorkennis
Applied Stochastic Modeling or equivalent knowledge

Doelgroep
mBA, mBA-D, mMath

Overige informatie
Attendance mandatory.

Performance of Networked Systems

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<td>dr. ing. T. Kielmann, prof. dr. R.D. van der Mei</td>
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**Doel vak**

Students will acquire basic knowledge of:
- performance aspects of networked systems, consisting of servers, services, and clients
- performance engineering principles and methods,
- quantitative models for predicting and optimizing the performance of networked systems,
- quantitative models for planning capacity of networked systems.

Students will gain experience in engineering and planning performance of networked systems, and will learn how to tackle practical performance problems arising in the ICT industry.

**Inhoud vak**

Over the past few decades, information and communication technology (ICT) has become ubiquitous and globally interconnected. As a consequence, our information and communication systems are expected to process huge amounts of (digital) information, which puts a tremendous burden on our ICT infrastructure. At the same time, our modern society has become largely dependent on the well-functioning of our ICT systems; large-scale system failures and perceivable Quality of Service (QoS) degradation may completely disrupt our daily lives and have huge impact on our economy.

Motivated by this, the course will focus on performance-related issues of networked systems. In the first part, we study capacity planning and modeling for server systems and networks. In the second part, we study the client side of performance while focusing on web applications for both desktop and mobile devices. We address questions like:

- How can we design and engineer networked systems for performance?
- How can we plan server capacity in networked systems?
- How can web applications improve performance across wired and wireless networks?

**Onderwijsvorm**

Classroom lectures and practical homework assignments.

**Toetsvorm**

The assessment will be based on both homework assignments and a written exam.
Literatuur
Textbook, supplemented with a reader on Stochastic Performance Modelling.

Vereiste voorkennis
The students should have basic knowledge of computer networks.

Doelgroep
mBA, mCS, mPDCS, mEct

Project Optimization of Business Processes

<table>
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Doel vak
Acquiring skills and experience necessary for building decision support systems, and learning to apply relevant scientific knowledge.

Inhoud vak
Project optimization of business processes concerns the construction and/or design of (part of) a decision support system (DSS) that:
- is designed and built in a scientifically sound way;
- can be used in practice (the DSS is built in VBA).
The DSS is built in groups of students.

Onderwijsvorm
Project

Toetsvorm
Individual test for VBA, individual grade for participation in group project based on observed participation and a short oral exam.

Literatuur
None.

Aanbevolen voorkennis
Applied Stochastic Modeling (X_400392).

Doelgroep
mBA, mBA-D

Overige informatie
Important note: you are expected to attend the kick-off meeting. If (due to circumstances) you are not able to attend this meeting, you should notify the lecturer in advance. Failing to do so may exclude you from this course.

Research Paper Business Analytics

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<tr>
<td>Coördinator</td>
<td>drs. H.J.M. van Goor-Balk</td>
</tr>
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<td>Hoorcollege</td>
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**Doel vak**
The objective of the report is to demonstrate the student's ability to describe a problem in a clear manner (the report should therefore be concise and 'to the point') for the benefit of an expert manager.

**Inhoud vak**
As part of the BA programme, students are required to produce a 'thesis'. This is an account of a research project undertaken by the student further to a specific problem statement. The input for this research may involve the use of computer-generated data, although it can also be drawn from the existing literature.

The student records his or her findings in a written report - the research paper - and also gives a verbal presentation, both in English. The paper should emphasize the business-related aspects of the programme as well as the more fundamental aspects of mathematics and/or computer science.

**Onderwijsvorm**
Supervision by a staff member of preferably the Faculty of Science.

**Toetsvorm**
A written report and a verbal presentation (both in English).

**Doelgroep**
mBA, mBA-D

**Overige informatie**
Students should consult the coordinator to find a topic and a supervisor. If you are planning to write your paper within two months, please make an appointment with Annemieke van Goor (H.J.M.van.Goor-Balk@vu.nl).

More information:
- [http://tinyurl.com/research-paper-nl](http://tinyurl.com/research-paper-nl) (NL)

**Scheduling**
**Inhoud vak**
This course is part of the joint national master programme in Mathematics.
For schedules, course locations and course descriptions see [http://www.mastermath.nl](http://www.mastermath.nl).

**Doelgroep**
mMath, mBA

**Intekenprocedure**
You have to register your participation in each Mastermath course via [http://www.mastermath.nl/registration/](http://www.mastermath.nl/registration/)
Registration is mandatory and absolutely necessary for transferring your grades from Mastermath to the administration of your university.

**Scientific Writing in English**

**Doel vak**
The aim of this course is to provide Master’s students with the essential linguistic know-how for writing a scientific article in English that is well organized, idiomatically and stylistically appropriate and grammatically correct.

At the end of the course students
- know how to structure a scientific article;
- know what the information elements are in parts of their scientific article;
- know how to produce clear and well-structured texts on complex subjects;
- know how to cite sources effectively;
- know how to write well-structured and coherent paragraphs;
- know how to construct effective sentences;
- know what collocations are and how to use them appropriately;
- know how to adopt the right style (formal style, cohesive style, conciseness, hedging)
- know how to avoid the pitfalls of English grammar;
- know how to use punctuation marks correctly;
- know what their own strengths and weaknesses are in writing;
- know how to give effective peer feedback.

Final texts may contain occasional spelling, grammatical or word choice errors, but these will not distract from the general effectiveness of the text.

Inhoud vak
The course will start with a general introduction to scientific writing in English. Taking a top-down approach, we will then analyse the structure of a scientific article in more detail. As we examine each section of an article, we will peel back the layers and discover how paragraphs are structured, what tools are available to ensure coherence within and among paragraphs, how to write effective and grammatically correct sentences and how to choose words carefully and use them effectively.

Topics addressed during the course include the following:
- Structuring a scientific article
- Considering reading strategies: who is your readership? How do they read your text? What do they expect? How does that affect your writing?
- Writing well-structured and coherent paragraphs
- Composing effective sentences (sophisticated word order, information distribution).
- Arguing convincingly – avoiding logical fallacies
- Academic tone and style: hedging – why, how, where?
- Using the passive effectively
- Understanding grammar (tenses, word order, etc.)
- Understanding punctuation
- Referring to sources: summarising, paraphrasing, quoting (how and when?)
- Avoiding plagiarism
- Vocabulary development: using appropriate vocabulary and collocations

Onderwijsvorm
Scientific Writing in English is an eight-week course and consists of 2 contact hours a week. Students are required to spend at least 6 to 8 hours of homework per week. They will work through a phased series of exercises that conclude with the requirement to write several text parts (Introduction, Methods, Discussion and Abstract). Feedback on the writing assignments is given by the course teacher and by peers.

Toetsvorm
Students will receive the three course credits when they meet the following requirements:
- Students hand in three writing assignments (Introduction, Methods, Discussion)
- Students get a pass mark for all writing assignments;
- Students provide elaborate peer feedback (Introduction, Methods, Discussion, Abstract);
- Students attend at least 7 out of 8 sessions;
- Students are well prepared for each session (i.e. do all homework assignments);
- Students participate actively in class;
- Students do not plagiarise or self-plagiarise.
Writing assignments:
1. If students have a BSc thesis in a traditional thesis form (e.g., 20+ pages) and written in English, they may use this for the writing assignments.
2. If students have a BSc thesis in a traditional form (e.g., 20+ pages) written in another language than English, they may use this for the writing assignments.
3. If students have written a paper or report in English that's not already in article form, they may use this for the writing assignments.
4. If students are working on their MSc thesis or internship report when taking Scientific Writing in English, they may use this for the writing assignments. They will have to notify their supervisor to make sure that they won't be accused of self-plagiarism.
5. If students cannot or do not wish to use any of the above-mentioned texts for the writing assignments (1-4), they are expected to do a limited Literature Review on a topic in their field of research, using at least 5 articles.

Students are not allowed to use the following texts for the writing assignments:
1. A BSc thesis written in English that's already in article form.
2. A MSc thesis written in English that's already in article form (and that has already been marked).
3. An internship report written in English that's already in article form (and that has already been marked).
4. A paper or report written in English that's already in article form.

Literatuur

Doelgroep
This course is only open to students of the two-year Master's programmes Business Analytics, Mathematics and Stochastics and Financial Mathematics of the Faculty of Sciences. These students are only eligible to the course if they have already conducted scientific research (e.g. for their Bachelor's thesis) or if they will be working on a research project when taking Scientific Writing in English.

Overige informatie
- To do well, students are expected to attend all lessons. Group schedules are to be found at VUnet and on Blackboard.
- A VUnet registration for this course automatically gives access to the corresponding Blackboard site. Group registration only takes place via Blackboard (general groups: registration by students following FEW programmes offering this course; groups assigned to specific studies: registration through programme and course coordinator).
- Make sure Scientific Writing in English does not overlap with another course.
- If you have registered for a group in Blackboard, you are expected to attend all sessions. If you decide to withdraw from the course, do so in time in VUnet. This all will avoid a 'fail' on your grade list for not taking part in this course and allows other students to fill in a possible very wanted group spot.
- For specific Blackboard matters concerning this course, please contact onderwijsbureau.beta@vu.nl.
Statistical Models

**Vakcode** | X. 400418 (400418)
---|---
**Periode** | Periode 1+2
**Credits** | 6.0
**Voertaal** | Engels
**Faculteit** | Faculteit der Exacte Wetenschappen
**Coördinator** | dr. E.N. Belitser
**Examiner** | dr. E.N. Belitser
**Docent(en)** | prof. dr. M.C.M. de Gunst, dr. E.N. Belitser
**Lesmethode(n)** | Hoorcollege
**Niveau** | 400

**Doel vak**
The goals of this course are to get acquainted with some of the most commonly used statistical models, to learn how to apply these models in valid settings, and to understand the basic theory behind these models.

**Inhoud vak**
Analysis of Variance, Generalized Linear Models, Non-linear Models, Time Series.

**Onderwijsvorm**
Course of lectures, exercises and tutorial.

**Toetsvorm**
Assignments and examination.

**Literatuur**
Lecture notes "Statistical Models" by M.C.M. de Gunst.

**Aanbevolen voorkennis**
Linear Algebra, Probability Theory and Statistics. Statistical Data Analysis (X_401029)

**Doelgroep**
mBA, mBA-D, mMath

**Overige informatie**
Students will use statistical package R ([www.r-project.org/](http://www.r-project.org/)) for data analysis.

Stochastic Optimization

**Vakcode** | X. 400336 (400336)
---|---
**Periode** | Periode 1+2
**Credits** | 6.0
**Voertaal** | Engels
**Faculteit** | Faculteit der Exacte Wetenschappen
**Coördinator** | dr. S. Bhulai
**Doel vak**
The goal of the course is to discuss techniques from the field of stochastic optimization and their applications.

**Inhoud vak**
This course deals with the theory and algorithms for stochastic optimization with an application to controlled stochastic systems (e.g., call center management, inventory control, optimal design of communication networks). We discuss aspects of semi-Markov decision theory and their applications in certain queueing systems. In a programming assignment, students learn to implement optimization algorithms and experiment with them. Experience with and insight into the more theoretical subject is obtained through homework exercises.

**Onderwijsvorm**
Lectures.

**Toetsvorm**
Programming and written exercises, final exam.

**Literatuur**
Lecture notes will be posted on BlackBoard

**Vereiste voorkennis**
Stochastische Methoden (400391) or equivalent and a programming language.

**Aanbevolen voorkennis**
Stochastische Processen (X_401026) and Wachtrijmodellen (X_401061) or equivalent courses on Stochastic Processes and Queueing Theory and a programming language.

**Doelgroep**
mBA, mBa-D, mMath, mSFM

**Stochastic Processes for Finance**

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Doel vak
Learn basics of stochastic processes in continuous time, including the concepts of martingales and stochastic integration; apply these concepts to price options on stocks and interest rates by the no-arbitrage principle.

Inhoud vak
Financial institutions trade in risk, and it is therefore essential to measure and control such risks. Financial instruments such as options, swaps, forwards, etc. play an important role in risk management, and to handle them one needs to be able to price them. This course gives an introduction to the mathematical tools and theory behind risk management.

A "stochastic process" is a collection of random variables, indexed by a set T. In financial applications the elements of T model time, and T is the set of natural numbers (discrete time), or an interval in the positive real line (continuous time). "Martingales" are processes whose increments over an interval in the future have zero expectation given knowledge of the past history of the process. They play an important role in financial calculus, because the price of an option (on a stock or an interest rate) can be expressed as an expectation under a so-called martingale measure. In this course we develop this theory in discrete and continuous time. Most models for financial processes in continuous time are based on a special Gaussian process, called Brownian motion. We discuss some properties of this process and introduce "stochastic integrals" with Brownian motion as the integrator. Financial processes can next be modeled as solutions to "stochastic differential equations". After developing these mathematical tools we turn to finance by applying the concepts and results to the pricing of derivative instruments. Foremost, we develop the theory of no-arbitrage pricing of derivatives, which are basic tools for risk management.

Onderwijsvorm
Lectures and exercises.

Toetsvorm
Assignments and written examination.

Literatuur
Lecture notes.
In addition, it is useful to have the following books:

Vereiste voorkennis
Probability (X_400622) and Analysis 1 (X_400005), or their equivalents.

Aanbevolen voorkennis
Measure Theory.

Doelgroep
mBA, mBA-D, mMath, mSFM, master Econometrics.

Overige informatie
A significant part of the course is used to introduce mathematical subjects and techniques like Brownian motion, stochastic integration and Ito calculus. In view of this, the course is NOT meant for students who already followed the master course “Stochastic Integration”. On the other hand, after completing this course, students may be motivated to follow the other one (Stochastic Integration) to study the above mentioned mathematical subjects in a deeper and more rigorous way.