



Study Plan

School: School of Sciences and Technology
Degree: Bachelor
Course: Applied Mathematics for Economics and Management (cód. 472)

1st Year - 1st Semester

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
MAT0900	Linear Algebra and Geometry I	Mathematics	6	Semester	156
MAT0905	Mathematical Analysis I	Mathematics	6	Semester	162
ECN2314	Principles of Microeconomics	Economy	6	Semester	156
INF0878	Programming	Informatics	6	Semester	156
GES2311	Introduction to Management	Management	6	Semester	156

1st Year - 2nd Semester

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
MAT0906	Mathematical Analysis II	Mathematics	6	Semester	162
ECN2319	Principles of Macroeconomics	Economy	6	Semester	156
MAT10689	Mathematics and Statistics Laboratory	Mathematics	6	Semester	156
MAT0920	Fundamentals of Operations Research	Mathematics	6	Semester	158
GES2351	Introduction to Business Finance	Management	6	Semester	156

2nd Year - 3rd Semester

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
MAT0907	Mathematical Analysis III	Mathematics	6	Semester	162
ECN2353	Macroeconomics I	Economy	6	Semester	156
ECN2352	Microeconomics I	Economy	6	Semester	156
MAT10690	Mathematics Programming	Mathematics	6	Semester	156
MAT2354	Probability and Statistics	Mathematics	6	Semester	156

2nd Year - 4th Semester

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
MAT0908	Mathematical Analysis IV	Mathematics	6	Semester	162
GES10218	Marketing Research	Management	6	Semester	156
MAT0912	Complements of Probability and Statistics	Mathematics	6	Semester	162
ECN2356	Microeconomics II	Economy	6	Semester	156
ECN2358	Econometrics I	Economy	6	Semester	156

3rd Year - 5th Semester

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
ECN2361	Econometrics II	Economy	6	Semester	156
MAT0927	Introduction to Stochastic Processes	Mathematics	6	Semester	156



3rd Year - 5th Semester

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
Group of Options					
Component code	Name	Scientific Area Field	ECTS	Duration	Hours
MAT0902	Sampling	Mathematics	6	Semester	156
MAT10693	Forecasting Models	Mathematics	6	Semester	157
MAT0919	Multivariate Statistics	Mathematics	6	Semester	156
MAT0926	Introduction to Quality Control and Reliability	Mathematics	6	Semester	156
MAT0932	Discrete Mathematics	Mathematics	6	Semester	156
MAT0939	Functional Optimization	Mathematics	6	Semester	156
ECN10694	Complements of Econometrics	Economy	6	Semester	156
Group of Options					
Component code	Name	Scientific Area Field	ECTS	Duration	Hours
ECN2357	Macroeconomics II	Economy	6	Semester	156
ECN2344	Financial Economics	Economy	6	Semester	156
ECN2360	Monetary Economics	Economy	6	Semester	156
GES0009	Real Investments	Management	6	Semester	156
GES2323	Management Accounting I	Management	6	Semester	156
GES10695	Financial Calculus	Management	6	Semester	156
GES0010	Decision and Negotiation Analysis	Management	6	Semester	156
Group of Free Options					
GES2332	Operation Management	Management	6	Semester	156

3rd Year - 6th Semester

Component code	Name	Scientific Area Field	ECTS	Duration	Hours
ECN10692	Project	*** TRANS-LATE ME: Matemática/Economia/Gestão ***	6	Semester	156
MAT0937	Computational Methods	Mathematics	6	Semester	160
Group of Options					
Component code	Name	Scientific Area Field	ECTS	Duration	Hours
MAT0902	Sampling	Mathematics	6	Semester	156
MAT10693	Forecasting Models	Mathematics	6	Semester	157
MAT0919	Multivariate Statistics	Mathematics	6	Semester	156
MAT0926	Introduction to Quality Control and Reliability	Mathematics	6	Semester	156
MAT0932	Discrete Mathematics	Mathematics	6	Semester	156
MAT0939	Functional Optimization	Mathematics	6	Semester	156
ECN10694	Complements of Econometrics	Economy	6	Semester	156
Group of Options					
Component code	Name	Scientific Area Field	ECTS	Duration	Hours
ECN2357	Macroeconomics II	Economy	6	Semester	156
ECN2344	Financial Economics	Economy	6	Semester	156
ECN2360	Monetary Economics	Economy	6	Semester	156
GES0009	Real Investments	Management	6	Semester	156
GES2323	Management Accounting I	Management	6	Semester	156
GES10695	Financial Calculus	Management	6	Semester	156
GES0010	Decision and Negotiation Analysis	Management	6	Semester	156
Group of Free Options					



Conditions for obtaining the Degree:

*** TRANSLATE ME: Matemática Aplicada à Economia e à Gestão

Para obtenção do grau de licenciado em Matemática Aplicada à Economia e à Gestão é necessário obter aprovação a 150 ECTS em unidades curriculares obrigatórias e 30 ECTS em unidades curriculares optativas distribuídas da seguinte forma:

1º Ano

1º Semestre:

5 UC Obrigatórias num total de 30 ECTS

2º Semestre:

5 UC Obrigatórias num total de 30 ECTS

2º Ano

3º Semestre:

5 UC Obrigatórias num total de 30 ECTS

4º Semestre:

5 UC Obrigatórias num total de 30 ECTS

3º Ano

5º Semestre

3 UC Obrigatórias num total de 18 ECTS

UC Optativas ou livre num total de 12 ECTS

6º Semestre

2 UC Obrigatórias num total de 12 ECTS

UC Optativas ou livre num total de 18 ECTS ***

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Linear Algebra and Geometry I (MAT0900)

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Mathematical Analysis I (MAT0905)

Sequences and series.

Real functions of one variable.

Differential calculus.

Sequences and series of functions.

Integral calculus and applications



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Principles of Microeconomics (ECN2314)

1. Introduction
 - 1.1 Economics as a science
 - 1.2 The economic problem: scarcity and choice
 - 1.3 Society's technological possibilities
 - 1.4 Review of mathematical tools and graphical analysis
 - 1.5 The economic circuit

2. Model of Supply and Demand - Introduction
 - 2.1 Market
 - 2.2 Demand curve
 - 2.3 Supply curve
 - 2.4 Joint analysis of supply and demand
 - 2.5 Consumer surplus and producer surplus

3. Consumer behaviour
 - 3.1 Utility and preferences
 - 3.2 Static equilibrium of the consumer
 - 3.3 Changes in income and prices: impact on consumer choices

4. Firm's behaviour
 - 4.1 Basic concepts
 - 4.2 Production
 - 4.3 Costs
 - 4.4 Firm's decision: optimal combination of productive factors

5. Markets
 - 5.1 Perfect Competition
 - 5.2 Monopoly

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Programming (INF0878)



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Introduction to Management (GES2311)

Part One - Fundamental concepts and challenges

- * Key-concepts of organization, system, company and management
- * Major challenges for management and managers
- * Manager roles

Part Two - Historical approaches of management

- * Classical and structuralist approaches
- * Human and Behavioral approaches
- * Systems and contingency approaches

Part three - Organizational legal, structures and dynamics

- * Organizational structures
- * Legal forms
- * Management system and sub-systems
- * Decision and organizational planning and controlling

Part four - Behavioral dimensions of management

- * Motivation and job satisfaction
- * Organizational leadership
- * Organizational Communication
- * Organizational culture, quality and excelency

Part five - Management issues

- * Enterpreneurship and innovation
- * Ethics and social responsibility
- * Technology role and management
- * Managing Knowledge
- * Managing change

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Mathematical Analysis II (MAT0906)

Topology and Sequences in \mathbb{R}^n .

Limits and continuity of functions in \mathbb{R}^n .

Differential Calculus of functions in \mathbb{R}^n .

Taylor Formula.

Inverse function and Implicit function.

Free extrema and Conditioned extrema.

Line integrals.

Multiple integrals.

Surface integrals.



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Principles of Macroeconomics (ECN2319)

1. Science of Macroeconomics. Macroeconomic variables & data. The time-dimension in macroeconomics..

2. Short run economic fluctuations.

Fiscal policy and the multiplier. Government budget, budget deficits & public debt.

Monetary system. What is money and how is it created, commercial banks & money supply. Central bank and its instruments for monetary policy. Taylor rule.

Open economy; the bases for international trade, the flow of goods, services and capital, nominal and real exchange rates, the (absolute and relative) purchasing power parity hypothesis and the uncovered interest rate parity. Exchange rates regime.

The aggregate demand: overview

3. The supply side economy

Labour market; structural and cyclical unemployment, the natural rate of unemployment, sources of labour rigidities. Inflation and Phillips curve.

Aggregate supply: the Okun's law, determinants of the aggregate supply .

Aggregat

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Mathematics and Statistics Laboratory (MAT10689)

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Fundamentals of Operations Research (MAT0920)

1 - Introduction to Operations Research methodology

2 - Problem Formulation

3 - Linear Programming

4 ? Duality; Shadow Prices and Opportunity Costs

5 - Optimization in networks and graphs

6 - Project Management

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Introduction to Business Finance (GES2351)

1. Introduction

2. The Role of Financial Markets

3. Financial Diagnostic

4. Fundamental Concepts of Financial Management

5. Analysis of Investment Projects

6. Study of Financing Mix (Funding Sources)



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Mathematical Analysis III (MAT0907)

-Introduction to Complex Analysis. Complex functions and analytic functions. Cauchy-Riemann equations. Laplace equation. Harmonic functions. Geometry of analytic functions. Elementary complex functions. Complex integration. Fundamental Theorem of Calculus. Cauchy's theorem and its evolution. Cauchy integral formula and applications.

NCE/13/00836 - Apresentação do pedido - Novo ciclo de estudos http://www.a3es.pt/si/iportal.php/process_form/print?processId=f1edd77de120301020131510

-Ordinary Differential Equations. Exact equations and integrating factors. Elementary equations of 1st order. 2nd order linear equations.

-Systems of ordinary differential equations. Introduction and notations. Linear systems. Systems with constant coefficients. Stability of solutions. Planar autonomous systems.

-Fourier series. Convergence and the sum of the Fourier series. Expansion in series of sines and cosines. Periodic extensions. Complex Fourier series. Fourier integrals.

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Macroeconomics I (ECN2353)

1- Economic short-term fluctuations: Review and Consolidation Theory of Income Determination

2- Open Economy: The Mundell-Fleming Model. The components of the balance of payment

3- Budget deficits and Government Budget: Government deficit and its financing; The instantaneous and intertemporal government budget constraint; Traditional versus Ricardian views of Government debt

4- Microeconomics Foundations:

a) Consumption - Forward-Looking Theory of Consumption, Life-Cycle and Permanent-Income Hypothesis, rational expectations-random walk Hypothesis

b) Investment - The optimal capital stock, Investment and the real interests; the accelerator principle, Investment and the tobin's q

c) Demand for Money - the portfolio and Transactions theories of Money Demand; Financial innovations and the rise of Near Money

d) Supply of Money - the process of money creation; A model of the Money Supply; Three instruments of money control: Monetary policy in a Open Economy; Rules or Constrained Discretion?

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Microeconomics I (ECN2352)

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Mathematics Programming (MAT10690)

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Probability and Statistics (MAT2354)

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Mathematical Analysis IV (MAT0908)

First order Difference Equations. Linear higher order Difference Equations and Systems of Difference Equations with constant coefficients. Applications.

Integral transforms.

Introduction to Partial Differential Equations.

Convex Analysis in \mathbb{R}^n .



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Marketing Research (GES10218)

I. – Introduction and basic concepts of Marketing

II - Methodology for Data Collection

Decision about the type of information to collect.

Methods to collect primary data.

Measure and Scale Methods.

Construction of the instrument to sample data.

Sampling method

Work Field

III - Methodology for data analysis.

Steps of the process preparation data

Statistic techniques

Some specific methods useful in Marketing

– Clusters analysis

– Factorial analysis

– Multidimensional Scaling (MDS)

– Correspondence analysis

– Conjoint analysis

- Preferences analysis

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Complements of Probability and Statistics (MAT0912)

Complements of Probability Distributions (includes, among others, the Gamma, Beta and Weibull distributions).

- Variable Transformations.

- Moment and probability generating functions

- Characteristics functions.

- Analysis of variance (1 and 2 factor)

- Introduction to Categorical data Analysis

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Microeconomics II (ECN2356)

1- Profit maximization

2- Duality on production

3- Competitive markets: partial equilibrium

4- General equilibrium and welfare

5- Market power

6- Game Theory

7- Oligopoly



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Econometrics I (ECN2358)

1- THE SIMPLE REGRESSION LINEAR MODEL WITH CROSS-SECTIONAL DATA:

- Specification
- Estimation
- Expected Values, Variances and Properties of the Estimators

2- MULTIPLE REGRESSION ANALYSIS WITH CROSS SECTIONAL DATA:

- Specification
- Estimation
- Functional Form and Transformation of Variables
- Effects of Changing the Unit of Measurement
- Expected Values, Variances and Properties of the Estimators
- Multicollinearity
- Inference
- Prediction

3- OTHER TOPICS OF LINEAR REGRESSION:

- Specification Analysis
- Qualitative Regressors
- Topics on Assymptotic Theory

4- HETEROSKEDASTICITY:

- Properties of the Estimators
- Estimation in the Presence of Heteroskedasticity
- Heteroskedasticity Tests

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Econometrics II (ECN2361)

1- MODELS FOR BINARY DATA: Linear probabilistic model; Maximum likelihood estimation; Logit and probit models.

2- BASICS OF THE LINEAR REGRESSION MODEL WITH TIME SERIES DATA: Types of models; Trends and seasonality; Stationary and non-stationary series.

3- AUTOCORRELATION AND HETEROSKEDASTICITY IN TIME SERIES: Autocorrelation tests; Generalized least squares; Dynamically complete models; Heteroskedasticity; ARCH models.

4- DYNAMIC MODELS AND FORECASTING: Infinite distributed lag model, Stationarity and unit roots tests, Spurious regression and cointegration models; Forecasting.

5- PANEL DATA MODELS: Fixed effects model, Random effects model.

6- INSTRUMENTAL VARIABLE REGRESSION: Motivation: Omitted variables and measurement error; Estimation; Endogeneity test and overidentifying restrictions test.

7- SIMULTANEOUS EQUATION MODELS: Reduced form model and structural model; The identification problem; Two-stages least squares.

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Introduction to Stochastic Processes (MAT0927)

General concepts of stochastic processes

Discrete-time Markov chains (including Monte Carlo simulation)

Introduction to branching processes

Continuous-time Markov chains (including Monte Carlo simulation)

Poisson processes

Birth-and-death processes

Introduction to queueing theory



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Sampling (MAT0902)

1. Basic notions on sampling and estimation.
2. Main steps about planning a sampling design and selection of sampling units.
3. Methods for data collection in survey sampling.
4. Simple random sampling.
5. Estimation of totals, means, proportions and ratios.
6. Ratio and regression estimation.
7. Stratified sampling.
8. Cluster and multi-step sampling designs.
9. Unequal probability sampling.

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Forecasting Models (MAT10693)

1. Introduction to generalized linear models
2. Time Series Linear models: ARMA, ARIMA and SARIMA models
3. Dynamic regression models
4. Application to real data using statistical software.

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Multivariate Statistics (MAT0919)

Exploratory Analysis of Multivariate Data
Multivariate techniques of dependence and interdependence
Populations and samples and Multivariate Multivariate Normal Distribution
Principal Component Analysis and Factor Analysis
Cluster Analysis
Discriminant Analysis
Introduction to Regression Trees
Software: SPSS and R

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Introduction to Quality Control and Reliability (MAT0926)

Basic Concepts in Quality Control and Reliability.
Control charts for variables.
Control charts for attributes.
Process capability analysis.
Acceptance sampling. Different sampling plans. MIL STD tables.
Sampling methods in quality control.
Optimization in quality control.
Reliability and survival.
Series and parallel systems.
Inspection systems policies.

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Discrete Mathematics (MAT0932)



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Functional Optimization (MAT0939)

Historical introduction.

Weak and strong variations.

Proof of validity of the Euler-Lagrange equation for simple integrals with C^1 lagrangian in spaces of functions in competition of class C^1 .

Generalizations of the Euler-Lagrange equation: simple integrals containing n -th order derivatives of the functions in competition; double integrals; piecewise C^1 functions in competition (Weierstrass-Erdmann corner point conditions).

Sufficient conditions for existence of minimum for integrals with lagrangean depending only on the velocity variable: weak and strong minima.

Necessary conditions for the existence of minimum under isoperimetric conditions.

Special important examples: geodesics, brachistochrone, minimal surfaces of revolution.

Control theory. Controlability. Optimal control.

Minimal time linear autonomous problems: existence of an optimal control and extremal controls; normality and uniqueness of the optimal control.

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Complements of Econometrics (ECN10694)

ESTIMATION METHODS: Maximum likelihood; Generalized method of moments; Quantile regression

MODELS FOR DISCRETE AND LIMITED DEPENDENT VARIABLES: Multiple choices; Count data; Proportions

MODELS FOR EXCESS OF ZEROS: Two-part models; Tobit; Self-selection

SAMPLING PROBLEMS: Missing data; Non-random samples; Measurement error; Outliers

ECONOMETRIC TIME SERIES MODELS; Economic long term relations; multivariate cointegration; VAR e VECM; Forecasting.

SIMULATION METHODS: Bootstrap; Monte Carlo.

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Macroeconomics II (ECN2357)

1. Supply Side of the Economy:

- Labour Market Equilibrium; Unemployment. Aggregate supply by various Schemes Flexibility/Rigidity Salary
- Inflation and Unemployment. The Phillips Curve. Expectations, NAIRU and Hysteresis.
- Economic stabilization: the AD-AS model

2. Fluctuations in Economic Activity:

- Simple Models of Kaldor, of Hicks, Accelerator of Samuelson and Stocks multiplier of Metzler;
- The new-keynesian economics and the Real Business Cycles Theory.

3. Economic Growth and its determinants: Physical Capital, Human Capital and Technical Capital.

- Economic Growth Models:

- Model of Harrod- Domar;
- Solow Model of Exogenous Growth (Convergence and Divergence)
- Models of Endogenous Growth.
- Economic Growth, Environment and Natural Resources

4. Financial and Economic Globalization: Macroeconomic Great Areas, the European Union and Portugal.



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Financial Economics (ECN2344)

1. THE FINANCIAL SYSTEM

- 1.1. Financial innovation in historical perspective
- 1.2. Financial intermediation and financing the Economy
- 1.3. The Portuguese financial system
- 1.4. The global financial crisis: causes, consequences and solutions

2. MARKETS AND FINANCIAL INSTRUMENTS

- 2.1. Capital markets
- 2.2. The money market and the foreign exchange market
- 2.3. The markets for financial derivatives

3. PORTFOLIO ANALYSIS OF FINANCIAL ASSETS

- 3.1. The risk in the financial markets
- 3.2. Diversification of investments and portfolio risk
- 3.3. The investment possibilities' curve
- 3.4. The choice of the investor in a context of uncertainty
- 3.5. Combination of assets with and without risk

4. EQUILIBRIUM MODELS OF CAPITAL MARKETS

- 4.1. The capital asset pricing model (CAPM)
- 4.2. Empirical analysis of the CAPM
- 4.3. The APT Model

5. MARKET EFFICIENCY

- 5.1.

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Monetary Economics (ECN2360)

- 1. CURRENCY : HISTORY , DEFINITION AND MEASUREMENT{\}\newline {\}\newline 1.1. The currency and financial system{\}\newline {\}\newline 1.2. Evolution of forms and monetary systems{\}\newline {\}\newline 1.3. Functional definition of money{\}\newline {\}\newline 1.4. Statistical definition : monetary aggregates{\}\newline {\}\newline 2 . The money supply{\}\newline {\}\newline 2.1. The Monetary Creation{\}\newline {\}\newline 2.2. The Monetary Control Creation{\}\newline {\}\newline 3 . A MONEY DEMAND{\}\newline {\}\newline 3.1. Classical perspective : quantitative relationship and dichotomous model{\}\newline {\}\newline 3.2. Keynesian Perspective : currency ratio - interest rate{\}\newline {\}\newline 3.3. Modern monetary theory and its influence on the conduct of economic policy{\}\newline {\}\newline 4 . MONETARY POLICY{\}\newline {\}\newline 4.1. The transmission mechanism of monetary policy{\}\newline {\}\newline 4.2. The monetary policy strategy of the ECB{\}\newline {\}\newline 4.3. Rules and reaction functions of monetary policy{\}\newline {\}\newline 5 . The INTERNATIONAL MONETARY SYSTEM{\}\newline {\}\newline 5.1. The foreign exchange market{\}\newline {\}\newline 5.2. Supervision of SMI{\}\newline {\}\newline 5.3. exchange rate regimes{\}\newline {\}\newline 6 . THEORY OF INTEREST RATES{\}\newline {\}\newline 6.1. The Fisher ratio and interest rate parities{\}\newline {\}\newline 6.2. Term Structure of Interest Rates

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Real Investments (GES0009)



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Management Accounting I (GES2323)

1. INTRODUCTION TO MA
 - 1.1. Definition, objectives, scope and conceptual framework
 - 1.2. MA and Financial Accounting
 - 1.3. MA and organizational management
2. BASIC CONCEPTS
 - 2.1. Economic and financial concepts
 - 2.2. Cost terms and concepts
 - 2.3. Costs and costs control
 - 2.4. The MA income statement
3. PRODUCT COSTING
 - 3.1. Product costing: direct materials costs, labor costs and overheads
 - 3.2. Cost assignment and cost accumulation methods
 - 3.3. Costing systems
 - 3.4. Joint product costing
4. COST CENTERS
 - 4.1. Main concepts
 - 4.2. Production centers and cost assignment to production centers
 - 4.3. Service centers: cost assignment and cost reallocation to other centers
5. ACTIVITY-BASED COSTING
 - 5.1. Fundamentals of activity-based costing and main concepts
 - 5.2. Developing an activity-based costing system
 - 5.3. A comparison of traditional and activity-based costing systems

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Financial Calculus (GES10695)

1. Introduction
2. Equivalence regimes and interest rates
3. Financial operations of short run
4. Ordinary annuities
5. Financial operations of medium and long run
6. Actuarial instruments and operations



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Decision and Negotiation Analysis (GES0010)

1. Introduction
 - 1.1 The different approaches to decision making
 - 1.2 Decision sciences
2. Individual decision making under uncertainty
 - 2.1 The elements and structuring a decision problem
 - 2.3 Choice criteria without probabilities
 - 2.4 Expected monetary value
 - 2.5 Expected utility theory
 - 2.6 Methods of preferences extraction
 - 2.7 Sequential decision problems
 - 2.8 Behavioral aspects
 - 2.9 Decision analysis software
3. Decision making with multiple objectives
 - 3.1 Objectives and attributes
 - 3.2 Efficient alternatives and tradeoffs among objectives
 - 3.3 Utility function and best alternative
 - 3.4 Software for multiple objectives decisions
4. Decisions in the presence of strategic interdependency
 - 4.1 Representation of a game
 - 4.2 Static games with complete information
 - 4.3 Dynamic games with complete information
 - 4.4 Applications of game theory to management and economics
5. Negotiation Analysis
 - 5.1 Characteristics of negotiation analysis
 - 5.2 Bilateral negotiation with one issue
 - 5.3 Bilateral negotiation with several issues

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Operation Management (GES2332)

Part 1 - Introduction to Operations Management

1. What is operations management?

2. Operations Strategy

Part 2 - Design, analysis and improvement of the operating system

1. Quality management and statistical quality control

2. Product/service design

3. Process design and technology choice

Part 3- Operations system management

1. Supply chain management

2. Demand forecasting methods

3. Independent demand stocks management

4. Aggregated production planning

5. Resources planning: MRP, CRP and ERP

6. Production scheduling and the theory of constraints

7. Lean production systems and Just in time

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Project (ECN10692)

Research and writing of a short monograph, according to the standards and practices of academic writing.

The development of the essay will be done at two levels, at the conceptual and theoretical level with the appropriate critical and analytical framework, and also with the applied level by using the mathematics tools applied to economics and management.



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Computational Methods (MAT0937)

The interactive programming system for symbolic and numerical computation, and data manipulation and visualization. Mathematical models, numerical algorithms and mathematical problems.

Implementation of some basic numerical algorithms.

Fundamentals of numerical computation: floating point systems, errors, conditioning, convergence, stability.

Resolution of nonlinear equations.

Solving systems of linear and nonlinear equations.

Interpolation and approximation of functions.

Derivation and numerical integration.

Numerical methods of optimization.

Introduction to numerical solution of ordinary differential equations.