Intended Learning Outcomes:
After successfully completing the module, students will be able to create effective visualizations of social and political data, make discoveries and communicate new insights. In addition, students can apply different approaches to graphically represent different types of evidence, including macroeconomic data, summaries of statistical models, data from social media, and other types of information.

Teaching and Learning Methods:
The module consists of a seminar. The seminar consists of lectures by the lecturer and programming with rmd or qmd scripts. The practical exercises allow students to test their understanding of the concepts and code snippets taught in the introductory sessions of the module.

Media:
Lecture slides for lectures and R (qmd) scripts for tutorials

Reading List:
A detailed list of both mandatory and recommended readings and online turiorals is posted on the course syllabus. Students are encourage to get a headstart by reviewing: Villanueva, R. A. M., & Chen, Z. J. (2019). ggplot2: elegant graphics for data analysis.

Responsible for Module:
Theocharis, Ioannis; Prof. Dr. phil.

Courses (Type of course, Weekly hours per semester), Instructor:
[SOT86603] Telling Stories with R and Data Visualizations (Seminar, 2 SWS)
Zilinsky J
For further information in this module, please click campus.tum.de or here.

Specialization in Technology: Industrial Engineering (minor) | Technik-Schwerpunkt: Industrial Engineering Basismodule (minor)

Module Description

BGU56058: Travel Behavior and Environmental Impacts | Verkehrsverhalten und Umweltauswirkungen [TBEI]

Version of module description: Gültig ab winterterm 2020/21

Module Level: Master	**Language:** English	**Duration:** one semester	**Frequency:** winter semester
Credits:* 6	**Total Hours:** 180	**Self-study Hours:** 120	**Contact Hours:** 60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The module examination is a written, closed book test with the duration of 120 minutes.
In the exam, the students demonstrate - without aids and under time constraints that they know the most important environmental effects of transportation, can classify emissions in a transportation context, understand their production mechanisms, their local and global impact and know standards for their measurement and limitation. They also demonstrate that they understand the contribution of transportation in global challenges, such as climate change and the exploitation of resources and can critically analyse different transportation solutions that aim into tackling those problems. Furthermore, they demonstrate that they understand the foundations of descriptions of transportation data. Based on practical tasks, they demonstrate that they understand fundamental travel behavior theories and are able to apply them to transport problems. Finally, students show that they know how to apply basic rules of multiple regression analyses and logit model estimation.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Basic competences in transportation planning, e.g. BV000029 "Traffic Engineering and Transport Planning Basic Module" or comparable bachelor level modules

Content:
The module covers the following topics:
-- Transport and Air Pollution

-- Vehicle Emissions Standards
-- Noise
-- Consumption of energy
-- Climate change
-- Sustainable transport
-- Travel behavior theory
-- Transportation data description
-- Statistical learning to describe transportation data
-- Linear regression to explain travel behavior
-- Logit models to explain travel behavior
-- Land use/transport interactions

Intended Learning Outcomes:
After the completion of the module, students are able to:
-- know the main environmental effects of traffic
-- know the main traffic related emissions, their sources and their health impacts
-- understand the common emission standards for vehicles and their measurement
-- understand the relation of sound and noise as well as the health impact of noise
-- understand the cause and impact of global climate change
-- know definitions and measures for a sustainable transport system
-- know and describe fundamental theories of travel behaviour
-- describe the interactions of land use and transport systems
-- know the guidelines for estimation of regression and logit models
-- apply independently regression and logit models to explain travel behavior.

Teaching and Learning Methods:
The module consists of lectures and discussions. During the lectures, the theoretical background is presented through presentations and PowerPoint slides. Current debates and developments are topics for interactive discussions. For special topics, there will be also used group games and interactions. Furthermore, exercise in R will be handed out to statistically explore travel behavior in household travel surveys.

Media:
PowerPoint presentation, open discussions, small group assignments, exercises in R

Reading List:
Edwards-Jones, G.; Davies, B.; Hussain, S. [2000]: Ecological Economics - An Introduction. Blackwell Science, Oxford.
Hensher, D.; Rose J. M. and W. H. Green [2015]: Applied Choice Analysis. University Press, Cambridge.
Schönfelder, S.; Axhausen, K.W. [2010]: Urban Rhythms and Travel Behaviour: Spatial and Temporal Phenomena of Daily Travel. Ashgate, Farnham.

Responsible for Module:
Dr.-Ing. Antonios Tsakarestos

Courses (Type of course, Weekly hours per semester), Instructor:
Verkehr und Umwelt (Vorlesung, 2 SWS)
Bogenberger K [L], Tsakarestos A (Dandl F, Ilic M, Waldorf I)

Verkehrsverhalten (Vorlesung, 3 SWS)
Moeckel R [L], Langer M, Moeckel R
For further information in this module, please click campus.tum.de or here.

Module Description

BGU68011: Service Concepts and Operation Models for New Mobility Solutions for Mixed-Use Residential Developments | Konzepte und Operationsmodelle für neue Mobilitätslösungen in gemischtgenutzten Siedlungsentwicklungen [Service Concepts and Operation Models]

Version of module description: Gültig ab winterterm 2019/20

Module Level: Master	**Language:** English	**Duration:** one semester	**Frequency:** winter semester
Credits:* 3	**Total Hours:** 90	**Self-study Hours:** 45	**Contact Hours:** 45

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
One report must be submitted at the end of the semester (80%). Students need to show that they understood the range of mobility concepts that could be implemented at a mixed-use residential development and develop one from the perspective of one stakeholder (real estate developer, mobility service provider, resident, etc.). Special focus will be given to shared mobility services as a complement of public transport and non-motorized modes. Students must demonstrate that they are able to discuss different case-based perspectives on integrated mobility planning and mixed-use residential development and apply them to actual new real estate development projects.
The written report will be complemented by a short 10-minute presentation (20%), through which the student will demonstrate their ability to present their main findings and communicate to an audience in the form of a mock client pitch.
The final grade is composed of the grade of the report (80%) and the presentation (20%).

Repeat Examination:

(Recommended) Prerequisites:
Transport Sociology and Psychology (Course number 240834759)

Content:
The aim of this course is to introduce students to mobility concepts that could be required in mixed-use residential developments.
The first half of this course aims to provide students with an overview and critical discussion of current and future urban and district planning best practice and the relevance of transport and mobility planning for district developments and building structures. The initial sessions will

introduce the students to how to quantify and qualify user types and user demands through urban and socio/cultural-demographic analysis as well as trip assessments. Basic principles of user centered design, user mapping, formal and informal mobility mapping will be presented.
The module offers the theoretical basis and tools for the development and realization of new approaches and methods towards integrated urban planning. Real case studies will be presented and discussed. The case studies will be selected from international research literature. The discussion will cover the perspectives of different stakeholders (real-estate developer, mobility service provider, resident, city urban planners, etc.).
In the second half of the course, the focus turns on the students, who will apply the gained knowledge to design integrated mobility service solutions. Through cost estimates, analysis of the specific regulatory and stakeholder framework and basic business modeling, the students learn how to conceptualize operative models and specify integrated service packages that add value to the end user and also the real estate developer. This is usually achieved through space gains (less parking) and financial gains (less car dependency).

Intended Learning Outcomes:
After completion of the course, the students understand the methodological basis for the development of mobility concepts for mixed-use residential developments. The students will apply familiar and new interdisciplinary assessment tools and methods from transport planning to problem solving and business modelling in urban planning.
The aim of this course enable the students to design with the principals of transport planning and create integrated, user centered mobility solutions. Students will learn the skill sets necessary to consult potential clients on the benefits of shared mobility solutions, economic implications and operative risks.

Teaching and Learning Methods:
The course is based around weekly interactive seminars. The course will apply different teaching methods from traditional lectures to discussions, group work, desktop research, in-class exercises, and presentation skill training. Students are expected to come prepared and engage actively throughout the semester.
In the first half, the lecturer will present the students literature and case studies, followed by discussion between students. Discussions will be facilitated by short PowerPoint presentations with key aspects, structured questionnaires and group work on some examples.
In the second half, the students will perform group work in teams to develop a mobility concept for a real-life large scale mixed use development. The project – in its early planning stage – is set in an urban/ peripheral location with substantial mobility and transportation demands. Each team will assume the perspective of a different stakeholder, and therefore a unique focus area (i.e. business plan, spatial planning, user segmentation etc.). The lecturer will supervise the students and discuss their intermediate results in the weekly interactive seminars. The outcome of the exercise is the development of different mobility concepts with different focus areas. At the end of the course, students will present their concepts in form of a mock client pitch.

Media:
Various reading materials and handouts, scientific articles, planning documents and websites. PowerPoint presentations, whiteboard and exercise sheets may be used in sessions.

Reading List:
Federal Ministry for Economic Cooperation and Development. (2016). Urban Mobility. Strategies for Liveable Cities.
Bormann, R., Gross, M., Holzapfel, H., Luehmann, K., Schwedes, O. (2017). Shaping urban change and promoting sustainable mobility. Friedrich-Ebert-Stiftung ISBN 978-3-95861-952-4.
Eleftheriou, V., Knieling, J. (2017). The urban project HafenCity. Today's Urban and Traffic profile of the area. Executive summary of methodology and traffic research conducted in the region. Transportation Research Procedia 24, 73-80.
Meurs, H.J., van Wee G.P. (2003). Land Use and Mobility: a Synthesis of Findings and Policy Implications. European Journal of Transport and Infrastructure Research 3(2), 219-233.
Banister, D. (2008). The sustainable mobility paradigm. Transport Policy 15(2), 73-80.
Bridge, G., Butler, T., Less, L. (2012). Mixed Communities: Gentrification by Stealth? Policy Press, 372 pp.
Jarass, J., Heinrichs, D. (2014). New Urban Living and Mobility. Transportation Research Procedia 1(1), 142-153.
Cirianni, F.M.M., Leonardi, G. (2006). Analysis of transport modes in the urban environment: an application for a sustainable mobility system. WIT Transactions on Ecology and the Environment 93, 637-645.
Circella, G ., F. Alemi, K. Tiedeman, S. Handy and P. Mokhtarian (2018). The Adoption of Shared Mobility in California and Its Relationship with Other Components of Travel Behavior Report, National Center for SustainableTransportation, United States
http://www.urban-transport-roadmaps.eu/

Responsible for Module:
Moeckel, Rolf; Prof. Dr.-Ing.

Courses (Type of course, Weekly hours per semester), Instructor:

For further information in this module, please click campus.tum.de or here.

Module Description

BGU68012: Applied Transport Modeling with MATSim | Angewandte Verkehrsmodellierung mit MATSim [Transport Modeling with MATSim]

Version of module description: Gültig ab summerterm 2020

Module Level: Master	**Language:** English	**Duration:** one semester	**Frequency:** winter semester
Credits:* 6	**Total Hours:** 180	**Self-study Hours:** 120	**Contact Hours:** 60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The module examination consists of a report of about 15 to 20 pages, in which on the one hand theoretical questions have to be answered and on the other hand practical applications of the simulation environment have to be presented. In the theoretical part the students prove that they can explain the logic and the underlying theory of multi-agent simulation in the context of traffic modeling. The students have to show that they are able to assess limitations, possible applications, advantages and disadvantages. In addition, they must be able to interpret existing simulation results in a comprehensible way. In the practical part the students have to prove that they can model and evaluate illustrative and own real applications. This includes, among other things, the generation of a simple traffic demand as well as the traffic supply for a self-chosen real investigation area. In addition, a freely selectable existing extension of the simulation environment must be described and applied.

Repeat Examination:

(Recommended) Prerequisites:
Transport Planning Models (240744419)

Content:
Group project focused work covering the following tasks:
- Introduction to object-oriented programming (Java)
- Introduction to integrated development environments (IDE) and versioning (Git)
- Understanding of microscopic agent-based models
- Creating transport networks from open source data
- Building activity-based travel demand
- Run illustrative transport simulation examples

- Create and simulate large-scale scenarios
- Analyzing scenario results and comparing them to traditional transport modelling approaches
- Use existing MATSim extensions that, for example, allow to model taxis and shared-autonomous vehicles within simulations, allow for environmental impact analyses (noise and air pollutants), or allow for traffic signal simulations
- Implement own, novel functionality

Intended Learning Outcomes:
Upon completion of the module, students are expected to be able to use and extend the multi-agent transport simulation, MATSim, to simulate and analyze travel demand in order to support transport planning in any area, such as freight logistics or public transport optimization. The students learn how to set up a transport model from scratch, i.e. create their own study area, and deal with scientific open source software to derive transport-specific insights from the resulting data. The module presents a blend of state-of-the-art transport modeling with computer and data science.

Teaching and Learning Methods:
The module consists of one seminar. The seminar is called Applied Transport Modeling with MATSim. A practical approach where students complete real-world tasks in groups with the support of the tutor(s). During the seminar, students will learn how to use the modeling software on their own computers. Theoretical background and practical application assisted by the tutor(s) will be alternated throughout the semester.

Media:
- PowerPoint presentations
- MATSim (Multi-Agent Transport Simulation)
- JOSM (Java OpenStreetMap Editor)
- Senozon Via (free or educational license, MATSim visualization tool)

Reading List:
- A. Horni, K. Nagel, K.W. Axhausen (Eds.), The Multi-Agent Transport Simulation MATSim, Ubiquity, London, 2016. URL http://matsim.org/the-book
- Sierra K., Bates B., Head First Java, O'Reilly & Associates Inc, Sebastopol, 2005.

Responsible for Module:
Moeckel, Rolf; Prof. Dr.-Ing.

Courses (Type of course, Weekly hours per semester), Instructor:
Applied Transport Modeling with MATSim (Seminar, 4 SWS)
Huang W [L], Cai Y, Huang W
For further information in this module, please click campus.tum.de or here.

Module Description

BGU70004: Discrete Choice Methods for Transportation Systems Analysis | Diskrete Wahlmethoden für Verkehrssystemanalyse

Discrete Choice Methods for Transportation Systems Analysis

Version of module description: Gültig ab winterterm 2017/18

Module Level:	Language:	Duration:	Frequency:
Master	English	one semester	winter semester
Credits:*	**Total Hours:**	**Self-study Hours:**	**Contact Hours:**
6	180	120	60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The learning outcomes be examined by excercises (Übungsleistungen).
The coursework and examination requirements will will be based on 3 individual homeworks that will aim at demonstrating that the students have understood the concepts presented in the lectures and are able to specify and evaluate discrete choice models using freely available software (such as pythonbiogeme and R). Each exercise will be conceptually stand-alone, i.e. will include one or more related questions/problems, aiming at demonstrating that the participants have grasped the material. Each homework will be graded individually and the final grade will be obtained as the weighted average of the individual grades. The weight of each homework will be indicated on the assignment.

This module is also available to the participants of the TUM Skills Excellence Program. For the participants of this programme there are 20 places available.

Repeat Examination:
End of Semester

(Recommended) Prerequisites:
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Content:
The module provides the participants with an overview of the tools and methods that are available to specify and estimate discrete choice models for transportation systems analysis. The following key areas will be covered:
• Mathematical Modeling of Behavior

- Logit and probit models
- Model estimation and specification tests
- Model specification
- Experimental design and data collection
- Mixtures/simulation based estimation
- Latent class and hybrid models
- Panel data and models
- Forecasting and aggregation
- Bayesian procedures

Intended Learning Outcomes:
After the completion of the module, the participants will have established a solid knowledge of the theoretical foundations of choice modelling, and they will be able to specify, estimate and interpret a wide range of discrete choice models, such as logit, probit, nested logit, mixed logit, latent class models. They will be able to obtain revealed-preference and stated-preference data as well as create a suitable experimental design, including the questionnaire. The participants will also be able to use available software tools, such as pythonbiogeme and R to evaluate these models.

Teaching and Learning Methods:
Format: Lecture with integrated practical exercises.
Lectures provide the students with the theoretical basics of Discrete Choice Methods, e.g. the various building parts of the models, related experimental designs and the survey data, as a Powerpoint presentation, supported by pictures, possibly films and discussions. Practical calculation tasks from realistic studies and models provide the quantitative methods for the data analysis and modelling of different Discrete Choice Methods and the calculation and interpretation of the model results.

Media:
Presentation slides, whiteboard, readings

Reading List:
Train, Kenneth E. Discrete choice methods with simulation. Cambridge University Press, 2009.
Ben-Akiva, Moshe E., and Steven R. Lerman. Discrete choice analysis: theory and application to travel demand. Vol. 9. MIT Press, 1985.
Louviere, Jordan J., David A. Hensher, and Joffre D. Swait. Stated choice methods: analysis and applications. Cambridge University Press, 2000.

Responsible for Module:
Antoniou, Constantinos; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
Discrete Choice Methods for Transportation Systems Analysis (Vorlesung mit integrierten Übungen, 4 SWS)
Antoniou C [L], Abouelela M, Adamidis F, Antoniou C, Lu Q, Yang N

For further information in this module, please click campus.tum.de or here.

Module Description

BGU70006: Statistical Learning and Data Analytics for Transportation Systems | Statistisches Lernen und Datenanalyse für Verkehrssysteme
[Statistical Learning and Data Analytics for Transportation Systems]

Version of module description: Gültig ab summerterm 2018

Module Level: Master	**Language:** English	**Duration:** one semester	**Frequency:** summer semester
Credits:* 6	**Total Hours:** 180	**Self-study Hours:** 120	**Contact Hours:** 60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The coursework is evaluated based on 4 problem sets (Übungsleistung), aimed at assessing the students' achievement of the learning outcomes. This method of evaluation has been chosen based on the nature of the module (working with real data, and exploring the applicability of alternative analysis methods).
Each individual problem set/homework assignment will aim at demonstrating that the students have understood the concepts presented in a specific topical set of lectures. The students will use synthetic and real data to demonstrate that they have learned the presented material. The module uses the freely available R software, but the students will be allowed to complete the problem sets in other environments (e.g. matlab, python), if they prefer that. Each problem set will be graded individually and the final grade will be obtained as the weighted average of the individual grades (the weights will be determined based on the work-load associated with each problem set).

This module is also available to the participants of the TUM Skills Excellence Program. For the participants of this programme there are 20 places available.

Repeat Examination:
End of Semester

(Recommended) Prerequisites:
linear algebra, applied statistics

Content:
The module provides the participants with an overview of the advanced methods that are available to perform statistical learning and big data analytics for transportation systems analysis. The following key areas will be covered:
• Visualization of high dimensional data
• Dimensionality reduction and data mining techniques
• Clustering and classification for high dimensional data
• Statistical Learning
• Going beyond (linear) regression
• The EM Algorithm
• Time series modeling and forecasting
• State space model and solution approaches, e.g. Kalman Filters

Intended Learning Outcomes:
After the completion of the module, the students will have established a solid theoretical foundation and knowledge base for statistical learning and data analytics. The aims of this module enable the students to:
• identify appropriate statistical learning and data analytics methods for a given transportation systems data set and research question;
• understand the ideas behind the methods, their purposes, their assumptions and their limitations;
• apply statistical learning and data analytics techniques using R (or another suitable software tool, e.g. matlab or python, if they so choose), and interpret the results;
• critically evaluate statistical learning and data analytics results from the literature.

Teaching and Learning Methods:
Format: Lecture with integrated practical exercises;
Lectures introduce the students to the concepts of statistical learning and data analytics using slide presentations, supported by whiteboard writing and discussions, and provide an overview of the available quantitative methods for statistical learning, big data analytics, and interpretation of the results. All methods and the calculation will be illustrated with real data sets, using open source statistical software. The given problems sets will be completed individually by each participant.

Media:
Presentation slides, whiteboard, readings

Reading List:
• Wolfgang Karl Härdle (2011) Applied Multivariate Statistical Analysis 3rd Ed.
• Brian Everitt, and Torsten Hothorn, (2011) An Introduction to Applied Multivariate Analysis with R. Springer
• Robert H. Shumway, David S. Stoffer, (2017) Time Series Analysis and Its Applications, 4th Ed. Springer

Responsible for Module:
Antoniou, Constantinos; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
Statistical Learning and Data Analytics for Transportation Systems (Vorlesung mit integrierten Übungen, 4 SWS)
Antoniou C [L], Antoniou C, Lyu C, Abouelela M, Putatunda A, Singh R, Wu H, Yang N
For further information in this module, please click campus.tum.de or here.

Module Description

BGU70008: Urban Transportation Systems: Operations Research and Emerging Mobility Technologies | Urbane Verkehrssysteme: Betriebsforschung und neue Mobilitätstechnologien [Urban Transportation Systems]

Version of module description: Gültig ab summerterm 2022

Module Level: Master	**Language:** English	**Duration:** one semester	**Frequency:** summer semester
Credits:* 6	**Total Hours:** 180	**Self-study Hours:** 120	**Contact Hours:** 60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The examination of the module consists of 2-3 problem sets on operations research and one take-home essay to be written for emerging mobility technologies.

Repeat Examination:
End of Semester

(Recommended) Prerequisites:
Applied probability and statistics (e.g. BGU70009)

Content:
The module provides students with an overview of the advanced mathematical analytics for modeling operations of urban transportation systems. The module covers the following components:

• Probabilistic modeling (Poisson Processes, Geometric Probability, Perturbation, Crofton's Method)
• Queueing Theory and Its Applications (Birth-and-Death Process)
• Network Optimization Models (Shortest-Path, Maximum Flow, Minimum Cost, Facility Location)
• Linear Programming (Network Simplex Method)

Besides, this module provides its students with an overview of the effects of emerging forms of transportation, such as ride-hailing and Mobility-as-a-Service (MaaS). The literature on behaviour effects and traffic externalities is analysed in detail, and then the elements for the regulation of these technologies are discussed. The following key areas will be covered:

- The concept of sharing economy
- Ride-hailing: effects on travel behaviour and traffic externalities
- Ride-hailing and substitute modes: competition and increased efficiency
- Regulation of ride-hailing: pricing and optimal fleet size.
- Shared fleet optimal deployment and optimal routing.
- Mobility-as-a-service: bundling future transportation modes.
- Shared mobility and vehicle ownership: future scenarios and the role of the regulator.

Intended Learning Outcomes:
After completion of the module, the students will understand the methodological and empirical basis for the analysis of emerging transportation technologies such that ride-hailing, shared ride-hailing and mobility as a service. The students will have established a solid theoretical foundation and knowledge base for modeling of urban transportation and service systems. Therefore, the students are able to:

- understand the mathematics behind urban operation research methods, their assumptions and limitations;
- apply modern techniques to formulate a mathematical operations research model and interpret the results;
- identify the main analytical models (e.g., optimization models) and econometric tools for the analysis of behaviour and traffic effects of such technologies.
- design an economic model for the regulation of ride-hailing and to solve it.
- discuss the latest research on merging transportation modes and identify the main elements that a regulation should have.

Teaching and Learning Methods:
The module consists of lectures with integrated exercises.
Lectures introduce the students to the concepts of probabilistic analysis and modeling, queueing models, graph theory, and linear programming methods for modeling urban transport systems or network-wide optimization.
Besides, integrated practical exercises provide the students with the theoretical basics of the assessment of emerging modes, e.g. the various parts of appropiate optimization and econometric models presented in the literature. A social welfare maximization model for the regulation of ride-hailing will be solved in the lectures by the students with support from the lecturer, and applied to realistic scenarios using empirical values for input variables and attributes. State-of-the-art papers will be presented and discussed.

Along the course, lectures will use slide presentations, supported by whiteboard writing. Student discussion and active participation will be encourged throughout the lectures. All methods and calculations will be illustrated with practical examples. Exercises will be given to students following each major topic, and the solutions will be presented and explained in the lectures.

The module will be shifted to the winter term, starting with winter semester 2022/23.

Media:
The contents are provided with presentation slides, whiteboard, exercises, readings.

Reading List:
Circella, G., F. Alemi, K. Tiedeman, S. Handy and P. Mokhtarian (2018). The Adoption of Shared Mobility in California and Its Relationship with Other Components of Travel Behavior Report, National Center for Sustainable Transportation, United States.
Docherty, I., G. Marsden and J. Anable (2018). The governance of smart mobility. Transportation Research Part A: Policy and Practice 115: 114-125.
Hall, J. D., C. Palsson and J. Price (2018). Is Uber a substitute or complement for public transit? Journal of Urban Economics 108: 36-50.
Henao, A. and W. E. Marshall (2018). The impact of ride-hailing on vehicle miles traveled. Transportation https://doi.org/10.1007/s11116-018-9923-2.
Hillier, S. F., Lieberman, J. G. (2001) Introduction to operations research, 7th ed., McGraw-Hill
Kamargianni, M. and M. Matyas (2017). The Business Ecosystem of Mobility-as-a-Service. 96th Transportation Research Board (TRB) Annual Meeting, 8-12 January 2017, Washington DC.
Larson, R. and Odoni, A. (1981) Urban Operations Research, Prentice Hall, (available at: http://web.mit.edu/urban_or_book/www/book/)
Matyas, M. and M. Kamargianni (2018). The potential of mobility as a service bundles as a mobility management tool. Transportation.
Rader, J. D. (2010) Deterministic Operations Research: Models and Methods in Linear Optimization. John Wiley and Sons
Shaheen, S. (2018). Shared Mobility: The Potential of Ridehailing and Pooling. Three Revolutions. Island Press, Washington, DC: 55-76.
Tirachini, A. and A. Gómez-Lobo (2018). Does ride-hailing increase or decrease vehicle kilometers traveled (VKT)? A simulation approach for Santiago de Chile. International Journal of Sustainable Transportation. Forthcoming.

Responsible for Module:
Antoniou, Constantinos; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
Emerging Mobility Technologies (Vorlesung mit integrierten Übungen, 2 SWS)
Antoniou C [L], Abouelela M, Yang N

Urban Operations Research for Transportation Systems (Vorlesung mit integrierten Übungen, 2 SWS)
Antoniou C [L], Antoniou C, Ardameh S, Sant' Anna Gualda Pereira L, Singh R, Yang N
For further information in this module, please click campus.tum.de or here.

Module Description

ED110106: Systems Engineering - Fundamentals | Systems Engineering - Grundlagen [SE-F]

Version of module description: Gültig ab winterterm 2024/25

Module Level: Master	**Language:** English	**Duration:** one semester	**Frequency:** winter semester
Credits:* 5	**Total Hours:** 150	**Self-study Hours:** 90	**Contact Hours:** 60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The module examination consists of a written exam of 90 minutes length. It will consist of a number of multiple-choice, single choice and free form answer questions. The participants are to prove that they are able to understand the basics of systems engineering sufficiently by answering questions and performing simple calculations. In addition to written answers and calculations, the students may be asked to draw sketches, models, plots, diagrams or other visualization or a combination of those.

Allowed Aids:
- Non-Programmable Calculator
- Dictionary Mother Tongue <-> English
- Drawing aids (Ruler, Set square, etc.)

Should a complex formula be needed during the exam, it will be given on the problem sheet.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
none

Content:
1 Introduction to Systems Engineering and the SE Project
2 Introduction to Systems Architecture
3 Project Formulation
4 System Life Cycle Management
5 Managing Complexity
6 Requirements Analysis

7 Risk Management
8 System Modeling
9 Project Management
11 Economic Evaluation of Engineering Systems

Intended Learning Outcomes:
After attending the module, the students will be able to:
- LO 1 - Describe and discuss the main tools and processes of systems engineering
- LO 2 - Identify the main project stakeholders and derive requirements from stakeholder needs
- LO 3 - Conduct trade-off analyses and simple systems architecture studies during the early stages of a design project
- LO 4 - Discuss system modelling techniques and apply selected techniques on engineering systems
- LO 5 - Discuss and tailor a systems engineering approach to manage an engineering project across its lifecycle
- LO 6 - Cooperate as a team to achieve common goals.
- LO 7 - Evaluate given systems engineering approaches and propose improvements

Teaching and Learning Methods:
The module consists of a lecture and an exercise. In the lecture, an overview of the theory of Systems Engineering will be given, as well as examples from real-life systems and situations.
In the Exercise, the basics will be applied to a sample engineering system in order to show the different aspects of systems engineering in the lecture and problems will be introduced that will give a feeling of the problems to be solved in the exam. The exercise will not only show good systems engineering approaches but also introduce purposefully flawed approaches as a basis for discussion and contrast to other approaches.

Through this, the students learn e.g.
- LO 1 - Describe and discuss the main tools and processes of systems engineering
- LO 2 - Identify the main project stakeholders and derive requirements from stakeholder needs
- LO 3 - Conduct trade-off analyses and simple systems architecture studies during the early stages of a design project
- LO 4 - Discuss system modelling techniques and apply selected techniques on engineering systems
- LO 5 - Discuss and tailor a systems engineering approach to manage an engineering project across its lifecycle
- LO 6 - Communicate effectively technical results to a large audience.
- LO 7 - Evaluate given systems engineering approaches and propose improvements

Media:
Presentation (PowerPoint, Mentimeter, Kahoot!, ..)
Current Research Papers where applicable
E-Learning-Course (Moodle)

Reading List:
INCOSE, INCOSE Systems Engineering Handbook. Wiley, 2023.

National Aeronautics and Space Administration, "NASA Systems Engineering Handbook". Washington DC, USA, 2017.

Responsible for Module:
Aliakbargolkar, Alessandro; Prof. Dr. phil.

Courses (Type of course, Weekly hours per semester), Instructor:
Systems Engineering - Fundamentals - Lecture (Vorlesung, 2 SWS)
Aliakbargolkar A [L], Aliakbargolkar A, Sindermann J, Messina V, Garcia Alarcia R

Systems Engineering - Fundamentals - Exercise (Übung, 2 SWS)
Sindermann J [L], Aliakbargolkar A, Sindermann J, Messina V, Garcia Alarcia R
For further information in this module, please click campus.tum.de or here.

Module Description

ED110181: New Space Economy | New Space Economy

Version of module description: Gültig ab summerterm 2025

Module Level: Bachelor/Master	**Language:** English	**Duration:** one semester	**Frequency:** summer semester
Credits:* 5	**Total Hours:** 150	**Self-study Hours:** 90	**Contact Hours:** 60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The module examination consists of a report by group of students, in the form of a case study, submitted at the end of the module. With this report, it will be checked whether the students are able to analyze a New Space company using the Six Elements Framework discussed in class and drawing general conclusions to define the unique traits of product, process, technology, business model, financing and stakeholders that characterize the company in the space industry.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Students may come to this track either with an engineering or management background, and during the course they will be able to acquire new knowledge in their missing domain. To get the most advantage out of the course, students from an engineering background should already possess basic knowledge in space engineering, for instance having taken courses on Spacecraft Design or Space Mission Analysis in the past. Students from a management background should already possess basic knowledge in analyzing business cases, defining business models, and understand the basics of the business cycle. Students from other engineering background (eg mechanical, electronic, others) are also well equipped to join the course. For other cases, please inquire directly with the course instructor by email.

Content:
The course will cover:

-History and evolution of the space sector

-Differences and Analogies between New Space and Traditional Space

-Space sector value chain overview

-Six elements framework for analyzing New Space ventures

-Innovation in: Product, Process, Technology, Business Model, Financing, Stakeholders

-Fundraising mechanism from New Space ventures: from seed funding to IPO

-Analysis and development of New Space company case studies

Intended Learning Outcomes:
After attending the module, the students will be able to:

Learning Outcome (LO)1 - Acquire basic knowledge on the history and evolution of the space sector

LO2 - Identify and analyze key elements of the space sector value chain

LO3 - Understand the key innovations in New Space from technology, product, service and business model perspectives

LO4 - Analyze the landscaping the New Space economy from technical and business perspectives

LO5 - Understand the application of New Space technologies and ventures in commercial domains

LO6 - Understand the key differences between New Space and Traditional Space activities

LO7 - Identify and size opportunities for innovation in space activities

Teaching and Learning Methods:
The module consists of a set of core lectures introducing the core topics of the class. Most of the time in the class is spent discussing and analyzing case studies. Students are provided case study material in advance of the class and asked to prepare before of the class session. During the class session, the instructor plays the role of facilitator asking key questions that the students need to address amongst each other. In this way, students get to share their knowledge while developing critical thinking and presentation skills.

By mid semester, students will be divided into small groups. Each group will be requested to select a New Space company on which they intend to develop a case study like the ones analyzed in the class.

Optionally, the course instructors may invite guest speakers from the companies chosen by the students for their case studies for in class discussion and interview, depending on their time availability and willingness to join the course.

Media:
Presentation (multimedia, e.g., PowerPoint, Video Excerpts, Mentimeter, Kahoot!)

Reading List:
Published case studies where applicable

Responsible for Module:
Aliakbargolkar, Alessandro; Prof. Dr. phil.

Courses (Type of course, Weekly hours per semester), Instructor:
New Space Economy - Lecture (Vorlesung, 2 SWS)
Aliakbargolkar A [L], Aliakbargolkar A, Schuberth L

New Space Economy - Exercise/Seminar (Übung, 2 SWS)
Iliasov R, Juan Oliver C, Schuberth L
For further information in this module, please click campus.tum.de or here.

Module Description

IN2211: Auction Theory and Market Design | Auction Theory and Market Design

Version of module description: Gültig ab summerterm 2024

Module Level: Master	**Language:** English	**Duration:** one semester	**Frequency:** irregularly
Credits:* 5	**Total Hours:** 150	**Self-study Hours:** 90	**Contact Hours:** 60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The examination takes the form of a written 90 minutes test, in which students solve problems to prove they are able to use, analyze and assess the game theoretical models of auctions. The additional answering of theory questions ensures participants understand the fundamental challenges of combinatorial auctions. Moreover, the correct responses require independent defense of the choice of auction format based on desired properties of the market allocation such as efficiency or revenue maximization for example. All problems and questions demand the students to phrase their individual responses.

Repeat Examination:

(Recommended) Prerequisites:
IN0022 Informations Systems II or IN0024 Operations Research, linear programming

Content:
- Basic game theoretical concepts (dominant strategies, Nash equilibrium under complete and incomplete information), - Mechanism Design Theory,
- basics of auction theory (sealed bid and open auction formats, Revenue Equivalence, Optimal Auctions),
- Combinatorial Auctions,
- Assignment Markets,
- challenges of combinatorial auction design (iterative combinatorial auctions and combinatorial clock auctions), applications of combinatorial auctions (spectrum and procurement auctions),
- approximation mechanisms,
- Matching Markets

Intended Learning Outcomes:
After successful completion of the module students understand the economic properties of various auction formats. They know different game theoretical approaches to model the strategic interactions between the auctioneer and bidders. Furthermore, they understand the fundamental strategical challenges of various auction mechanisms and computational questions related to the determination of allocations and payments. Moreover, they can independently defend the choice of auction format based on desired properties of the market allocation such as efficiency or revenue maximization for example.

Teaching and Learning Methods:
The module consists of a lecture and a content-aligned tutorial. The lecturer presents the content of the module, parts of the corresponding literature and application examples for various auctions interactively. Students are accustomed with different auction formats and their modeling, and learn to differentiate their applications. In the tutorial participants solve exercises in single person and team work, and evaluate the respective game- and auction theoretical models. Thus, students learn particularly to assess the basic challenges of combinatorial auction design and to constructively criticize their own work.

Media:
Script, exercise sheets, PowerPoint, PC and E-Learning platform

Reading List:
Y. Shoham and K. Leyton-Brown: Multiagent Systems: Algorithmic, Game-Theoretic, and Logical Foundations. Chapters 3, 5, 6, 10, 11, 12. For class 2 and 3.: N. Nisan, T. Roughgarden, E. Tardos and V. Vazirani (editors): Algorithmic Game Theory. Chapters 9 and 11 by Nisan. For class 2, 4 and 6: V. Krishna: Auction Theory. Chapters 16 and 17 on multi-object auctions.

Responsible for Module:
Bichler, Martin; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:

For further information in this module, please click campus.tum.de or here.

Module Description

IN8005: Introduction into Computer Science (for non informatics studies) | Einführung in die Informatik für andere Fachrichtungen

Version of module description: Gültig ab summerterm 2023

Module Level: Bachelor	**Language:** English	**Duration:** one semester	**Frequency:** winter semester
Credits:* 5	**Total Hours:** 150	**Self-study Hours:** 90	**Contact Hours:** 60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
Type of Assessment: written exam (90 minutes)
The exam takes the form of written test. Knowledge questions allow to assess acquaintance with and understanding of the basic concepts of Computer Science. Small programming and modelling problems allow to assess the ability to practically apply the learned programming- and query-languages and modelling-techniques for the solution of small problems.
Homework will be scored and upon achieving a minimum equired number of points, a 0,3 bonus for the final grade is granted.

In case of epidemiologic emergencies, the exam may be substituted by a graded electronic exercise or a proctered exam.

Repeat Examination:
End of Semester

(Recommended) Prerequisites:
Recommended requirements are Mathematics modules of the first year of the TUM-BWL bachelor's program as well as the module WI000275 'Management Science'.

Content:
The module IN8005 is concerned with topics such as:
- Database Management Systems,.ER models, Relational Algebra, SQL
- Java as a programming language:
++ basic constructs of imperative programming (if, while, for, arrays etc.)
++ object-oriented programming (inheritance, interfaces, polymorphism etc.)
++ basics of Exception Handling and Generics
++ code conventions

++ Java class library
- Basic algorithms and data structures:
++ algorithm concept, complexity
++ data structures for sequences (arrays, doubly linked lists, stacks & queues)
++ recursion
++ hashing (chaining, probing)
++ searching (binary search, balanced search trees)
++ sorting (Insertion-Sort, Selection-Sort, Merge-Sort)

Intended Learning Outcomes:
Upon successful completion of the module, participants understand important foundations, concepts and ways of thinking of Computer Science, in particular object-oriented programming, databases and SQL, and basic algorithms and data structures, have an overview over these topics and be able use them for the development of own programs with a link to a database in a basic way.

Teaching and Learning Methods:
Lecture and practical tutorial assignments. A central tutorial deepens the understanding of the concepts introduced in the lecture using example assignments in regard to being able to solve given problems. In the tutorials, the students solve basic assignments under intensive supervision, which contributes to providing them with the basic skills in programming, in order to be able to apply the knowledge acquired by self-study of the accompanying materials of lecture and central tutorial for autonomously solving the programming assignments of the homework. During the second half of the semester, the students work on a small practical project, which aims at deepening the connected understanding of the desired learning outcomes. Programming aspects of this project are distributed over tutorial and homework assignments and are aligned with the topics of the respective week.

Media:
Slides, blackboard, lecture- and central tutorial recording, discussion boards in suitable e-learning platforms

Reading List:
Chapters from textbooks, which are closely associated with the module content and are provided to the students online.

Responsible for Module:
Groh, Georg; Prof. Dr. rer. nat. habil.

Courses (Type of course, Weekly hours per semester), Instructor:
Einführung in die Informatik für andere Fachrichtungen (TUM BWL) (IN8005) (Vorlesung, 2 SWS)
Groh G

Übung zur Einführung in die Informatik für andere Fachrichtungen (TUM BWL) (IN8005) (Übung, 2 SWS)
Groh G [L], Dall'Olio G, Groh G, Steinberger C
For further information in this module, please click campus.tum.de or here.

Module Description

MA4800: Foundations of Data Analysis | Foundations of Data Analysis

Version of module description: Gültig ab winterterm 2022/23

Module Level: Master	**Language:** English	**Duration:** one semester	**Frequency:** summer semester
Credits:* 8	**Total Hours:** 240	**Self-study Hours:** 150	**Contact Hours:** 90

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The exam will be in written form (90 minutes). Students demonstrate that they have gained deeper knowledge of definitions and main mathematical tools and results in linear algebra, convex optimization, differential geometry presented in the course and their applicability in data analysis. The students are expected to be able to derive the methods, to explain their properties, and to apply them to specific examples.

Repeat Examination:
End of Semester

(Recommended) Prerequisites:
MA0001 Analysis 1, MA0002 Analysis 2, MA0004 Linear Algebra 1, MA0005 Linear Algebra 2 and Discrete Structures, MA0901 Lineare Algebra für Informatik, MA0902 Analysis für Informatik, IN0018 Diskrete Wahrscheinlichkeitstheorie, MA0009 Introduction to Probability and Statistics.
Vorteilhaft: MA2012 Introduction to Optimization

Content:
I) Representations of data as matrices
a. Many data vectors form a matrix
b. Review of basic linear algebra
c. Linear dependence and concept of rank
d. Approximate linear dependence with varying degree of approximation: Singular value decomposition /Principal Component Analysis
e. Redundancy of data representations -> orthonormal bases, frames and dictionaries
f. Fourier basis as singular vectors of spatial shift
g. Fast Fourier Transform
II) Linear dimension reduction
a. Johnson-Lindenstrauss (JL) Lemma

b. Review of basic probability, random matrices
c. Random Matrices satisfying JL with high probability
d. Fast JL embeddings
e. Sparsity, low rank as structured signal models
f. Compressed sensing
g. Matrix completion and low rank matrix recovery
h. Optimization review
j. Dictionary Learning
III) Non-linear dimension reduction
a. Manifolds as data models
b. Review of differential geometry
c. ISOMAP
d. Diffusion maps
e. Importance of Nearest neighbor search, use of JL
IV) Outlook: Data Analysis and Machine Learning

Intended Learning Outcomes:
After successful completion of the module students are able to understand and apply the basic notions, concepts, and methods of computational linear algebra, convex optimization, differential geometry for data analysis. They master in particular the use of the singular value decomposition and random matrices for low dimensional data representations. They know fundamentals of sparse recovery problems, including compressed sensing, low rank matrix recovery, and dictionary learning algorithms. They understand the representation of data as clusters around manifolds in high dimension and they know how to use methods for constructing local charts for the data.

Teaching and Learning Methods:
The module is offered as lectures with accompanying practice sessions. In the lectures, the contents will be presented in a talk with demonstrative examples, as well as through discussion with the students. The lectures should animate the students to carry out their own analysis of the themes presented and to independently study the relevant literature. Corresponding to each lecture, practice sessions will be offered, in which exercise sheets and solutions will be available. In this way, students can deepen their understanding of the methods and concepts taught in the lectures and independently check their progress. At the beginning of the module, the practice sessions will be offered under guidance, but during the term the sessions will become more independent, and intensify learning individually as well as in small groups.

Media:
The following media are used
- Blackboard
- Slides

Reading List:
Golub, Gene H.; Van Loan, Charles F. Matrix computations. Fourth edition. Johns Hopkins Studies in the Mathematical Sciences. Johns Hopkins University Press, Baltimore, MD, 2013

Foucart, Simon; Rauhut, Holger A mathematical introduction to compressive sensing. Applied and Numerical Harmonic Analysis. Birkhäuser/Springer, New York, 2013
P. Gritzmann. Grundlagen der mathematischen Optimierung, Springer, 2013.
D. P. Bertsekas, A. Nedic, A. E. Ozdaglar. Convex Analysis and Optimization, Athena Scientific, 2003.
J.-B. Hiriart-Urruty, C. Lemarechal. Fundamentals of Convex Analysis, Springer, 2001.
Dasgupta, Sanjoy; Gupta, Anupam, "An elementary proof of a theorem of Johnson and Lindenstrauss" (PDF), Random Structures & Algorithms 22 (1): 60–65, 2003
Krahmer, Felix; Ward, Rachel New and improved Johnson-Lindenstrauss embeddings via the restricted isometry property. SIAM J. Math. Anal. 43 (2011), no. 3, 1269–1281.
J. B. Tenenbaum, V. de Silva, J. C. Langford, A Global Geometric Framework for Nonlinear Dimensionality Reduction, Science 290, (2000), 2319–2323.
Saxena, A. Gupta and A. Mukerjee. Non-linear dimensionality reduction by locally linear Isomaps, . Lecture Notes in Computer Science, 3316:1038–1043, 2004.
Chen, Guangliang; Little, Anna V.; Maggioni, Mauro Multi-resolution geometric analysis for data in high dimensions. Excursions in harmonic analysis. Volume 1, 259–285, Appl. Numer. Harmon. Anal., Birkhäuser/Springer, New York, 2013.

Responsible for Module:
Fornasier, Massimo; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
Exercises for Foundations in Data Analysis [MA4800] (Übung, 2 SWS)
Krahmer F, Scagliotti A

Foundations in Data Analysis [MA4800] (Vorlesung, 4 SWS)
Krahmer F, Scagliotti A, Alt J
For further information in this module, please click campus.tum.de or here.

Module Description

MGT001299: Introduction to Deep Reinforcement Learning | Introduction to Deep Reinforcement Learning

Version of module description: Gültig ab summerterm 2021

Module Level: Master	**Language:** English	**Duration:** one semester	**Frequency:** winter semester
Credits:* 6	**Total Hours:** 180	**Self-study Hours:** 120	**Contact Hours:** 60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The overall grading bases on a written exam (120 minutes) that consists of a multiple-choice part (50%) and open questions (50%). In the multiple-choice part, students have to answer methodological questions and demonstrate that they understood the theoretical content of the course. In the open questions, the students apply the gained knowledge to practical questions and exercises, e.g., by developing specific algorithmic components. By so doing, the students have to show that they can transfer the gained knowledge to practical problems and can apply deep learning algorithms to solve analytics and business problems in practice.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
To successfully attend this course, students should be comfortable with math-centric content, algorithms, and proofs. Students should have a general understanding of:
• basic linear algebra, including for example matrix multiplication and matrix-vector multiplication
• multivariate calculus, including for example partial derivatives, the chain rule, and gradients
• basic stochastics, including for example discrete and continuous random variables and probability distributions, as well as the notions of expectation and variance
• basics of mathematical optimization, including for example constrained optimization problems and the notion of convergence
For the programming exercises, which are a part of this course and its exam, we use the Python programming language and the NumPy library. Thus, students should ideally be familiar with Python. Alternatively, knowledge of a general purpose programming language (e.g., C++, Java) or Matlab is sufficient as well, as students will be able to adapt to Python very quickly.

Content:
The module content covers the theory of Deep Reinforcement Learning and required fundamentals. Specifically, topics include but are not limited to:
- fundamentals (e.g., stochastic gradient descent, logistic regression, artificial neural networks)
- Deep Q-Networks and Rainbow DQNs
- policy gradients, trust region policy optimization, proximal policy optimization
- actor critic methods, soft actor critic methods
- applied case studies

Intended Learning Outcomes:
After attending this course, students will have acquired …
… basic knowledge in the domain of search algorithms, e.g., graph and tree search, and understand the fundamental theory behind it
... the competence/capability to analyze a practical problem by modelling it as a Markov Decision Process (MDP)
… profound knowledge in the domain of reinforcement learning and understanding of fundamental reinforcement learning theory, e.g., Q-learning, TD learning
… basic knowledge in deep learning and understanding of fundamental machine learning and deep learning theory, e.g., stochastic gradient descent, logistic regression, artificial neural networks
… profound knowledge in the domain of deep reinforcement learning (DRL) that combines the previous two competence areas and understanding of fundamental DRL theory, e.g., deep Q-networks (DQN), advanced policy gradient methods such as proximal policy optimization (PPO)
… the competence/capability to apply a DRL framework to a practical problem
… the competence/capability to evaluate DRL methods w.r.t. to advantages and disadvantages
… the competence/capability to evaluate practical applications w.r.t. typical pitfalls (e.g., convergence issues with non-independent samples) when using DRL and how to circumvent them

Teaching and Learning Methods:
Students learn the theory behind deep reinforcement learning in lectures. In additional exercises and coding labs, students learn how to apply this knowledge to practical problems.

Media:
slides, readings, exercises, coding labs

Reading List:
Sutton, R. S., & Barto, A. G. (2018). Reinforcement learning: An introduction. MIT press.
Bengio, Y., Goodfellow, I., & Courville, A. (2017). Deep learning. MIT press.
Russell, S., & Norvig, P. (2010). Artificial Intelligence: A Modern Approach. Prentice Hall.

Responsible for Module:
Schiffer, Maximilian; Prof. Dr. rer. pol.

Courses (Type of course, Weekly hours per semester), Instructor:
Introduction to Deep Reinforcement Learning (MGT001299, englisch) (Vorlesung, 2 SWS)

Schiffer M, Nouli G, Hoppe H

Introduction to Deep Reinforcement Learning (MGT001299, englisch) (Exercise) (Übung, 2 SWS)
Schiffer M, Nouli G, Hoppe H
For further information in this module, please click campus.tum.de or here.

Module Description

MGT001307: Data Analytics in Applications | Data Analytics in Applications

Version of module description: Gültig ab summerterm 2021

Module Level: Master	**Language:** English	**Duration:** one semester	**Frequency:** winter/summer semester
Credits:* 6	**Total Hours:** 180	**Self-study Hours:** 140	**Contact Hours:** 40

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
As part of the seminar, students are given a Data Challenge from companies with real world data - a unique opportunity to work "hands-on" on a data analytics project in an interdisciplinary way.

Students apply their theoretical knowledge to this real project and work on the challenge. The module grade is composed of the seminar paper evaluation (90%) and a final presentation (10%). The submission of the seminar paper includes the documentation of the developed solutions as well as the commented out program code (python) in digital form. The duration of the final presentation is 30 minutes. The assignment will be done in teamwork.

The mentors of the Data Challenge will also be present at the presentation - the best groups will receive a prize and the opportunity to get in closer contact with excellent companies.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Basic programming knowledge is required. In the course there will be short sessions on selected models as review, as well as on data preprocessing & modeling with python.

Students without programming experience can qualify for the course, by working out the gaps in advance.

Upon successful completion, students receive a certificate.

Content:
The module consists of two sub-modules: In the first sub-module, the necessary theoretical basics are taught in the form of seminars and exercises. Exemplary use cases are presented and the methodology for processing data analytics use cases is taught. In the second submodule, students work on a self-identified or specified use case. Support will be provided in the form of consultation hours.

The seminar takes place in cooperation with the TUM KI-Lab, which consists of a consortium of well-known representatives from industry. The cooperation partners provide possible use cases, data sources and contact persons, so that the seminar has a strong practical character. In addition, exclusive insights into the data analytics applications of the cooperation partners are provided through guest lectures. Students will have the opportunity to establish valuable industry contacts.

Contents:
- CRISP-DM & ML-Ops
- Business Understanding for Data Analytics
- Data Understanding & Data Preperation (+exercise)
- Modeling (Descriptive Analytics, Classification, Clustering, Regression) (+exercise)
- Evaluation of ML-Models
- Deployment of ML-Models

Students of the seminar have the unique opportunity to participate on-site at the Munich Management Colloquium and receive free tickets to this event.

Intended Learning Outcomes:
After completing the seminar, students will be able to identify data analytics projects in a structured way, work on them independently and implement them (via python and from a management perspective). The seminar promotes interdisciplinary group work, offers students the opportunity to learn with and from each other, and also provides students with the unique opportunity to work on a concrete, real-world data project. Students can apply their theoretical knowledge and programming skills in practice. The "learning-by-doing" concept, applied to a data challenge of a partner company of our AI Lab is the focus of this seminar and promises excellent learning experiences.

Students learn: (i) the identification of valuable and practical data analytics use cases, (ii) the structured project planning of programming tasks as well as the processing of a data analytics use case in a team using state-of-the art software, (iii) the targeted compilation of results and program code. In addition, the students learn in a kind of hackathon (Data Challenge) over 2 months the structured implementation of a Proof of Concepts (PoC) via python in a team (iv). The seminar is based on the CRISP-DM process (v). The Data Challenge is intentionally designed to be very open in order to challenge and encourage the creativity and initiative of the students (vi) with regard to business case and value proposition.

Teaching and Learning Methods:
The module consists of 4 seminar units of 4 hours each including exercises in the form of Jupyter notebooks (python). This is followed by independent work on a data project in teamwork. Consultation hours are available for support during the team project.

Media:

Reading List:
Applied Data Mining for Business Analytics - Dursun Delen
Learning Python: Powerful Object-Oriented Programming - Mark Lutz
Machine Learning mit Python und Keras, TensorFlow 2 und Scikit-learn: Das umfassende Praxis-Handbuch für Data Science, Deep Learning und Predictive Analytics (mitp Professional) - Sebastian Raschka

Responsible for Module:
Wildemann, Horst; Prof. Dr. Dr. h.c. mult.

Courses (Type of course, Weekly hours per semester), Instructor:
Data Analytics in Applications (MGT001307, englisch) (Seminar, 4 SWS)
Blümelhuber B, Junker S, Stepanek N
For further information in this module, please click campus.tum.de or here.

Module Description

MGT001370: Designing Manufacturing Systems | Designing Manufacturing Systems

Version of module description: Gültig ab winterterm 2022/23

Module Level: Master	**Language:** English	**Duration:** one semester	**Frequency:** winter semester
Credits:* 6	**Total Hours:** 180	**Self-study Hours:** 120	**Contact Hours:** 60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The students demonstrate that they can create appropriate designs for different production systems using the approaches introduced in the lecture. Furthermore, students show that they are able to explain the fundamentals of the different design approaches and evaluate them. At the end of the lecture students will have a good understanding of the design of production systems and layouts, like job shops, flow lines, single flow rows, production centers, and flexible assembly layouts.

3 assignments (50%) and a written test (50%). Each assignment consists of 4–5 questions, with the points equally distributed among the assignments, i.e., each assignment is worth 30 points (90 points in total). Similarly, the written test is also worth 90 points.

Allowed aids for the test will be announced at the beginning of the semester.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
PLEASE NOTE:
This module cannot be attended if WI100967 Designing and Scheduling Manufacturing Systems was attended previously.
Knowledge of quantitative approaches to production and supply chain management. The modules "Management Science" and "Production and Logistics" or similar modules at other universities are a prerequisite. Also, basic programming experience in Python is strongly recommended.

Content:
Decisions related to designing of a production system play an important role in all manufacturing industries. Decisions like configuration of a layout and planning of material flow are all essential for maximizing the profit of a company. In this course, the students learn how to support these decisions by applying various quantitative methods in application areas such as assembly systems, process industries, automotive industry and AGVs in flexible assembly layouts and production centers.

Content:
• Layout types
• Job shops
• Single flow row
• Traditional assembly lines
• Flexible assembly lines
• Production systems under uncertainty

Intended Learning Outcomes:
After the module the students will be able to:
• Give an overview of methods used in designing production systems.
• Distinguish the most important production layout types (job shop, flow lines and production centers). Analyze the
layout types advantages and disadvantages, decide for practical layout problems, which type to choose.
• Apply rough and exact planning approaches for the most important layout types, including the application of
heuristics and the formulation and adaption of mathematical models.

Teaching and Learning Methods:
The module uses a blended learning approach with online on-demand lectures for the students to study on their own pace. Weekly in-class lectures are intended to re-cap the lecture material from the recorded videos, clarify questions and discuss extensions. The optional assignments involve the modelling of the design problems discussed in class and the implementation of these mathematical models.

Media:
Lecture slides, lecture video recordings and case studies, in-class exercises, homework assignments and their solutions.

Reading List:
Books

Cachon, G., Terwiesch, C., Matching Supply with Demand: An Introduction to Operations Management, Fourth edition, McGraw-Hill, 2019, ISBN: 9781260084610

Günther, H.-O., Tempelmeier, H., Supply Chain Analytics, 13th edition, Springer, 2020, ISBN: 9783750437661

Heragu, S. S., Facilities Design, Fourth edition, CRC Press, 2016, ISBN: 9781498732895

Hopp, W. J., Spearman, M. L., Factory Physics, Third edition, Waveland Press, 2011, ISBN: 1577667395, 9781577667391

Williams, H. P., Model building in mathematical programming, Fifth edition, Wiley, 2013

General papers

Benjafaar, S., Heragu, S. S., Irani, S. A., Next generation factory layouts: research challenges and recent progress, Interfaces, 32(6), 2002, 58-76

Singh, S. P., Sharma, R. R. K., A review of different approaches to the facility layout problems, International Journal of Advanced Manufacturing Technology, 2006, 30 (5-6), 425-433

Drira A., Pierreval H., Hajri-Gabouj S., Facility layout problems: A survey, Annual Reviews in Control, 31 (2), 2007, 255-267

Job shops

Heragu, S. S., Kusiak, A., Efficient models for the facility layout problem, European Journal of Operational Research, 53 (1), 1991, 1-13

Single row flow

Ho, Y.C., Moodie, C.L., Machine layout with a linear single row flow path in an automated manufacturing system, Journal of Manufacturing Systems, 17(1), 1998, 1-22

Flow systems design

Higle, J. L., Stochastic Programming: Optimization When Uncertainty Matters. INFORMS, 30–53, 2005

Sundaramoorthy A, Evans JMB, Barton PI (2012) Capacity Planning under Clinical Trials Uncertainty in Continuous Pharmaceutical Manufacturing, 1. Mathematical Framework. Industrial & Engineering Chemistry Research 51(42):13692–13702.

Stefansdottir, B., Grunow, M., Selecting new product designs and processing technologies under uncertainty: Two-stage stochastic model and application to a food supply chain. International Journal of Production Economics 201 89–101, 2018

Assembly lines

Boysen, N., Fliedner, M, Scholl, A., Assembly line balancing: Which model to use when?, International Journal of Production Economics, 111 (2), 2008, 509-528

Scholl, A., Becker, C., State of the art exact and heuristic solution procedures for simple assembly line balancing, EJOR; 168, 2006, 666- 693. (excluding sections 3.3-3.5, 4.2, 4.3, 5.2, 5.3)

Becker, C., Scholl, A.: A survey on problems and methods in generalized assembly line balancing, European Journal of OperationsResearch. 168, 2006, 694-715

Gökcen, H., Erel, E., Binary integer formulation of mixed-model assembly line problem, Computers and Industrial Engineeing, 34, 1998,451-461

Flexible Assembly Layouts

Hottenrott, A., Grunow, M., Flexible layouts for the mixed-model assembly of heterogeneous vehicles, OR Spectrum, 41, 2019, 943-979

Responsible for Module:
Grunow, Martin; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
Designing Manufacturing Systems(MGT001370, englisch) (Vorlesung, 4 SWS)
Grunow M, Okumusoglu B
For further information in this module, please click campus.tum.de or here.

Module Description

MGT001371: Scheduling Manufacturing Systems | Scheduling Manufacturing Systems

Version of module description: Gültig ab winterterm 2022/23

Module Level: Master	**Language:** English	**Duration:** one semester	**Frequency:** summer semester
Credits:* 6	**Total Hours:** 180	**Self-study Hours:** 120	**Contact Hours:** 60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The focus is on scheduling short term operations on the different manufacturing layout types.
The students have to show that for different production systems they are able to apply suitable scheduling approaches taught in the lecture.
Furthermore, the students demonstrate that they are able to explain the fundamentals of the different scheduling approaches and evaluate them.

3 assignments (50%) and a written test (50%). Each assignment consists of 4–5 questions, with the points equally distributed among the assignments, i.e., each assignment is worth 30 points (90 points in total). Similarly, the written test is also worth 90 points.

Allowed aids for the test will be announced at the beginning of the semester.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
PLEASE NOTE:
This module cannot be attended if WI100967 Designing and Scheduling Manufacturing Systems was attended previously.
Knowledge of quantitative approaches to production and supply chain management. The modules "Management Science" and "Production and Logistics" or similar modules at other universities are a prerequisite. Also, basic programming experience in Python is strongly recommended.

Content:
Decisions related to scheduling of a production system play an important role in all manufacturing industries. Decisions like configuration of a layout and planning of material flow are all essential

for maximizing the profit of a company. In this course, the students learn how to support these decisions by applying various quantitative methods in application areas such as assembly systems, process industries, automotive industry and AGVs in flexible assembly layouts and production centers.

Content:
• Layout types
• Introduction to scheduling
• Job shops
• Flexible assembly systems
• Economic lot scheduling, block planning
• Scheduling AGV‘s in centers (online vs. offline scheduling)

Intended Learning Outcomes:
After the module the students will be able to:
• Give an overview of methods used in scheduling production systems.
• Give an overview of the scheduling objectives and requirements in manufacturing.
• Evaluate and apply different planning procedures (shifting bottleneck, scheduling of flexible assembly systems,
economic lot scheduling, block planning and online vs. offline scheduling) to develop production schedules for
different types of systems such as assembly lines, food processing systems and AGVs in flexible assembly layouts
and production centers.
• Apply heuristics and formulate and solve mathematical models

Teaching and Learning Methods:
The module uses a blended learning approach with online on-demand lectures for the students to study on their own
pace. Weekly in-class lectures are intended to re-cap the lecture material from the recorded videos, clarify questions and discuss extensions. The assignments involve the modelling of the scheduling problems discussed in class and the implementation of these mathematical models.

Media:
Lecture slides, lecture video recordings and case studies, in-class exercises, homework assignments and their solutions.

Reading List:
Books
Pinedo, M., Planning and Scheduling in Manufacturing and Services, Second edition, Springer, 2009, ISBN: 978-1-4419-0909-1, e-ISBN 978-1-4419-0910
Williams, H. P., Model building in mathematical programming, Fifth edition, Wiley, 2013

Paced assembly systems

Boysen, N., Fliedner, M., Scholl, A., Sequencing mixed-model assembly lines: Survey, classification and model critique. European Journal of Operational Research, 192 (2), 2009, 349–373.
Boysen, N.; Fliedner, M., Comments on “Solving real car sequencing problems with ant colony optimization”. European Journal of Operational Research 182 (1), 2007, 466–468.
Gagné, C., Gravel, M., Price, W. L., Solving real car sequencing problems with ant colony optimization, European Journal of Operational Research, 174(3), 2006, 1427-1448
Solnon, C., Cung, V.D., Nguyen, A., Artigues, C., The car sequencing problem: Overview of state-of-the-art methods and industrial case-study of the ROADEF’2005 challenge problem, European Journal of Operational Research 191(3), 2008, 912-927.

Block planning
Günther, H.O., An application of MILP-based block planning in the chemical industry, Proceedings of the Eighth International Symposium on Operations Research and Its Applications (ISORA’09), Zhangjiajie, China, September 20–22, 2009, 103–110. Günther, H.O., The blockplanning approach for continuous time-based dynamic lot sizing and scheduling, Business Research, published online 2014
Kilic, O. A., Akkerman, R., van Donk, D. P., & Grunow, M. (2013). Intermediate product selection and blending in the food processing industry. International Journal of Production Research, 51(1), 26–42.
Lütke-Entrup, M., Günther, H.O., van Beek, P., Grunow, M., Seiler, T., Mixed integer linear programming approaches to shelf-life integrated planning and scheduling in yogurt production, International Journal for Production Research, 43(23), 2005, 5071-5100.

Flow lines
Stefansdottir, B., Grunow, M., Classifying and modeling setups and cleanings in lot sizing and scheduling, European Journal of Operational Research, 216(3), 2017, 849-865

Responsible for Module:
Grunow, Martin; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
Scheduling Manufacturing Systems (MGT001371, englisch) (Vorlesung, 4 SWS)
Grunow M, Dörr J, Okumusoglu B, Schömig-Beißner M
For further information in this module, please click campus.tum.de or here.

Module Description

WI000819: Applied Discrete Optimization | Applied Discrete Optimization [DO]

Version of module description: Gültig ab winterterm 2012/13

Module Level: Master	**Language:** English	**Duration:** one semester	**Frequency:** winter/summer semester
Credits:* 6	**Total Hours:** 180	**Self-study Hours:** 120	**Contact Hours:** 60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
Exercises (Any combination of homework assignments, semester project or report, and presentation) and
Test (written)

The final grade is composed of individual or group exercises, as well as a written individual test at the end of the semester. The exercises will count for 40%-60% and the test for 60%-40% respectively, of the final grade.

In the exercises, the students show their theoretical understanding and, thus, ability to apply different methodologies, either exact or heuristic, to solve problems including the real-world applications in the field of operations research. In the test, the theoretical understanding of each student is queried.

Repeat Examination:
End of Semester

(Recommended) Prerequisites:

This module is dedicated to advanced students who have background in Management Science or Operations Research, specifically in linear programming and duality theory. To work on the assignments, students should have knowledge in using any optimization packages such as OPL/CPLEX, GUROBI, LINGO, or Excel Solver. Knowledge in programming languages is not expected but can be useful for the assignments.

Content:
Discrete optimization problems arise in many practical applications and functional areas. The module Applied Discrete Optimization focuses on the underlying polyhedral theory and both exact and heuristic solution methods to solve
large - scale and complex mathematical models. Topics include
1. Review of linear programming
2. Revised simplex and column generation methods
3. Discrete optimization problems and model formulations
4. Computational complexity
5. Basic exact solution methods:
a. Branch-and-Bound methods
b. Cutting-Plane methods
6. Advanced exact solution methods:
a. Strong Valid Inequalities
b. Branch-and-Cut
c. Dantzig-Wolfe Decomposition
d. Branch-and-Price / Branch-Price-Cut
e. Lagrangian Relaxation
f. Bender's Decomposition
7. Heuristic / Metaheuristic methods

Intended Learning Outcomes:
At the end of the module, students shall understand the complexity of discrete optimization models, the polyhedral theory, and the theoretical concepts underlying the advanced methods in solving the discrete models. These methods include Branch-and-Cut, Branch-and-Price, Branch-Price-Cut, Benders' Decomposition, and Lagrangian relaxation. Students will be able to apply appropriately these solution approaches to solve their complex problems either by exact or heuristic methods.

Teaching and Learning Methods:
The module consists of a series of lectures that describe the fundamental theories behind the solution methods and illustrate their examples and applications. A few selected technical papers addressing specific problems and solutions to the described problems will be discussed. Assignments are of student groupwork to practice the solution methods learned in class and to review the real-world applications.

Media:

Reading List:

1. Nemhauser G.L. and L.A. Wolsey. Integer and Combinatorial Optimization. Wiley. 1988.
2. Wolsey, L.A. Integer Programming. Wiley. 1998.
3. Wintston, Operations Research: Applications and Algorithms. 1993.
4. Any reference or textbook in management science or operations research.

Responsible for Module:
Schulz, Andreas; Prof. Dr. rer. nat.

Courses (Type of course, Weekly hours per semester), Instructor:
Applied Discrete Optimization (WI000819, englisch) (Vorlesung mit integrierten Übungen, 4 SWS)
Schulz A
For further information in this module, please click campus.tum.de or here.

Module Description

WI000977: Stochastic Modeling and Optimization | Stochastic Modeling and Optimization

Version of module description: Gültig ab summerterm 2016

Module Level: Master	**Language:** English	**Duration:** one semester	**Frequency:** winter semester
Credits:* 6	**Total Hours:** 180	**Self-study Hours:** 120	**Contact Hours:** 60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The grading is based on a written exam (90 minutes) consisting of 4 questions, the participants can choose 3 out of 4. Each question has several parts assessing the different competence levels. Students show that they understand a set of advanced stochastic methods. Each question requires the application of a stochastic method, or combinations of several methods. That shows students' ability to compare, choose and, combine different stochastic methods. Students have to conduct 1) practical implementation exercises and 2) theoretical proofs. The exam is open-book, students are allowed to use their own laptops for solving the programming exercises.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
The module requires a solid knowledge in probability theory and linear optimization. The knowledge of a programming language is helpful and the course “Modelling, Optimization, and Simulation” due to extensive use of Mixed-Integer Programming and Simulation methods.

Content:
The module covers different state-of-the art methods for decision support in stochastic real-world environments. This contains methodology for multi-period problems and takes into account different states of the world. The module covers both, the mathematical theory behind the methods and presents their applications to industry problems such as inventory management or call center staffing.
Specifically, the module covers the topics:
• Uncertainty Modeling: Probability Theory, Stochastic Processes,
• Fuzzy Set Theory,
• Newsvendor Problems, Bayes Updating, Forecast Evolution

• Stochastic Dynamic Programming and Approximate Dynamic Programming
• Markov Chains and Markov Decision Processes: LP, Value Iteration, Policy Iteration
• Stochastic Programming: Chance Constrained Programming,
• Two-Stage Models with Recourse, Sample Average Approximation, Sampling Strategies
• Simulation Optimization Applications: Queuing Theory, Queuing Networks, Factory Physics, Inventory Theory (single echelon, multi-echelon)

Intended Learning Outcomes:
After participating in this module, students are able to understand and interpret a set of advanced stochastic methods. They are able to apply these concepts in practice and transfer the methods to real life. Students further comprehend the weaknesses and strengths of the methods. They are able to assess which method to apply in which context. Students further have the ability to make appropriate use of related software. Through (voluntary) homework and the discussion and presentation of different solutions in class, students further improve their skills of carrying out discussions within a research environment. They gain insights into academic work, as most material will be learned from scientific papers rather than from books. The course will prepare the students for their master thesis.

Teaching and Learning Methods:
In lectures, students learn to understand the mathematical theory and obtain insights in applications of the stochastic methods to a practice context. Students get exercise sheets with problems that go beyond the examples in the lecture and allow them to reproduce and extend their knowledge. For solving the exercises, they are provided with the necessary software, such as Matlab or Xpress. In exercise classes, students discuss their solutions of the homework, and find out about the differences in practicability of one method over the other. In addition, there are guest lectures of practitioners who apply advanced methodology in their daily work and motivate new fields of application of the models beyond the scope of the lectures.

Media:
Literature, Slides, Case studies, Exercises, Software

Reading List:
• Tijms, H.C. (2003), A First Course in Stochastic Models, Wiley
• King, A.J., Wallace, S.W. (2012), Modeling with Stochastic Programming, Springer
• Kleijnen, J.P.C. (2008), Design and Analysis of Simulation Experiments, Springer
• Powell, W. (2011), Approximate Dynamic Programming, 2nd ed., Wiley

Responsible for Module:
Minner, Stefan; Prof. Dr. rer. pol.

Courses (Type of course, Weekly hours per semester), Instructor:
Stochastic Modeling and Optimization (WI000977, englisch) (Limited places) (Vorlesung mit integrierten Übungen, 4 SWS)
Minner S [L], Minner S, Abbaszadeh Nakhost M

For further information in this module, please click campus.tum.de or here.

Module Description

WI001088: Advanced Modeling, Optimization, and Simulation in Operations Management | Advanced Modeling, Optimization, and Simulation in Operations Management [AMOS]

Version of module description: Gültig ab summerterm 2016

Module Level: Master	**Language:** English	**Duration:** one semester	**Frequency:** winter/summer semester
Credits:* 6	**Total Hours:** 180	**Self-study Hours:** 120	**Contact Hours:** 60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
The offered module is composed of the sections optimization and simulation. In both sections, basic knowledge and skills for designing and evaluating service and production processes are taught. The solution of analyzed problems is gained either through the application of optimization methods or through simulation. Due to the different problem-solving approaches (and the use of different software packages), both sections are thought separately. To facilitate the learning success, the learning outcomes are examined directly at the end of each section. At the end of the optimization section, there is a written exam on modeling linear optimization problems. In addition to theoretical knowledge, the students' skills in modeling with OPL and IBM ILOG CPLEX are tested. At the end of the simulation section, there is also a written exam, in which the learning outcomes in discrete-event simulation, using the software AnyLogic are tested. Both exams evaluate the individual performance of the acquired theoretical and practical skills, requiring own calculations and argumentative answers. Exams are worth 60 points each and noncumulative. To pass the course, students need to pass both exams individually. The final grade of the module is the truncated average of the exam grades. Both exams take 60 minutes each. In the exams, no aids are allowed. In addition, students can achieve a 0.3/0.4-grade bonus (according to APSO/ FPSO midterm) in each section through the successful participation in the respective homework assignments.

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Management Science, Basic course in Statistics, Basic Couse in Mathematics, Production and Logistics

Content:
The acquired skills are used in the field of operations management to understand, redesign, control and optimize the production of goods and services. The students learn quantitative methods for the analysis of decision problems in operations management, and therefore, the basis for all subsequent lectures at the Department of Operations & Supply Chain Management. The presented methods can be subdivided into two distinct study sections: optimization and simulation.
Optimization section:
- Introduction to linear programming, CPLEX Studio IDE, and IBM ILOG OPL
- LP formulations, e.g. production planning problems
- Model building with OPL, e.g. generic modeling, model testing with instances, scripting for pre- and post-processing
- Interpreting and using the solution of a LP model
- Spreadsheet input/output with OPL
Simulation section:
- Introduction to simulation, AnyLogic
- System; event; model; steps in a simulation study
- Data collection, statistical analyse and input modeling
- Fundamental simulation concepts in AnyLogic
- Simulation of simple systems together with verification, calibration, and validation
- Statistical simulation data output analysis having regard to different scenarios

Intended Learning Outcomes:
At the end of the module, students will be able to create mixed integer linear programming formulations, and discrete event simulation models of simple problems in production and operations management.
Furthermore, students will be able to solve MILP formulations in OPL and IBM ILOG Script, and implement discrete event simulation models in AnyLogic. The students also learn, how to evaluate and compare the calculated problem solutions.

Teaching and Learning Methods:
The weekly sessions consist of a lecture with an integrated exercise class. During the lecture, the content is presented and discussed. The students are invited to improve the acquired knowledge by studying the suggested literature. In the exercise, the students apply the acquired knowledge by solving and implementing given problems. The homework assignments allow students to individually improve their skills, by answering theoretical questions and implementing problems, using the respective software. After each homework assignment, the students are free to discuss their solutions and open questions in a Q&A session.

Media:
PowerPoint, Exercise sheets, Whiteboard

Reading List:
Optimization
- Williams, H. P. (1999): Model Building in Mathematical Programming. 4th edition.

Supplementary reading materials about optimization and linear programming
- Domschke, W. and Drexl, A. (2005): Einführung in Operations Research. 6th edition, Springer.
- Domschke, W., Scholl, A. and Voss, S. (1997): Produktionsplanung. 2nd edition, Springer.
- Hillier, F. S. and Lieberman, G. J. (2004): Introduction to Operations Research. 8th edition, McGraw-Hill.
- Klein, R. and Scholl, A. (2004): Planung und Entscheidung. Vahlen.
- Winston, W. L. (2004): Operations Research. 5th edition, Thomson.

Simulation:
- Kelton, W. D., Sadowski, R. P. and Sturrock, D. T. (2010): Simulation with ARENA. 5th edition, Boston: McGraw-Hill.
Supplementary reading materials about simulation and statistics
- Banks J., Carson J. S., Nelson, B. L. and Nicol. D. M. (2009): Discrete-Event System Simulation. 5th edition, Upper-Saddle-River: Prentice Hall.
- Law, A.M. (2007): Simulation modeling and analysis. 4th edition, McGraw-Hill, New York
- Bleymüller, J., Gehlert, G., Gülicher, H. (2008): Statistik für Wirtschaftswissenschaftler. 15th edition, München: Verlag Vahlen.

Responsible for Module:
Kolisch, Rainer; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
Advanced Simulation in Operations Management (WI001088, englisch) (Limited places) (Seminar, 2 SWS)
Jost C, Pahr A

Advanced Modeling and Optimization in Operations Management (WI001088, englisch) (Limited places) (Seminar, 2 SWS)
Jost C, Pahr A
For further information in this module, please click campus.tum.de or here.

Module Description

WI200541: Planning and Scheduling of Complex Operations: Models, Methods and Applications | Planning and Scheduling of Complex Operations: Models, Methods and Applications

Version of module description: Gültig ab summerterm 2017

Module Level: Master	**Language:** English	**Duration:** one semester	**Frequency:** summer semester
Credits:* 6	**Total Hours:** 180	**Self-study Hours:** 120	**Contact Hours:** 60

Number of credits may vary according to degree program. Please see Transcript of Records.

Description of Examination Method:
Grading of the module will be based on the following four assessments: 1) At the end of the module the students have to take an open book written test of 60 minutes length. Through the course students have to hand in two assignments and have to make a 15 minute presentation followed by a 5 minute discussion. Taking the test the students show that they have understood the problems, models, methods and applications treated in the module. By undertaking the two assignments students demonstrate that they have acquired the capability of i) coding and implementing a scheduling approach by using a computer programming language (first assignment), and ii) implementing a scheduling optimization model by using a modelling language and a solver (second assignment). With the presentation students showcase their understanding and capability of presenting a scheduling application from the scientific literature so far not treated in the module. The assessments are weighted with 50% (test), 15% (coding assignment), 20% (optimization assignment) and 15% (presentation).

Repeat Examination:
Next semester

(Recommended) Prerequisites:
Students should have knowledge in the mandatory undergraduate courses Mathematics (Linear Algebra), Statistics (probabilities, distributions), Management Science or Operations Research (Linear and Integer Programming), Production and Logistics or Operations Management, Programming, as well as a course in modelling and simulation such as in the elective undergraduate course “Modelling, Optimization and Simulation”.

Content:
Scheduling is about planning the timing of activities subject to scarce resources such as machines in order to fulfill an objective such as minimizing the flow time in the best possible way. Many scheduling problems in manufacturing and services are complex in the sense that there are precedence constraints enforcing minimum or maximum time lags between activities, more than one unit or type of scarce resource is required for processing an activity, capacity of resources is changing over time and complicated objective functions such as net present value have to be taken into account. The theory of resource-constrained project scheduling offers powerful modeling and solution techniques in order to address these kind of problems. The module empowers students to apply the main modeling and solutions concepts in order to successfully addressing real-world scheduling problems. The module is divided into four main parts which relate to different modelling concepts. Within each part the modelling concept, a linear programming formulations, heuristic and metaheuristic approaches as well as applications will be addressed. Next to its practical relevance, the module serves as a good starting point in order to undertake a master-thesis or a PhD-thesis.
• Scheduling activities with general precedence constraints
o Linear Program formulation
o Network flow algorithms for scheduling activities with general precedence constraints: Label correcting algorithm and Floyd-Warshall algorithm
o Applications
• Scheduling activities with renewable resource constraints: The Resource-constrained project scheduling problem
o Linear program formulations
o Special cases
o Heuristics and Metaheuristics
o Applications
• Scheduling activities with multiple modes, renewable and nonrenewable resource constraints: The Multi-mode resource-constrained project scheduling problem
o Linear program formulation
o Special cases
o Heuristics and metaheuristics
o Applications
• Scheduling activities with renewable resource constraints and stochastic durations: The stochastic resource-constrained project scheduling problem
o Heuristics and metaheuristics
o Applications

Intended Learning Outcomes:
Upon completion of the module students are empowered to analyze and optimize scheduling problems in services and manufacturing. In particular they 1) know the prevalent models and methods available in the literature. 2) They are capable of coding and implementing relevant algorithms. 3) They know how to model and solve linear programs in the field with off-the-shelf software. And 4) they understand and are able to present new approaches available in the scientific literature.

Teaching and Learning Methods:
The topics will be treated based on book chapters and papers in the scientific journals. Students are advised to prepare for the lecture by reading these material ahead of class. The content will be presented by the lecturer and discussed with the students. Then, students have to prepare applications of the approaches by solving small cases which will be discussed afterwards. The cases will be helping students to understand the problems addressed and the solution approaches provided. In order to empower students to implement the approaches in practice students will undertake two assignments. In the first assignment students implement an approach (exact procedure or heuristic) by using a programming language such as JAVA. In the second assignment students implement a linear programming model with the modelling language OPL and the solver CPLEX. The assignments will be provided at the beginning of the course giving students some time in order to undertake them . During the time of working at the assignments students can consult the teaching assistant in the exercise for help. In order to empower students to address problems not treated in class, students have to select and present a problem and an associated solution approach from the literature in class.

Media:
Slides, book chapters and papers, will be electronically made available in moodle.

Reading List:
• Brucker, P. and Knust, S. Complex Scheduling. GOR Publications. Springer, Berlin, 2. edition, 2012
• Schwindt, C. and Zimmermann J. editors. Handbook on Project Management and Scheduling Vol. 1. Springer, Heidelberg, 2015.
• Schwindt, C. and Zimmermann J. editors. Handbook on Project Management and Scheduling Vol. 1. Springer, Heidelberg, 2015.
• Neumann, K., Schwindt, C.and Zimmermann, J.. Project Scheduling with Time Windows and Scarce Resources. Springer, Heidelberg 2. edition, 2003.

Responsible for Module:
Kolisch, Rainer; Prof. Dr.

Courses (Type of course, Weekly hours per semester), Instructor:
Complex Scheduling in Manufacturing and Services: Models, Methods and Applications (WI000541, englisch) (Limited places) (Vorlesung, 4 SWS)
Kolisch R, Ammann P
For further information in this module, please click campus.tum.de or here.