Optimization

M.EIC – 2022.2023

HELLO!

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For this course you can also find me in moodle.up.pt and in Discord …(I'll send you the invite..)

OPTIMIZATION

Optimization & Operations Research

- Operations Research (O.R.) is the discipline of applying advanced analytical methods to help make better decisions.
- Central for any quantitative decision analysis are the foundation on mathematical models and the application of mathematical theories and methods such as mathematical programming/optimization, simulation, and graph theory.
- In this respect, model building can be viewed as the essence of the OR approach to problem solving, and optimization methods as OR’s powerful tool-box.

Optimization and Operational Research

Optimization

is a discipline within applied mathematics that deals with optimization models, their mathematical properties (optimization theory), and the development and implementation of algorithms.

Operational research

is the discipline of developing quantitative tools to assist decision-makers with complex decisions. Operational Research will generate user-friendly models, will provide a clear formulation of the criteria guiding the choices, and thereby rationalise the decision-making process.

- “Operational Research is the art of giving bad answers to problems where otherwise worse answers are given”

T.L.Satty

- “Operational Research is the art of winning wars without actually fighting”

Arthur Clarke

The origins of Operational Research (in the US it is called Operations Research)

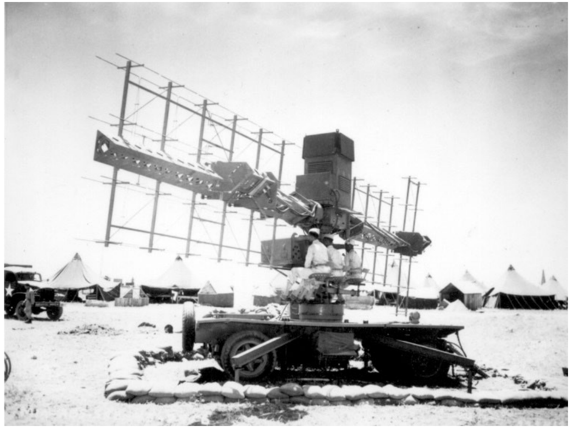
During 2nd World War, some military leaders asked for help to reputed scientists and mathematicians in order to analyse and solve several military operational problems:

- radar installation
- railways and submarine operations
- planning guard teams
- mines and bombs placing.

This field of study was initially called Military Operational Research

Later, since these methodologies and techniques could be applied to several different areas, the name was adapted to Operations Research in the USA.

https://www.youtube.com/watch?v=ILWbaWrjgU4



Optimization problems - General characteristics

- A limited quantity of resources.
- The resources are used for some activity (known as decision variables) such as to produce something or to provide some service.
- There are a number of alternative ways in which the resources can be used.
- Each activity in which the resources are used yields a return in terms of the stated goal (known as objective function)
- The allocation of resources is usually restricted by several limitations (known as constraints).

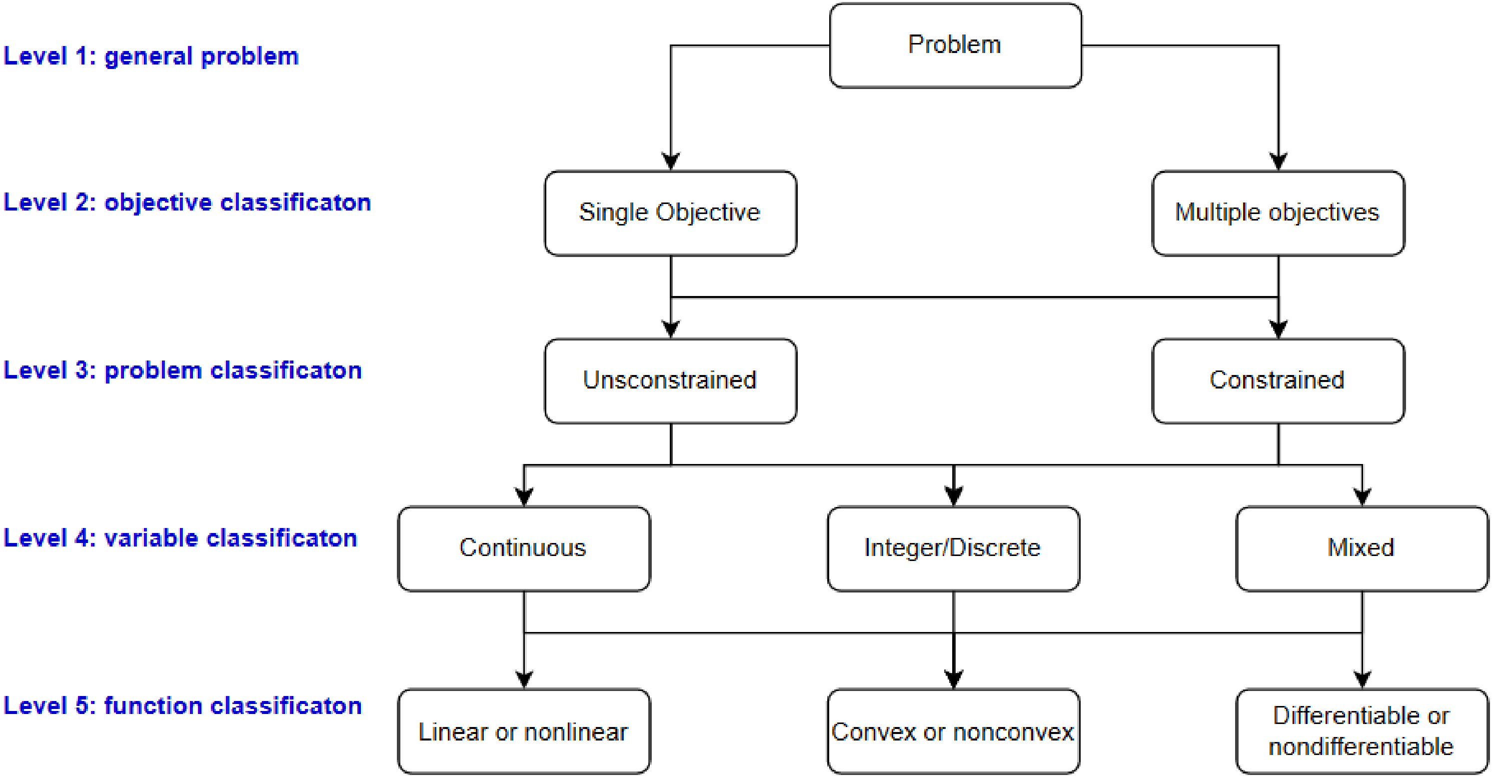
UPS ORION: Driving Performance by Optimizing Driver Behavior

- The number of possible routes a UPS driver can take on any day to make their deliveries is enormous.
- Optimizing the route for delivery, fuel, and time would save the company significant money. Unlike a traditional traveling salesman problem, finding the shortest route alone isn't the answer.
- Once ORION is fully deployed in the US, it's expected to save UPS up to $400 million per year and reduce greenhouse emissions by 100,000 metric tons every year.

- UPS contributes to the broader Data Science community through the UPS George D. Smith Prize.
- UPS looks at learning institutions that are preparing students to practice operations research in the field and having an impact.
- The award is a $10,000 prize and a very prestigious trophy.

Optimization problems

Classification



Course Syllabus

📌 Course Objectives

- To discuss the importance of modelling to the decision-making process.
- To discuss alternative modelling approaches for certain problem.
- To propose solution approaches and use of software packages in solving optimization models
- To model of a number of well-known theoretical problems and several interesting real-world problems.
- To present a brief review of some practical problems, with their modelling and solution approaches.
- To discusses the difficulties and practical issues of modelling, problem solving, and implementation of solutions.

Course Syllabus

- Linear Programming
  - Formulating Linear Problems
  - Solving LP: the Simplex Method
  - Discussing: Sensitivity Analysis & Duality
- Integer Programming
  - Formulating Integer and Mixed Integer Linear Problems
  - Solving IP & MILP: Branch & Bound
  - Discussing: Comparing alternative formulations
- Decision Theory
  - Decision trees and the value of information
  - Behavioural economics

Course structure

- During this semester, we will be using IBM CPLEX Studio and/or Excel Solver for solving optimization problems.
- Each class (3h) will have two parts:
    - 1st part (1h30) - Theoretical concepts and exercises
    - 2nd part (1h30) - Using CPLEX to formulate and solve problems
- In some classes, students may be asked to present and discuss a paper with an approach to a particular problem

Evaluation

Course Evaluation

- In class work: 20%
- Homework assignments: 20%
- Group Project (3 students): 20%
- Exam: 40%

Let’s have a break

Methodology of OR

The scientific method consists of the application of the following phases that overlap and interact with each other.

1. Problem definition and data gathering
2. Modeling the problem through a mathematical formulation
3. Model validation
4. Obtaining one (or more) solutions for the proposed model
5. Implementing the obtained solution or system

1. Problem definition and data gathering

Need to:

- study the organization and the system for which the problem appears
- Identify the decision agents
- Identify the main objectives of the organization (strategic, tactical, operational)
- Select the objectives suited for the problem
- Identify the minimal, reasonable, and ideal levels for objective satisfaction

Need of multidisciplinary teams, gathering and selecting relevant information:

- already available (databases, other systems)
- to collect (e.g: a new database, surveys)

2. Modeling the problem

A model: an idealized representation of reality

Mathematical model: a set of mathematical expressions representing the behavior of a complex system.

Choosing the most adequate model is a complex task:

- When the model is too simple, probably it will not consider some important aspects of the problem.
- When the model is too complex, it may no not be computationally tractable

A problem may be modeled in different ways, so choosing the appropriate model could be a success decision factor for the project.

It is very important to consider the availability and precision of the model input data.

2. Modeling the problem (2)

There are four broad categories of mathematical models:

1. descriptive model, which allows the analyst to represent some physical situation in a visual mode. Simulation models and queuing models belong to this category.
2. normative or optimization model, also called the prescriptive model. Most of the techniques, such as linear programming, transportation algorithms, and project management techniques fall into this category. These types of models aim to optimize some objective function subject to certain limitations.
3. heuristic model, that basically employs rules of thumb or intuitive rules, typically guided by common sense. Heuristic models provide good solutions, but not necessarily optimal.
4. predictive model, which has been developed so that estimates of future trends can be made, for example, in areas such as manpower planning and financial planning. This category includes models of regression and time series analysis.

Guidelines for building models

Simple: Models should be kept as simple as possible so that they can be described in terms that can be understood by non-specialists, who often do not have a scientific background.

Robust: Models should be developed so that they are general enough to give valid answers over a wide range of input values.

Adaptive: If a model is developed to represent the real world, which is a very dynamic system, then the model must be sufficiently adaptive to be able to incorporate those rapid changes, which may be experienced in the present or future worlds.

Complete: As models are to represent the total problem and its environment, the model should address all aspects of the problem and not just some components of the problem.

User friendly: The user must be able to change inputs easily and to obtain answers quickly without having to rely on expert support.

3. Model validation

Usually implies the implementation and execution of the chosen algorithm in order to guarantee that:

- The input data and parameters do not contain errors
- The algorithm does not have logical errors
- The software does not have errors
- The algorithm represents correctly the model
- The results seem reasonable: sometimes, the algorithm is executed with historical data (if available) and the algorithm results are compared with the real past results.

4. Solving the model

We can use generic software (Excel, CPLEX) or develop a particular algorithm for the specific problem.

The proposal of a solution involves the analysis of several solutions obtained under different conditions in order to acquire some sensibility to the data variability.

- For example, if the input data was different would the solution be affected? Why or why not? This type of questions is called what-if analysis.

Attention: the optimal solutions are obtained for a particular model !!

- they should correspond to “satisfying” solutions for the problem.
- the ideal solution may not be attainable.

5. Implementing the obtained solution

Implementation of the results of the study or the algorithm as an operational tool or a software application.

Many OR projects successfully cross the previous phases and fail in the implementation ☹ lots of work that will not have any effect in the organization…

In order to avoid this, we must:

- Timely plan the implementation phase;
- Involve the client since the beginning;
- Provide adequate formation to the users;
- Provide user manuals and project documentation;
- Keep on testing and validating the proposed solutions, correcting deviations that can still occur.

- *It's better
to solve approximately the exact problem than
to solve exactly the approximate problem*

“

Some interesting videos about OR

- https://www.youtube.com/watch?v=0oMVVx81kCs
- http://www.youtube.com/watch?v=-dKKN-hnDzI
- http://www.youtube.com/watch?v=bS9Py1vDFUM
- http://www.youtube.com/watch?v=tEXUV8vsDo8
- http://www.youtube.com/watch?v=u2u-PRopD4M