Univerza v Mariboru

Fakulteta za naravoslovje in matematiko

UČNI NAČRT PREDMETA / COURSE SYLLABUS	
Predmet:	**Operacijske raziskave z matematičnim programiranjem**
Course title:	**Operations Research with Mathematical Programming**

Študijski program in stopnja Study programme and level	Študijska smer Study field	Letnik Academic year	Semester Semester
Matematika 2. stopnja	Modul R1	**1. ali 2.**	**1. ali 3.**
Mathematics 2^{nd} cycle	Module R1	**1. or 2.**	**1. or 3.**

Vrsta predmeta / Course type: obvezni / compulsory

Univerzitetna koda predmeta / University course code:

Predavanja Lectures	Seminar Seminar	Sem. vaje Tutorial	Lab. vaje Laboratory work	Teren. vaje Field work	Samost. delo Individ. work	ECTS
30	15	30			135	7

Nosilec predmeta / Lecturer: Drago Bokal

Jeziki / Languages:		
	Predavanja / Lectures:	Slovensko/Slovene
	Vaje / Tutorial:	Slovensko/Slovene

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:	**Prerequisits:**
Poznavanje enostavnih algoritmov. Poznavanje osnov linearne algebre in vektorske analize.	Knowledge of simple algorithms. Knowledge of basic linear algebra and calculus.

Vsebina:	**Content (Syllabus outline):**
Obvezna vsebina, ki pri študentih vzpostavi temeljni nabor znanj s področja operacijskih raziskav in matematičnih programov: • Nevezani ekstrem, Newtonova metoda. • Vezani ekstrem. Lagrangeovi multiplikatoriji. Potrebni in zadostni pogoji za nastop vezanega lokalnega	Mandatory content, that familiarizes the students with fundamentals of operations research and mathematical programs: • Unconstrained optimization. Newton's method. • Constrained optimization. Lagrange multipliers. Necessery and sufficient

ekstrema. Wolfe-ov dual konveksnega programa.

- Kvadratično programiranje. Lagrangeovske metode in metoda aktivne množice. Programi z linearnimi vezmi. Cikcakanje.
- Nelinearno programiranje. Kazenska in odbojna funkcija. Langrange-Newtonova methoda (SQP).
- Stožčasto programiranje. Lorentzov in semidefinitni stožec. Stožčasto kvadratično programiranje.
- Semidefinitno programiranje. Aplikacije v kombinatorični optimizaciji.
- Metoda notranje točke za linearno in konveksno programiranje. Dokaz obstoja centralne poti. Primarno-dualna metoda sledenja centralni poti.

V okviru vsebine študentje izberejo zahtevnejši problem - projekt, s katerimi se poglobljeno ukvarjajo pri seminarski nalogi. Problem je povezan z njihovo bodočo kariero (praktični problemi iz gospodarstva, teoretični problemi iz teorije matematičnega programiranja in pripadajočih numeričnih algoritmov). Preostala predavanja se prilagodijo problemom, ki so jih izbrali študentje, in obsegajo vsebine z naslednjega seznama:

- Robustna optimizacija po metodi cene robustnosti.
- Imunizacija portfelja in stohastično programiranje.
- Stohastično nelinearno programiranje (diskretna in zvezna slučajna spremenljivka). Dekompozicija.
- Aplikacije semidefinitnega programiranja: kvadratični problem prirejanja, problem trgovskega potnika, problem maksimalnega prereza grafa.
- Aplikaciji stohastičnega programiranja: Markowitzevi modeli optimizacije portfelja, modeli večfaznega stohastičnega načrtovanja.
- Modeli največjega verjetja, metoda najmanjših kvadratov, umerjanje

conditions for a constrained local optimum. Dual of a convex program.

- Quadratic programming. Lagrange methods and active set methods. Programs with linear constraints. Zigzagging.
- Nonlinear programming. Penalty and barrier functions. Lagrange-Newton method. Sequential Quadratic Programming.
- Conic programming. Lorentz and semidefinite cone. Conic quadratic programming.
- Semidefinite programming. Applications in combinatorial optimization.
- Interior point methods for linear and convex programming. Existence of the central path. Primal-dual methods of following the central path.

Within the coursework, the students select a problem - project whose result is coursework report. The problem is related to their future career (practical problems from industry and business, theoretical problems from the areas of optimization, algorithms, modelling). The content of the remaining lectures is selected according to these projects from the following list:

- Price of robustness robust optimization method.
- Portfolio immunization using stohastic programming.
- Stohastic nonlinear programming (discrete and continuous stohastic variables). Decomposition.
- Applications of semidefinite programming: quadratic assignment problem, travelling salesman problem, max cut problem.
- Applications of stohastic programming: Markowitz models of portfolio optimization, multiperiod stohastic planning models.
- Maximum likelihood models, least squares method, parameter fitting for given data.

modelov na znane podatke, inverzni problemi, druge podatkovne analize. • Optimizacijski matematični modeli s področja kontrolnih sistemov, obdelave signalov. • Metoda podpornih vektorjev. • Druge vsebine s področja operacijskih raziskav in matematičnega modeliranja, povezane s študentskimi projekti. V okviru seminarskih nalog se študentje srečajo tudi s programsko opremo za matematično modeliranje. komercialno (Excel, Lindo, Matlab) oz. prostodostopno in odprtokodno (SciLab, NEOS, R).	• Optimization mathematical models from control theory and signal processing. • Support Vector Machine. • Other content from the domain of operations research and mathematical programming, related to students' problems. Within their coursework and exercisces, the students familiarize themselves with software for mathematical modelling, either commercial (Excel, Lindo, Matlab) or freely avaliable open source (SciLab, Neos, R).

Temeljni literatura in viri / Readings:

R. Rardin. Optimization in Operations Research. Prentice Hall, Inc., Upper Saddle River, New Jersey, 2000.

J. Curwin, R. Slater. Quantitive Methods for Business Decisions. Third Edition. Chapman & Hall, London, 1991.

S. A. Zenios, Financial Optimization. Cambridge University Press, Cambridge, 1993.

R. Fletcher, Practical Methods of Optimization. Second Edition. Wiley, Chichester, 2001.

A. Ben-Tal, A. Nemirowski: Lectures on modern convex optimization. H. Milton Stewart School of Industrial & Systems Engineering, Georgia Institute of Technology, Atlanta, 2012.

C. Huang, R. H. Litzenberger. Foundations for Finacial Economics. Prentice Hall, Inc., Upper Saddle River, New Jersey, 1988.

P. Kall, S. W. Wallace. Stochastic Programming. Wiley, Chichester, 1994.

L. Neralić, Uvod u matematičko programiranje 1. Udžbenici Sveučilišta u Zagrebu, Zagreb, 2001.

R. Rardin. Optimization in Operations Research. Prentice Hall, Inc., Upper Saddle River, New Jersey, 2000.

J. Renegar. A Mathematical View of Interior-Point Methods in Convex Optimization. MPS-SIAM Series on Optimization. SIAM, Philadelphia, 2001.

S. A. Zenios, Financial Optimization. Cambridge University Press, Cambridge, 1993.

Cilji in kompetence:	**Objectives and competences:**
Usvojiti proces matematičnega modeliranja na zveznih optimizacijskih problemih. Razviti kompetenco samostojnega apliciranja matematičnih metod na probleme iz finančne optimizacije, ekonomije, ter širše iz gospodarstva. Spoznati tehnološka orodja, s katerimi se srečujemo pri reševanju optimizacijskih	Familiarize the students with the process of mathematical modelling of continuous optimization problems. Develop competent skills of independent application of mathematical methods to the problems from financial optimization, economics, and broader from industry. Familiarize the students with technological

problemov in problemov matematičnega modeliranja.	tools that assist solving optimization problems and problems related to mathematical modelling.

Predvideni študijski rezultati:	Intended learning outcomes:
Znanje in razumevanje: • Razumevanje zahtevnejših principov matematičnega programiranja. • Poglobi znanje iz sodobnih numeričnih metod za reševanje matematičnih programov. • Poglobiti znanje iz Markowitzevih modelov in drugih zahtevnih aplikacij matematičnega programiranja v finančni optimizaciji in širše. Prenesljive/ključne spretnosti in drugi atributi: • Direktne aplikacije v finančni matematiki, ekonomiji, poslovnih vedah, inžinirstvu, fiziki in številnih drugih družboslovnih in naravoslovnih vedah. • Suvereno obvladovanje procesa matematičnega modeliranja in uporabe tehnik matematičnega progamiranja v problemih s področja finančne optimizacije, ekonomije in širše. • Izdelava temeljitega elaborata ali zgoščenega članka uporabe matematičnega modela na konkretnem matematičnem problemu, ki ga študent najde ob razmisleku o svoji bodoči karieri.	Knowledge and Understanding: • To be able to understand advanced principles of mathematical programming. • To deepen the knowledge of modern numerical methods for solving mathematical programs. • To deepen the knowledge of details of Markowitz models and other advanced applications of mathematical programming, financial optimization and wider. Transferable/Key Skills and other attributes: • Direct applications in finacial mathematics, economy, business, engineering, physics, and numerous other social and natural sciences. • Competent mastering of the process of mathematical modelling and applications od its techniques in problems from financial optimization, economics, and wider.

Metode poučevanja in učenja:	Learning and teaching methods:
• Pri predavanjih študentje spoznajo snov predmeta. Z uporabo obrnjenega (flipped) poučevanja na predavanjih aktivno spoznavajo povezavo med snovjo in njihovimi projekti. • V okviru seminarskih vaj študentje	• At the lectures, the students are familiarized with the course content. Applying flipped learning approach, they discuss their coursework projects in relation to the material of the course. • At the tutorials, the student deepen their

razumevanje snovi utrjujejo na večjem projektu, povezanem z njihovo bodočo kariero. Razporejeni so v večje skupine, ki po metodah problemskega učenja obravnavajo izbrani problem od zbiranja podatkov, preko razvoja modela, izbora in prilagajanja ustreznih tehnoloških rešitev do razmisleka o implementaciji rešitve. Koncept poučevanja je podrobneje predstavljen kot ciljni aplikativni predmet.	understanding of the material by working on an extensive problem related to their future career. They are organized in larger groups who research the choosen problem guided by methodologies of problem-based learning. Within solving the problem, they experience all the stages from requirements and data gathering, model development, selecting and adapting technological solutions to discussing various aspects of implementation of the results.

Načini ocenjevanja: **Assessment:**

Način (pisni izpit, ustno izpraševanje, naloge, projekt):	Delež (v %) / Weight (in %)	Type (examination, oral, coursework, project):
Seminarska naloga	80%	Coursework report
Ustni izpit	20%	Oral exam
Vsaka izmed naštetih obveznosti mora biti opravljena s pozitivno oceno.		Each of the mentioned commitments must be assessed with a passing grade.
Pozitivna ocena pri seminarski nalogi je pogoj za pristop k izpitu.		Passing grade of the seminar exercise is required for taking the exam.

Reference nosilca / Lecturer's references:

1. BOKAL, Drago, CHIMANI, Markus, NOVER, Alexander, SCHIERBAUM, Jöran, STOLZMANN, Tobias, WAGNER, Mirko H., WIEDERA, Tilo. Properties of large 2-crossing-critical graphs. *Journal of graph algorithms and applications*. 2022, vol. 26, no. 1, str. 111-147. ISSN 1526-1719. DOI: 10.7155/jgaa.00585. [COBISS.SI-ID 144719363]

2. BOKAL, Drago, JEREBIC, Janja. Guarding a subgraph as a tool in pursuit-evasion games. *Discussiones mathematicae. Graph theory*. 2022, vol. 42, no. 1, str. 123-138. ISSN 1234-3099. https://www.dmgt.uz.zgora.pl/publish/view_vol_article.php?E8F29296C3FB4B933A2E. [COBISS.SI-ID 8147219]

3. SMOLE, Andreja, JAGRIČ, Timotej, BOKAL, Drago. Principal/Two-Agent model with internal signal. *Central European journal of operations research*. sep. 2021, vol. 29, no. 3, str. 791-808, ilustr. ISSN 1435-246X. https://link.springer.com/content/pdf/10.1007/s10100-020-00719-0.pdf, DOI: 10.1007/s10100-020-00719-0. [COBISS.SI-ID 75068163]

4. VEGI KALAMAR, Alen, ŽERAK, Tadej, BOKAL, Drago. Counting Hamiltonian cycles in 2-tiled graphs. *Mathematics*. 2021, vol. 9, iss. 6, str. 1-27. ISSN 2227-7390. DOI: 10.3390/math9060693. [COBISS.SI-ID 61574403]