Optimizing Communication Networks

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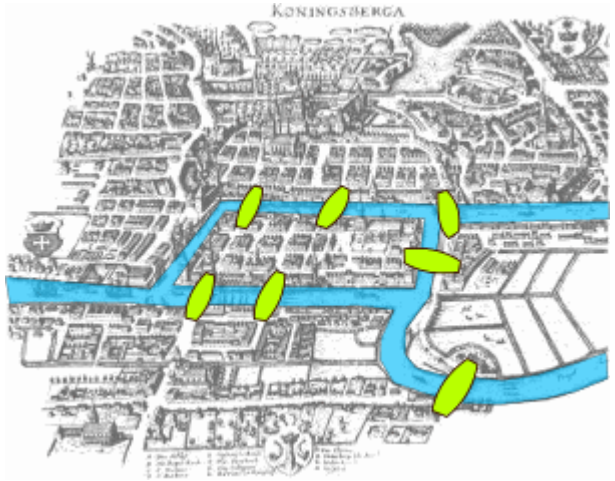
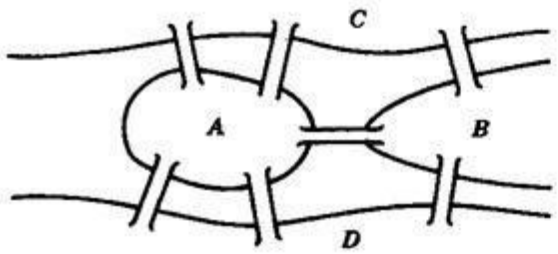
The Seven Bridges of Königsberg: Euler says «a city is a graph»!

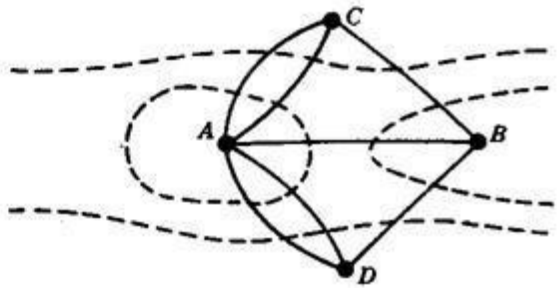
Remember: a graph consists of nodes and edges!



A graph is a powerful tool for abstraction, hence modeling!

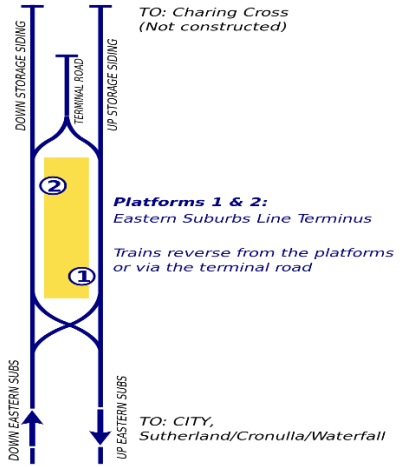


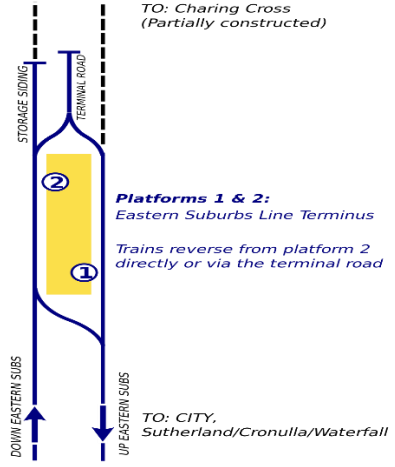
(a) Königsberg in 1736

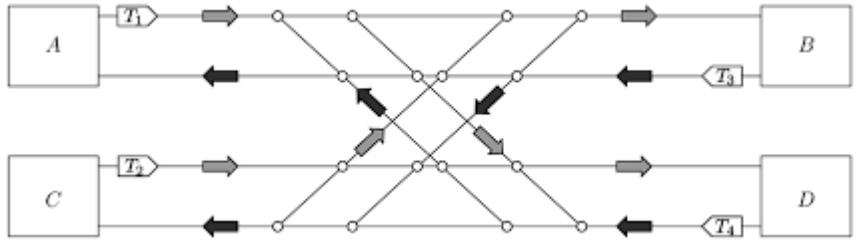


(b) Euler's graphical representation

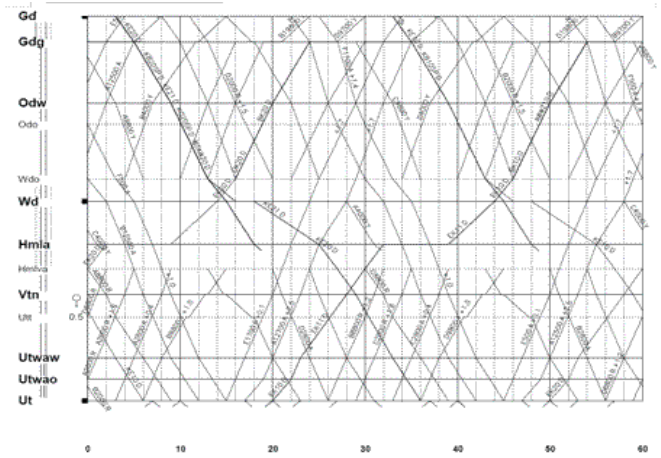
Logistics networks



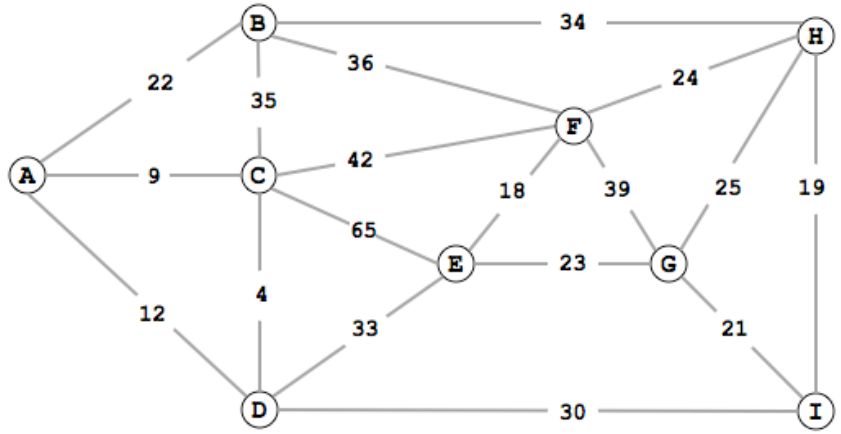




Line planning, timetabling, platforming and routing in railways

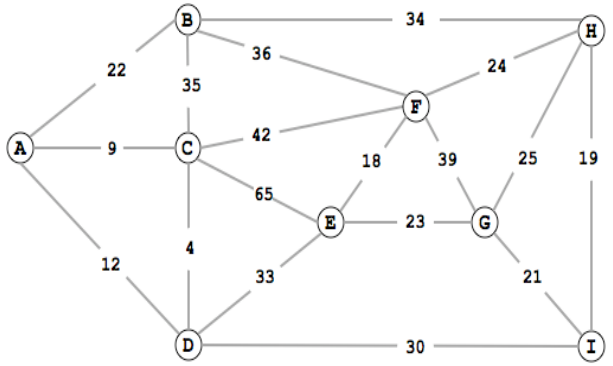


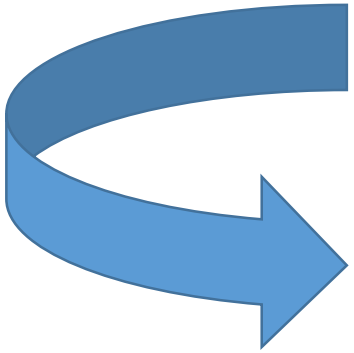
A graph can be many...



Inventory control, supply chain, rolling stock and crew planning

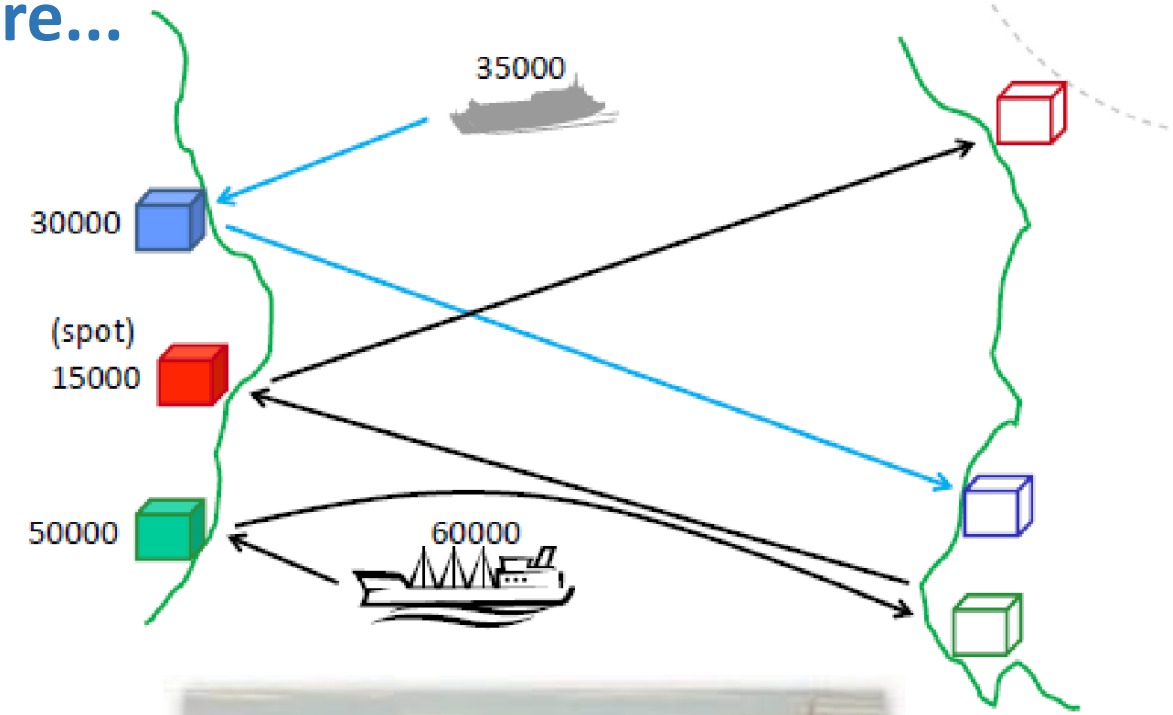
- ...many things...



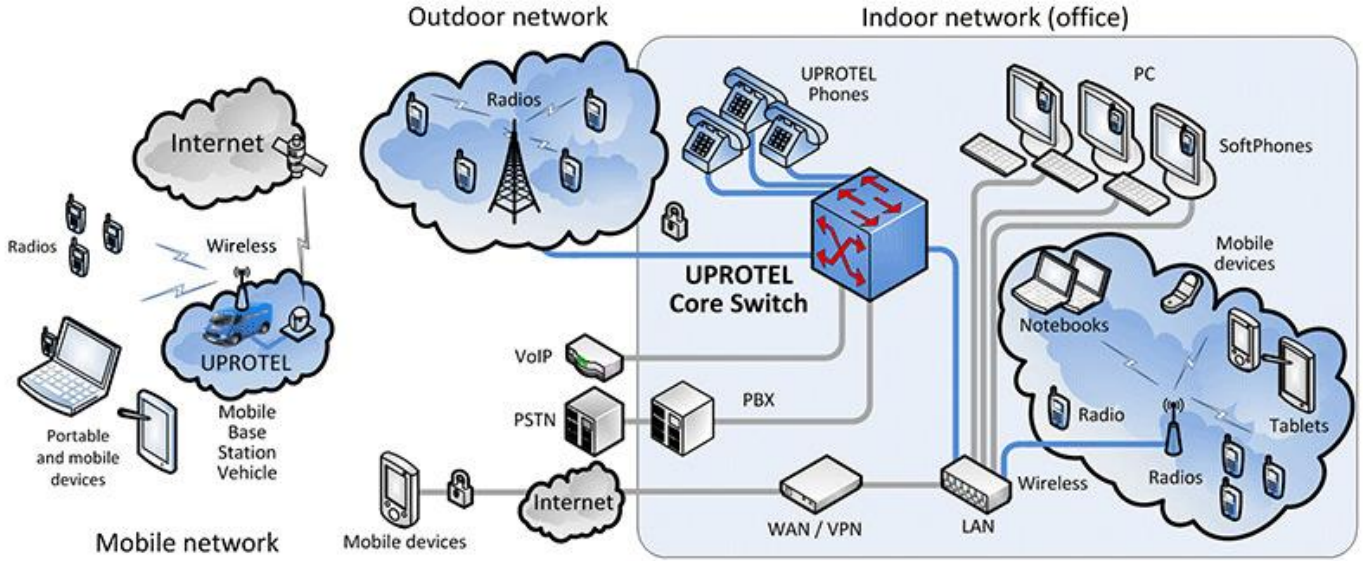


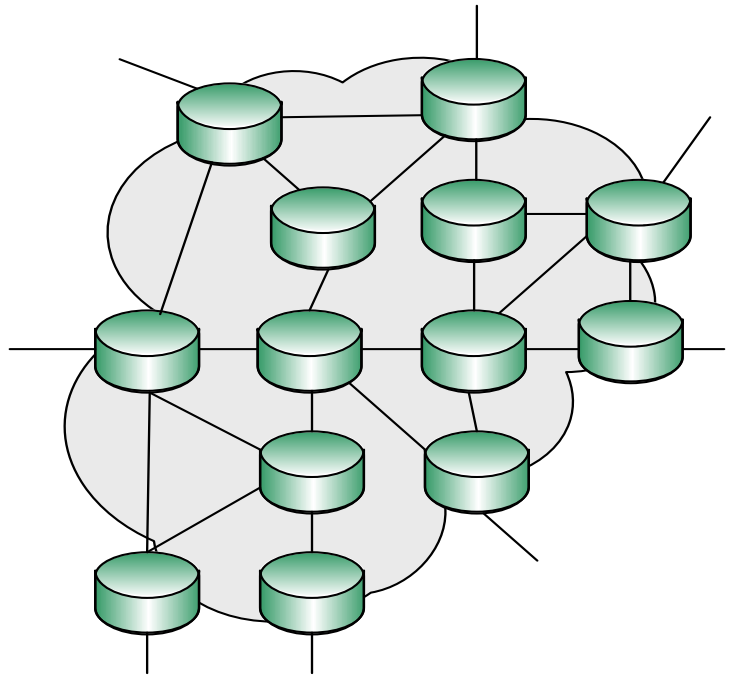
Crew condition	Rest time required by FRA
10 hours of continuous covered service	10 hours off duty
Over 12 hours of covered service	24 hours off duty
6 consecutive days of duty	1 day off duty

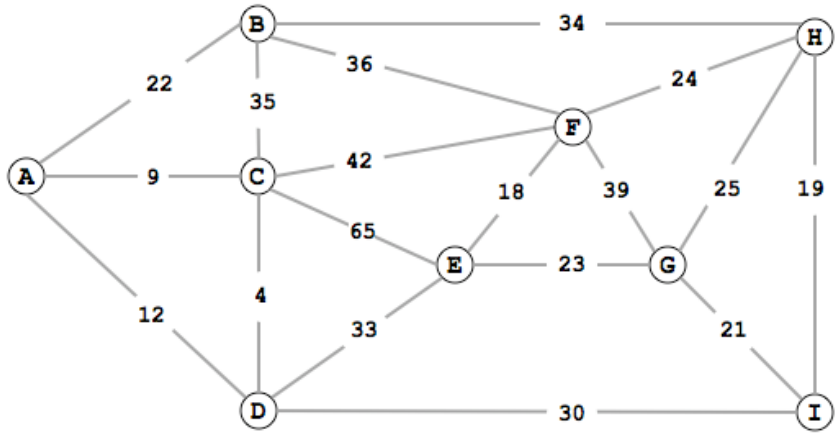
Maritime and Airline transportation, (air-)port operations and much much more...



TC networks


Outdoor network
Indoor network (office)
Internet
Radios
Wireless
UPROTEL
Mobile
Base
Station
Vehicle
Portable
and mobile
devices
Mobile network
Radios
UPROTEL
Phones
PC
SoftPhones
UPROTEL
Core Switch
Mobile
devices
Notebooks
Radio
Tablets
Radios
VoIP
PBX
PSTN
Internet
Mobile devices
WAN / VPN
LAN
Wireless

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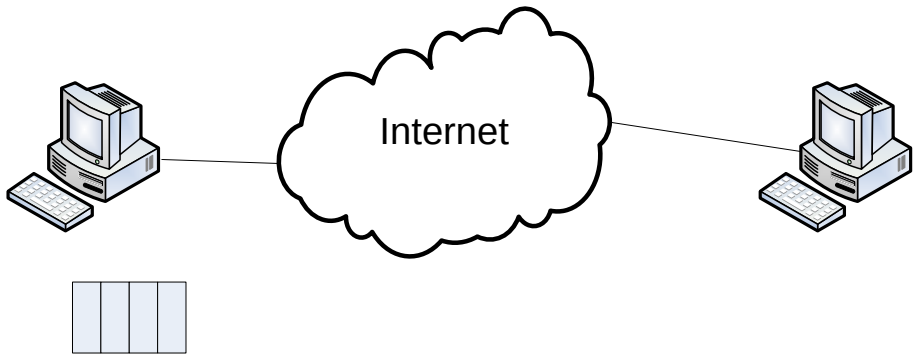
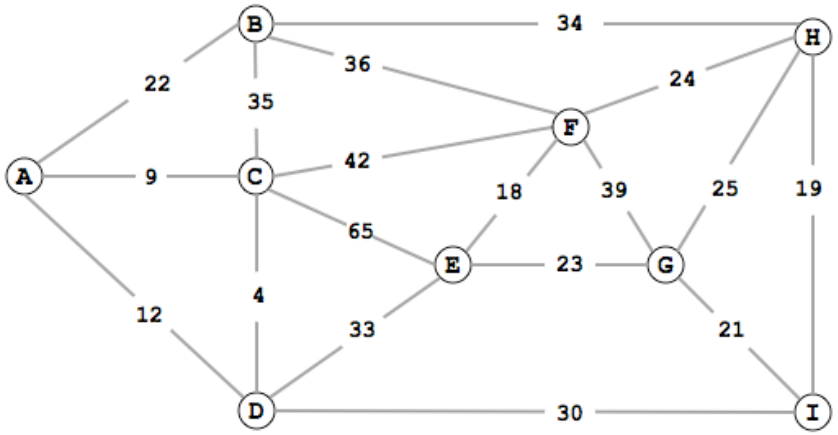

Internet

Health Care

Assignment



Routing

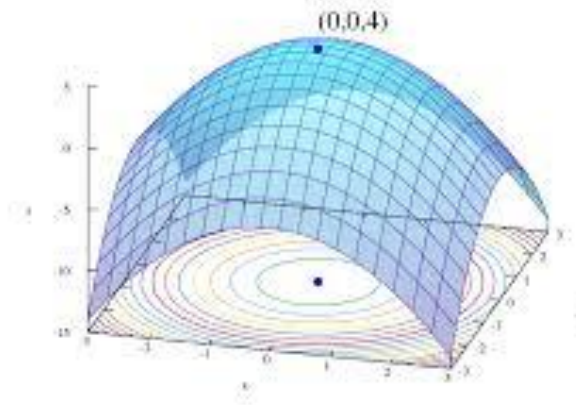
Scheduling

Mathematical Optimization

$$\begin{aligned} \text{minimize} \quad & f_0(x_1, \ldots, x_n) \\ \text{subject to} \quad & f_1(x_1, \ldots, x_n) \leq 0 \\ & \cdots \\ & f_m(x_1, \ldots, x_n) \leq 0 \end{aligned}$$

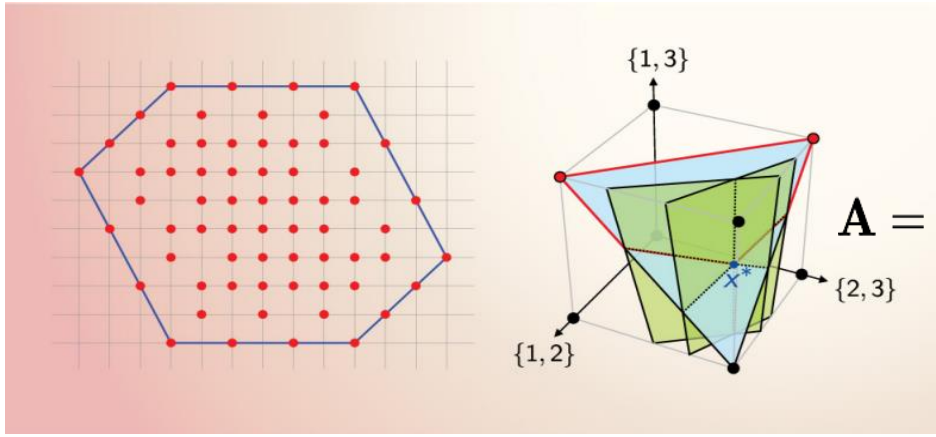
- $x = (x_1, x_2, \ldots, x_n)$ are decision variables
- $f_0(x_1, x_2, \ldots, x_n)$ gives the cost of choosing x
- inequalities give constraints that x must satisfy

a mathematical model of a decision, design, or estimation problem



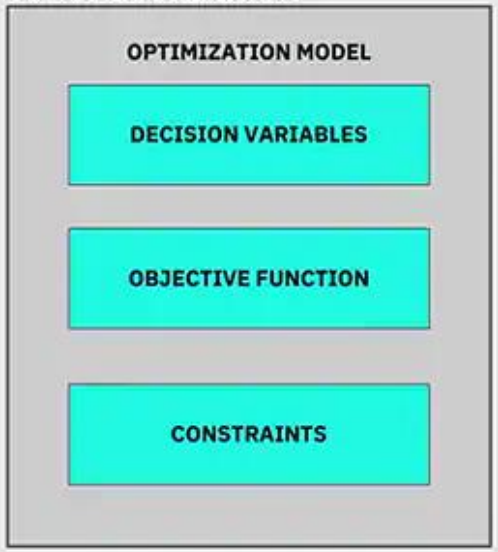
Optimization Solver

- Branch-and-Bound
- Decomposition methods
- Heuristics



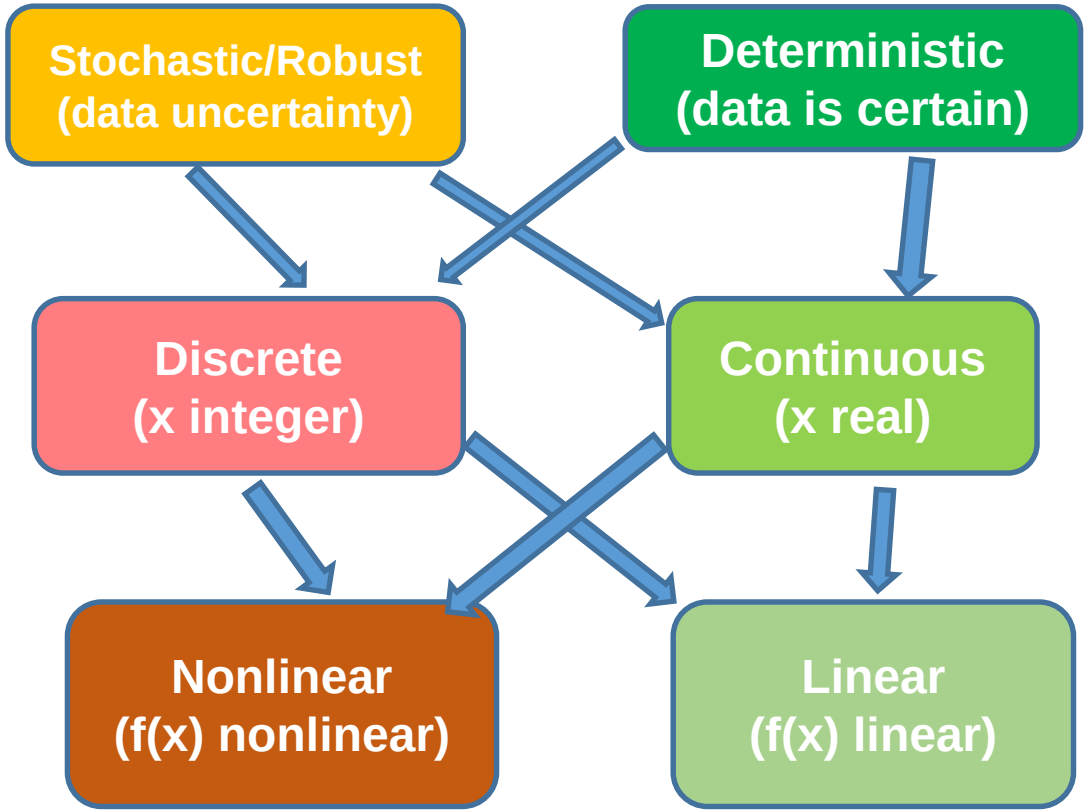
$$\mathbf{A} = \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{pmatrix}$$

Model declaration

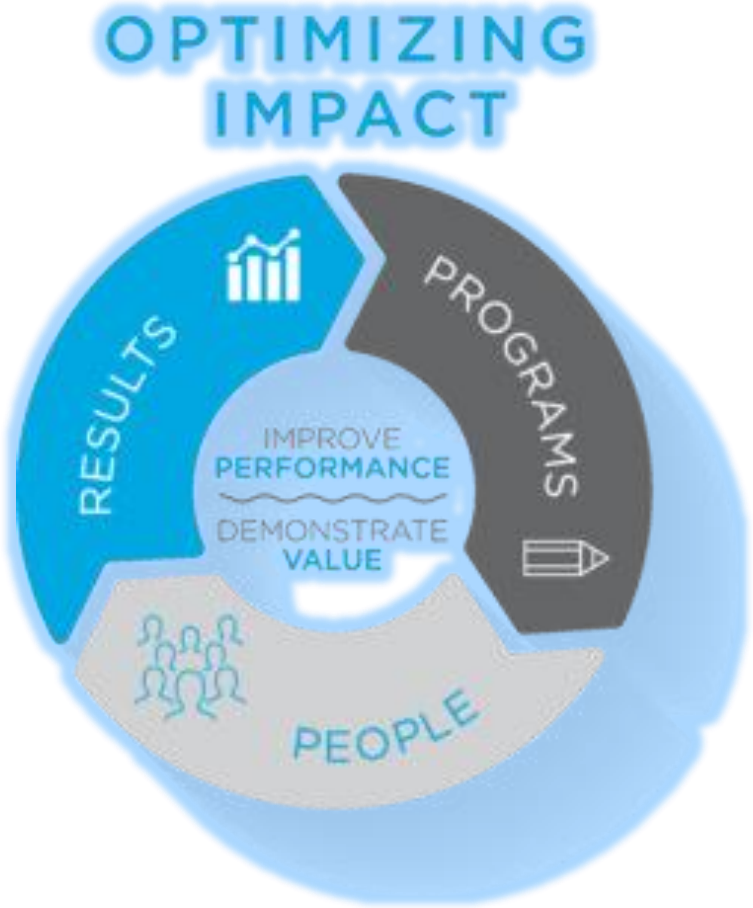



```
dvar float+ inside[Products];
dvar float+ outside[Products];

minimize
   sum(p in Products)
      (insideCost[p] * inside[p] +
       outsideCost[p]* outside[p] );

subject to {
  forall (r in Resources)
     sum (p in Products)
       consumption[p][r]*inside[p] <=
capacity[r];

  forall (p in Products)
```

Types of Optimization Models



+ Multicriteria



- **Increase profit**
- **Cost reduction**
- **Better use of resources**
- **QoS**
- **Fairness**
- **… …**

References

- (Book) **Network Flows: Theory, Algorithms, and Applications** by R.K. Ahuja et al.
- (Book) **Integer Programming** by L. A. Wolsey
- (Article) V. Cacchiani, L. Galli & P. Toth (2015)
  "A Tutorial on Non-Periodic Train Timetabling and Platforming".
  Eur. J. Trans. Log., 4(3), 2015, 285-320
- (Article) A. Frangioni, L. Galli & M.G. Scutellà (2015)
  "Delay-Constrained Shortest Paths: Approximation Algorithms and Second-Order Cone Models".
  J. Optimiz. Theory. App., 164(3), 1051-1077.
- (Article) P. Cappanera, M. G. Scutellà, F. Nervi & L. Galli (2018)
  "Demand uncertainty in Robust Home Care Optimization".
  Omega, 80, 95-110.