Introduction
Operations Research Technologies

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Overview of the presentation

- Presentation of the course
  - Content
- Operations research technologies
  - General definition
  - Operations research vs practical methods
  - Origins of the field
  - Scientific approach
- Application examples

Presentation of the course

Content

General themes :

1. Modeling decisional problems
   - Understanding the context in which decisional problems appear
   - Define what constitutes a solution to the problems
     - What are the decisions to make ?
   - Define the criteria used to evaluate the possible solutions
     - What are the objectives pursued ?
     - What goals need to be reached ?
   - Define the limits / restrictions that need to be enforced
     - What defines a feasible versus infeasible solution ?
   - **Important considerations**
     - Quantitative elements $\Rightarrow$ Objective measurements
     - Qualitative elements $\Rightarrow$ Subjective measurements

Presentation of the course

Content

General themes (cont'd) :

2. Solution algorithms
   - Prescriptive numerical tools
   - Exact methods
     - Provide an ***optimal solution***
     - Apply systematic search
   - Heuristic methods
     - Provide a ***feasible solution***
     - Exploit specific characteristics of the optimization model
   - Quality vs. effort
3. Simulation methods
   - Descriptive numerical tools
   - Formulate and represent complex decisional contexts
     - Stochastic parameters

Operations Research Technologies

General definition

- Operations research field :

  Definition Operations research, or operational research, is a discipline that deals with the application of advanced analytical methods to help make better decisions.

  It employs techniques from other mathematical sciences (i.e., mathematical modeling, statistical analysis, and mathematical optimization), to find optimal or near-optimal solutions to complex decision-making problems.

  see "About Operations Research", INFORMS.org

- Problems addressed
  - Critical path analysis (project management)
  - Floor planning
  - Network optimization
  - Allocation problems
  - Assignment problems
  - Routing
  - etc.

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Operations research vs practical methods

- In practical settings :
  - Managers oftentimes apply intuition to solve problems
  - Is it always a good idea ?
- Intercity truck transportation

Problem 1 : Load assignments

Context : A company has seven trucks, which are currently located in seven different cities. Seven loads, each corresponding to a truck's capacity and also located in a specific city, need to be collected and then delivered to a final terminal. Therefore, each load will be assigned to a single truck and each truck will be used to transport one of the loads to the final destination.

Objective :

The company is interested in minimizing the total distance travelled to bring the seven loads to the final terminal.

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Operations research vs practical methods

- Intercity truck transportation (cont'd)

Distances (km) :

	Loads						
	1	2	3	4	5	6	7
Trucks	NY	NY	Dover	Paterson	Flemington	Easton	Newton
1 Scranton	229	229	139	176	146	116	125
2 Honesdale	212	212	114	155	153	123	91
3 Franklin	111	111	32	54	108	81	25
4 Edison	62	62	69	68	46	81	82
5 Princeton	92	92	84	95	38	88	89
6 Warwick	116	116	62	69	130	111	44
7 Newark	54	54	43	26	80	101	76

Question :

How should the company proceed to solve this transportation problem ?
$\rightarrow$ **Exercise**.

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Operations research vs practical methods

- Intercity truck transportation (cont'd)

  Intuitive solution approach :

  1. Treat assignments one by one
  2. For each assignment, identify, among all available options, the one that minimizes the distance travelled

  Heuristic method ⇒ **Greedy algorithm**

  Question : Is this the best approach to solve the problem ?

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Operations research vs practical methods

- Intercity truck transportation (cont'd)

Solution comparison

Greedy Solution		Optimal Solution	
Assignments	Distance	Assignments	Distance
$1 \to 6$	116 km	$1 \to 6$	116 km
$2 \to 1$	212 km	$2 \to 7$	91 km
$3 \to 7$	25 km	$3 \to 3$	32 km
$4 \to 2$	62 km	$4 \to 1$	62 km
$5 \to 5$	38 km	$5 \to 5$	38 km
$6 \to 3$	62 km	$6 \to 4$	69 km
$7 \to 4$	26 km	$7 \to 2$	54 km
Total	541 km	Total	462 km

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Operations research vs practical methods

- Intercity truck transportation (cont'd)

Advantages of the greedy algorithm

- Extremely fast
- Easy to implement

Disadvantages of the greedy algorithm

- Does not necessarily produce the best solution to the problem

Systematic search approach :

1. Enumerate all the possible solutions to the problem
2. Evaluate the total distance traveled for each possible solution
3. Choose the solution for which the total distance is minimum

Exact method $\Rightarrow$ **Complete Enumeration**

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Operations research vs practical methods

- Intercity truck transportation (cont'd)

Assumption

Using a computer capable of treating (i.e., finding and evaluating) one billion solutions within one second of computation time

Computation time as a function of the size of the problem, where n represents the number of trucks / loads

n	$n!$	Computation time
3	6	6 nanoseconds
5	120	120 nanoseconds
15	$\approx 1,307674 \times 10^{12}$	$\approx$ 22 minutes
20	$\approx 2,432902 \times 10^{18}$	$\approx$ 77 years

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Operations research vs practical methods

- Intercity truck transportation (cont'd)

Advantages of complete enumeration

- Finds an optimal solution to the problem

Disadvantages of complete enumeration

- Extremely long search process in the case of larger problems

Operations Research proposes technological tools to solve these types of problems (i.e., **Assignment Problems**)

These tools are much more efficient than either the greedy method or the complete enumeration procedure

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Operations research vs practical methods

- Intercity truck transportation (cont'd)

  Using such technological tools, the computation time as a function of the size of the problem n are as follows

n	Assignment Problem
10	$<$ 1 seconds
50	1 seconds
100	2 seconds
200	10 seconds

Operations Research Technologies

Operations research vs practical methods

- Managing human ressources

Problem 2 : Planning schedules

Context : A company needs to plan its needs for a certain type of staff for the next day of operations. The following table provides the minimum numbers of staff members that need to be present to perform operations throughout the next day.

Objectives :

Minimize the number of staff that are scheduled for the day, **or**, minimize the number of hours they work

Periods	:00 à :15	:15 à :30	:30 à :45	:45 à :60
06 :00	-	-	2	2
07 :00	2	3	3	3
08 :00	3	3	3	4
09 :00	4	5	5	5
10 :00	4	3	3	2
11 :00	3	3	3	3
12 :00	3	3	2	2
13 :00	1	1	2	2
14 :00	2	2	2	2
15 :00	2	2	3	3
16 :00	3	3	3	3
17 :00	3	2	4	4
18 :00	4	4	4	4
19 :00	4	3	3	3
20 :00	3	4	4	4
21 :00	3	2	3	3
22 :00	3	2	2	2
23 :00	2	2	2	2
24 :00	1	1	1	1
01 :00	1	-	-	-

Operations Research Technologies

Operations research vs practical methods

- Managing human ressources (cont'd)

Considered staff are unionized and their collective agreement specifies the following conditions :

- A staffer must work at least 4 hours on a day shift
- A staffer can work at most 10 hours on a day shift

Greedy algorithm :

1. Establish the next scheduled shifts at the earliest non-covered period of the day
2. Number of required staff $\Rightarrow$ required number of staff to cover the identified period
3. Shifts are prolonged as far as possible without exceeding the required minimum number of staff of subsequent non-covered periods, while enforcing union requirements

Operations Research Technologies

Operations research vs practical methods

- Managing human ressources (cont'd)

Solution comparison

Greedy Solution		Optimal Solution	
Number	Shift	Number	Shift
2	06 :30 à 13 :00	2	06 :30 à 10 :30
1	07 :15 à 12 :30	1	07 :15 à 12 :30
1	08 :45 à 13 :30	1	08 :45 à 13 :00
1	09 :15 à 13 :15	1	09 :15 à 19 :15
2	13 :30 à 23 :30	1	13 :30 à 21 :00
1	15 :30 à 21 :15	1	15 :30 à 24 :00
1	17 :30 à 01 :15	1	17 :30 à 22 :15
1	21 :15 à 01 :15	1	20 :15 à 01 :15

In terms of the objectives

- Greedy solution $\Rightarrow$ 10 employees who will work 64.5 hours
- Optimal solution $\Rightarrow$ 9 employees who will work 53.25 hours

Operations Research Technologies

Origins of the field

- The Industrial Revolution

  Description : transition to new manufacturing processes in the period from about 1760 to sometime between 1820 and 1840

  - manual/hand production methods $\Rightarrow$ machines
  - new processes (manufacturing and iron production)
  - $\Uparrow$ steam power and factory systems
  - Development of machine tools

- Managing projects of ever increasing complexity
  - Hydroelectric Dams
  - Interstate highway systems

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Origins of the field

- Taylorism

  Description : theory of management that analyzes and synthesizes workflows and whose main objective is improving economic efficiency and labour productivity

  - measuring and evaluating simple operations
  - use measurements for better management

- Fordism

  Description : standardization of mass production processes and the development of more efficient production chains

  - Taylorism applied on more complex operations

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Scientific Approach

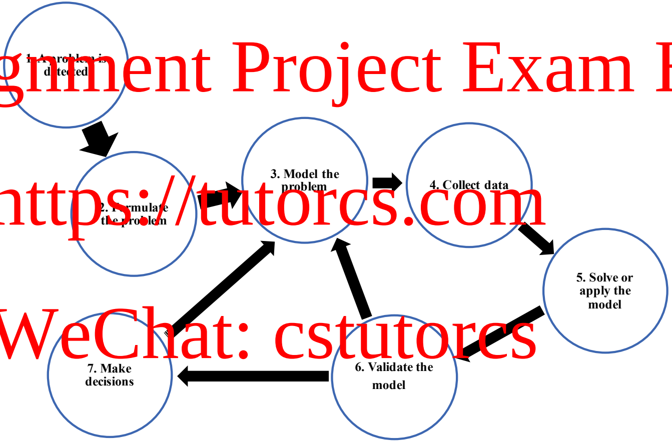

Figure – A general 7 step process

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Scientific Approach : Abstraction of reality and the model

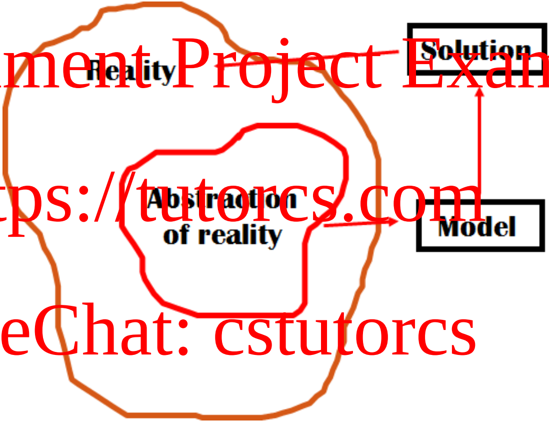

Figure – The optimization model is based on the abstraction of the real-world

Application examples

- Logistics

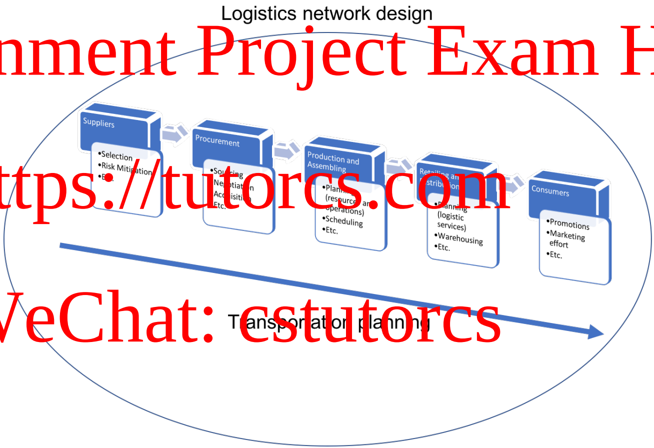

Figure – Supply chain management

Application examples

- Logistics (cont'd)
  - Vehicle routing problems

    Context : Considering a fleet of vehicles, determine an optimal set of routes for them to traverse overtime in order to deliver (or pickup) a set of products to a given set of customers.

    Different variants :
    - Capacity constraints
    - Time windows
    - Periodicity of deliveries
    - Multiple depots
    - Multiple trips
    - Simultaneous pickups and deliveries
    - etc.

Application examples

- Logistics (cont'd)
  - Vehicle routing problems (cont'd)

Note : Even in its simplest form, this type of problem is extremely complex to solve.

Travelling salesman problem

Context : Given a list of cities (or customers) and the distances between each pair of cities, find the shortest possible route that visits each city once.

Consider the case where there are 3 cities to visit, how many possible routes? $\rightarrow 3 \times 2 \times 1 = 6$.

$n!$	Number of solutions
3 !	6
5 !	120
10 !	3 628 800
20 !	2 432 902 008 176 640 000

Application examples

- Finance

Enterprise-wide risk management

Context : Strategy that aligns a firm's business with risk factors of its environment in the pursuit of strategic objectives.

see *Managing Risk, Reaping Rewards, Changing financial world turns to Operations Research*, OR/MS Today, 2001, S. A. Zenios.

4 key functions :

- Pricing ⇒ models to measure risks
- Securitization ⇒ design financial products that are adjusted to an organization's needs
- Asset and liability management ⇒ portfolio optimization
- Indexation ⇒ design of market benchmarks (i.e., indices)

Application examples

- Marketing

Media selection and promotional effort

Context :

- Set of markets that need to be reached
- Set of media outlets that are available
- Promotional impact (outlet → market)
- Promotional budget

Question :

How to design a marketing plan (i.e., a set of outlets to be applied through time) to $\max$ impact over considered markets ?

Application examples

- Marketing (cont'd)

Sales Territory Design

Context :

- Set of potential (or recurring) clients

- Set of salespersons
- Workload per client
- Value per client

Question :

How to assign salespersons $\rightarrow$ clients to ensure that either the overall workload (or client value) per salesperson is uniform and to $\min$ costs ?

Application examples

- Information technology

Data mining

Context : computing process of discovering patterns in large data sets involving methods at the intersection of machine learning, statistics, and database systems

Objective :

extract information from a data set and transform it into an understandable structure for further use (i.e., organizational decision making)

Common tasks :

- Anomaly detection ⇒ outlier, change and deviation detection
- Association rule learning ⇒ dependency modelling (relationships between variables)
- Clustering⇒discovering ***similar*** groups and structures in the data
- Classification⇒ generalizing known structures to apply to new data
- Regression⇒ formulate models to estimate the relationships between different data, or datasets, with the least error
- Summarization⇒ compact representation of the data set (visualization and report generation)

Application examples

- Managing human ressources

Scheduling

Context :

- Schedule ⇒ list of times at which possible tasks, events, or actions are intended to take place

- Scheduling ⇒ deciding how to order the tasks and how to commit the necessary resources to perform them

Scheduling problem

Scheduling a number of employees with typical constraints such as rotation of shifts, limits on overtime, etc. to cover the demands for treatment and care for a set of patients

Application examples

- Managing human ressources (cont'd)

Scheduling problem (cont'd)

Specific components :

- Hard constraints ⇒ a constraint that absolutely needs to be enforced (otherwise, the schedule is invalid)
  Examples :

  - specification of shifts (e.g., morning, afternoon, and night)
  - a nurse should be assigned to no more than one shift per day
  - all patients be covered
- Soft constraints ⇒ a constraint that should preferably be enforced (however, not meeting them does not make the schedule invalid)

  Examples :
  - min and max numbers of shifts assigned to a given nurse in a given week
  - min and max days worked consecutively
  - shift preferences of individual nurses