CIVIL-557

Decision Aid Methodologies In Transportation

Lecture 1:
Introduction to decision science

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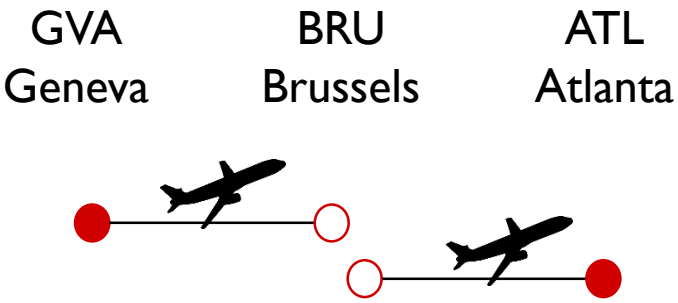
Introduction

DELTA

Introduction



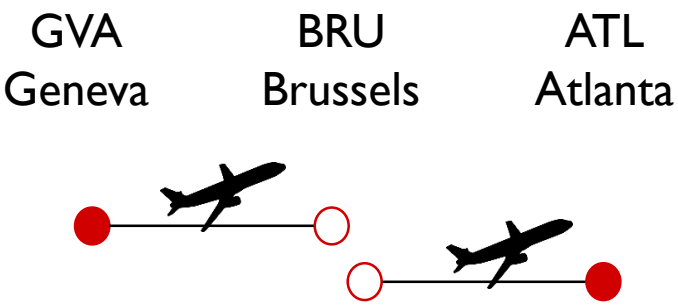
Which aircraft type should be assigned to each flight leg?

Airline fleet assignment problem

Maximize revenues from seats - finding the optimal balance:

1. Demand > Capacity
2. Demand < Capacity

Introduction



Which aircraft type should be assigned to each flight leg?

Minimizing operating costs:

- Flight crew
- Fuel consumption
- Maintenance operations
- …

Under a variety of constraints:

- Cover constraint
- Balance constraint
- Availability constraint
- …

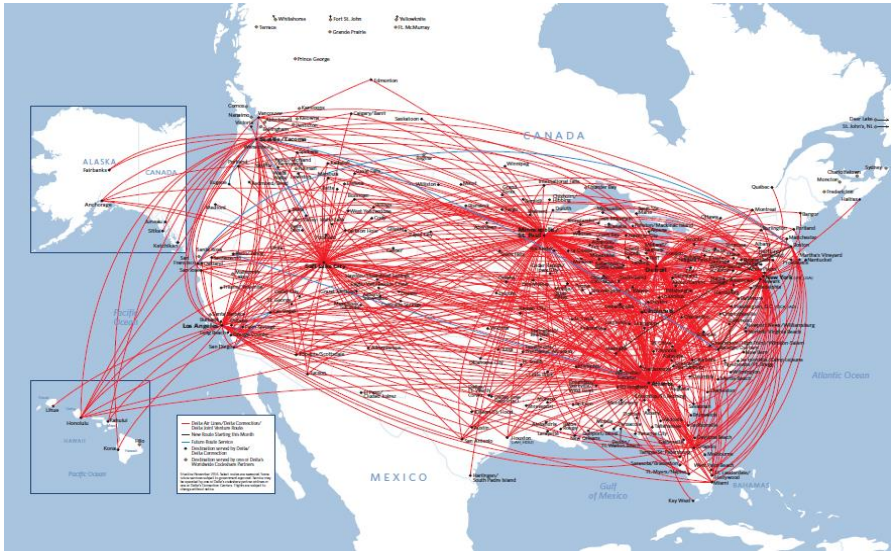
Introduction

Delta Air Lines international network:

- **325 destinations**
- **60 countries**
- **6 continents**

- Over **5,400 daily flights**
- More than **800 aircraft**
- **19 different fleets**

North America



Introduction

Fleet Assignment at Delta Air Lines:

- *September 1992:*

How to solve this problem ?

Coldstart system (1992)

- Use advances in mathematical programming and computer hardware
- Savings in the June 1, 1993 to August 31, 1993 schedule: **$220,000/day**

The Coldstart system is a successful real-world applications of Operation Research

Introduction

What is Operations Research?

Operations Research (O.R.) is ***a discipline*** *that deals with the* ***application of advanced analytical methods*** *to help make* ***better decisions****.*

INFORMS, *What is Operations Research ?*

Operations research encompasses a wide range of ***problem-solving*** ***techniques and methods*** *applied in the pursuit of* ***improved decision-making*** ***and efficiency*** *(…).*

INFORMS, *What is Operations Research ?*

In its most basic form, Operations Research (O.R.) may be viewed as a ***scientific approach to solving problems****; it abstracts the essential elements of the problem into* ***a model****, which is then* ***analyzed to yield an optimal solution for implementation.***

Jayant Rajgopal, *Principles and Applications of Operations Research*.

OR: The ***Science of Better****.*

INFORMS, http://www.scienceofbetter.org/.

Introduction

Introduction

"Trying to wrangle a clear definition of analytics, statistics, data science, machine learning, and even operations research can be as messy as cleaning up a typical data set! These are distinct disciplines, related but not the same. Increasingly analytics is used synonymously with data science, which is derived in large part from statistics, which also is a foundation for machine learning, which relies upon from optimization techniques, which I'd argue are part of analytics".

Agenda

- Lecture (8:15 – 10:00)
  - Course information
  - Operations research modeling approach
- Lab (10:15 – 12:00)
  - Practice examples

Course information

Course information

- 2 lecturers :
  - Dr. Virginie Lurkin
  - Dr. Nikola Obrenovic
- Course based on concrete case studies
  - Lectures: 2 hour(s) per week x 14 weeks
  - Exercises: 2 hour(s) per week x 14 weeks
- 1 guest lecture:
  - Dr. Iliya Markov from BestMile
  - Dr. Alessandro Zanarini from ABB

Evaluation

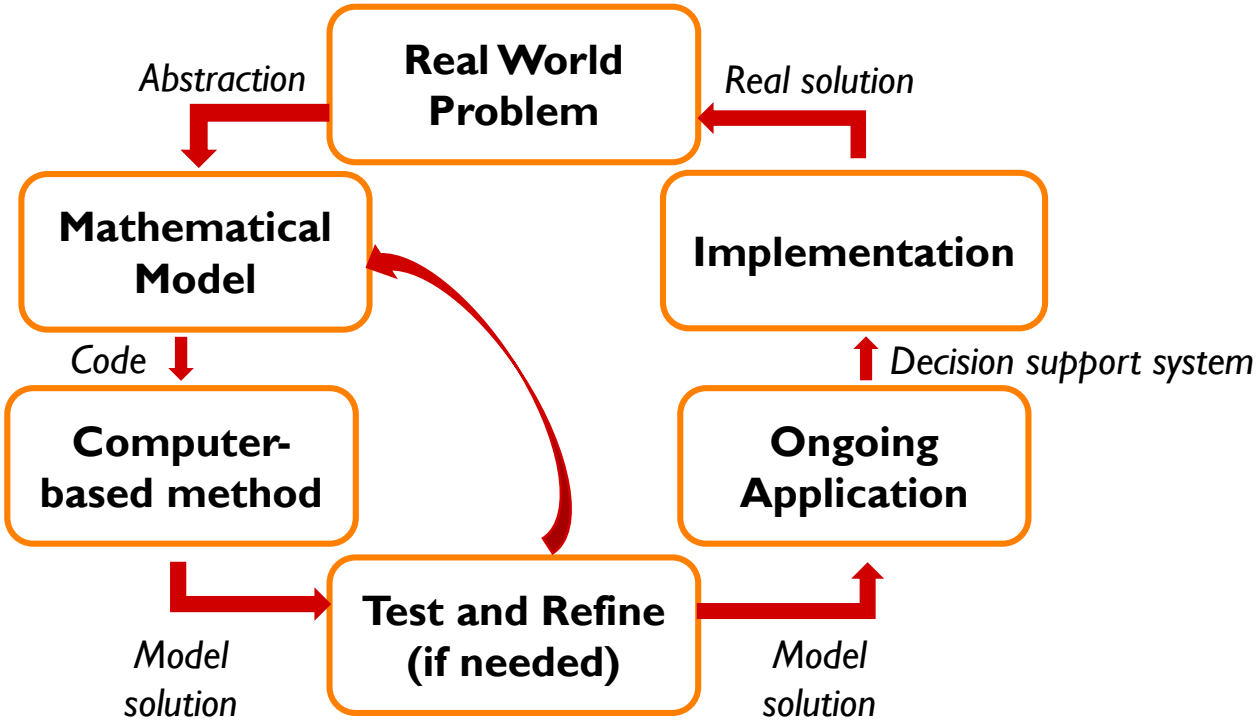
- **Mid-term exam (20%)**
  - **20 multiple choice questions**
- **Final exam (80%)**
  - **Groups of 2-3 members each**.
  - **Oral exam** organized in June
    - **Project-based**
    - **Presentation of maximum 20 minutes**
    - Questions about the presentation itself, but also on any material covered during the semester
    - **No authorized material**

Lectures

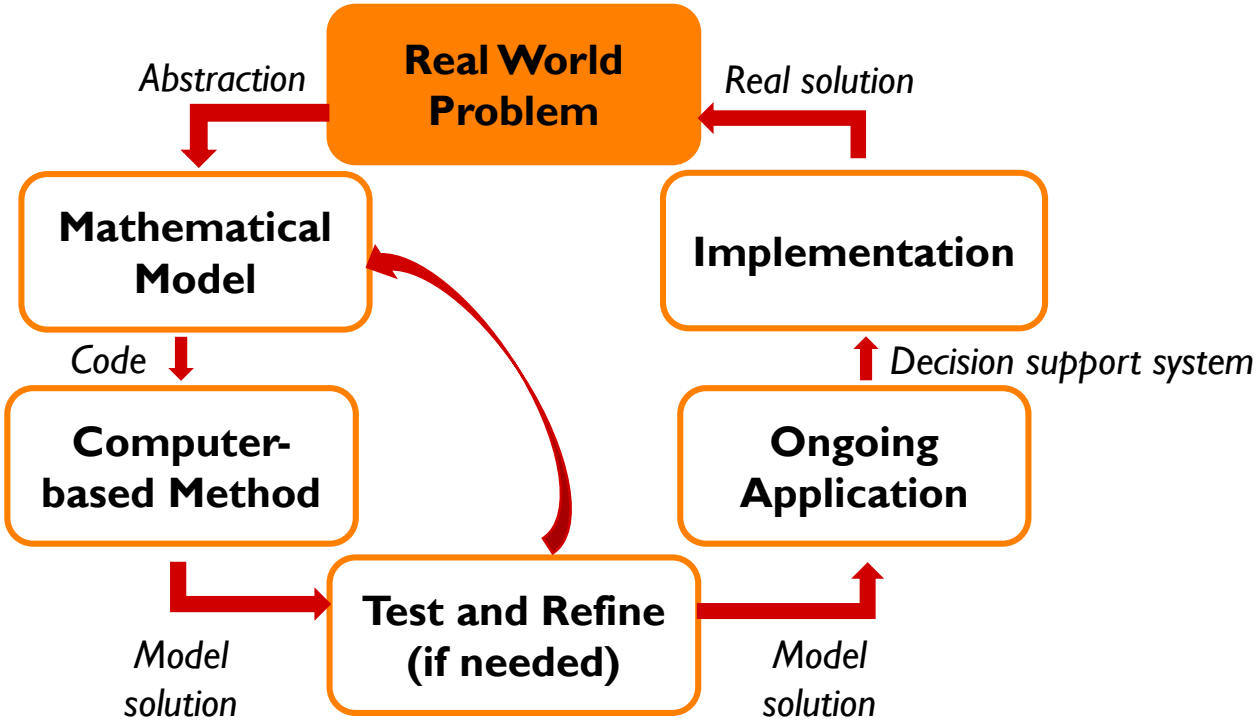
Date	Lecturer	Topic
Feb 20	Virginie Lurkin	Introduction to decision science
Feb 20	Virginie Lurkin	Modelisation and Linear Programming
mars-06	Virginie Lurkin	Linear Programming and Duality
mars-13	Virginie Lurkin	Integer programming I: Branch and Bound
mars-20	Virginie Lurkin	Integer programming II: Valid Inequalities
mars-27	Guest Speakers	Operations Research in Practice
Apr 3		No Lecture (Easter Holidays)
Apr 10		Mid-term exam
Apr 17	Nikola Obrenovic	Multicommodity Network Design I - Exact Methods
Apr 24	Nikola Obrenovic	Multicommodity Network Design II - Heuristics
May 5	Nikola Obrenovic	Data Mining in Transportation I
May 8	Nikola Obrenovic	Data Mining in Transportation II
May 15	Nikola Obrenovic	Data Mining in Transportation III
May 22	Virginie Lurkin	Research Topics from TRANSP-OR and Presentation of the Final Projects
May 29	Virginie Lurkin	Questions and Answers

Overview of the operations research modeling approach

6-steps O.R. Modeling Approach



6-steps O.R. Modeling Approach



Defining the problem of interest

Textbook examples	Real-world problems
Described in a simple, precise way	Described in a vague, imprecise way

"It is difficult to extract a *right* answer from the *wrong* problem"

- Real-world problems are **complex**, **multi-dimensional problems**
- Importance of developing a **well-defined statement of the problem**

Delta Air Lines Example

- What are the appropriate objectives ?
- Are there constraints on what can be done ?
- Are there interrelationships with other areas of the organization?
- Is there a time limit to make a decision?
- …

Defining the problem of interest

- OR team members are advising management
- Tradeoff between operational cost and quality of service provided to the users
- Different parties with different objectives
  - Owners
  - Employees
  - Customers
  - Suppliers
  - Government

Delta Air Lines Example

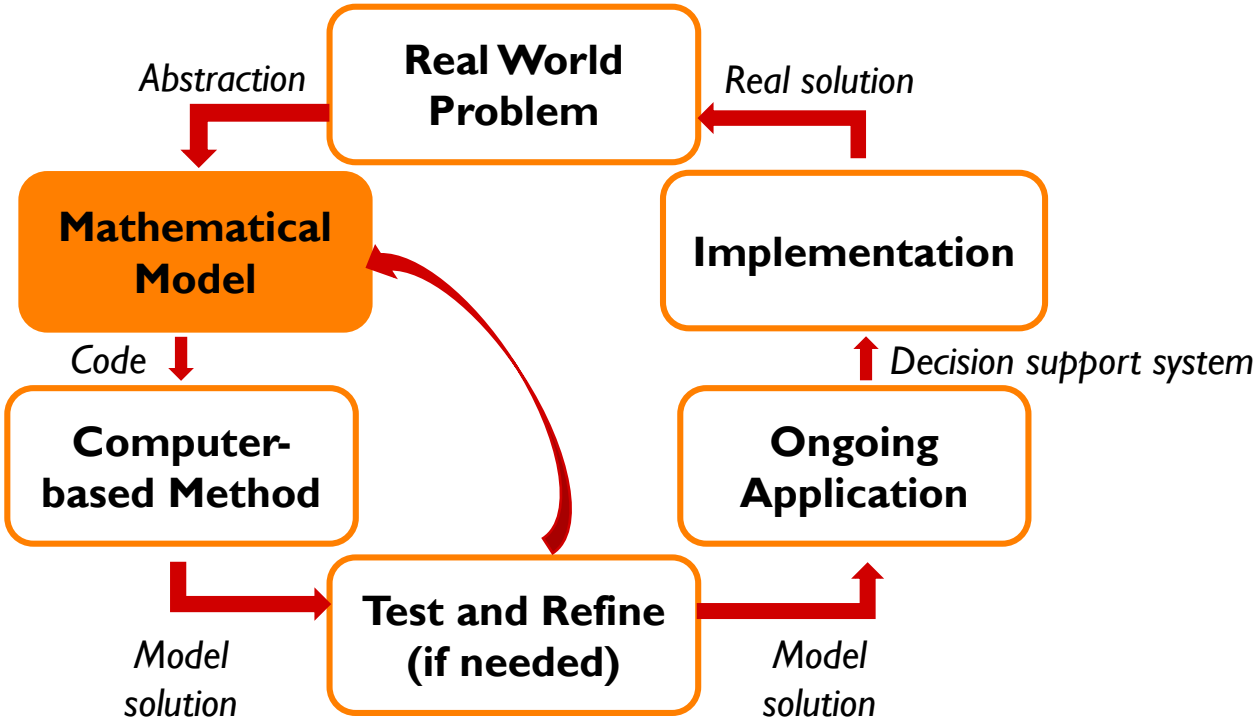
- OR should be concerned with the welfare of the entire organization

Gathering relevant data

- Gathering relevant data is crucial but takes time
- Much data are needed to:
  - Gain an accurate understanding of the problem
  - Provide the input for the mathematical model
- Much data are not available when the study begins:
  - Information has never been kept
  - What was kept is outdated or in the wrong form
  - Information is confidential
- Much effort has to be devoted on gathering all the needed data
- Most of the time you only have rough estimates

Delta Air Lines Example

6-steps O.R. Modeling Approach



Formulating a mathematical model

- A mathematical model is used as an abstraction of the real-world
- There are pros and cons:
  - Standardized form of displaying a decision problem
  - Reveal cause-and-effect relationship
  - Indicate more clearly what data are relevant
  - Enable the use of high-powered mathematical techniques and computers
  - Abstract idealization of the problem
  - Require approximations and simplifying assumptions
  - Rely on the experience and judgment of the modeler
  - Are the result of a trade-off between precision and tractability

Main components of the mathematical model

Three main components:

1. **The decision variables**:
   - The decisions to be made
   - Their respective values have to be determined

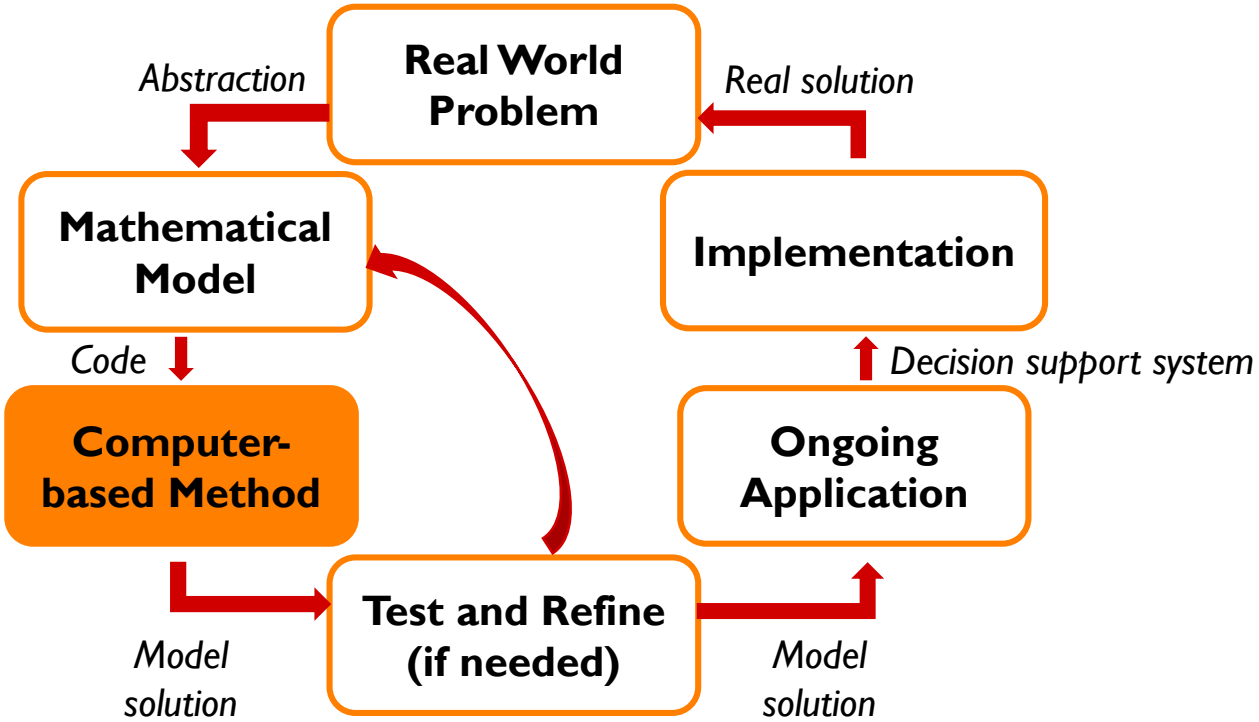
Delta Air Lines Example

2. **The objective function**:
   - The goal to achieve
   - Mathematical function of the decision variables

3. **The constraints**:
   - Any restriction on the values that can be assigned to the decision variables
   - Mathematical expressions of the decision variables

Determine the values of the decisions variables so as to minimize/maximize the objective function, subject to the specific constraints.

6-steps O.R. Modeling Approach



Developing a computer-based method

- A **computer-based algorithm** is used to solve the model
- Two main categories of optimization algorithms:
  1. **Exact methods**
     - Guarantee to give an optimum solution of the problem
     - Can be very expensive in terms of computation time on large-size problem instances
  2. **Heuristics**
     - Attempt to yield a good, but not necessarily optimum solution
     - Used for their speed

Balance between the quality of the solution and the time spent on computation

Post-optimality analysis

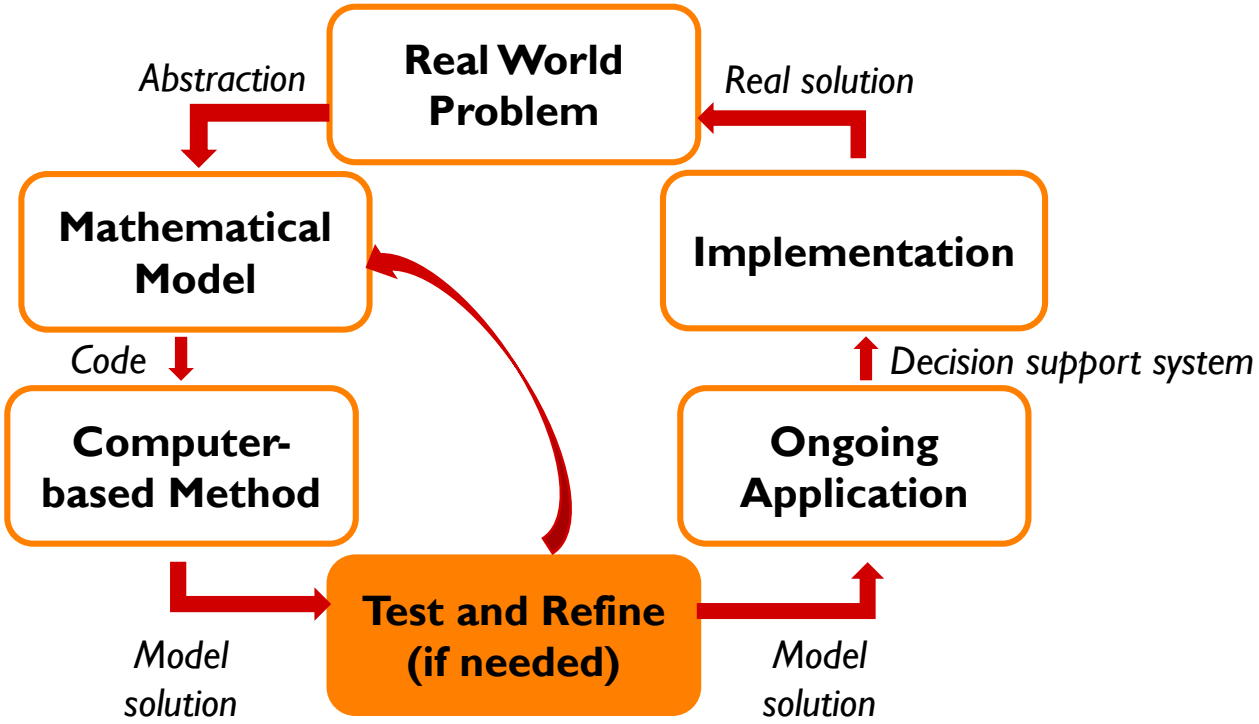
- Post-optimality analysis is important:
  - Sensitivity analysis:

Delta Air Lines Example

    - What if the demand for some specific flights increases or decreases?
    - What if the cost of operating some flights increases or decreases?

  - Scenario analysis:
    - Analyzing possible future events by considering alternative possible outcomes
    - Different recommendations can be concluded for each scenario

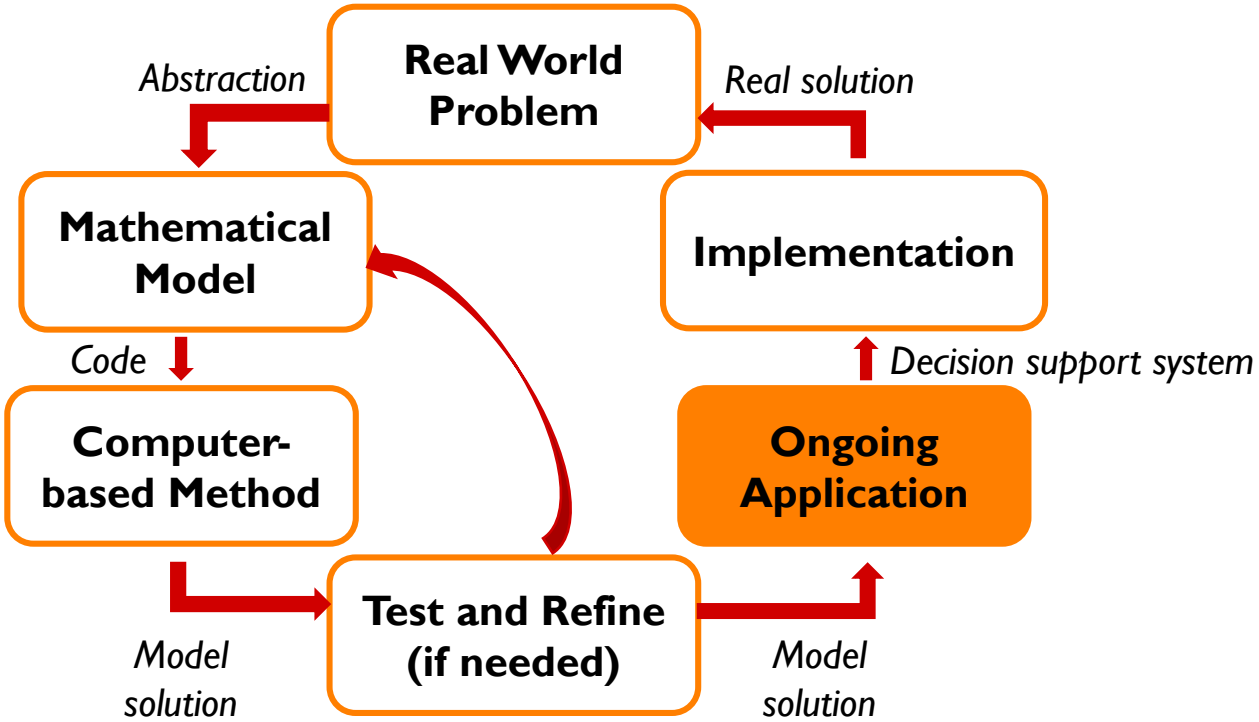
6-steps O.R. Modeling Approach



Testing the model

- The first version of a computer program often contains bugs
- A long succession of tests is needed
  - Tests can reveal flaws in the mathematical model
  - Tests lead to a succession of improved models
- Model validation is the process of testing and improving a model:
  - Preimplementation phase
  - Feedback from the user team
- Documenting the process used for model validation is also very important

6-steps O.R. Modeling Approach

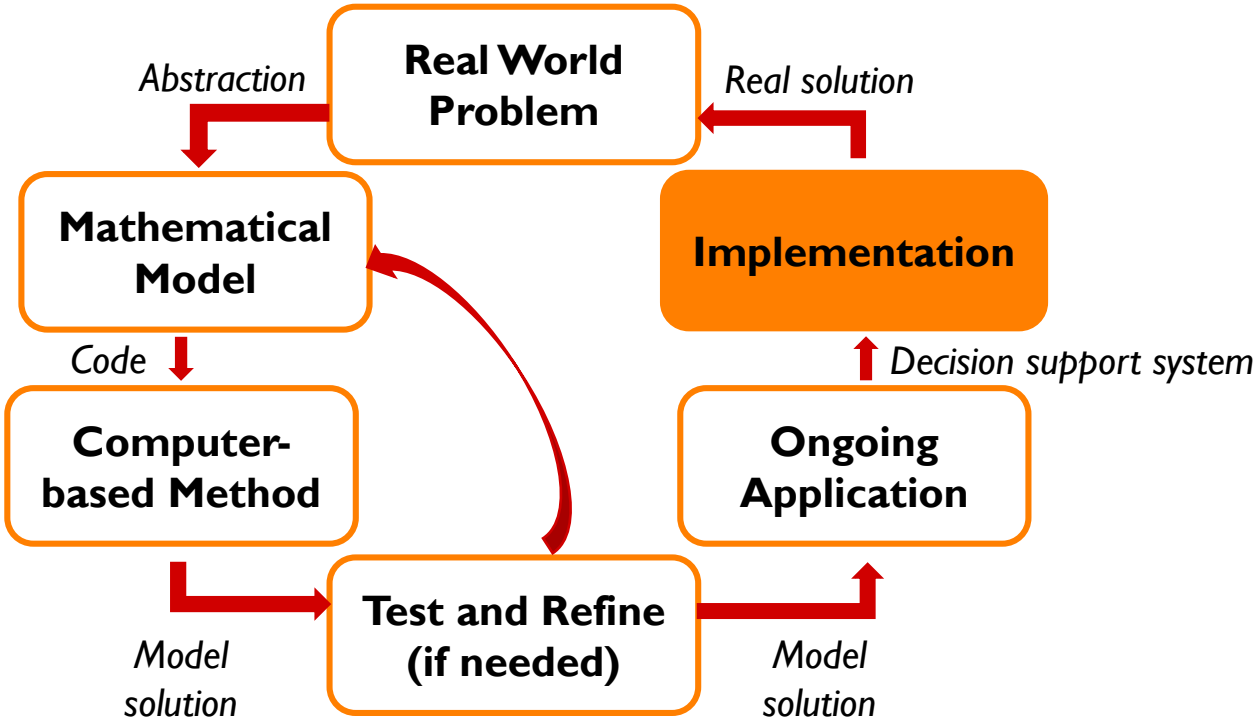


Preparing to apply the model

- Developing a **well-documented** **decision support system** is critical
- This system includes:
  - The model
  - The solution procedure
  - The operating procedures for implementation
- The system is usually **interactive** and **computer-based**
- **Maintaining** this system throughout its future use is very important

Delta Air Lines Example

6-steps O.R. Modeling Approach



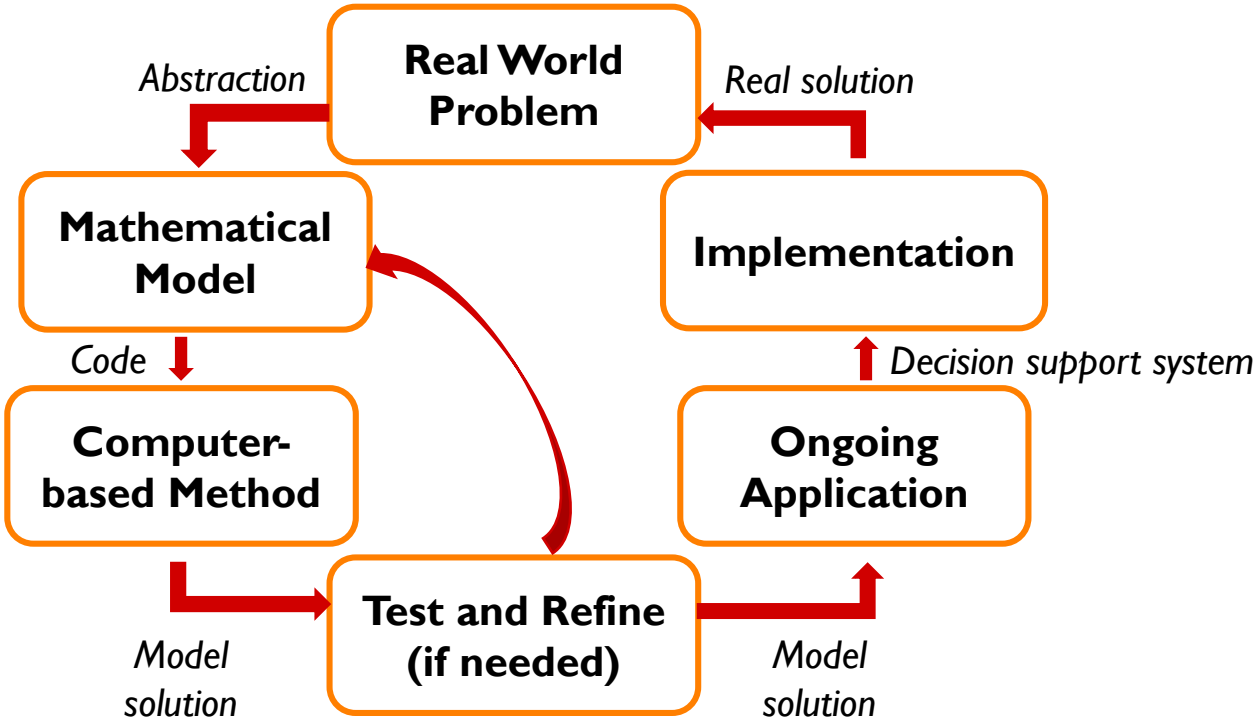
Implementation

- Implementation is a **critical phase**
- Success depends on the support of the top management:
  - Sell the concept
  - Demonstrate the effectiveness of the system
- Success depends on the support of the operation management:
  - Provide the needed support tools
  - Train the personnel who will use the system
  - Convince the personnel of the usefulness of the system

Implementation

- **Good communication** is needed
- **Continuous feedback** on:
  - How well the system is working
  - Whether the assumptions of the model continue to be satisfied

6-steps O.R. Modeling Approach



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"Operational research is no longer abstract calculus: we're solving real day-to-day business challenges"

Michael Trick's Operations Research Blog
Thoughts on the world of operations research

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Practice examples

Decision Aid Methodologies **in Transportation**

Focus on the Transport & Logistics industry

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Cargo loading problem

How to optimally load a set of containers/pallets (ULDs) into a cargo aircraft that has to serve multiple destinations under some safety, structural, economical, environmental and maneuverability constraints?

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Rolling stock allocation problem

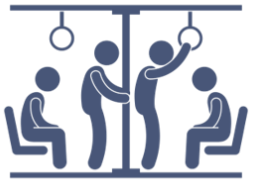
How to optimally assign physical train units to timetable schedules?

Number of unit-kilometers

Passenger travel time

Number of composition changes

Shortage of seats



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Railway cargo network design problem

What is the optimal number and location of marshaling and shunting yards in a railway network in order to reduce freight transport and shunting costs?

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Passenger centric train timetabling problem

How to optimally design a timetable?

Cyclicity?

Profit

Passenger travel time

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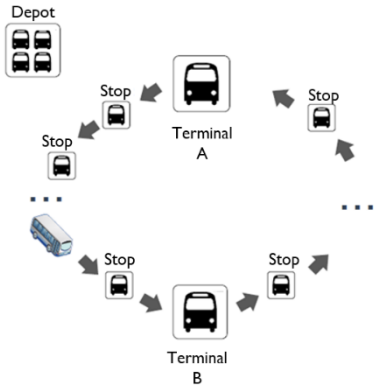
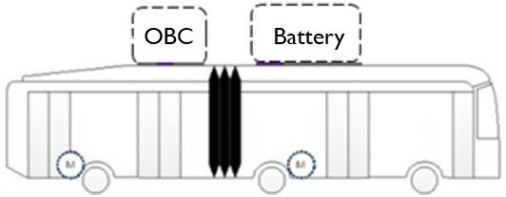
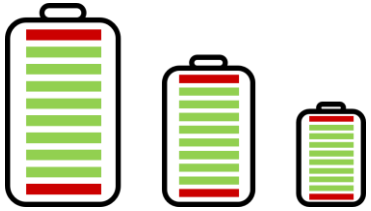
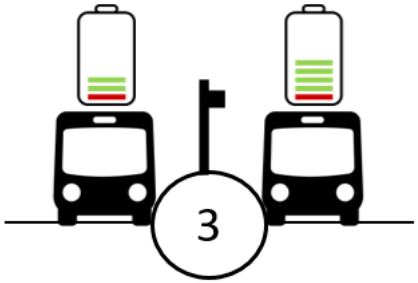
Network design problem for battery electric bus

At which stations should we install a feeding station, which type of feeding station should be installed at these stations and with which battery should we equip the buses in order to minimize the total cost of the system ?









Laboratory

- Lecture (8:15 – 10:00)
  - Course information
  - Operations research modeling approach
- Lab (10:15 – 12:00)
  - UPS example

Main references

- Gass, S. I. (1983). Decision-aiding models: validation, assessment, and related issues for policy analysis. Operations Research, 31(4), 603-631.
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- Rajgopal, J. (2004). Principles and applications of operations research. Maynard's Industrial Engineering Handbook, pages11-27.