Guide for the Industrial Optimization Course Topics and Final Exam

Dear students:

Here is a detailed guide to help you study for the Industrial Optimization Course and the final exam. All the documents are on the “Modules” section of the canvas page.

**Topic : Lagrange Multipliers.**

1. Study the document "Lagrange\_Example" in the module “Introduction to Industrial Optimization”.
2. Study the video “Lagrange Multipliers – Khan Academy”, in the module “Introduction to Non-Linear Programing”.
3. Study the link “Geometric Interpretation of Lagrange Multipliers”, in the module “Introduction to Non-Linear Programing”.

Competences:

* Make sure that you can solve by hand simple optimization problems with equality constraints using Lagrange Multipliers.
* Understand the geometric interpretation of the Lagrange multipliers extrema points necessary conditions as those where the gradient of the function has the same direction than the gradient of the constraints (the contour lines representing the function and the equality constraint are tangent).

**Topic: Net Present Value Method**.

1. Study section 3.2 of the text book. Focus on the Net Present Value method.
2. Study the document: NPV: Problem3-12-Solution.docx in the section (under “Modules”) “Objective functions, control variables…”

Competences:

* Make sure you understand the concept of different value of money in time.
* Make sure you are able to calculate the Net Present Value of a project given an interest rate, using a simple calculator.

**Topic: Linear Programming**

1. Start by watching the "Videos 2" in the “Objective functions, control variables…” section (under “Modules”).
2. At this point just try to get an overall understanding of the problem, and how the model is settled. Notice the equality constraints that are generated by doing mass and energy balances (energy and mass conversations). Notice that the objective function and all the constraints (equality and inequality constraints) are linear. DO NOT SOLVE THE PROBLEM AT THIS STAGE.
3. Carefully read the tutorials on the link "Tutorials LP", in the module: “Introduction to linear programming”. These are tutorials from an MIT course on Optimization Methods on Management Science, and are some of the best tutorials I have found explaining LP (linear programming) in a clear and enjoyable form. Read carefully tutorials 1 to 4, and tutorial 6.   Tutorials 5 and 7 are optional.  NOTICE THAT THE EMPHASIS of the course is on formulating the optimization problems, i.e., establishing the objective functions, bounds and constraints, and NOT in the algorithms to solve them. For solving the problems we will use Excel and Matlab.
4. Solve the "Post Office" problem from Tutorial one in Excel.  Explore the solutions when the variables are treated as "real" numbers, and when they are forced to be integers (there is an option in Excel to indicate when a variable is integer). Chapter 7 of your text book has a detailed description on how to use the solver in Excel for Linear programming problems.
5. Watch the video “Videos 3”, in the module “Introduction to Linear Programming”. This video shows the solution of the optimization problem from Videos 2 in matlab.
6. Solve the problem in Matlab using the linprog function of the Optimization Toolbox, as shown on the video.
7. Solve the "Post Office" problem from the LP tutorial 1 in Matlab, using the linprog  and the intlinprog functions in matlab. Compare both results.  (You can type "help intlinprog" in matlab to get an example of how to use it, when some or all of the variables are integers.

Competences:

* You should be able to identify problems that can be modeled as a Linear Programing optimization problems, both for the case of real variables and integer variables.
* You should be able to state a Linear Programming problem in standard form (all the equality constraints are equal to zero, all inequalities constraints are less equal than zero).
* You should be able to transform inequality constraints into equality constraints using “slack variables”.
* You should be able to transform some simple non-linear constraints into linear constraints.
* You should be able to set up and solve Linear Programing problems using the Excel’s Solver.
* You should be able to set up and solve Linear Programming in matlab using the “linprog” and “intlinprog” functions in matlab.

**Topic: Nonlinear Programming.**

1. Watch the video presentation "Fundamental Concepts of Optimization" in module “Introduction to Nonlinear Programming”.
2. Watch the video: “Nonlinear Programing Numeric Methods” in the module “Introduction to Nonlinear Programming”. This video has a review of the use of gradients and hessians to solve optimization problems.
3. Study again the links "Lagrange Multipliers- Khan Academy", and "Geometric Interpretation of Lagrange Multipliers" in the “Introduction to Nonlinear Programming”. They have a nice justification and geometric interpretation of why the Lagrange method works, when we have equality constraints. Remember that inequality constraints can be transformed into equality constraints by using slack variables

Competences:

* You should be able to describe what is the general formulation for a general nonlinear programming (remember the word "programming" in this context means optimization) subject to equality and inequality constraints.
* You should understand the concept of "local optima" points and global optimum.  (In two the examples showed on the presentation of two-dimension problems, the global optimum is the bigger "bump" on the graphic, and the local optima all the smaller ones).
* Realize that in general, an optimization method can "not guarantee" that we find the global optimum.  Numerical optimization methods can easily get stuck on local optima points.
* Understand why starting the optimization methods from different initial values, can lead to different solutions representing local optimum.
* Understand that in the specific case that the function we are optimizing is convex and the feasible region is also convex, the optimum (a minimum for convex functions) is global.  Maximization problems of concave functions can be converted in minimization problems of convex functions by multiplying the function by minus one.
* Understand that Linear Programming and Quadratic Programming using positive definite weighting matrices are convex problems, so the solutions found by the numerical methods are global optima.
* Understand that in general, most non-linear programming problems are not convex, so we cannot guarantee that we find the global optimum.
* Be able to calculate by hand the Gradient and Hessian of simple functions.
* Understand the limitations of numeric optimization methods based on the gradient (Gradient descent method) and the hessian of the function (Newton’s method).

**Topic: Nonlinear programming applications.**

1. Watch the video "NonLinearRegression.mp4" in the module “Introduction to Nonlinear Programming”.  It shows an application of nonlinear programming to estimate parameters using the Least Squares method. There are many applications of nonlinear programming.  Estimation of parameters is just one. The problem solved in this example was selected from the document "Application Example: NonlLinearRegression.pdf", included in canvas as a link.
2. Watch the video "Video Example on Data Reconciliation" in the module “Introduction to Nonlinear Programming”  that shows how a data reconciliation problem (reconciliation information from several sensors) leads to a nonlinear optimization problem. This is another example of application on nonlinear programming.
3. Watch the video “Mass Balances Data Reconciliation: voice version” in the module “Introduction to Nonlinear Programming”. This video show a more general application of data reconciliation to mass flows in processes.

Competences:

* You should be able to set up and solve nonlinear least-squares regression problems using the Excel Solver and matlab.
* You should understand the relation between least squares regression and "maximum likelihood".
* You should be able to set up and solve (by hand if it is a simple problem, or using a computer for complex ones) data reconciliation problems involving redundant sensors and mass balances.
* You should be able to identify other kinds of problems in your area of engineering that can be modeled as a non-linear programming optimization problem (for example, Model Predictive Control).
* You should be able to set up and solve general nonlinear programming problems using the Excel Solver or different functions from the Matlab Optimization Toolbox.

**Topic: Mixed-Integer Linear and Non-Linear Programming**.

1. Read the following sections on chapter 9 of the text book (Optimization of Chemical Processes, Second Edition):
   1. Introduction.
   2. 9.1 Problem formulation.
   3. 9.2 Branch and bound methods using LP relaxations.
   4. Example 9.1 Branch and bound analysis of an integer linear program.
   5. Example 9.3 Optimal selection of processes.
   6. 9.6 Disjunctive programming.
2. Watch the zoom lecture from 05.10.20 (check link in the syllabus) and solve the example 9.3 in Excel (use the Excel Solver).

Competences:

* You should be able to identify problems in your area of engineering that can be modeled as mixed-integer, linear or nonlinear programming optimization problems (problems involving continuous variables, integer variables and binary decision variables).
* You should be able to set up and solve general nonlinear programming problems using the Excel Solver.

**Topic: Global Optimization**.

1. Watch the video: “Genetic Algorithms: voice version” in the “Global Optimization” module.
2. Watch the video: “Using Penalty Functions: voice version”, in the “Global Optimization Module”.
3. Study the examples on the “Global Optimization Toolbox Manual”. The link is provided in the “Global Optimization” Module.

Competences:

* You should understand the difference between “local search” and “global search” for optimization algorithms.
* You should understand the basic terms used in Genetic Algorithms.
* You should be able to set up nonlinear optimization problems and use the Genetics Algorithms function provided in the Matlab Global Optimization Toolboox to find approximate solutions.
* You should be able to use Penalty Functions to transform Optimization problems with constraints to equivalent non-constrained ones.

**Topic: Multi-Objective (Pareto) Optimization.**

1. Watch the video “Multi-Objective Optimization. Voice version”, in the “Multi-Objective (Pareto) Optimization” module.
2. Study the “Recommended Multi-Objective Optimization Presentation”, which link is provided in the “Multi-Objective (Pareto) Optimization” module.
3. Study the Pareto optimization examples provided on the Matlab Tutorial “Multi-objective Optimization”, which link is provided in “Multi-Objective Optimization in Matlab”, in the Multi-Objective (Pareto) Optimization

Competences:

* You should understand the concept of multi-objective optimization with conflicting objectives.
* You should understand the concept of “set of no dominated solutions”, or "Pareto Front".
* You should be able to obtain the Pareto front for simple problems involving the optimization of two conflicting objectives.
* You should be able to set up multi-objective problems and solve them using the Matlab Multi-Objective Optimization toolbox (obtain an approximation to the Pareto front).

I recommend you to work all the assignments and solve the past final exams. Remember you should complete and deliver at least half of the assignments plus one to me (usually 4 assignments). The deadline to deliver the assignments is November 11, 23:59. Remember that you need to deliver the assignments to have the right to take the final exam!

You must deliver the assignments through Canvas.

Regards,

Carlos F. Pfeiffer

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