Entry Requirements MSc BAOR

In order to be able to enter the MSc BAOR***, the topics and the corresponding skills related to mathematical proofs and mathematical reasoning*** covered in the following nine courses offered by the BSc Econometrics and Operations Research (EOR) at Tilburg University is required

Year 1 (30 ECTS, to be followed parallel to 2nd year of your regular program)					
#	Semester	Unit	Course name	Course number	ECTS
1	1	1	Linear Algebra	35B203	6
2	1	1 & 2	Introduction Analysis and Probability Theory	35B113	6
3	1	2	Mathematical Analysis 1	35B105	6
4	2	3	Mathematical Analysis 2	35B107	6
5	2	3 & 4	Probability and Statistics	35B402	6
6	1	1 & 2	Computer Programming for EOR	346022	6
#	Semester	Unit	Course name	Course number	ECTS
7	1	2	Linear Optimization	35B108	6
8	2	3 & 4	Stochastic Operations Research Models	35B204	6
9			At least 1 course from the BAOR cluster:		
	1	1 & 2	- Combinatorial Optimization (preferred!)	35V5A3	6
	2	3 & 4	- Inventory and Production Management	35V3A4	6
	2	3 & 4	- Operations Research Methods	35V3A3	6

The content of these nine courses is available below.

Linear Algebra

Linear Algebra and Its Applications – David C. Lay

1. Linear Equations in Linear Algebra
    1.1 Systems of Linear Equations
    1.2 Row Reduction and Echelon Forms
    1.3 Vector Equations
    1.4 The Matrix Equation Ax=b
    1.5 Solution Sets of Linear Systems
    1.6 Applications of Linear Systems

- 1.7 Linear Independence
- 1.8 Introduction to Linear Transformations
- 1.9 The Matrix of a Linear Transformation
- 1.10 Linear Models in Business, Science and Engineering

2. Matrix Algebra
   - 2.1 Matrix Operations
   - 2.2 The Inverse of a Matrix
   - 2.3 Characterizations of Invertible Matrices
   - 2.4 Partitioned Matrices
   - 2.5 Matrix Factorizations
   - 2.8. Subspaces of R^n
   - 2.9. Dimension and Rank
3. Determinants
   - 3.1 Introduction to Determinants
   - 3.2 Properties of Determinants
   - 3.3 Cramer's Rule, Volume, and Linear Transformations
4. Vector Spaces
   - 4.1 Vector Spaces and Subspaces
   - 4.2 Null Spaces, Column Spaces, and Linear Transformations
   - 4.3 Linearly Independent Sets; Bases
   - 4.5. The Dimension of a Vector Space
   - 4.6. Rank
   - 4.7. Change of Basis
6. Orthogonality and Least Squares
   - 6.1. Inner Product, Length, and Orthogonality
   - 6.2. Orthogonal Sets
   - 6.3. Orthogonal Projections

Introduction Analysis and Probability Theory

Introduction Analysis (reader)

1. Equations, inequalities and absolute value
   - 1.1. Number sets
   - 1.2. Solving equations
   - 1.3. Solving inequalities
   - 1.4. Absolute value
   - 1.5. Mixed exercises
2. Logic reasoning and the set of real numbers
   - 2.1. Logic reasoning
   - 2.2. The Algebraic Axioms
   - 2.3. The Ordering Axioms
   - 2.4. The Axiom of Completeness
   - 2.5. Mixed exercises
3. The principle of induction

   3.1. The summation and product sign
   3.2. The principle of induction
   3.3. Newton's binomium
   3.4. Mixed exercises
4. Geometry
   4.1. Plane geometry
   4.2. Space geometry
5. Sets and maps
   5.1. Set theory
   5.2. Maps
   5.3. Cardinality of sets
6. Differentiation and Integration
   6.1. Difference quotients and derivatives
   6.2. Partial derivatives
   6.3. Integration

Introduction to Probability and Mathematical Statistics – Bain/Engelhardt

1. Probability
   1.1. Introduction
   1.2. Notation and terminology
   1.3. Definition of probability
   1.4. Some properties of probability
   1.5. Conditional probability
   1.6. Counting techniques
2. Random Variables and their Distributions
   2.1. Introduction
   2.2. Discrete random variables
   2.3. Continuous random variables
   2.4. Some properties of expected values
   2.5. Moment generating functions
3. Special Probability Distributions
   3.1. Introduction
   3.2. Special discrete distributions
   3.3. Special continuous distributions
   3.4. Location and scale parameters

Mathematical Analysis 1

Mathematical Analysis 1 (reader)

1. Convergence of Sequences
    1.1. Sequences
    1.2. The limit of a sequence
    1.3. Properties of convergent sequences
    1.4. Arithmetic rules for limits of sequences
    1.5. Monotone sequences
    1.6. The number e
    1.7. Mixed exercises
2. Subsequences
    2.1. Subsequences
    2.2. Convergent subsequences
    2.3. Cauchy sequences
    2.4. The contraction theorem
    2.5. Mixed exercises
3. Limits of Functions
    3.1. Limit of a function
    3.2. A criterion for the limit of a function
    3.3. Arithmetic rules for limits of functions
    3.4. Extentions of the concept limit
    3.5. Mixed exercises
4. Continuity
    4.1. Continuous functions
    4.2. Artithmetic rules for continous functions
    4.3. Continuous functions on an interval
    4.4. Continuity and the inverse function
    4.5. Mixed exercises
5. Derivative
    5.1. Differentiable functions
    5.2. Arithmetic rules for differentiable functions
    5.3. Linear approximation and differential
    5.4. Marginality
    5.5. Elasticity
    5.6. Partial derivatives
    5.7. Mixed exercises
6. Differentiable Functions
    6.1. Mean Value Theorem
    6.2. Monotone and differentiable functions
    6.3. Differentiability of the inverse function
    6.4. Taylor’s Theorem
    6.5. Rule of de l’Hopital
    6.6. Mixed exercises
7. Summability of a Sequence
    7.1. Summable sequences

   7.2. Arithmetic rules for summable sequences
   7.3. Two summability criteria
   7.4. Power sets
   7.5. Mixed exercises
8. Integration
   8.1. The integral
   8.2. The Principal Theorem of Integral Calculus
   8.3. A list with primitive functions
   8.4. Arithmetic rules for integration
   8.5. Indefinite integral
   8.6. Mixed exercises

Mathematical Analysis 2

Introduction Analysis 2 (reader)

1. The n-Dimensional Euclidean Space
   1.1. The space R^n
   1.2. Functions on R^n
   1.3. Sets in R^n
   1.4. Sequences in R^n
   1.5. Mixed exercises
2. Limits of Functions and Continuity
   2.1. Limit of a function
   2.2. Continuity of a function
   2.3. Arithmetic rules for continuous functions
   2.4. Continuous functions on a compact set
   2.5. Mixed exercises
3. Differentiation in R^n
   3.1. Partial differentiable functions
   3.2. Total differentiable functions
   3.3. (Total) differential
   3.4. (Arithmetic rules for (total) differentiable functions
   3.5. Continuously differentiable functions
   3.6. Directional derivative
   3.7. Marginality and marginal rate of substitution
   3.8. Higher order partial derivatives
   3.9. Mixed exercises
4. Equations and implicit functions
   4.1. Analysis of an economical model
   4.2. Implicit Function Theorem
   4.3. Inverse Function Theorem
   4.4. Comparative Statics
5. Differentiable Functions
   5.1. Convex sets
   5.2. Taylor's Theorem
   5.3. Quadratic functions
   5.4. Concave and convex functions
   5.5. Homogeneous functions
   5.6. Mixed Exercises
6. Optima of a Differentiable Function
   6.1. Free optima
   6.2. Concavity and optima
   6.3. Least-squares-method
   6.4. A constrained optimization problem

   6.5. The substitution method
   6.6. The method of Lagrange
   6.7. The Lagrange multiplicator
   6.8. Mixed exercises
7. Integration
   7.1. Integrals for functions of more variables
   7.2. Mixed exercises

Handout Constrained Optimization

1. Constrained Optimization: Inequality Constraints
   1.1. The Directional Derivative
   1.2. Two Variables and One Inequality Constraint
   1.3. The General Case
   1.4. Some Pathological Examples

Probability and Statistics

Introduction to Probability and Mathematical Statistics – Bain/Engelhardt

4. Joint Distributions
    4.1. Introduction
    4.2. Joint discrete distributions
    4.3. Joint continuous distributions
    4.4. Independent random variables
    4.5. Conditional distributions
    4.6. Random samples
5. Properties of Random Variables
    5.1. Introduction
    5.2. Properties of expected values
    5.3. Correlation
    5.4. Conditional expectation
    5.5. Joint moment generating functions
6. Functions of Random Variables
    6.1. Introduction
    6.2. The CDF technique
    6.3. Transformation methods
    6.4. Sums of random variables
    6.5. Order statistics
7. Limiting Distributions
    7.1. Introduction
    7.2. Sequences of random variables
    7.3. The central limit theorem
    7.4. Approximations for the binomial distribution
    7.5. Asymptotic normal distributions
    7.6. Properties of stochastic convergence
    7.7. Additional limit theorems
8. Statistics and Sampling Distributions
    8.1. Introduction
    8.2. Statistics
    8.3. Sampling distributions
    8.4. The t, F, and beta distributions
    8.5. Large-sample approximations
9. Point Estimation
    9.1. Introduction
    9.2. Some methods of estimation
    9.3. Criteria for evaluating estimators

Linear Optimization

Text book: Introduction to Linear Optimization by Dimitris Bertsimas and John N. Tsitsiklis.

Objectives

The goal is to learn how to formulate and solve linear optimization models:

1. Learn how to formulate linear and integer optimization models;
2. Understand the simplex algorithm for linear optimization;
3. Understand duality theory and its economic interpretation (shadow prices);
4. Learn how to solve integer optimization problems using branch and bound and Gomory cuts.
5. Learn how to use state-of-the-art optimization software and the modeling language AIMMS, and to use this to solve a realistic case study.

Content

Linear optimization is one of the fundamental computational tools in Operations Research, and is used for airline scheduling, production planning, and in many other industrial settings. In fact, it has been called one of the mathematical problems “using up most of the computer time in the world”.

1. Linear optimization models from practical decision problems.
2. Links with linear algebra and geometry.
3. The simplex method
4. Dual problem, and economic interpretation in terms of “shadow prices” 5. Integer decision variables: branch-and-bound, and Gomory cuts.

Computer Programming for EOR

The course can help with implementing the following strategic educational objectives of the Tilburg University and TiSEM: i) developing knowledge, skills, character students need to confront today’s challenges; ii) preparing students for the labor market, and iii) creating value from data.

Content

- Running and debugging the codes,
- Data Types, variables, and basic operations,
- Conditions (also called branches or if statements),
- Loops,
- Arrays and lists,
- Functions and methods,
- Recursion
- Modules,
- File, data analysis

- Object-oriented programming

Stochastic Operations Research Models

Text book: Hand outs are provided

Objectives

This course deals with some of the techniques for modeling and optimizing systems under uncertainty. It aims to increase the capability of analyzing managerial problems under uncertainty which occur, for example, in inventory and production control, telecommunications, maintenance, and insurance. The emphasis is on providing insight in the theory, on formulating an economic situation into a mathematical model and on providing practical examples in which the discussed models can be applied.

Content

1. Markov Chains
2. Inventory models: newsvendor, EOQ, (s,Q), (R,S) policies 3. Forecasting: moving average; exponential smoothing

4. Elementary Queueing models and networks.

Combinatorial Optimization

Text book: Hand outs are provided

Objectives

1. The student knows a wide scope of combinatorial optimisation models and the corresponding relevant algorithms and heuristics.
2. The student has insight in the complexity of combinatorial problems, especially the difference between 'easy' and 'hard' problems.

Contents

Many decision problems from practice can be described as combinatorial optimization problems. Typically, these problems have a finite set of possible solutions such that an optimal solution always exists.
In general combinatorial optimization problems can be translated to integer linear programming problems (ILP). So one way to solve them is by solving the ILP. Often however, these algorithms are time consuming. For some combinatorial optimization problems (the 'easy' problems) fast solution methods exist while for other problems (the 'difficult' problems) finding the optimal solution is time consuming and only practical achievable if the problem is 'small'. The field of mathematics that formalizes this distinction in 'easy' and difficult' is the complexity theory. For difficult problems one often has to be satisfied with an approximation of the optimal solution. In these cases it is important to have good bounds for the accuracy of the approximate solution.

In this course we will treat the aspects mentioned above as well as a number of concrete problems and solution methods.

1. Easy problems: 'shortest path', 'maximal flow' and 'assignment'
2. Difficult problems: 'traveling salesman', 'knapsack', 'vehicle routing' and 'truck loading'
3. Methods: 'greedy', 'branch and bound', 'dynamic programming' and 'local search'.
4. Scheduling problems:. For these problems the aim is to find an optimal scheduling of operations in a production process. On the one hand these problems are clearly applicable while on the other hand they are very illustrative since all aspects of combinatorial optimization appear.

Inventory and Production Management

Text book: Silver, Pyke, and Peterson, Inventory Management and Production Planning and Scheduling, 3rd Edition, John Willy & Sons, 1998. Also, hand outs are provided

Objectives

This course is in general designed to introduce students to the basic principles, models and techniques of inventory and production management. Specific objectives are:

1. To develop an understanding and appreciation for the field of inventory and production management.
2. To identify and discuss typical problems facing the inventory and production manager.
3. To develop a working familiarity with relevant analytic concepts and quantitative techniques.
4. To provide experience in structuring and solving inventory and production problems.
5. To introduce and use various management production models in the solution to a wide array of inventory and production decisions.
6. To develop an understanding of how inventory and production managers interact with other segments of an organization.
7. To develop a framework for operational decision-making.
8. To provide a basis for more advanced and more specialized study of inventory and production management.

Content

In this course the "state-of-the-art", as well as the current theoretical and applied work being done in inventory and production management, are investigated. This thorough and in-depth course will expose the role of Inventory & Production Managers, providing you with the confidence and skills to analyze major problems in these fields.

The world of manufacturing and distribution has changed in the last three decades. Global supply networks are reality. World class manufacturing companies have been created to engage in sales, manufactoring, and purchasing activities in all corners of the world. The justin-Time philosophy is being applied in every environment. Flexible Manufacturing Systems are common. Computer integrated manufacturing is being realized.

Newer, more powerful, computerized planning and control systems are implemented to integrate sales, manufacturing and distribution in these world class companies. This course covers model development for finished goods inventories, production planning; lot-sizing, dispatching, scheduling, releasing, material requirements planning; and distribution inventory problems. This course also covers the concepts like demand management, MRP (Manufacturing Resources Planning), JIT (Just in Time), TOC (Theory of Constraint), FMS (Flexible Manufacturing System).

Operations Research Methods

Text book: Hand outs are provided

Objectives

The objective of this course is to study solution methods for optimization problems where the basic linear/integer programming methods do not apply.

Content

In the first part of the course we study large scale linear/integer programming. Some real life optimization problems tend to be large in size, either in the number of variables or constraints, and thus the common solvers, are unable to solve these problems.However there are several methods to solve large scale problems by exploiting the structure of the problem to reduce it to smaller ones.

In the second part we will study Heuristic techniques that are used to solve more general nonlinear programs. Heuristics apply "rules of thumb" to find solutions, without any guarantee in the optimality or quality of them. Yet, given the complexity of some problems, heuristics might be the only real option to solve a problem. Also, heuristic methods have proven to be very successful in solving some families of problems.

Applications of the methods studied in the course are common in telecommunication, VLSIdesign, production and energy planning, traffic and transport or scheduling. As part of the course a project in one of these areas or similar will be given.