Optimization-based decision support within healthcare and transportation

eVITA Scientific Meeting
Geilo, Norway January 28, 2010
Geir Hasle, SINTEF ICT

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- Atle Riise, SINTEF
- Martin Stølevik, SINTEF

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

”Det er mye god omsorg i effektivitet”
P. Syrstad presentasjon på Ringerikskonferansen 2008.

- 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

Planning
- Visualisere
- Optimere
- Simulere

Ambulanseallokering
- Simulere
- Optimere
- Visualisere

Sykehusplanlegging og -design

Optimering
- Blodbank

Pasientforløp
- Visualisere
- Simulere
- Optimere

Turnusplanlegging
- Stillingsprosenter
- Bemanningsbehov

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

Workforce Training
- ”What if” Scenario
- Lagerdesign

Supply chain optimisation
- Blodbank
- Organer
- …

Funksjonsfordeling
- Hvilken behandling
- Behandlingsmix

Lagerbeholdning
- Simulere beholdning
- Optimere beholdning
- Lagerdesign

Optimized Patient Transports in Hospitals
- Visualisere
- Simulere
- Optimere

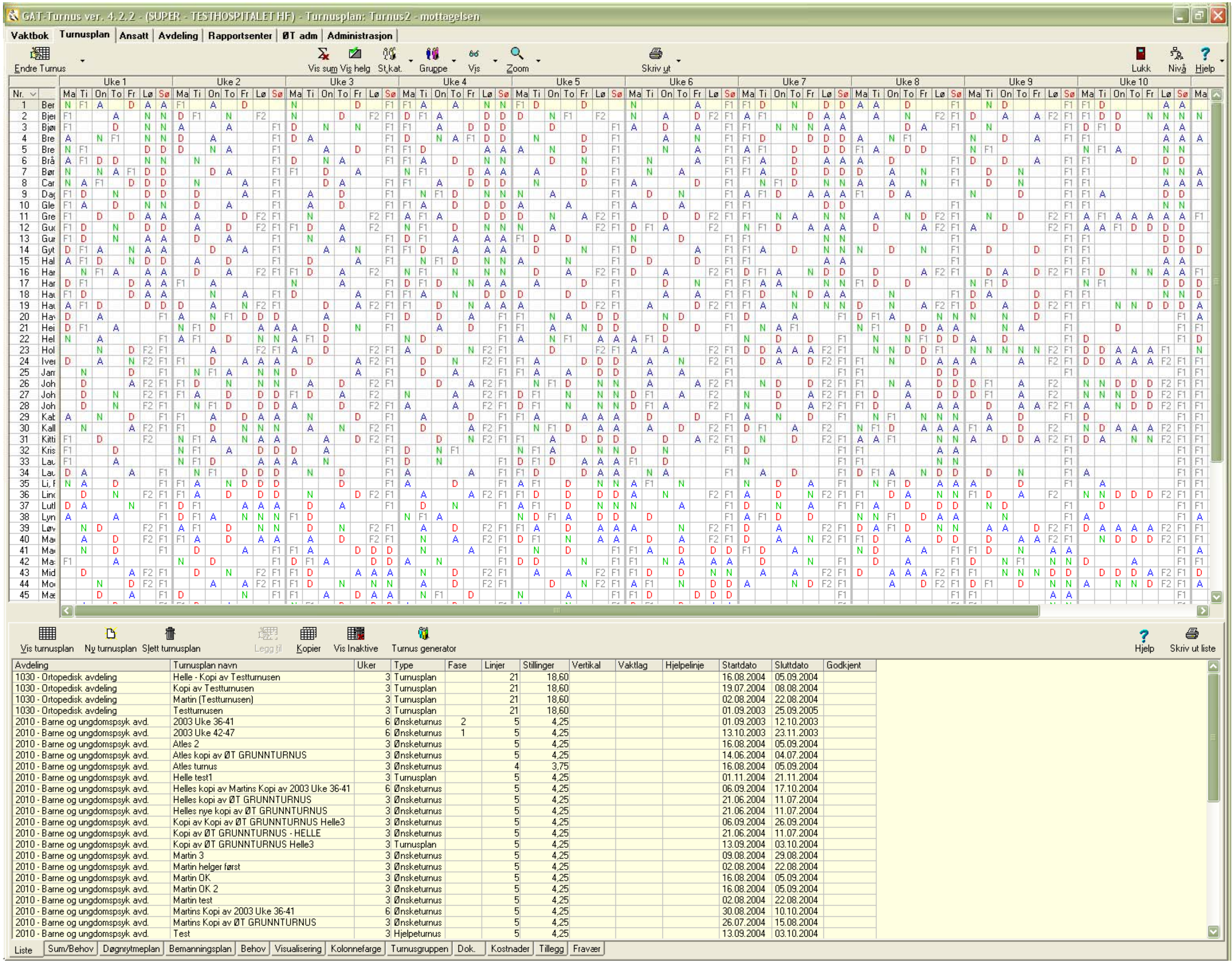
Vision: An optimized healthcare system

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

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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Endre Turnus
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Skriv ut
Lukk Nivå Hjelp
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Nr. Ma Ti On To Fr Lø Sø
Vis turnusplan Ny turnusplan Slett turnusplan Legg til Kopier Vis Inaktive Turnus generator
Hjelp Skriv ut liste
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Liste Sum/Behov Døgnrytmeplan Bemanningsplan Behov Visualisering Kolonnefarge Turnusgruppen Dok. Kostnader Tillegg Fravær

Discrete optimization (1)

- Central to real-life problems across many application areas
  - routing
  - scheduling
  - planning
  - design

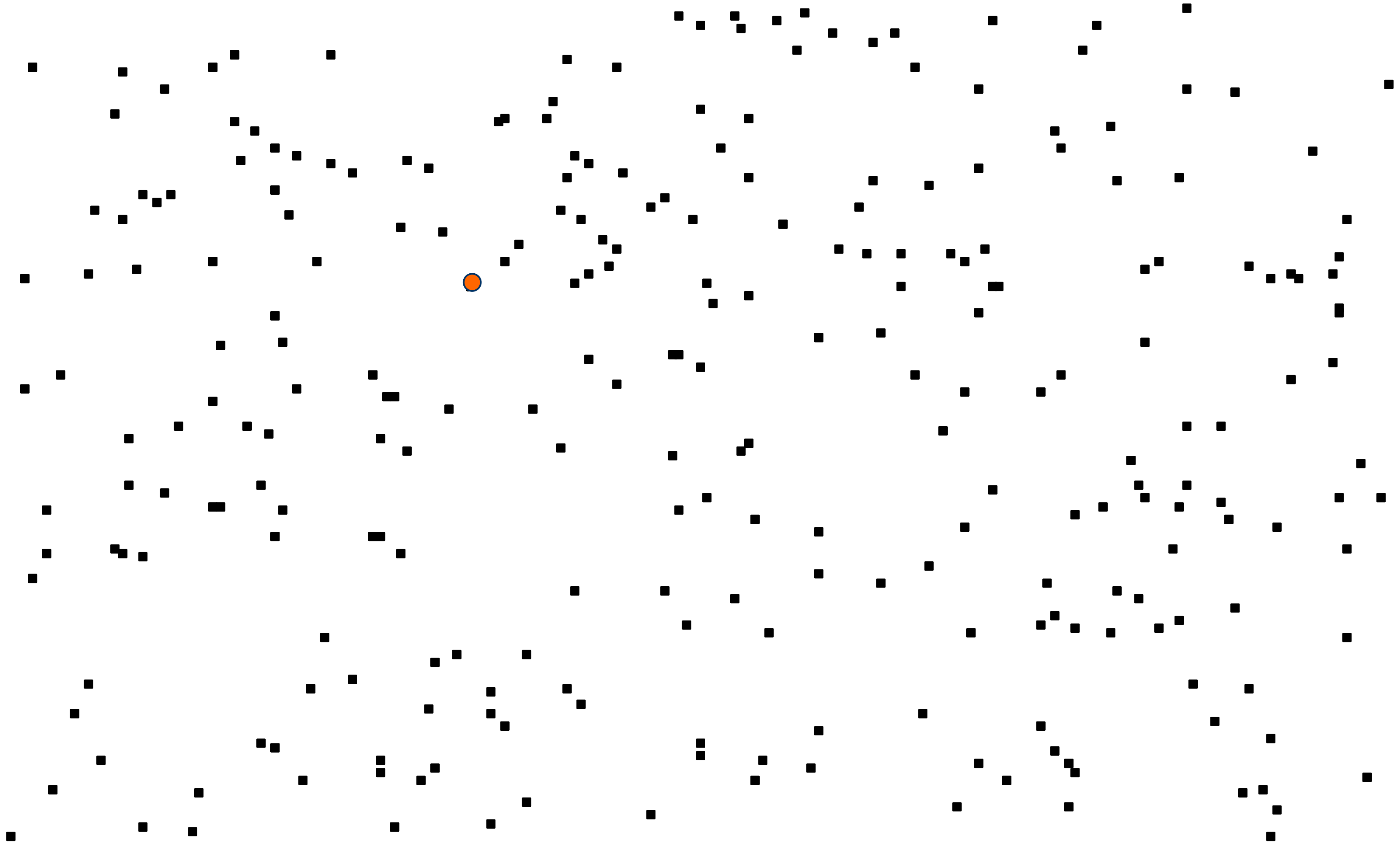
  - resources, time, activities
  - economy, environmental effects
- Healthcare, transportation, manufacturing, oil & gas, finance, sports
- Computationally hard

- Physics, chemistry, biology, electronics, statistics, geometry, ...

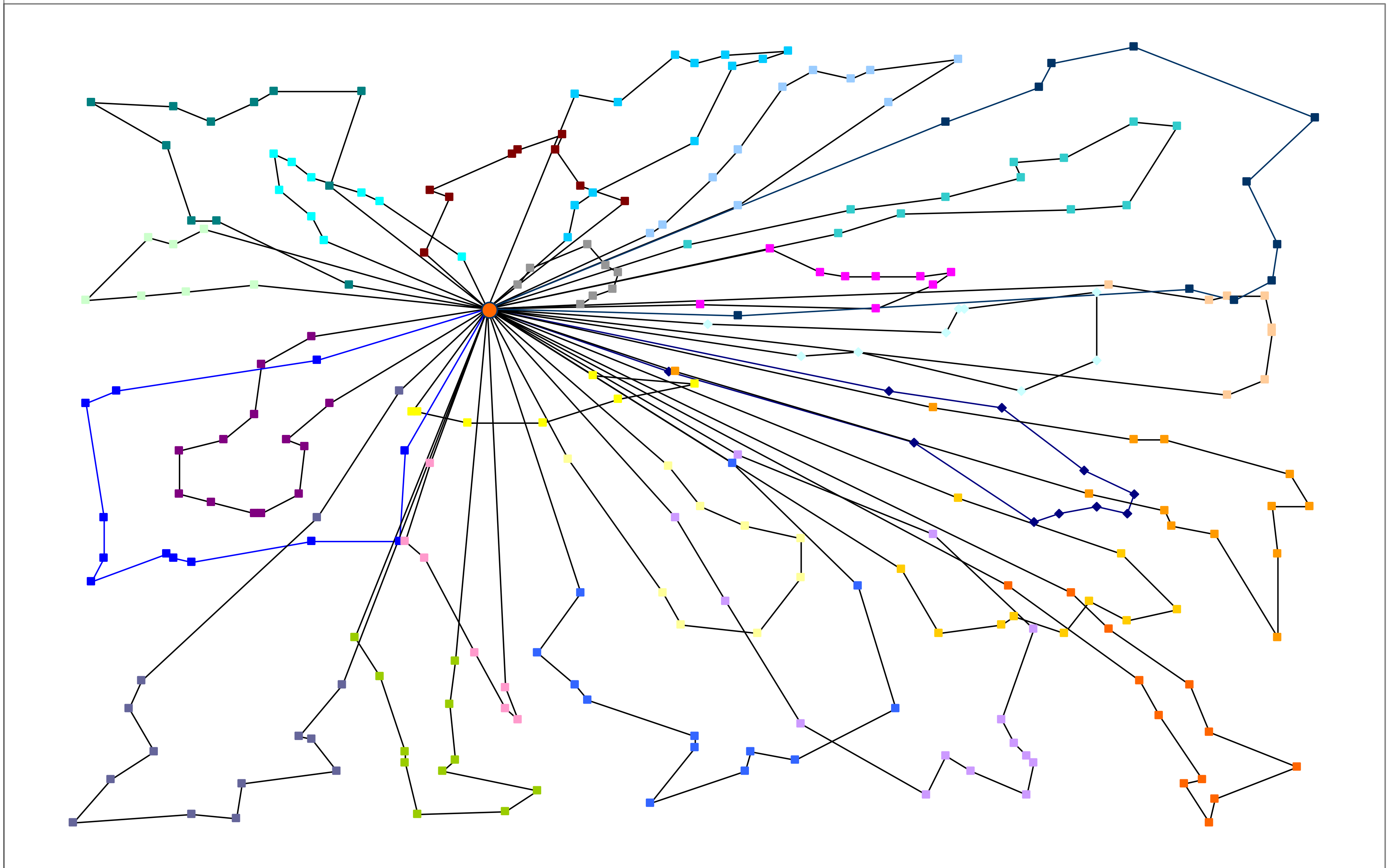
Discrete optimization (2)

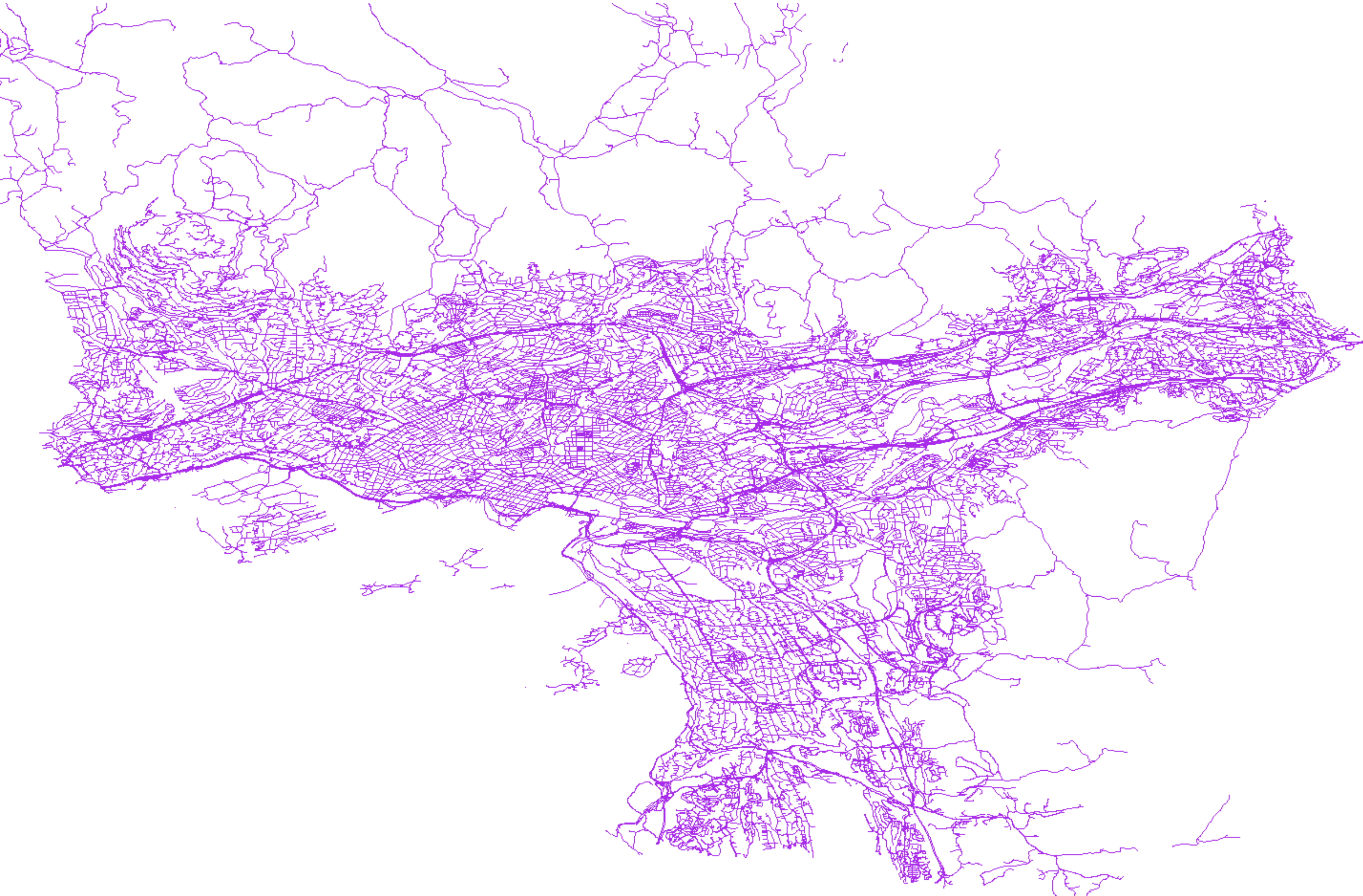
- Two basic types of method
- Exact, mathematical programming
  - guarantees to find the optimal solution
  - response time problematic
  - may be interrupted for feasible solution
  - low quality, but upper bound on error
- Approximative (typically heuristics)
  - greedy
  - local search
  - metaheuristics
  - good solutions in limited time
  - no useful error bound

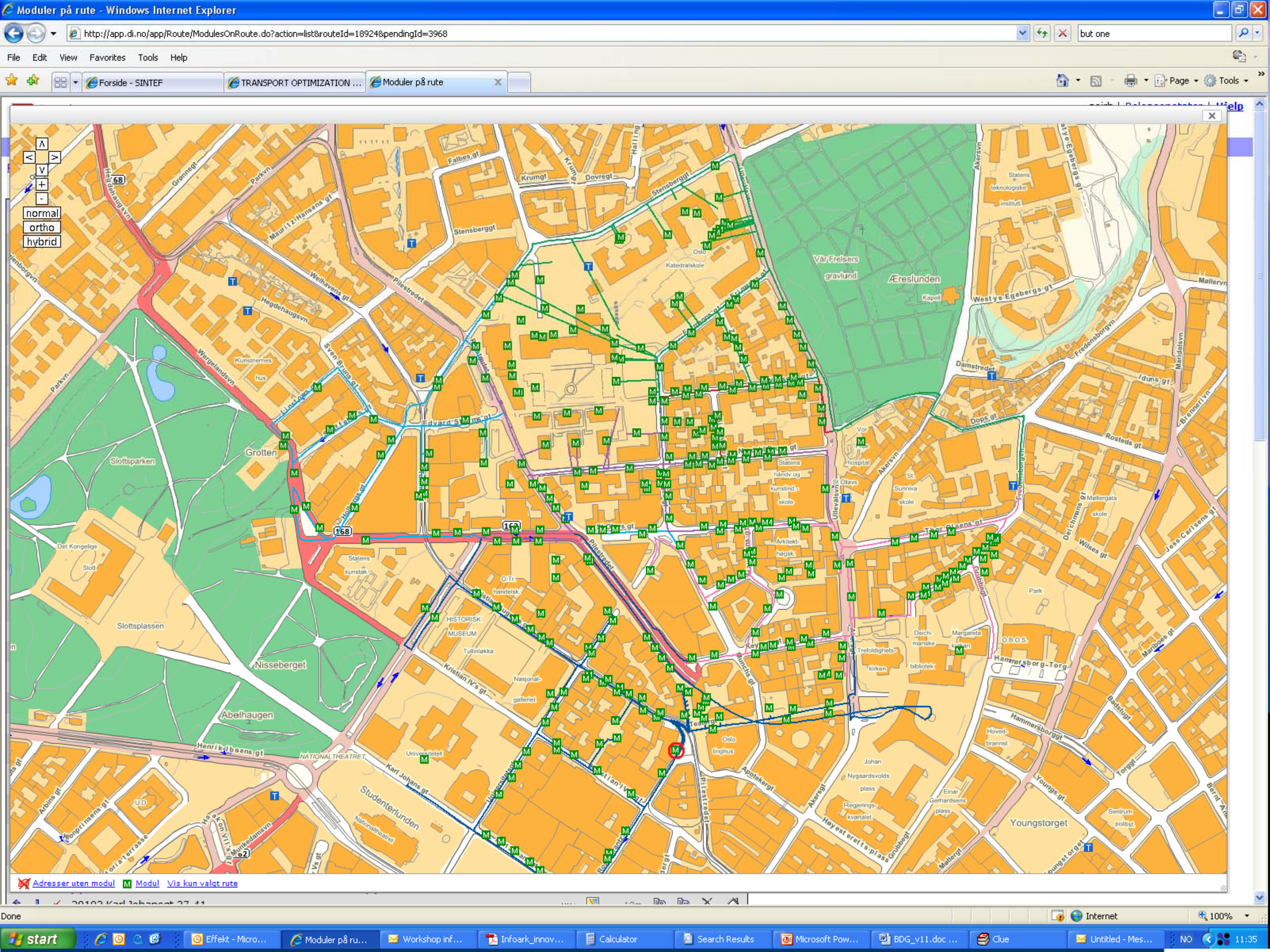
Standard test instance G-n262-k25 (Gillett & Johnson 1976)



"The world record" for G-n262-k25: 5685 vs. 6119
(SINTEF 2003)






Moduler på rute - Windows Internet Explorer
http://app.di.no/app/Route/ModulesOnRoute.do?action=list&routeId=18924&pendingId=3968
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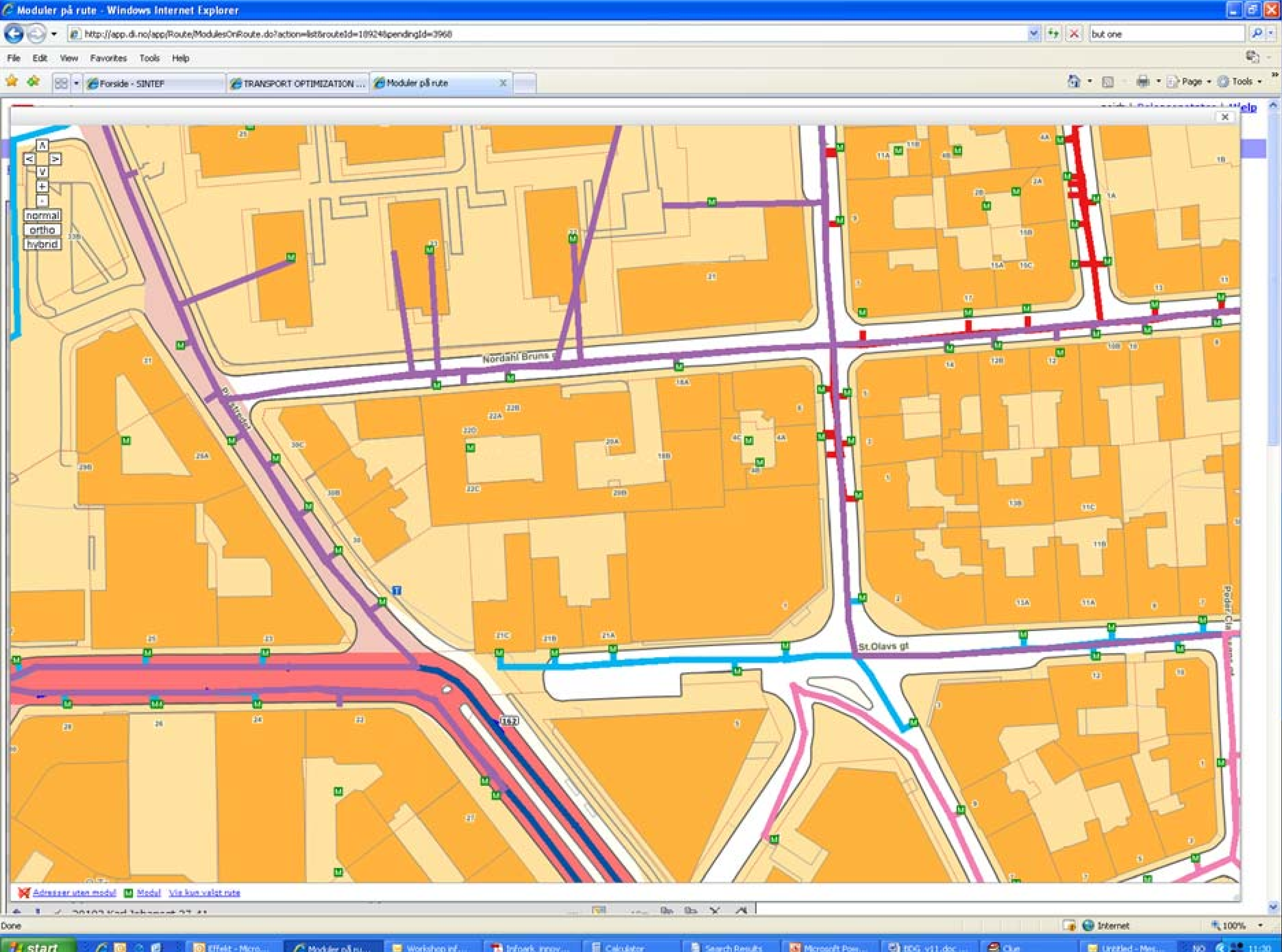

Moduler på rute - Windows Internet Explorer
http://app.di.no/app/Route/ModulesOnRoute.do?action=list&routeId=18924&pendingId=3968
File Edit View Favorites Tools Help
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TRANSPORT OPTIMIZATION ...
Moduler på rute
normal
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Nordahl Bruns
St.Olavs gt
Adresser uten modul
Modul
Vis kun valgt rute
Done
Internet
100%
start
Effekt - Micro...
Moduler på ru...
Workshop inf...
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Calculator
Search Results
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Clue
Untitled - Mes...
11:30

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

SINTEF   Molde University College   NTNU Norwegian University of Science and Technology

Main objective

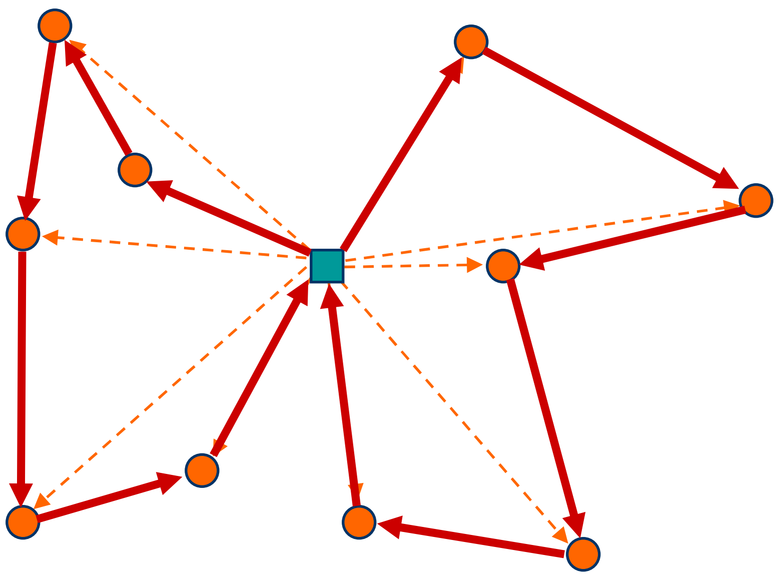
- More efficient methods for rich, industrial variants of computationally hard discrete optimization problems in maritime and road-based transportation

- Two types of problems
  - Inventory routing
  - Fleet composition

Classical VRP(TW)

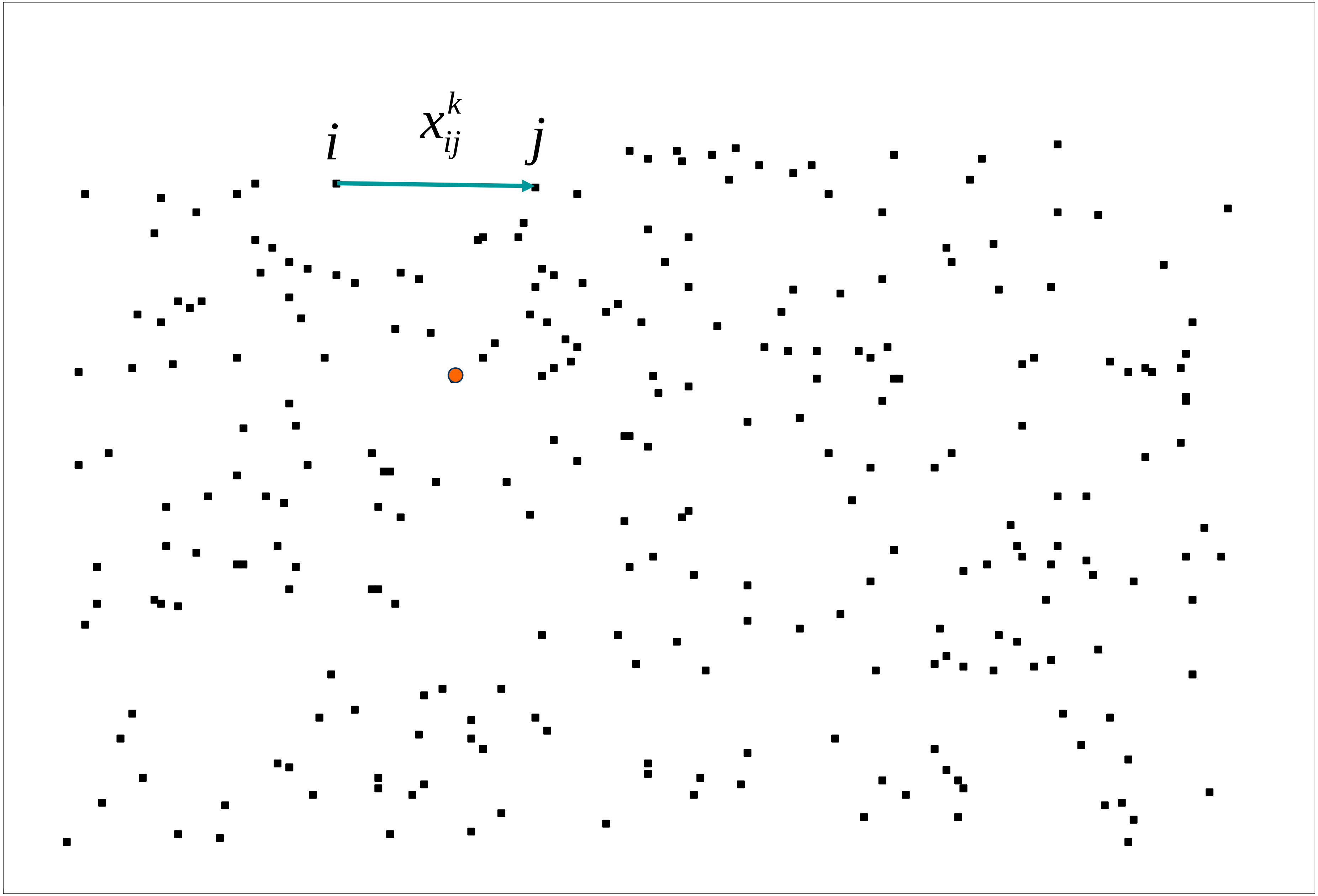
- Deliveries from a single depot
- Given customer demand
- Homogeneous fleet
- Sizes/capacities
- Minimize total transportation cost
- (Single time windows)

- More than 1000 references



VRP with Capacity Constraints (CVRP)

- Graph $G=(N,A)$
  - $N=\{0,\dots,n+1\}$ *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


i
x_{ij}^{k}
j

A mathematical model for VRPTW
(Network Flow Formulation)

minimize	$\sum_{k \in V} \sum_{(i,j) \in A} c_{ij} x_{ij}^k$		(1)	minimize cost
subject to:				
	$\sum_{k \in V} \sum_{j \in N} x_{ij}^k = 1,$	$\forall i \in C$	(2)	each customer 1 time
	$\sum_{i \in C} d_i \sum_{j \in N} x_{ij}^k \le q,$	$\forall k \in V$	(3)	Capacity
	$\sum_{j \in N} x_{0j}^k = 1,$	$\forall k \in V$	(4)	k routes out of depot
	$\sum_{i \in N} x_{ih}^k - \sum_{j \in N} x_{hj}^k = 0,$	$\forall h \in C, \ \forall k \in V$	(5)	flow balance for each customer
	$\sum_{i \in N} x_{i,n+1}^k = 1,$	$\forall k \in V$	(6)	k routes into depot (redundant)
	$x_{ij}^k (s_i^k + t_{ij} - s_j^k) \le 0,$	$\forall (i,j) \in A, \ \forall k \in V$	(7)	sequence and driving time
	$a_i \le s_i^k \le b_i,$	$\forall i \in N, \ \forall k \in V$	(8)	arrival time in time window
	$x_{ij}^k \in \{0,1\},$	$\forall (i,j) \in A, \ \forall k \in V$	(9)	arc (i,j) driven by vehicle k

Variables -arrival time

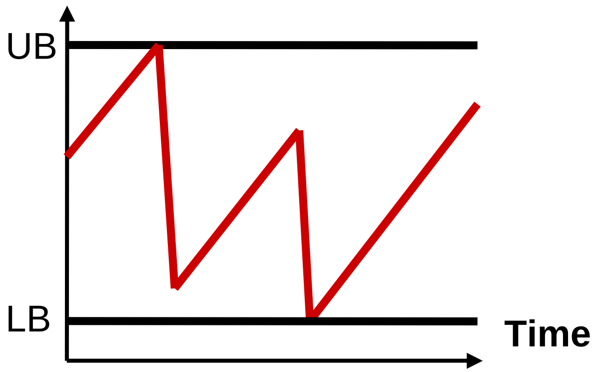
Arc Decision variables

VRP Research in general

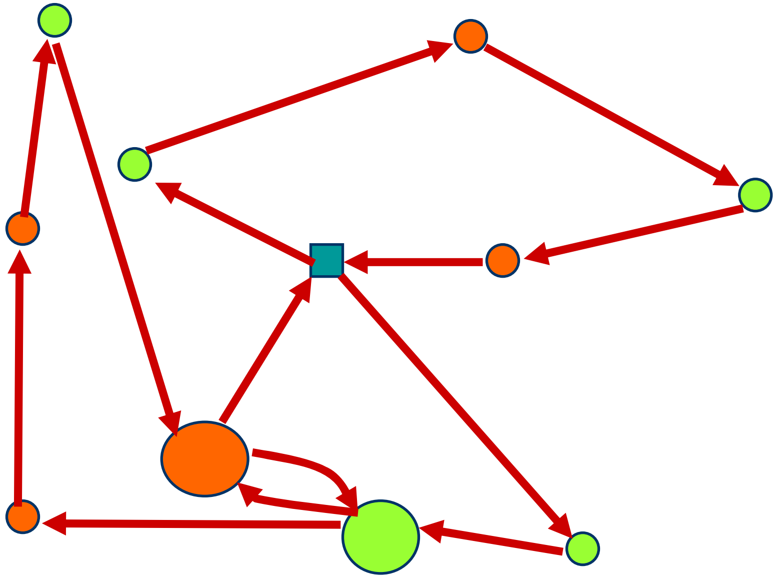
- Since 1959
- Much harder than the TSP
- Thousands of papers
- More popular than ever
- Important vehicle for development of generic methods
- One of the great successes of Operations Research
- Industry of tools for transportation optimization
- Quick dissemination and exploitation of scientific advances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

Inventory routing problem (IRP)

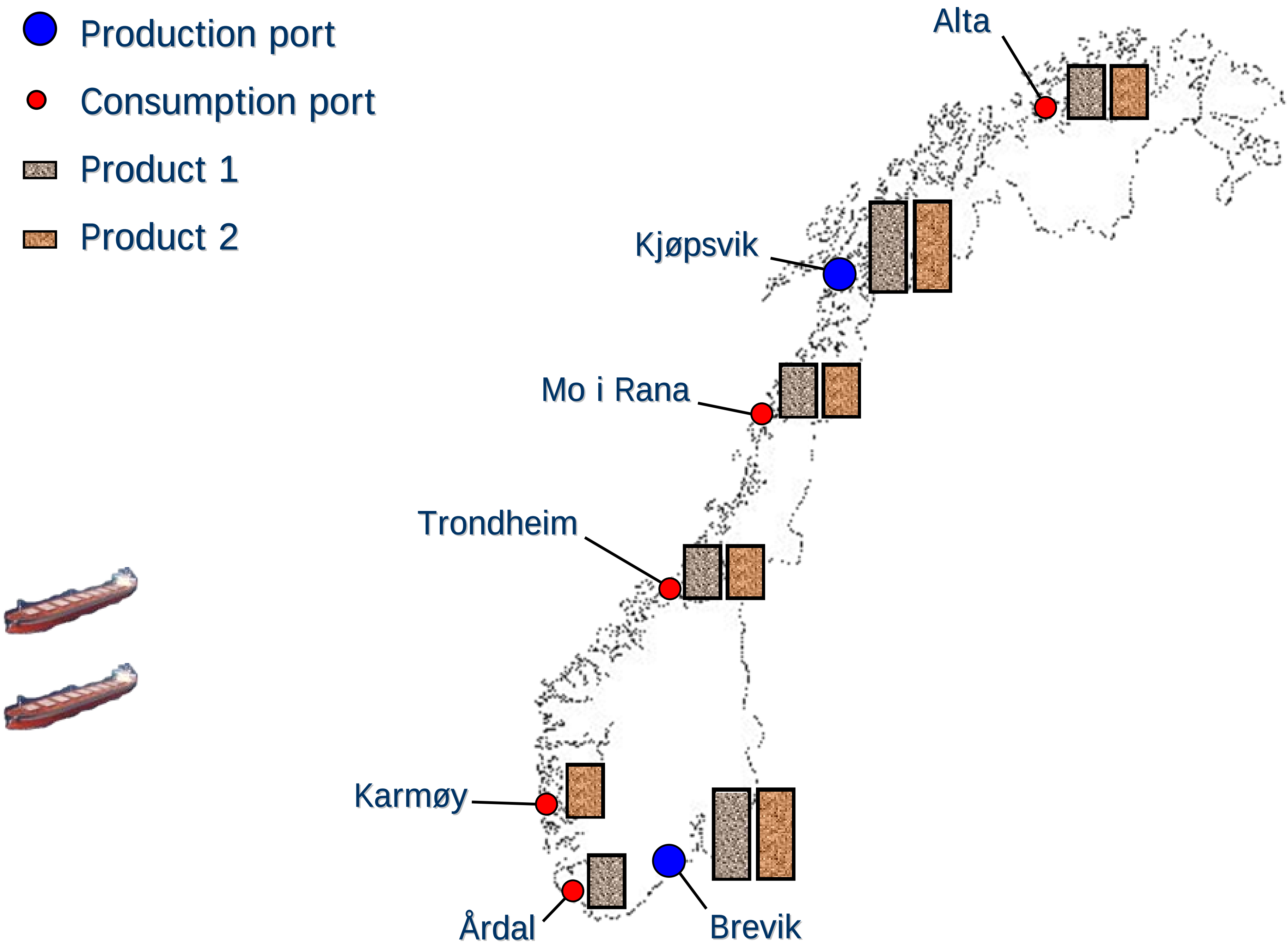
Inventory level, production



- 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


Production port
Consumption port
Product 1
Product 2
Alta
Kjøpsvik
Mo i Rana
Trondheim
Karmøy
Årdal
Brevik

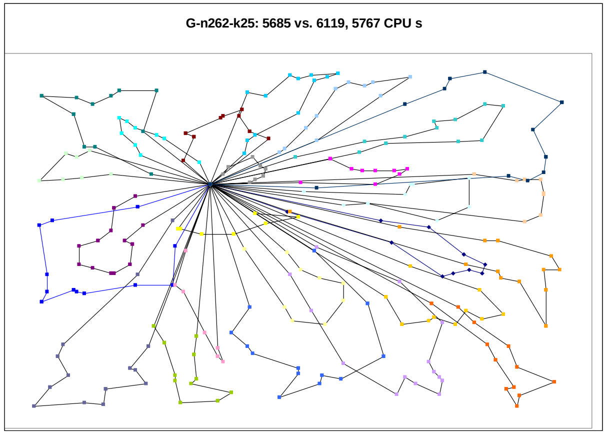
Practical applications - IRP

- 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,..)

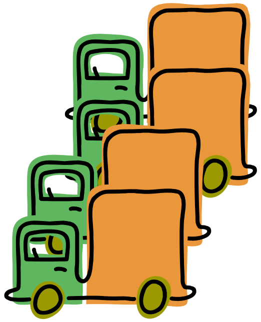
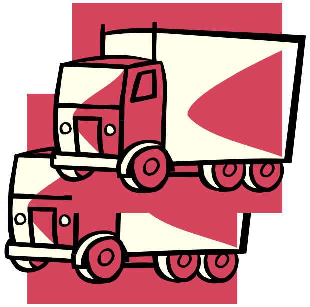
- Industry cases
  - Ammonia – Yara
  - LNG - Suez Energy International, StatoilHydro, RasGas, QuatarGas
  - Cement - Norcem
  - Fuel oil - Hydro Texaco
  - Animal fodder - Landbruksdistribusjon, Felleskjøpet

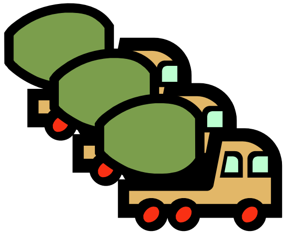
Daily charter rate	USD 60,000
Shipload of LNG worth	USD 10,000,000
Purchase price LNG tanker	USD 150,000,000

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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