Chalmers University of Technology/Göteborg University
Mathematical Sciences
Optimization
Ann-Brith Strömberg

MVE165/MMG630
Applied optimization
Course information 2009
6th March 2009

MVE165 Applied Optimization, 7.5 hec

A main purpose with the course is to give the students an overview of important areas where optimization problems often are considered in applications, and an overview of some important practical techniques for their solution. Another purpose of the course is to provide insights into such problem areas from both a application and theoretical perspective, including the the analysis of an optimization model and suitable choices of solution approaches. Work with concrete problems during the course enable the establishment of these insights.

After completion of this course, the student should be able to understand the main principles behind the modelling of optimization problems and have a clear overview of the most important classes of optimizationproblems. Within each class the student shall have reached insights about at least one basic solution technique and be able to complete an entire optimization project within this class, including all parts of the chain modelling → model analysis → implementation in suitable algorithm/software → (sensitivity) analysis of an optimal solution.

EXAMINER/LECTURER: Ann-Brith Strömberg, PhD, researcher, Department of Mathematical Sciences, room L2087; tel: 772 5378; e-mail: anstr@chalmers.se

GUEST LECTURERS:
- Fredrik Hedenus, Ph.D., Physical Resource Theory, Department of Energy and Environment, Chalmers, e-mail: hedenus@chalmers.se
- Michael Patriksson, Prof. Applied Mathematics, Department of Mathematical Sciences, Chalmers and GU, e-mail: mipat@chalmers.se
- Elin Svensson, M.Sc., Heat and Power Technology, Department of Energy and Environment, Chalmers, e-mail: elin.svensson@chalmers.se
- Caroline Olsson, M.Sc., Radiation Physics, Institute of Clinical Sciences, Sahlgrenska Academy, GU, e-mail: caroline.olsson@vgregion.se

SUBSTITUTE LECTURERS: Adam Wojciechowski and Peter Lindroth.

CONTENTS: This course describes with the aid of practical cases how optimization problems are modelled and solved in practice. In addition to a lecture series given by staff at Mathematical Sciences there is a series of guest lectures mainly by staff at other departments of Chalmers and Göteborg University. The contents of the course may therefore vary in terms of topics between the years, but a common thread is the practical solution of optimization problems. The lectures and guest lectures are connected to computer exercises and assignments, which constitute the main basis for examination.

The variety of problems covered often over the years include investment, blending, models of energy systems, production and maintenance planning, network models, routing and transport, multi-objective optimization, and inventory planning. Among the algorithm techniques discussed are simplex and interior points methods for linear programming, gradient based methods for non-linear optimization, branch–and–bound and heuristics for integer linear programming, simulation, and dynamic programming. The software used to solved practical problems include AMPL, Cplex, Matlab and Tomlab.

PREREQUISITES: Passed courses on analysis (in one and several variables) and linear algebra; familiarity with matrix/vector notation and calculus.

ORGANIZATION: The course consists of a lecture series of mathematical material, a guest lecture series of practical material, computer exercises, assignments, and student presentations of the assignments.

COURSE LITERATURE:

(i) Main course book: *Optimization in Operations Research* by R. L. Rardin, published by Prentice-Hall, Inc. New Jersey, 1998, found at Cremona.

(ii) Alternative book: *An Introduction to Optimization* by N. Andréasson, A. Evgrafov, and M. Patriksson, published by Studentlitteratur in 2005, found at Cremona. (This book covers only a subset of the course material.)

(iii) Hand-outs from books and articles and descriptions of exercises and assignments.

COURSE REQUIREMENTS: The course content is defined by the literature references **(i)** and **(iii)** in the plan below. The importance of each moment of the course is defined by the respective emphasis given during the lectures.

EXAMINATION:

- Two correctly solved computer exercises (oral examination).
- Written reports of three assignments (Assignments 1, 2, and 3a or 3b).
- A written opposition to Assignment 2.
- An oral presentation of Assignment 3a or 3b.
- To be able to receive a grade higher than 3 or G, the written reports and opposition as well as the oral presentation must be of high quality. Students aiming at grade 4, 5, or VG must also pass an oral exam.

SCHEDULE:

Lectures are given on Mondays 13.15–15.00 in MV:F33, Tuesdays 13.15–15.00 in MV:H11, and Fridays 10.00-11.45 in room MV:H11, according to the course plan below. The first lecture is on Monday 16/3. The lectures are given in English (if not all involved are Swedish-speaking).

Exercises and assignments can be performed individually, but preferably in groups of two persons. Deadlines for handing in reports are indicated in the course plan below.

Oral presentations of the respective Assignments 3 (a or b) are held by the students according to the course plan below. *Presence at each of these occasions is compulsory.*

Computer laborations: MV:F25 is booked according to the schedule below; presence is *not* compulsory; teachers are available for questions and oral examination of the exercises according to the course plan below.

Information about the assigmnents and exercises are found on the homepage
`http://www.math.chalmers.se/Math/Grundutb/CTH/mve165/0809`
This course information, assignment and computer exercise materials, and most hand-outs will also be found on this page.

COURSE PLAN (including literature references)**:**

Lecture 1 Monday 16/3, 13–15, MV:F33 **Week 12**
Introduction; course map; modelling optimization applications; linear, nonlinear and integer programs; graphic solution; software solvers.
(i): Chapter 1–2, 4. **(ii):** Chapter 1.1, 7.1–7.3, 8.1.

Lecture 2 Tuesday, 17/3, 13–15, MV:H11
Basic feasible solutions; the simplex method; degeneracy; unbounded solutions; starting solutions.
(i): Chapter 5.1–5.7, 3.5. **(ii):** Chapter 8.2, 9.

Lecture 3 Friday 20/3, 10–12, MV:H11
Sensitivity analysis; duality; economic interpretation; post-optimal analysis.
Information on Exercise 1.
(i): Chapter 7.1–7.6 (7.7). **(ii):** Chapter 7.4–7.5, 10.

Lecture 4 (Fredrik Hedenus) Monday 23/3, 13–15, MV:F33 **Week 13**
Application to Energy System Modelling. Information on Assignment 1.
(iii): Hand-outs.

Lecture 5 Tuesday 24/3, 13–15, MV:H11
Shortest paths; maximum flows; linear programming formulations of flows.
(i): Chapter 9.1–9.6 (9.7). **(ii):** $\emptyset$.

Computer laboration time Tuesday 24/3, 17–21, MV:F25
Oral examination of Exercise 1: 17–19.

Lecture 6 Friday 27/3, 10–12, MV:H11
Network flows, transportation and assignment models.
(i): Chapter 10.1–10.7. **(ii):** Chapter 8.1.

Deadline: Exercise 1 Friday 27/3, 24.00

Lecture 7 Monday 30/3, 13–15, MV:F331 **Week 14**
Discrete optimization models, applications.
(i): Chapter 11.1–11.6 (11.7). **(ii):** $\emptyset$.

Lecture 8 Tuesday 31/3, 13–15, MV:H11
Algorithms for discrete optimization models.
(i): Chapter 12.1–12.6 (12.7–12.8). **(ii):** $\emptyset$.

Computer laboration time Tuesday 31/3, 17–21, MV:F25

Lecture 9 (Adam Wojciechowski) Friday 3/4, 10–12, MV:H11
Exercises on linear programming, network models and integer linear programming.

Deadline: Assignment 1 Friday 3/4, 24.00
Hand in report.

Lecture 10 (Michael Patriksson) Monday 20/4, 13–15, MV:F33 **Week 17**
Application to Maintenance Planning. Information on Assignment 2.
(iii): Hand-outs.

Lecture 11 Tuesday 21/4, 13–15, MV:H11
Unconstrained non-linear programming.
(i): Chapter 3.1–3.4, 13.1–13.4. **(ii):** Chapter 4.1–4.3.

Computer laboration time Tuesday 21/4, 17–21, MV:F25

Lecture 12 (Peter Lindroth) Friday 24/4, 10–12, MV:H11 *Unconstrained non-linear programming algorithms.*
(i): Chapter 3.2–3.3, 13.5–13.6 (13.7–13.8). **(ii):** Chapter 11.1–11.5.

Lecture 13 Monday 27/4, 13–15, MV:F33 **Week 18**
Constrained non-linear programming and algorithms, optimality conditions. Information on Exercise 2.
(i): Chapter 14.1–14.7. **(ii):** Chapter 12.1, 4.4, 5.

Deadline: Assignment 2 Monday 27/4, 24.00
Hand in report, also to opponent.

Lecture 14 Tuesday 28/4, 13–15, MV:H11
Exercises on non-linear programming.

Computer laboration time Tuesday 28/4, 17–21, MV:F25
Oral examination of Exercise 2: 17–19.

Lecture 15 Monday 4/5, 13–15, MV:F33 **Week 19**
Multiple objective optimization and optimization under uncertainty.
(i): Chapter 8, 2.6, 1.6. **(ii):** ∅.

Deadline: Opposition of Assignment 2 Monday 4/5, 24.00
Hand in report.

Lecture 16 (Elin Svensson) Tuesday 5/5, 13–15, MV:H11
Application to Investments in Process Integration. Information on Assignment 3a.
(iii): Hand-outs.

Computer laboration time Tuesday 5/5, 17–21, MV:F25
Oral examination of Exercise 2: 17–19.

Computer laboration time Thursday 7/5, 17–21, MV:F25

Lecture 17 (Caroline Olsson) Friday 8/5, 10–12, MV:H11
Application to Radiation Therapy. Information on Assignment 3b.
(iii): Hand-outs.

Deadline: Exercise 2 Friday 8/5, 24.00

Computer laboration time Tuesday 12/5, 17–21, MV:F25 **Week 20**

Computer laboration time Thursday 14/5, 17–21, MV:F25

Deadline: Assignment 3 Friday 15/5, 24.00
Hand in report.

Lecture 18 Monday 18/5, 13–15, MV:F33 **Week 21**
Students' presentations of Assignment 3 (b), discussions. **Presence is compulsory**.
This lecture may be longer than two hours, depending on the number of presentations.

Lecture 19 Tuesday 19/5, 13–15, MV:H11
Students' presentations of Assignment 3 (a), discussions. **Presence is compulsory**.
This lecture may be longer than two hours, depending on the number of presentations.

RECOMMENDED EXERCISES:
(the exercises indicated are preliminary and may be adjusted during the course)

Exercises from the book by Rardin:

Chapter	Exercises
1	1–5, 8, 9
2	1, 2, 5, 6, 8, 10, 17–20, 25
3	1, 4, 6, 9, 11, 16, 17
4	2, 3, 7, 12
5	1, 3, 5, 6, 8, 10, 15, 16, 19, 23
7	5–7, 10, 12–17, 20
8	2, 6, 8, 14, 21, 33
9	2, 4, 6, 8, 14, 17, 20, 23, 30, 33
10	2, 4, 6, 7, 10, 12, 16, 18, 26, 28, 31, 40
11	2, 6, 7, 9, 12, 16, 21, 26
12	1–7, 9, 16, 19, 20, 27, 30, 32, 45
13	5, 7, 12–15, 18, 26–30
14	1, 3, 7, 9, 10, 23, 25, 29–32, 36, 48, 51

Exercises from the book by Andréasson et al. (does *not* cover the course)**:**

Chapter	Exercises
1	1, 2, 4
4	1–3, 6, 7
5	3–6, 8, 9
8	1, 2, 4–7
9	1, 2
10	1, 2, 7, 8, 13, 14
11	2–6
12	3–5