Optimization-based decision support within healthcare and transportation

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Outline

- Motivation – relevance to practice and eVita
- Discrete optimization
- Challenges
- Summary and conclusion
Messages

- Discrete optimization problems
  - central to better performance
  - hard
- Strong need for more powerful methods
- Several challenges and promising research avenues
- Short road from theoretical to practical improvements
- Important part of eScience
Healthcare

- Need for better coordination
  - Increasing demands
  - Patient focus: high quality treatment
  - Resource focus: Need to curb cost increase

- Design, planning
  - Crucial to performance
  - Too complex for manual decision-making
  - Time consuming and repetitive

- Need for decision support systems
  - Automated planning
  - Objectives and constraints
  - Computationally complex Discrete Optimization Problems

- Need for models and effective solution algorithms
Coordination challenges in healthcare

- Ambulanseallokering
  - Visualisere
  - Optimere
  - Simulere

- Turnusplanlegging
  - Stillingsprosenter
  - Bemanningsbehov

- Sykehusplanlegging og -design
  - Surgical mix
  - Inntaksplanlegging
  - Ukeplanlegging
  - Open schedule
  - Block schedule
  - Dagsplanlegging
  - Master Surgery Schedule

- Pasientforløp
  - Visualisere
  - Simulere
  - Optimere

- Operasjonsplanlegging
  - Inntaksplanlegging
  - Ukeplanlegging
  - Open schedule
  - Block schedule
  - Dagsplanlegging
  - Master Surgery Schedule

- Supply chain optimisation
  - Blodbank
  - Organer
  - "What if" Scenario
  - Lagerdesign

- Optimized Patient Transports in Hospitals
  - Visualisere
  - Simulere
  - Optimere

- Workforce Training
  - "What if" Scenario
  - Lagerdesign

- Workforce Training
  - "What if" Scenario
  - Lagerdesign

- Optimizing Workforce Training
  - Blodbank
  - Organer
  - Lagerdesign

- Funksjonsfordeling
  - Hvilken behandling
  - Behandlingsmix

- Lagerbeholdning
  - Simulere beholdning
  - Optimere beholdning
  - Lagerdesign
Vision: An optimized healthcare system

- Enterprise Models
- Information
- High quality data
- OR models
- Solution algorithms
- Computing power

ICT
Two cases in point

- Nurse rostering
  - Solved manually by experienced nurses
  - Timetabling problem
  - Computationally hard discrete optimization problem

- Surgery scheduling
  - Solved manually by experienced nurses
  - Long-term, mid-term, short term
  - Critical resources: operation theaters, surgeons
  - Variants of the Job-Shop Scheduling Problem
  - Computationally hard discrete optimization problem
Discrete optimization (1)

- Central to real-life problems across many application areas
  - routing
  - scheduling
  - planning
  - design
  - resources, time, activities
  - economy, environmental effects

- Healthcare, transportation, manufacturing, oil & gas, finance, sports

- Computationally hard

- Physics, chemistry, biology, electronics, statistics, geometry, ...
Discrete optimization (2)

- Two basic types of method
  - Exact, mathematical programming
    - guarantees to find the optimal solution
    - response time problematic
    - may be interrupted for feasible solution
    - low quality, but upper bound on error
  - Approximative (typically heuristics)
    - greedy
    - local search
    - metaheuristics
    - good solutions in limited time
    - no useful error bound
"The world record" for G-n262-k25: 5685 vs. 6119
(SINTEF 2003)
Discrete optimization – main challenges

- More powerful methods – exact and approximative
  - better solutions in shorter time
  - new applications
- Combining the strengths of exact methods and heuristics
- Decomposition and aggregation
- Multi-level solvers, different levels of abstraction
- Stochastic models
- Parallelization
  - fine grained, e.g. to exploit the architecture of modern commodity computers
  - multi-core and heterogeneous computing
  - coarse grained, e.g. cooperative hybrid solvers, multi-level solvers
- Self-adaptive methods
- Better benchmarks
DOMinant
Discrete Optimization Methods
In Maritime and Road-based Transportation

Norwegian University of Science and Technology (NTNU),
Molde University College (HiM)
and SINTEF ICT
Main objective

- More efficient methods for rich, industrial variants of computationally hard discrete optimization problems in maritime and road-based transportation

- Two types of problems
  - Inventory routing
  - Fleet composition
Classical VRP(TW)

- Deliveries from a single depot
- Given customer demand
- Homogeneous fleet
- Sizes/capacities
- Minimize total transportation cost
- (Single time windows)
- More than 1000 references
VRP with Capacity Constraints (CVRP)

- Graph $G=(N,A)$
  - $N=\{0,\ldots,n+1\}$ Nodes
  - 0 Depot, $i \neq 0$ Customers
  - $A=\{(i,j): i,j \in N\}$ Arcs
  - $c_{ij} > 0$ Transportation Costs
- Demand $d_i$ for each Customer $i$
- $V$ set of identical Vehicles each with Capacity $q$
- Goal
  - Design a set of Routes that start and finish at the Depot - with minimal Cost.
  - Each Customer to be visited only once (no order splitting)
  - Total Demand for all Customers not to exceed Capacity
  - Cost: weighted sum of Driving Cost and # Routes
- DVRP – distance/time constraint on each route
- VRPTW – VRP with time windows
- Pickup and Delivery
  - Backhaul – VRPB(TW)
  - Pickup and delivery VRPPD(TW)
  - PDP
A mathematical model for VRPTW
(Network Flow Formulation)

minimize \[ \sum_{k \in V} \sum_{(i,j) \in A} c_{ij} x_{ij}^k \] \hspace{1cm} (1) minimize cost

subject to:

\[ \sum_{k \in V} \sum_{j \in N} x_{ij}^k = 1, \quad \forall i \in C \] \hspace{1cm} (2) each customer 1 time

\[ \sum_{i \in C} d_i \sum_{j \in N} x_{ij}^k \leq q, \quad \forall k \in V \] \hspace{1cm} (3) Capacity

\[ \sum_{j \in N} x_{0j}^k = 1, \quad \forall k \in V \] \hspace{1cm} (4) k routes out of depot

\[ \sum_{i \in N} x_{ih}^k - \sum_{j \in N} x_{hj}^k = 0, \quad \forall h \in C, \forall k \in V \] \hspace{1cm} (5) flow balance for each customer

\[ \sum_{i \in N} x_{i,n+1}^k = 1, \quad \forall k \in V \] \hspace{1cm} (6) k routes into depot (redundant)

\[ x_{ij}^k (s_i^k + t_{ij}^k - s_j^k) \leq 0, \quad \forall (i,j) \in A, \forall k \in V \] \hspace{1cm} (7) sequence and driving time

\[ a_i \leq s_i^k \leq b_i, \quad \forall i \in N, \forall k \in V \] \hspace{1cm} (8) arrival time in time window

\[ x_{ij}^k \in \{0,1\}, \quad \forall (i,j) \in A, \forall k \in V \] \hspace{1cm} (9) arc \((i,j)\) driven by vehicle \(k\)

Variables
- arrival time

Arc Decision variables

ICT
VRP Research in general

- Since 1959
- Much harder than the TSP
- Thousands of papers
- More popular than ever
- Important vehicle for development of generic methods
- One of the great successes of Operations Research
- Industry of tools for transportation optimization
- Quick dissemination and exploitation of scientific advances
- The road is short from scientific to practical improvements
Inventory routing problem (IRP)

- Inventories with capacities
- Production/consumption rate
- Heterogeneous fleet
- Design routes that minimize the transportation cost without interrupting production and consumption of the products
- No pickup and delivery pairs
- Quantity loaded unknown
- Number of visits unknown
Practical applications - IRP

- Both road-based and maritime transportation
  - One/multiple products
  - VRP and PDP structure (with and without depot)
  - Variable production/consumption rate
  - Stochastic demand/production
  - Combining inventory routing with other planning aspects (production, allocation,...)

- Industry cases
  - Ammonia – Yara
  - LNG - Suez Energy International, StatoilHydro, RasGas, QuatarGas
  - Cement - Norcem
  - Fuel oil - Hydro Texaco
  - Animal fodder - Landbruksdistribusjon, Felleskjøpet
- Daily charter rate: USD 60,000
- Shipload of LNG worth: USD 10,000,000
- Purchase price LNG tanker: USD 150,000,000
Fleet composition

- VRP, PDP (or IRP) structure

- Variable heterogeneous vehicle fleet
  - capacities
  - acquisition costs….

- **Objective:** find a fleet composition and a corresponding routing plan that minimizes the sum of routing and vehicle acquisition/depreciation/rental costs
Practical applications – Fleet composition

• Both road-based and maritime transportation
  • Strategic and tactical fleet dimensioning
  • One/multiple products
  • VRP and PDP structure (with and without depot)
  • Stochastic demand and price/cost structure

• Industry cases
  • Cars - Høegh Autoliners
  • LNG – Statoil
  • Dairy products - Tine Midt-Norge
  • Newspapers - Aftenposten, Dagbladet
  • Ice cream - Henning Olsen, Diplom is
  • local distribution - Linjegods
  • Chemicals – Broström Tankes (now Maersk)
  • Cement – Norcem
  • Animals Norsk Kjøtt, Gilde
Research approach

- Mathematical formulations for industrially relevant variants of inventory routing and fleet composition problems

- Analysis

- Solution methods
  - Exact methods (Column generation and Lagrangian relaxation)
  - Bounds, relaxations and reductions
  - Approximative methods (heuristic column generation, metaheuristics)
  - Hybrid methods (combining exact methods and metaheuristics)

- Prototype solvers

- Computational experiments on instances from literature and industry
Relevance to eScience

- Mathematics
  - mathematical modelling
  - polyhedral theory
  - mathematical programming methods

- Computing science, informatics
  - conceptual modelling
  - search methods
  - decision support systems

- Applications

- Numerics

- High-performance computing
  - computational experiments
  - automated code generation for metaheuristics
Summary

- Challenges in industry and the public sector
  - coordination
  - activities, time, resources
  - planning, design
- Computationally hard DOPs often at the core
- There is a strong need for more powerful methods
- Many challenges, promising research avenues
- Application oriented and scientifically challenging
- eScience
- Norway has a strong position
  - good scientists
  - good access to application cases
  - good infrastructure
  - good funding opportunities
- The road is short from scientific to practical improvements
Conclusion

Applied research in discrete optimization deserves further funding in eVITA
Optimization-based decision support within healthcare and transportation

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