Vehicle Routing in Practice

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Outline

- Background and Context
- The Vehicle Routing Problem
- Industrial Aspects
- Spider - A Generic VRP Solver
- Specific cases
- Ongoing and Further Research

Technology for a better society

SINTEF

- An Independent Multi-Disciplinary Contract R&D Organisation
- Established in 1950
- Among the Largest CRO in Europe

Vision:

- Technology for a better Society

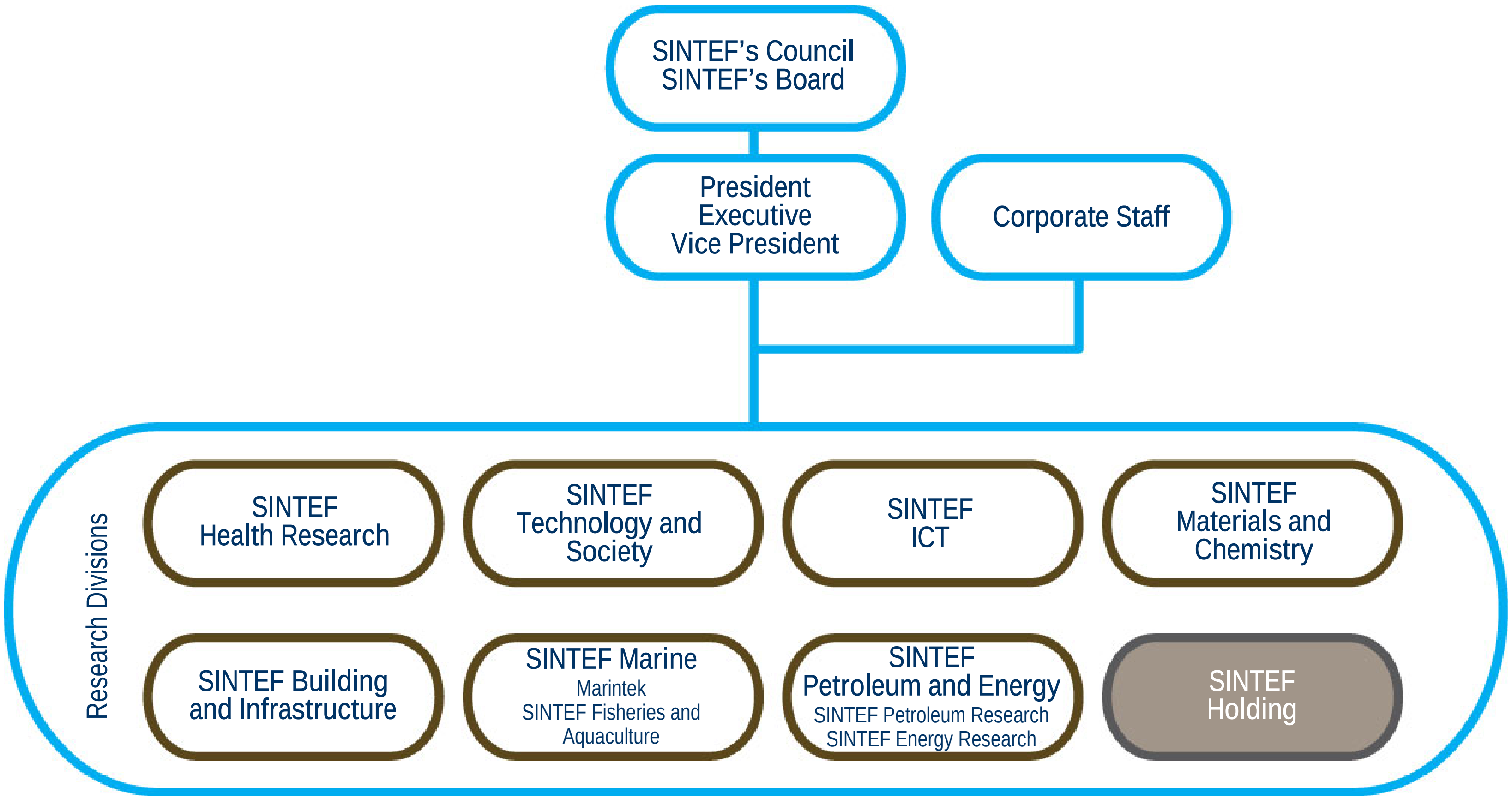
Business Concept:

- To meet the needs for Research-Based Innovation and Development for the Private and Public Sectors

SINTEF - A Norwegian Contract Research Institute

- Science and engineering – social sciences, health care
- Connected with
  - The Norwegian University of Science and Technology, Trondheim
  - The University of Oslo, Faculty of mathematics and natural sciences
- > 90 % of turnover from industry and public sector contracts
- Annual turnover ~ 200 M€
- Activities
  - Strategic, long term, basic research
  - Contract Research
  - Consultancy
  - Commercialization and spin-offs

The SINTEF Group



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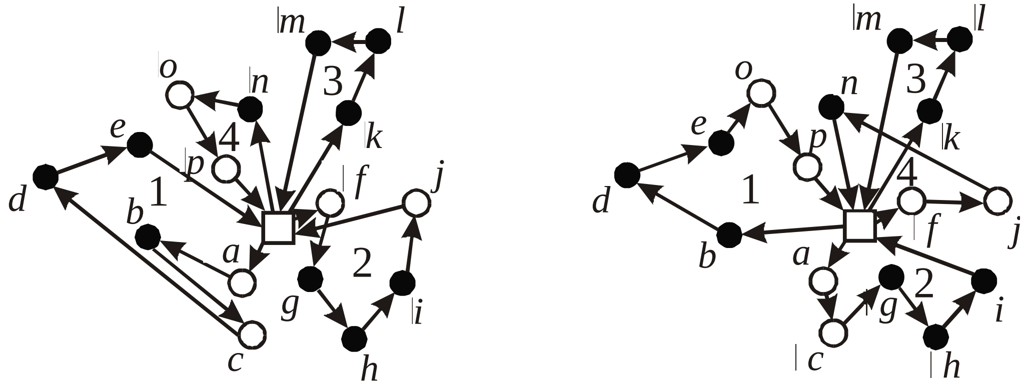
The Vehicle Routing Problem (VRP)

Given a fleet of vehicles and a set of transportation orders, find a minimum cost routing plan. That is: allocate each order to a vehicle, and for each vehicle, sequence the stops.

- The VRP central to efficient transportation management
- Applications
  - Distribution or pick-up of goods
  - Dial-a-ride
  - Municipal services
  - Repairman problem
  - Newspaper distribution
  - Waste management
  - Gritting, snow clearing
- Very hard, discrete optimization problem

The Capacitated VRP (CVRP)



- Graph $G=(N,A)$
  - $N=\{0,\ldots,n\}$ *Nodes*
  - *0 Depot*, $i \neq 0$ *Customers*
  - $A=\{(i,j): i,j \in N\}$ *Arcs*
  - $c_{ij} > 0$ *Arc cost*
- *Demand* d_i for each *Customer i*
  - either all pickups or all deliveries
- *V* set of (identical) *Vehicles,* each with *Capacity q*
- Goal
  - Construct a set of minimum cost *Routes* that start and finish at the *Depot.*
  - Each *Customer* shall be visited once (no order splitting)
  - Total *Demand* for all *Customers* serviced less than *Capacity q*
  - *Cost*: Total *Arc cost* (also # *Routes* in richer VRP variants)

- DVRP – constraint on route length
- VRPTW – VRP with time windows
- VRPB – VRP with backhauling (deliveries first, then pickups)
- PDP – pickup and delivery without going through the depot

Mathematical formulation of VRPTW
(vehicle 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 once
	$\sum_{i \in C} d_i \sum_{j \in N} x_{ij}^k \le q,$	$\forall k \in V$	(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)	start of service and driving time
	$a_i \le s_i^k \le b_i,$	$\forall i \in N, \ \forall k \in V$	(8)	start of service within TW
	$x_{ij}^k \in \{0,1\},$	$\forall (i,j) \in A, \ \forall k \in V$	(9)	arc (i,j) driven by k

The VRP is very hard, computationally

- Belongs to class of strongly **NP**-hard optimization problems
- Computing time for **all VRP optimization algorithms** grows ”exponentially” with the number of nodes (probably ...)
- Exact methods are ”easy” to design, may take forever
- Currently, exact methods for the C/DVRP can **consistently** solve instances with **some 70 customers only** to optimality within a few minutes
- For generic industrial VRP tools, we must give up the quest for optimality and resort to some form of approximation
- What is the optimal plan, anyway?

VRP in Operations Research

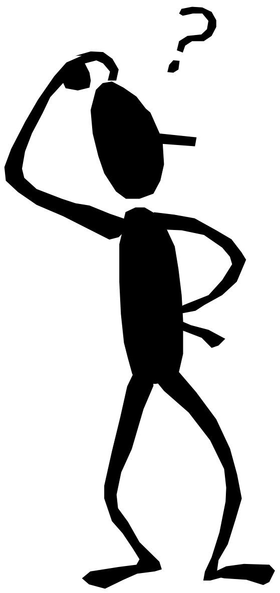
- since 1959
- thousands of papers
- mostly generic work on idealized VRP models
- still, one of the successes of OR
- a tool industry has emerged, based on research results
- tremendous increase in ability to ”solve” VRP variants
  - general increase of available computing power
  - methodological improvement
- still much to do, VRP research has never been more active
- short road from research results to industrial benefits

VRP in Operations Research

- General, idealized formulations
- Extensions studied in isolation
  - time windows
  - multiple depots
  - inventory constraints
  - ....
- Very fruitful for
  - understanding VRP variants
  - developing highly targeted algorithms
- Not always relevant to real-life problems
- Some application specific work
- Recently: More holistic approach: ”Rich VRPs”
  - General model, many aspects of industrial problems
  - Robust algorithms

Extensions in the VRP-literature

Location Routing	LRP
Fleet Size and Mix	FSMVRP
VRP With Time Windows	VRPTW
General Pickup and Delivery	GPDP
Dial-A-Ride	DARP
Periodic VRP	PVRP
Inventory Routing	IRP
Dynamic VRP	DVRP
Capacitated Arc Routing Problem	CARP



- All kinds of algorithmic approaches
  - exact
  - approximation methods
    - based on systematic, exact methods
    - metaheuristics

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Industrial aspects – VRP tool

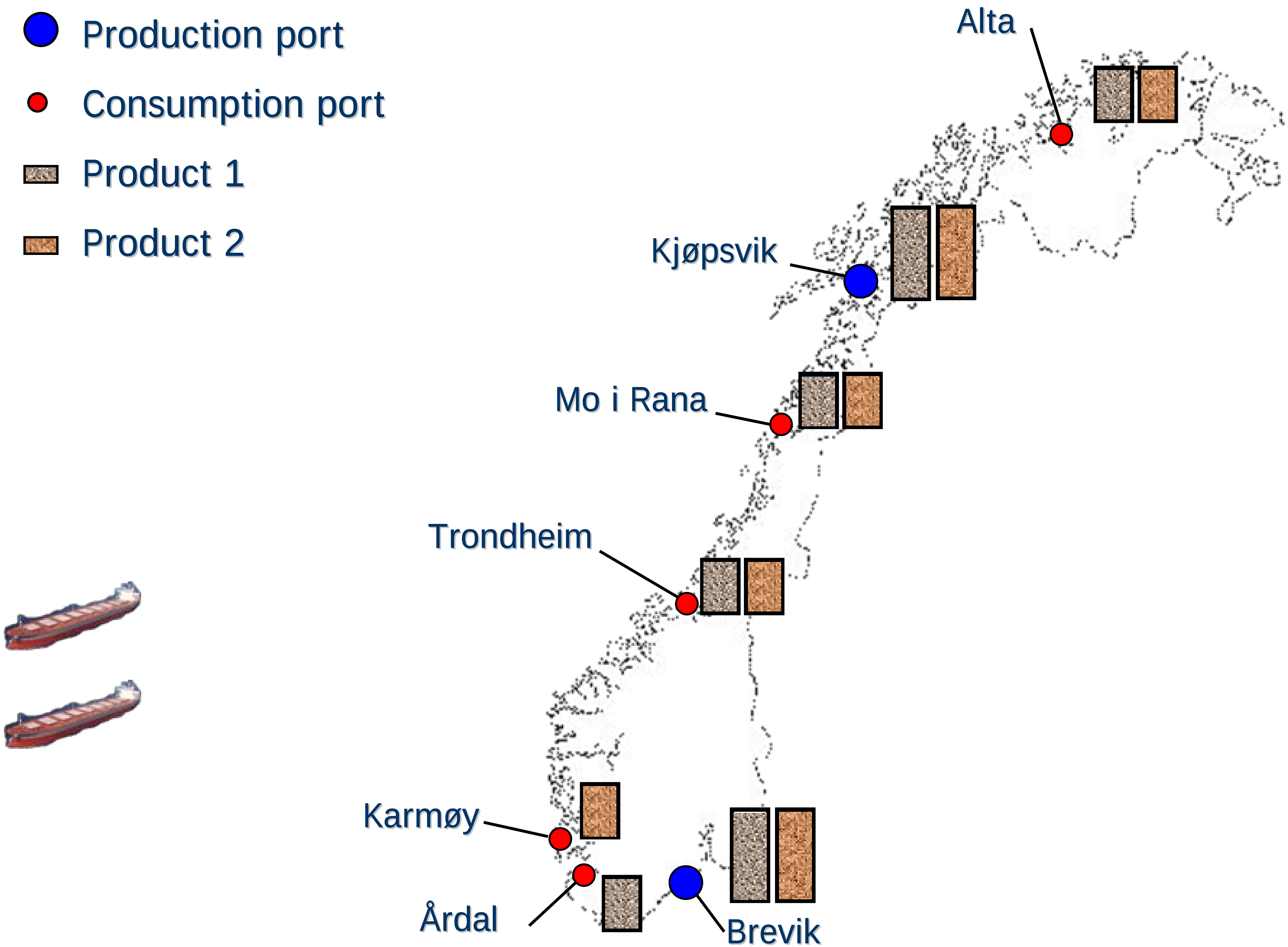
- Adequate model of the applications
- Wide range of applications
- High quality information
  - addresses
  - distances, times, costs
  - orders
  - fleet and driver information
- Manual planning, user interface
- Ease of use
- Software issues
  - Integration with ERP etc.
  - Extendability
  - Maintainability
  - Documentation
- High quality solution in short time – powerful VRP solver

Industry needs rich VRP models

- Type of service and operation
  - multiple depots, no depot
  - different order types (delivery, pickup, direct, service, ...)
  - order splitting, flexible order volumes
  - node routing, arc routing, mixed
  - multiple tours per day
  - periodic problems
  - connection to inventory and manufacturing
- Constraints
  - capacity, several dimensions, hard and soft
  - time windows, multiple, hard and soft
  - precedences
  - (in)compatibilities
- Realistic distances, times, costs
- Cost components
  - multiple criteria
  - soft constraints and penalties
- Uncertainty and Dynamics

Research on Rich VRPs & related problems at SINTEF

- Industrial Contracts since 1995
- Strategic Research
  - European Commission FP III, IV, V (e.g., GreenTrip 1996-1999)
  - Norwegian Research Council (RCN)
  - Internal Projects, students
- Generic VRP Solver - Spider (1995→)
  - Commercialization from 1999
  - GreenTrip AS → Spider Solutions AS
- TOP Programme 2001-2004 (RCN) http://www.top.sintef.no/
  - Basic Research on Rich VRP and related problems
  - VRPTW
  - Shortest Path Problem in Dynamic Road Topologies
- Innovation Projects supported by Research Council of Norway
  - "I Rute" (2001 – 2004) Bulk transportation
  - "DOiT" (2004 – 2007) Stochastic and Dynamic Routing
  - "EDGE" (2005 – 2008) Large Scale Routing
  - "Effekt" (2008 – 2011) Media Product Distribution Routing
- Ship routing
  - TurboRouter 1995 ->
  - SINTEF Internal Strategic Project (2005-2008)
  - LNGShipping



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

Invent –
solving maritime routing problems

Invent is a software library that can model and solve a wide class of maritime routing problems. This includes both traditional tramp shipping and industrial shipping problems with inventory management.

Vessels can be modeled at tank level with the possibility of detailed tank stowage and cleaning operations.

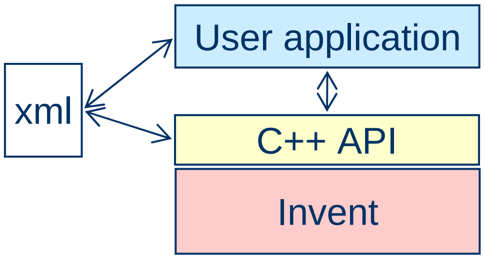
Inventories can have a time varying production or consumption profile together with an upper and lower limit on the inventory level.

The inventories can be combined with traditional orders with laycan and quantity intervals for a pair of pickup and delivery locations.

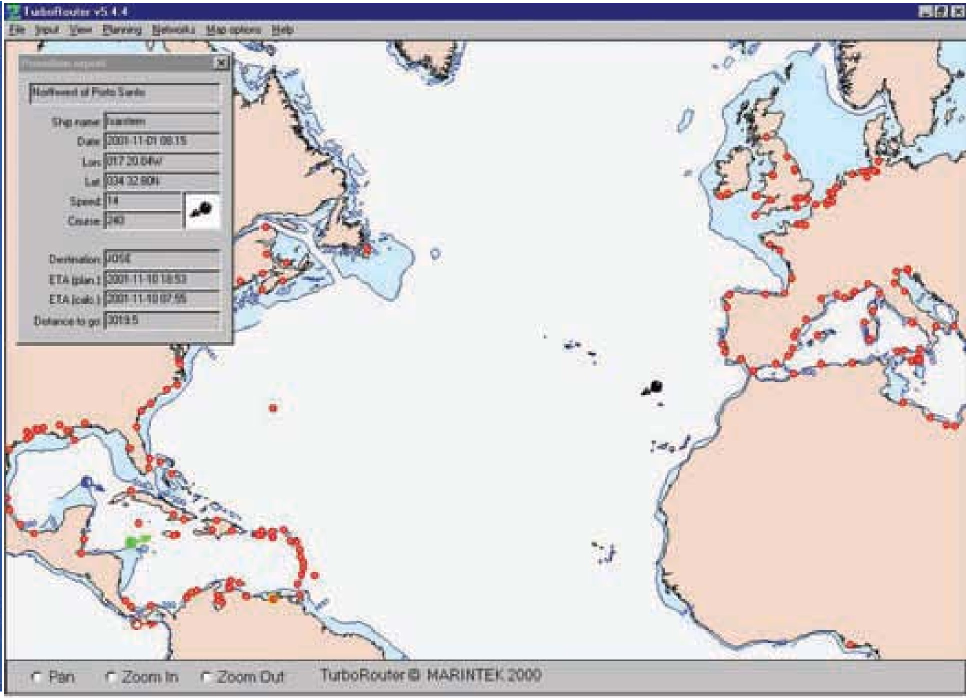
It is also possible to include contracts with details on required pickup or delivery in given periods, and time varying price curves for income and cost.

Problem instances are described in a general XML format that can be used as input for the automatic planning process.

Invent generates optimized plans for the problems based on advanced heuristic methods that are able to provide high quality solutions in short time.



TurboRouter



Maritime Transport Optimization
AN OCEAN OF OPPORTUNITIES

- ORMS Today, Special International Issue, Vol 36 No 2 pp 28-31, April 2009.

- http://viewer.zmags.com/publication/1368b369#/1368b369/28

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Spider - A Generic VRP Solver

- Designed to be widely applicable
- Based on generic, rich model
- Predictive route planning
- Plan repair, reactive planning
- Dynamic planning with stochastic model

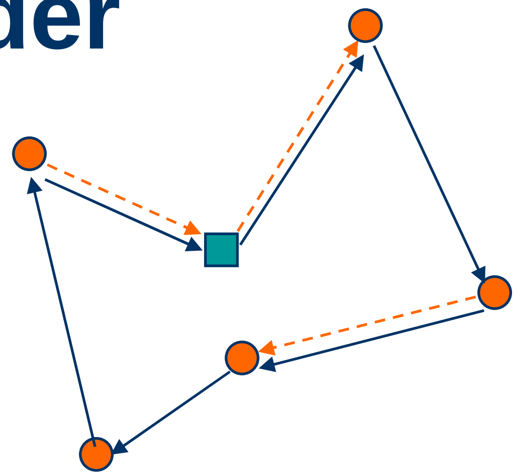
- Framework for VRP research

SPIDER - Generalisations of CVRP

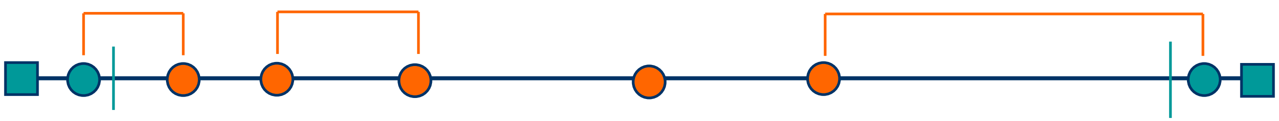
- Heterogeneous fleet
  - Capacities
  - Equipment
  - Arbitrary tour start/end locations
  - Time windows
  - Cost structure
- Linked tours with precedences
- Mixture of order types
- Multiple time windows, soft time windows
- Capacity in multiple dimensions, soft capacity
- Alternative locations, tours and orders
- Arc locations, for arc routing, mixed problems and aggregation of node orders
- Alternative time periods
- Non-Euclidean, asymmetric, time-varying travel times
- Compatibility constraints
- A variety of cost components and soft constraints
  - driving time restrictions
  - visual beauty of routing plan, non-overlapping routes
  - levelling

Transportation Order

- Different types:
  - Delivery
  - Pickup
  - Direct (P&D)
  - Service

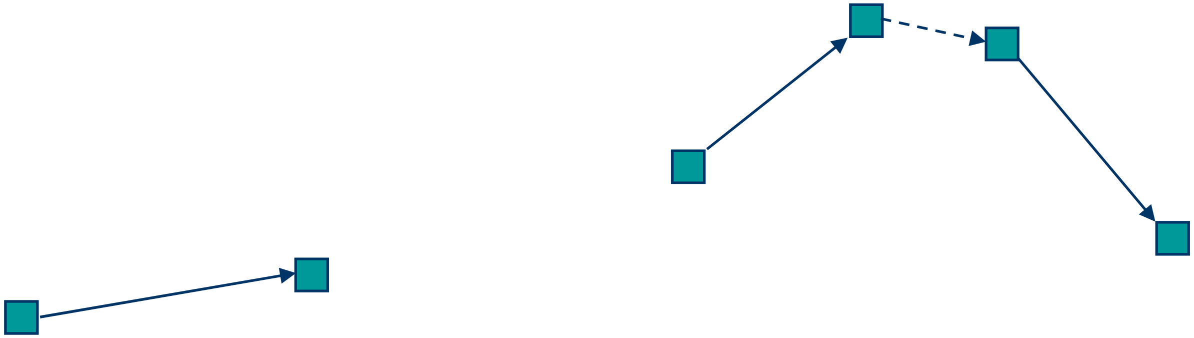


- Plan structure
  - task
  - task sequence
  - tour
  - plan



Tour

- Time windows and locations given by start/stop tasks
- Selected vehicle and driver (alternative equipages)
- Linked tours
  - (may have different vehicles)



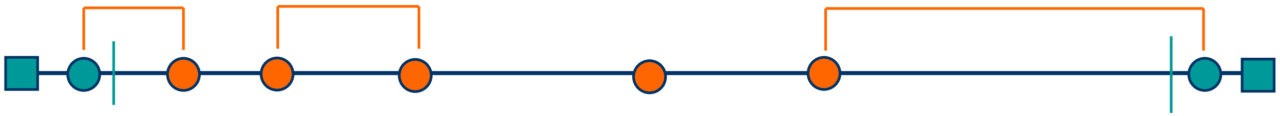
Vehicle and Driver

- Capacity
- Travelling attributes
  - Speed profile
  - Height, weight, length
  - Obey one-way restrictions?
- Driving time regulations

Cost elements

- Travel cost (distance, time, tolls)
- Tour usage cost
  - Cost for starting a tour
  - Cost per order on tour
- Cost for unserviced order
- Waiting time cost
- Cost for alternative locations
- Cost for same/different location
- Cost for breaking work regulations
- Cost for “ugly”, overlapping routes

Constraints



- Consistency
  - Complete order
  - Pickup/delivery (Direct orders) same tour and precedence
- Time
  - Travel time, Duration
  - Time windows, multiple, hard and soft
- Vehicle capacities, multiple dimensions, hard and soft
- Total capacities over a set of tours

Constraints

- Compatibility vehicle/order vehicle/location product/compartment
- Orders on same tour
- Corresponding locations (when alternatives)
  - Order: Choose corresponding locations for pickup and delivery task
  - Tour: Choose corresponding locations for start/stop tasks
- Corresponding time periods for sets of orders
  - E.g. Delivery day 1,3,5 or day 2,4,6

Locks

- Prevent optimiser changing part of plan
- Task: Time lock
- Tour: Lock whole or initial part of tour
- Order: Lock (un)assignment

Uniform Algorithmic Approach

- Goals
  - Reach a good local optimum fast
  - Explore interesting parts of search space efficiently
- 3 phases
  - Construction
  - Iterative Improvement: Iterated Variable Neighborhood Descent
  - Tour Depletion
- Based on
  - Iterated Local Search (Martin, Lourenço et al)
  - Variable Neighborhood Descent (Hansen & Mladenovic)
  - Diversification when VND reaches local optimum

Construction of Initial Solution

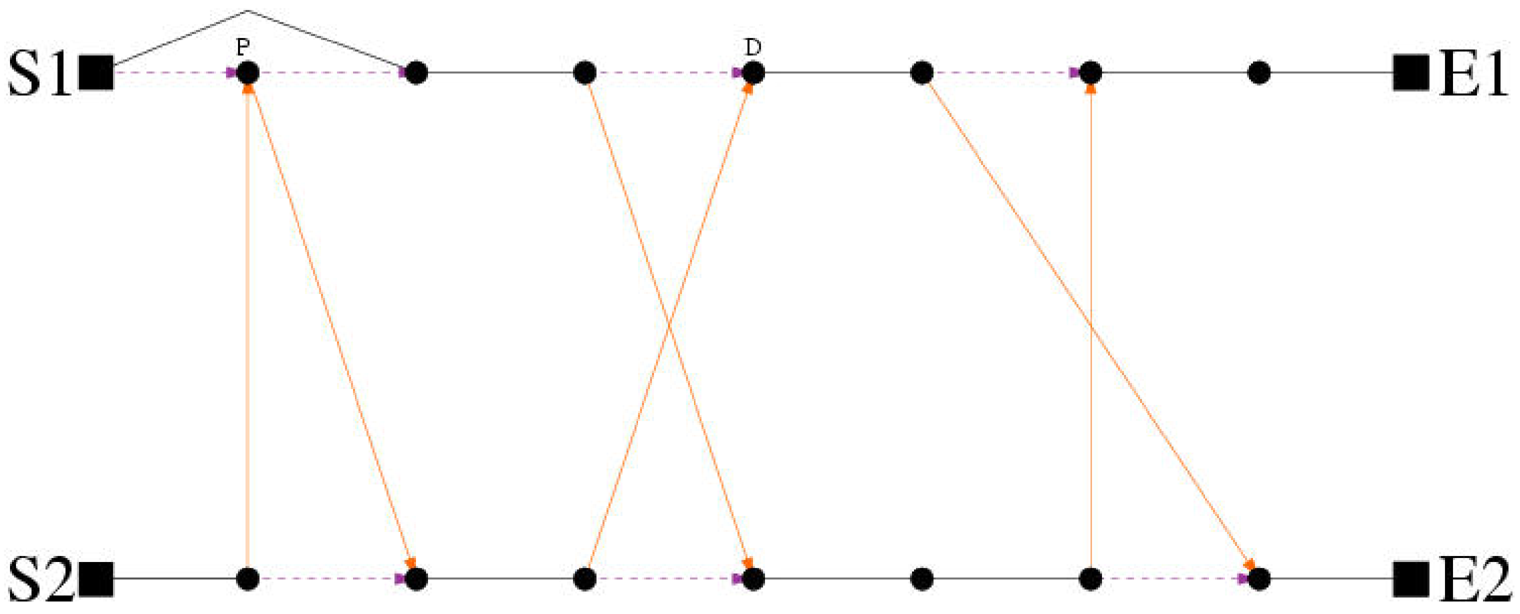
- Various Sequential Construction Heuristics
- Extended to cover Richer Model
  - Several types of order
  - Non-standard constraints
  - Non-homogeneous fleet
  - Multiple Depots
  - Multiple Tours per Vehicle
- New Constructor
  - Inhomogeneous problems
  - Multiple depots
  - Multiple tours per vehicle
  - More search

Variable Neighborhood Descent - Operators

- Insert
- Remove
- 2-opt
- Or-opt
- 3-opt
- Relocate
- Cross (2-opt*)
- Exchange (Cross-Exchange)
- Tour Depletion
- Change alternative location
- Change alternative time period
- Change vehicle
- ...
- Variety, efficiency, sequence?

Illustration: Exchange

- Inter-tour operator
- Full neighborhood is typically large
- Remedy: Limit on maximum segment length
- Alternative: Focus on promising cut points



Iterated Local Search (Martin, Lourenço et al)

- Goal: Efficient search in new basins of attraction
- When VND reaches local optimum: diversify
- Random restart
- Alternative initial solution
- Path relinking
- Noising: perturb problem data
- Change objective
- LNS, VLNS

Large Neighborhood Search (Shaw)

- Take away a substantial number of commitments
  - randomly
  - “similar” commitments
- Reconstruct with fast insertion method
  - Cheapest insertion
  - Regret-based insertion
- Accept new solution if
  - better, diverse
  - Threshold Acceptance
  - Simulated Annealing
- Iterate
- Alternative modifications
  - Limited Local Search
  - Full VND Machinery
  - Distance Metrics

Computational Experiments

- Standard test problems in literature for most VRP variants
- ”World championship” in Vehicle Routing
- For most instances, the optimal solution is not known
- Testing against the best methods reported in the literature
- ”Unfair” comparison: competing with solvers optimized for solving a specific, idealized problem
- Nice to know how well you perform ...

Experimental studies PDPTW http://www.sintef.no/top

- 354 standard test problems Li & Lim: 100 – 1.000 orders

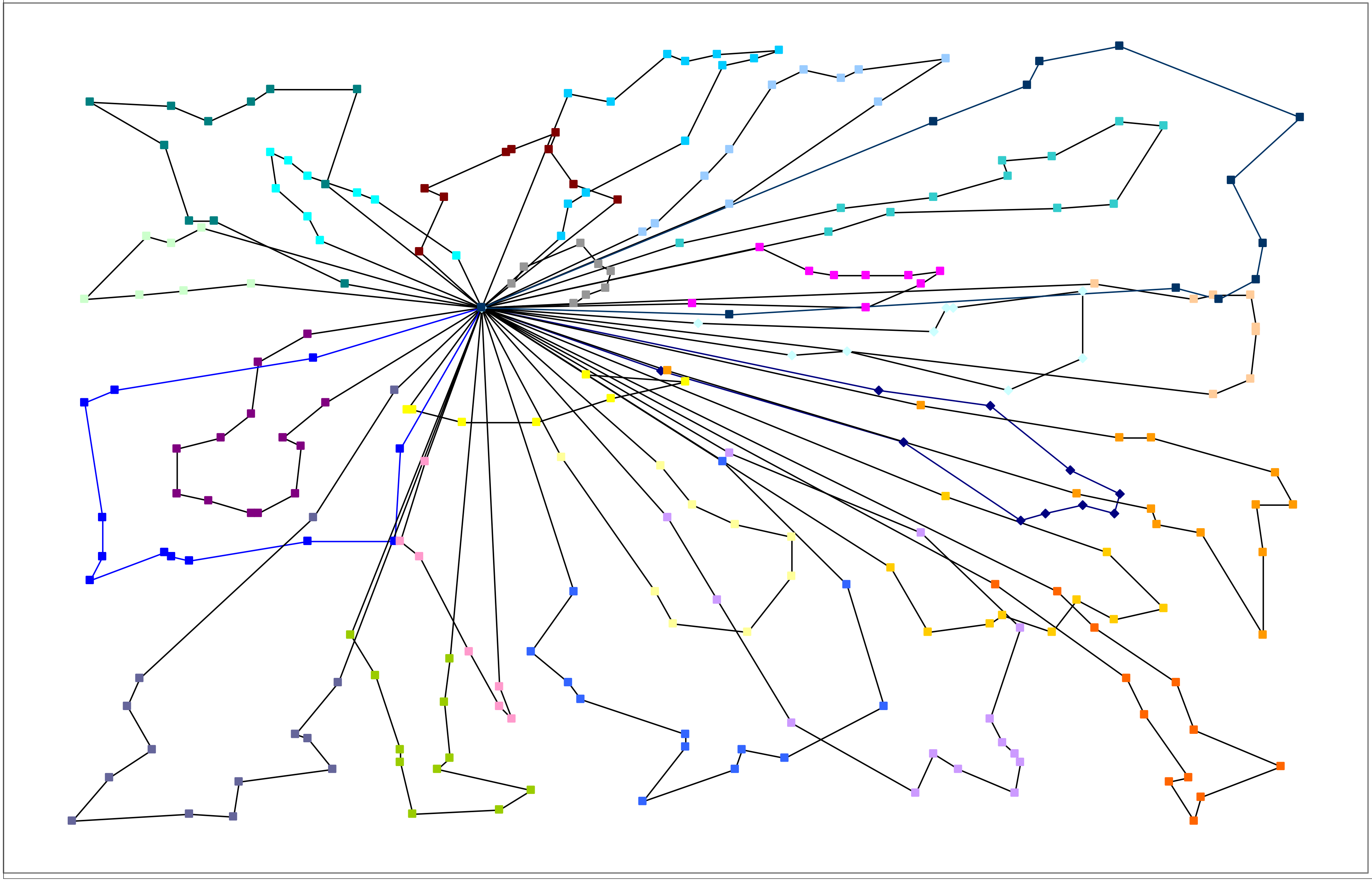
Author	100	200	400	600	800	1000	Total
Li & Lim	41	14	6	2	0	0	63
Spider	13	11	5	4	9	4	46
BVH	2	8	6	3	4	1	24
TS	0	1	2	0	0	2	5
SR	0	26	41	51	47	51	216
Total	56	60	60	60	60	58	354

- BVH: Bent & Van Hentenryck: Two-stage, Hybrid Local Search
  - 1. Minimize # tours by SA, modified objective
  - 2. Minimize Distance with Large Neighborhood Search
- TS: Tetrasoft, Danish tool vendor, Method unknown
- SR: Stefan Röpke, Univ. Copenhagen
  - Adaptive Large Neighborhood Search

Results on CVRP
- Rounded distances (1)

- Augerat et al
  - 74 instances, 15-100 customers, limit on # vehicles
  - A (27): 0.15% from optimum, 19 optimal, 0-541 s, average 100 s
  - B (23): 0.11% from optimum, 17 optimal, 1-582 s, average 95 s
  - P (24): 0.23% from optimum, 15 optimal, 0-450 s, average 99 s
- Christofides & Eilon (1969)
  - 13 instances, 12-100 customers, limit on # vehicles
  - E (13): 0.32% from optimum, 2 optimal, 7 - 487 s, average 178 s
- Fisher
  - 3 instances, 44 - 134 customers, limit on # vehicles
  - F (3): 0.27% from optimum, 7 optimal, 0-289 s, average 103 s
- Gillett & Johnson, 1 instance: **G-n262-k25**
  - best known, -7.09% from previous best known (5685)

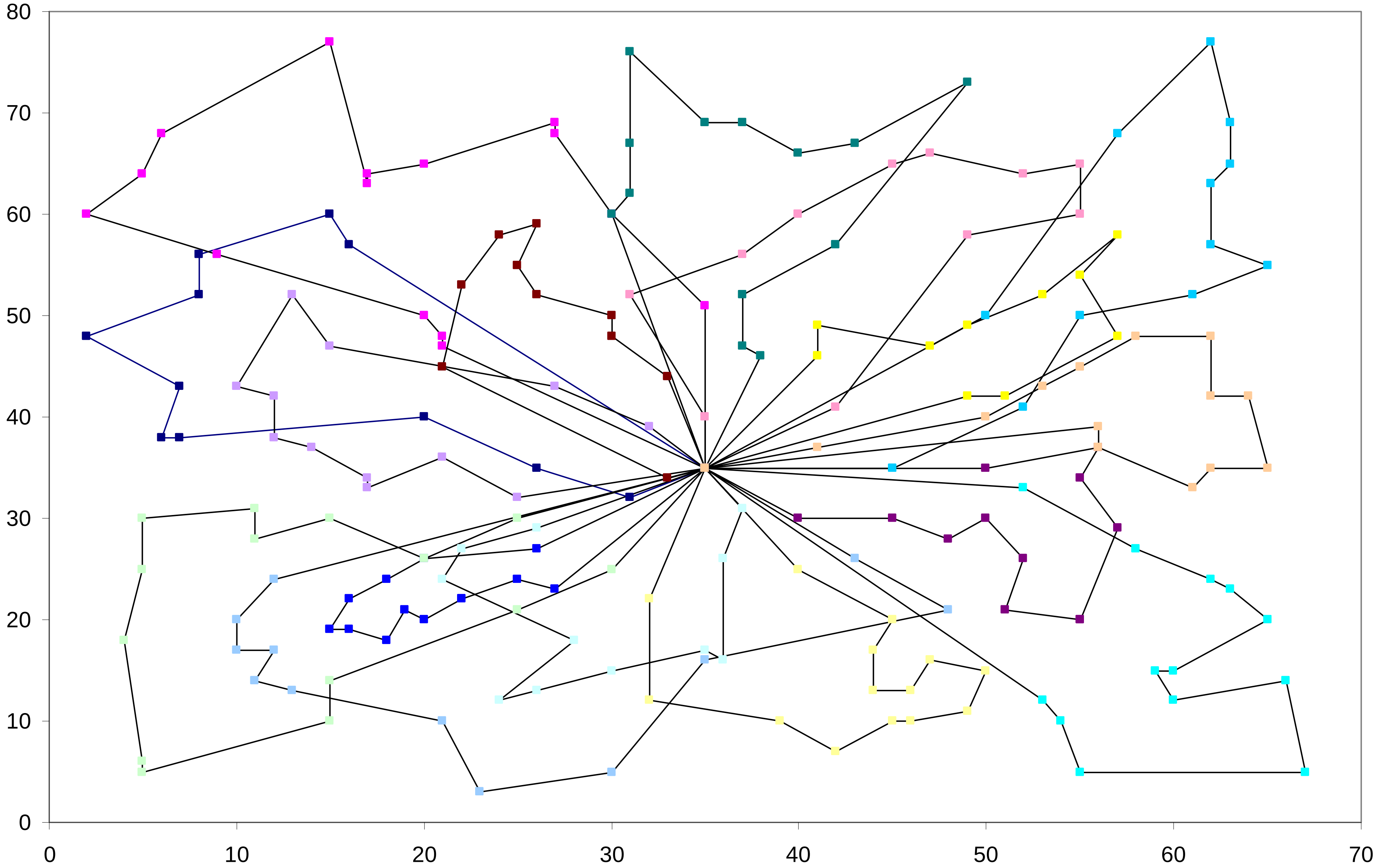
G-n262-k25: 5685 vs. 6119



Results on CVRP
- Rounded distances (2)

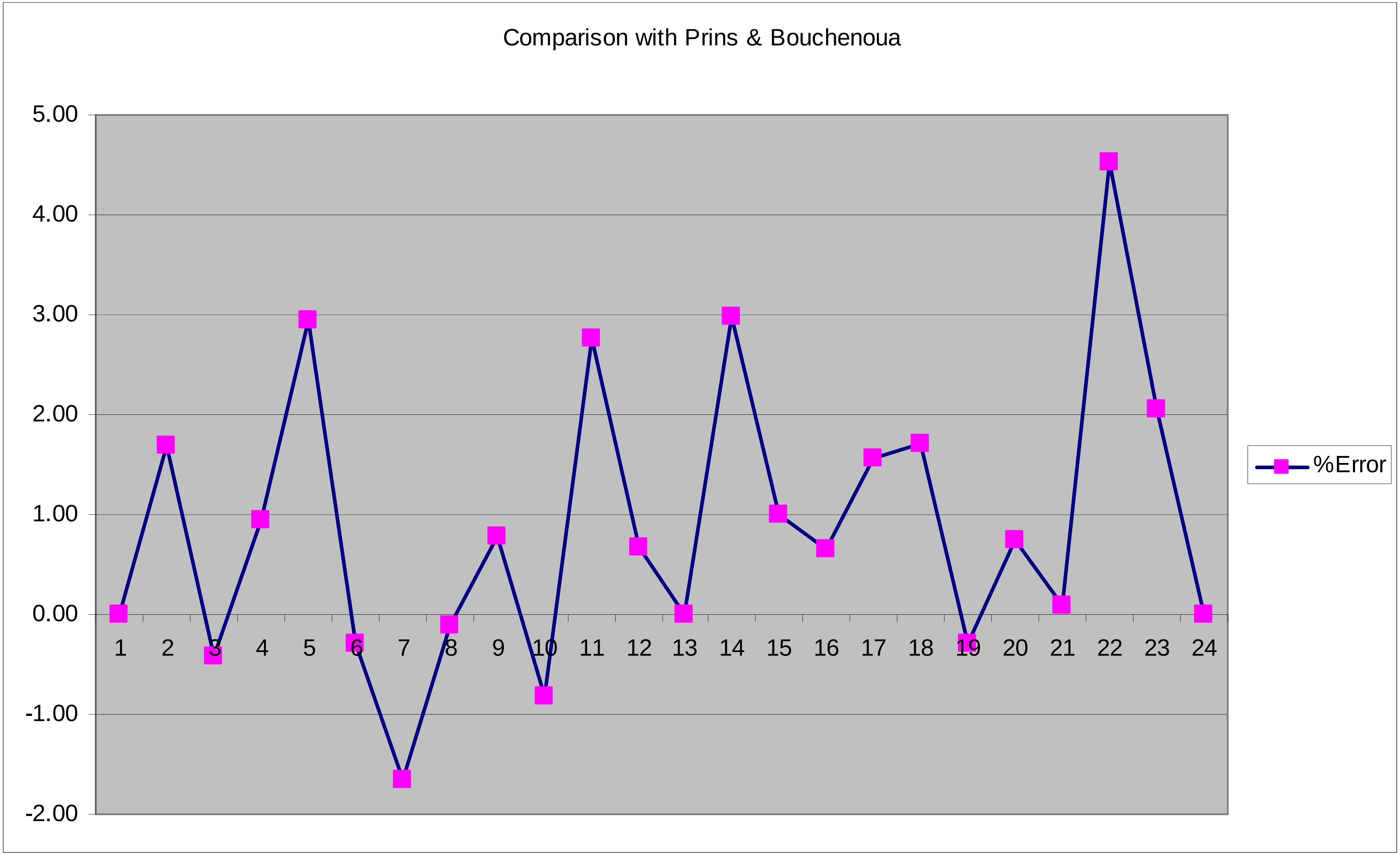
- Christofides, Mingozzi & Toth (1979)
- 5 CVRP instances, 100-199 customers, limit on # vehicles
- 0.99 % from optimum, 21-1255 s, average 404s
- 1 optimal
- 1 new best known -1.6 %
- 1 worse by 2.7 %
- 1 worse by 2.9 %
- M-n200-k16: no feasible solution previously known
- Feasible solution found
  - after 533s: distance 1371

M-n200-k16: First known feasible solution



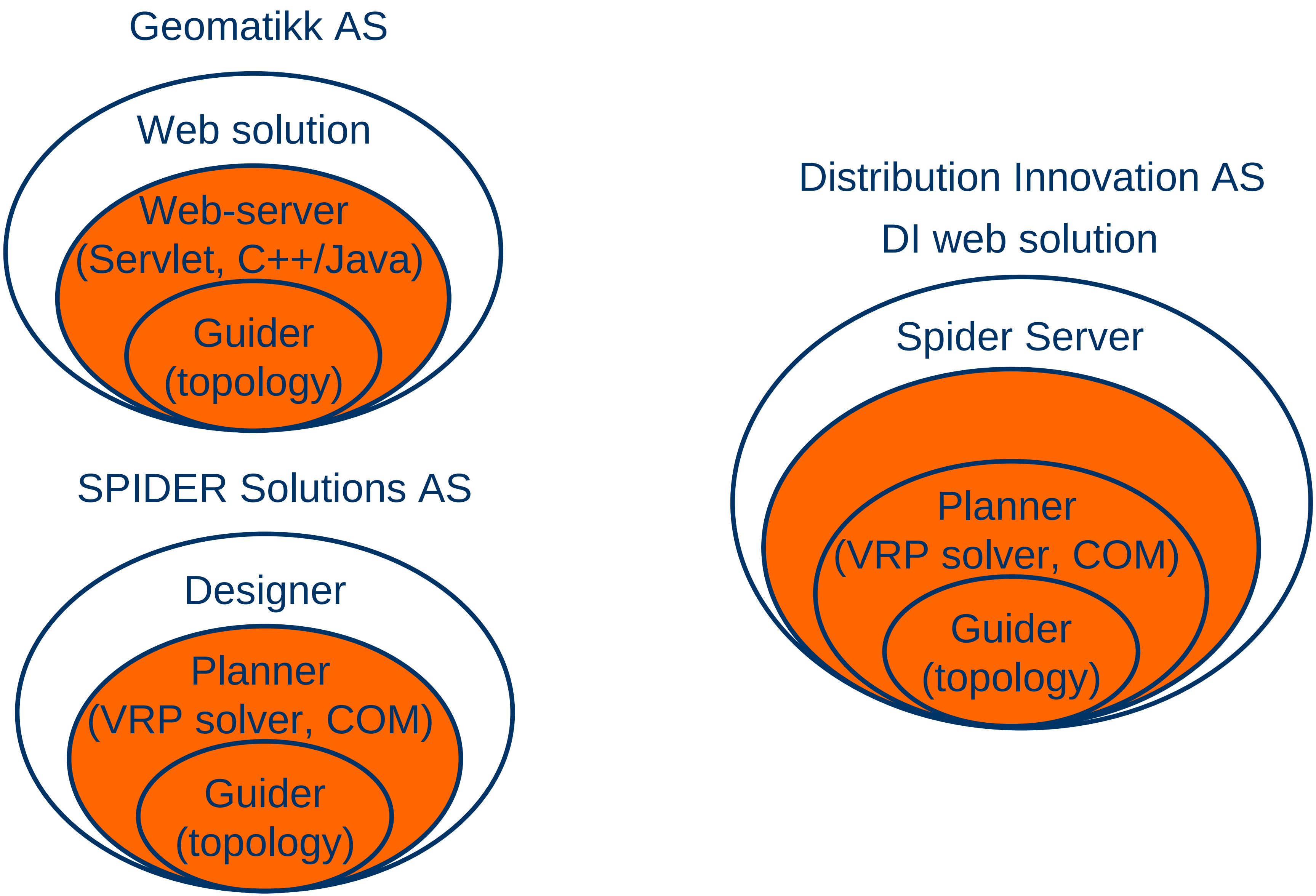
Computational tests - NEARP

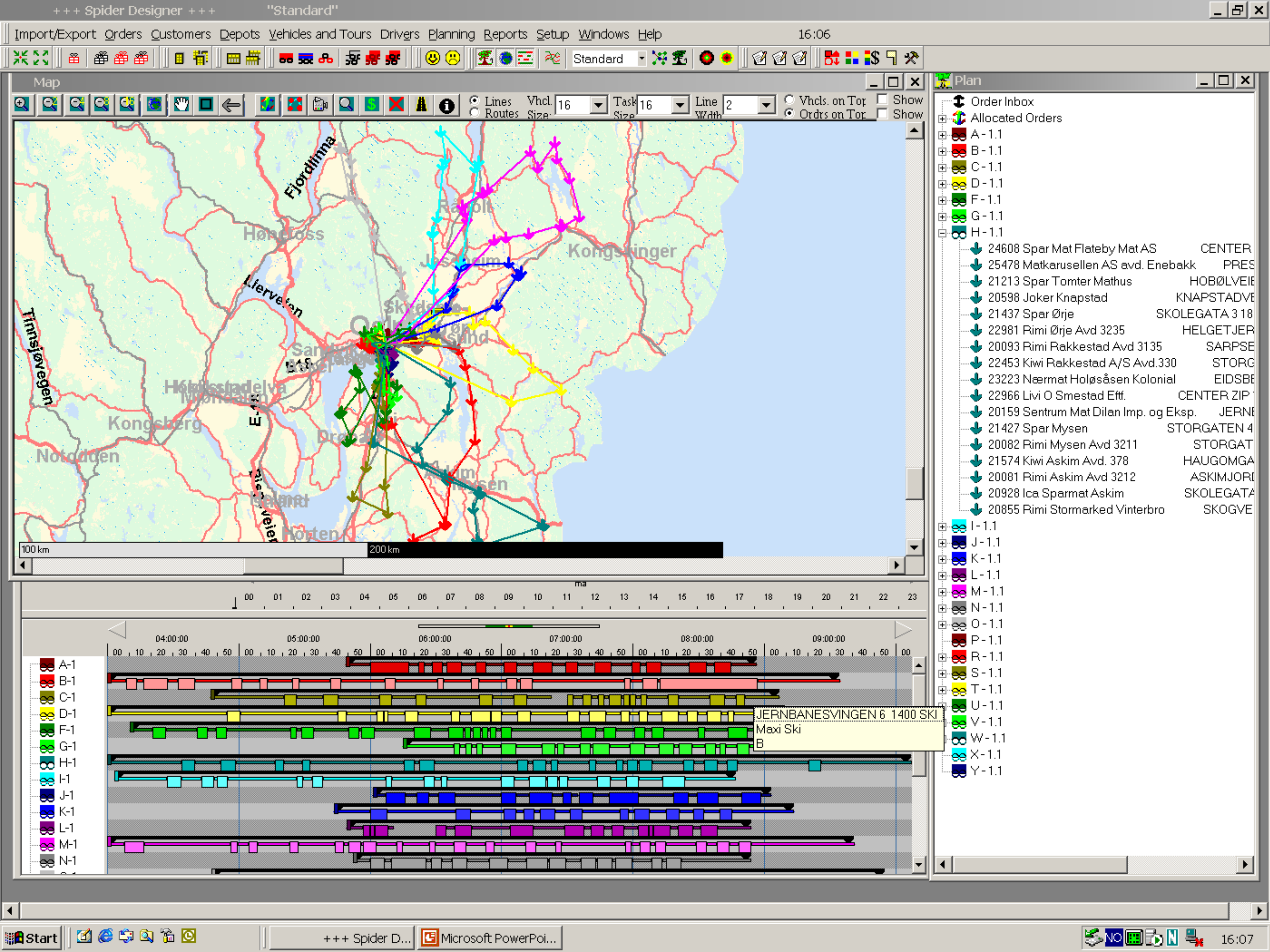
- Prins & Bouchenoua CBMix (23 instances)
- No lower bounds, no proven optima, only one competitor
- UB error 0.94%
- 8 best known solutions (6 new)



Comparison with Prins & Bouchenoua
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
%Error

Products - architecture





+++ Spider Designer +++ "Standard"
Import/Export Orders Customers Depots Vehicles and Tours Drivers Planning Reports Setup Windows Help
16:06
Standard
Map
Lines
Routes
Vhcl. Size:
16
Task Size
16
Line Width
2
Vhcls. on Top
Ordrs on Top
Show
Show
100 km
200 km
Plan
Order Inbox
Allocated Orders
A - 1.1
B - 1.1
C - 1.1
D - 1.1
F - 1.1
G - 1.1
H - 1.1
24608 Spar Mat Flateby Mat AS CENTER
25478 Matkarusellen AS avd. Enebakk PRES
21213 Spar Tomter Mathus HOBØLVEIE
20598 Joker Knapstad KNAPSTADVE
21437 Spar Ørje SKOLEGATA 3 18
22981 Rimi Ørje Avd 3235 HELGETJER
20093 Rimi Rakkestad Avd 3135 SARPSE
22453 Kiwi Rakkestad A/S Avd.330 STORG
23223 Nærmat Holøsåsen Kolonial EIDSBE
22966 Livi O Smestad Eftf. CENTER ZIP
20159 Sentrum Mat Dilan Imp. og Eksp. JERNE
21427 Spar Mysen STORGATEN 4
20082 Rimi Mysen Avd 3211 STORGAT
21574 Kiwi Askim Avd. 378 HAUGOMGA
20081 Rimi Askim Avd 3212 ASKIMJORE
20928 Ica Sparmat Askim SKOLEGATA
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Maxi Ski
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Microsoft PowerPoi...
16:07

Spider Designer - Applications

- Distribution of bread (Bakers)
- Mail collection and distribution (Posten Norge)
- Local pickup and delivery (Schenker)
- Newspaper distribution, 1st tier (Aftenposten, Dagbladet)
- Newspaper distribution, last mile (Aftenposten, Stavanger Aftenblad)
- Collection of milk from farms (TINE)
- Distribution of fodder to farms (Landbruksdistribusjon)
- Distribution of fuel oil (Hydro Texaco)
- Location analyses, depot (obnoxious facility location, Norsk Gjenvinning AS)
- Distribution of blood (Ullevål sykehus)
- Distribution of groceries (REMA 1000)
- Distribution of magazines (Bladcentralen)
- Distribution of ice cream (Diplom Is; Hennig Olsen)
- Dial-a-ride, elderly, hospital patients (Nor-Link)

- Savings 2-35%, depending on application

Challenges for Routing Technology

- Industrial awareness
- Range of applications
- Information availability and quality
- User interfaces
- Model adequacy and flexibility
- Software engineering
- Robustness of solution method
- Solution quality for large-size and complex problems

Challenges for Spider

- Electronic road network - GIS
- Instance robustness
  - all kinds of instances
- Scalability
  - very large size problems
- Extendability
  - new operators, new VND sequence

- Exploiting modern commodity computers
  - multi-core, heterogeneous, GPUs

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Scalability – Solving ”Huge” VRPs

- Faster VRP solver
  - heuristic investigation of neighborhoods
  - clever sequencing of constraint and objective component evaluation
  - more powerful metaheuristics
  - hybrid methods, even combining exact methods and heuristics
- Problem Decomposition
  - geographically
  - temporally
  - based on product
  - clustering methods will be useful
  - subproblem
- Abstraction and Aggregation
  - clustering methods will be useful
- Exploit modern parallel and heterogeneous computer architectures
- Multi-level search and collaborative solvers

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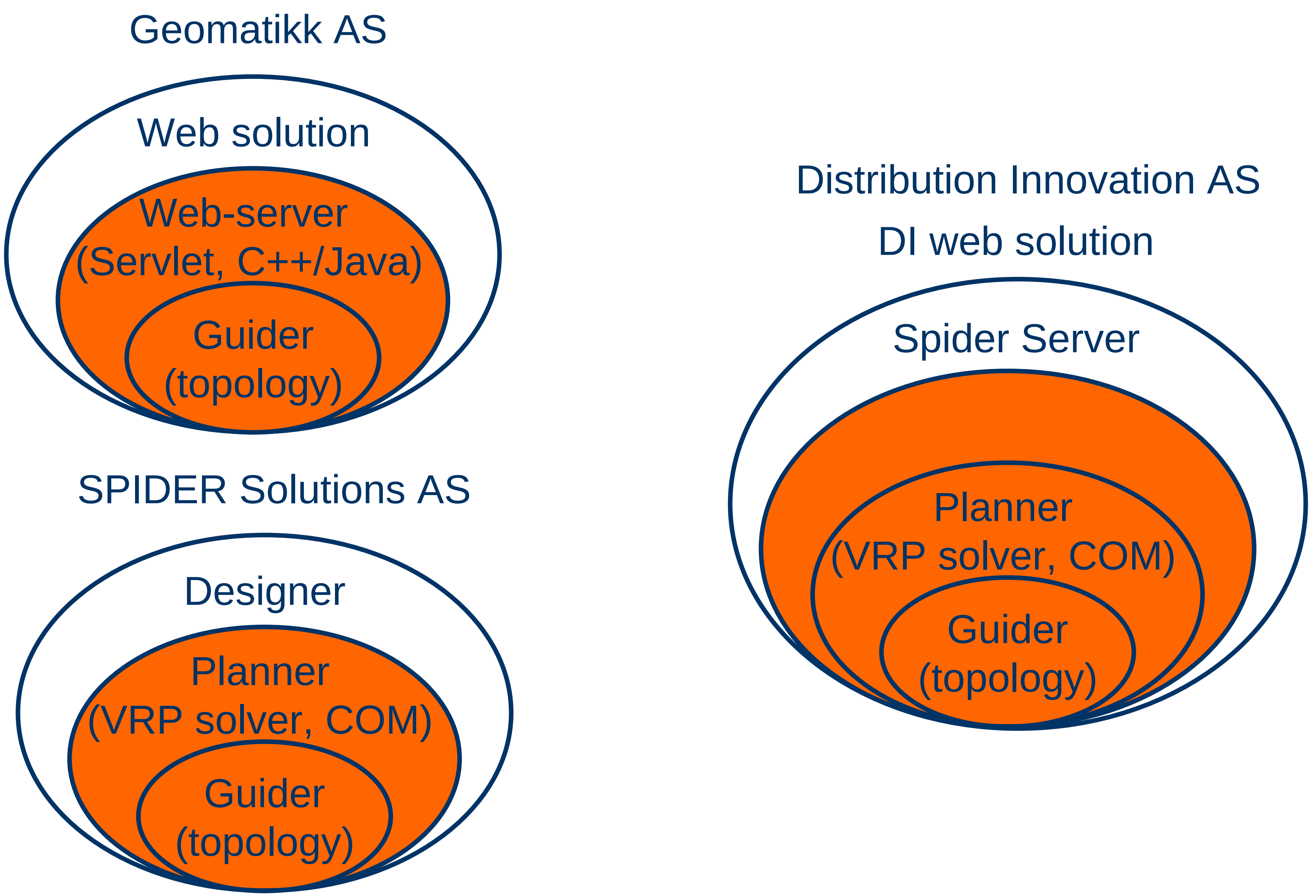
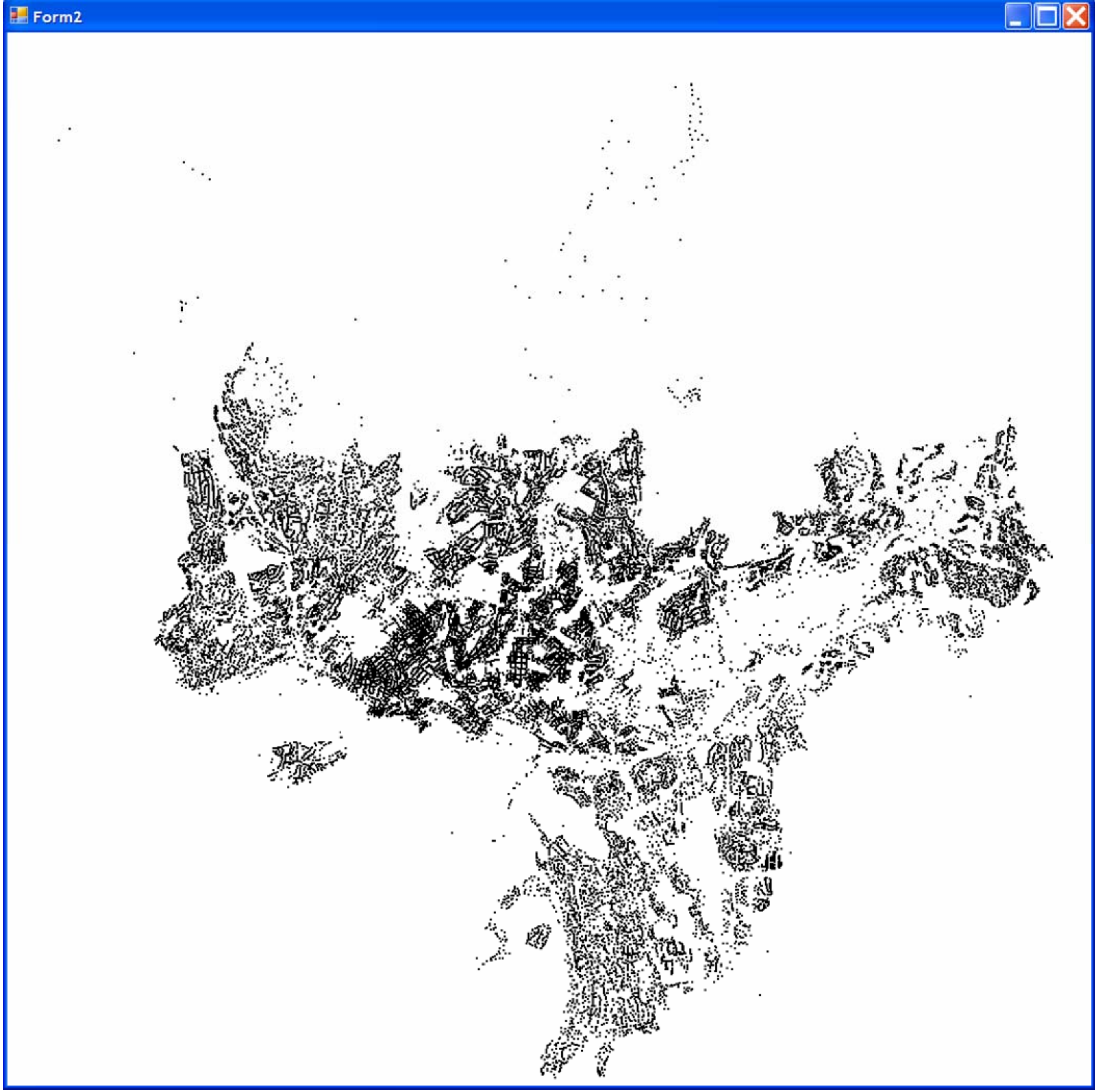
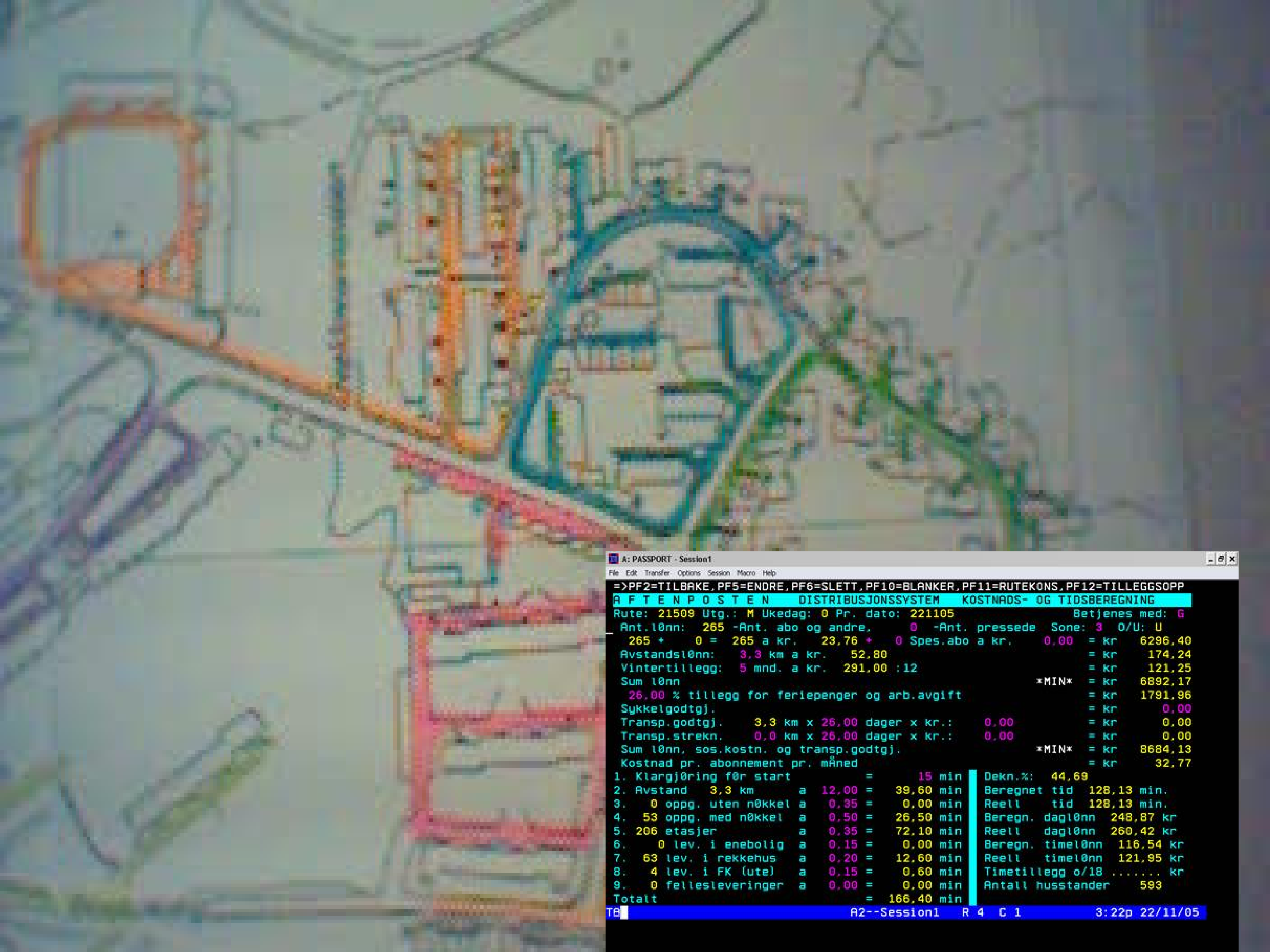
Products - architecture



- Newspaper distribution
- City of Oslo
- 500k inhabitants
- 200k households
- 35k modules

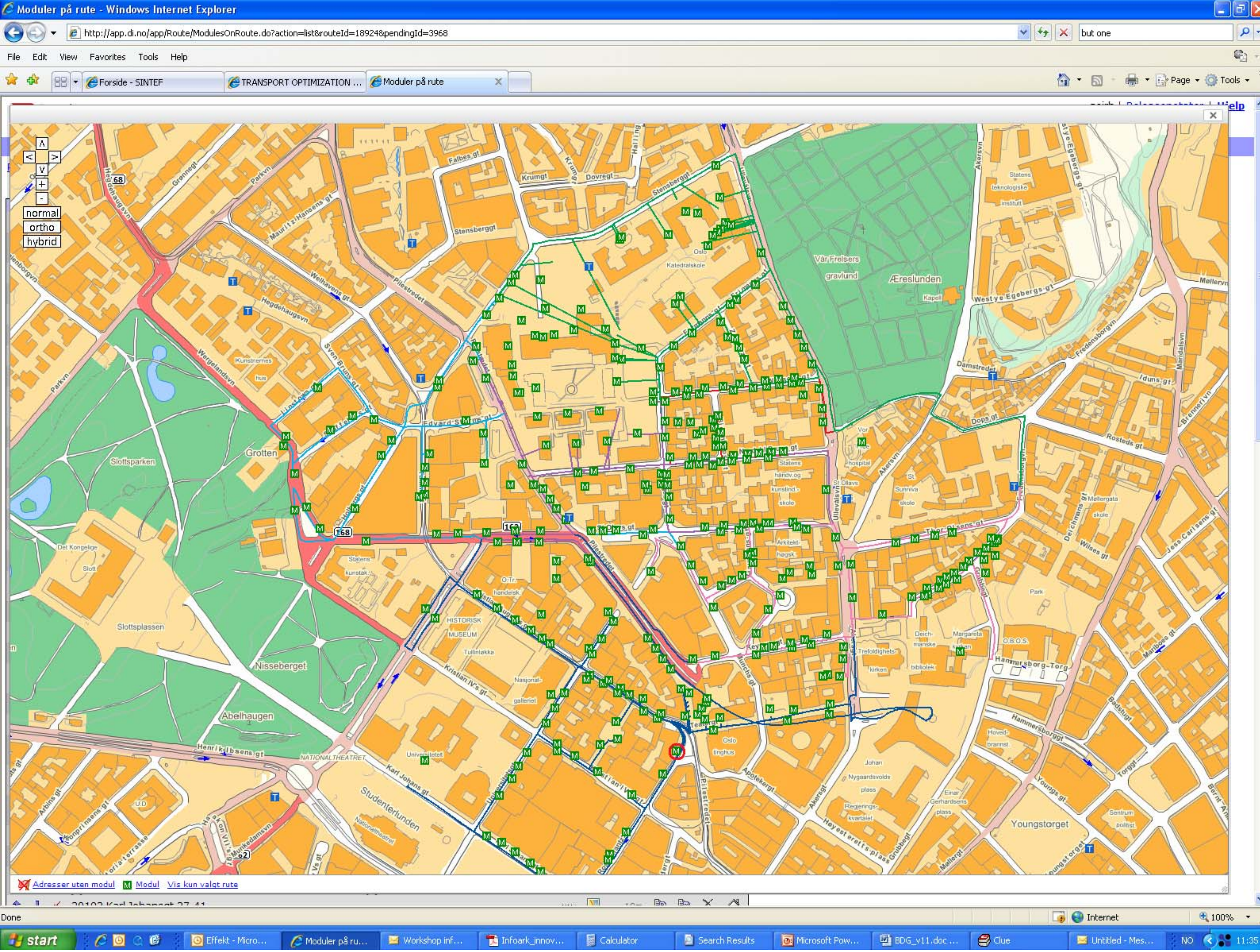


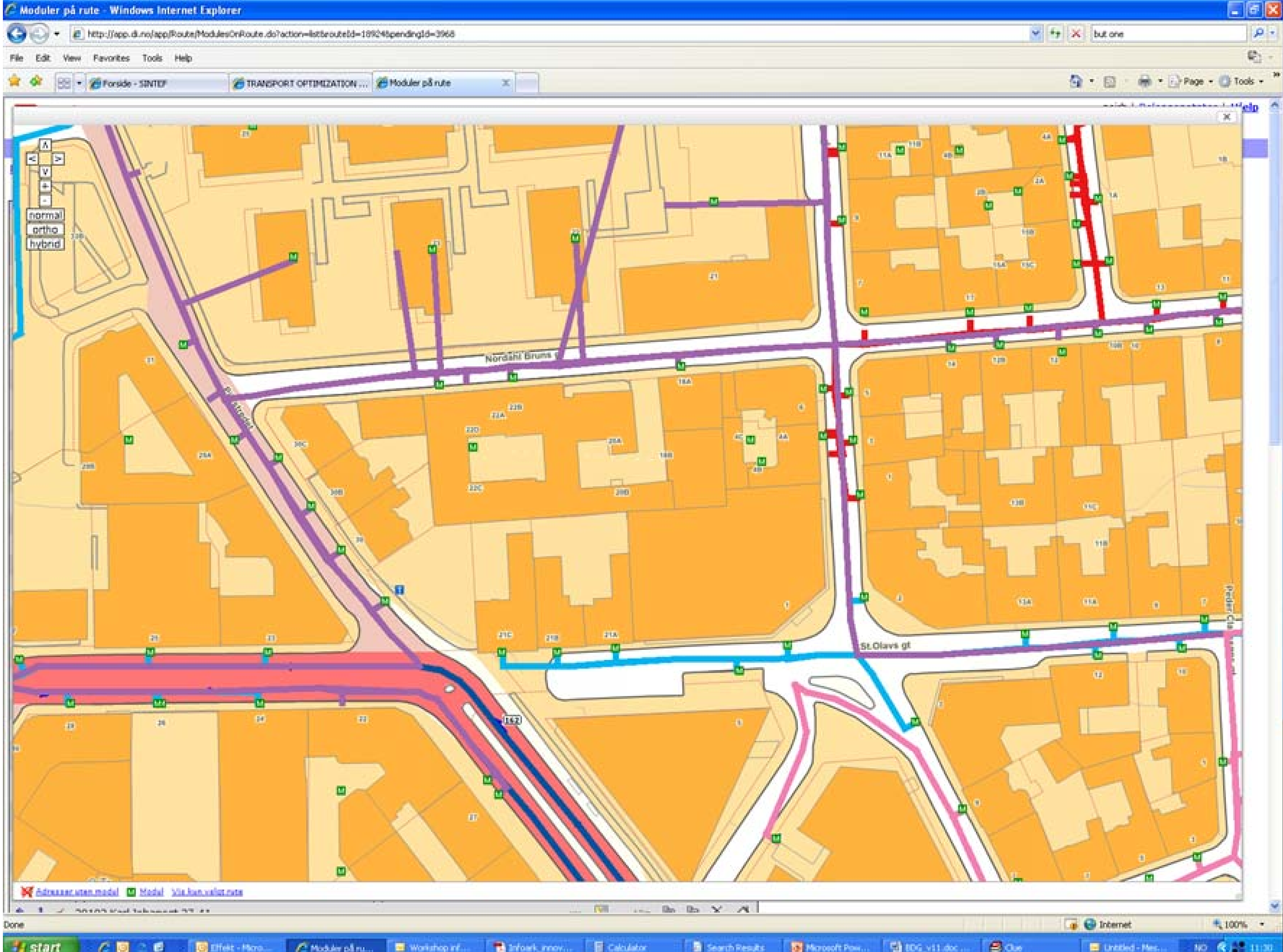


A: PASSPORT - Session1

File Edit Transfer Options Session Macro Help

```
=>PF2=TILBAKE,PF5=ENDRE,PF6=SLETT,PF10=BLANKER,PF11=RUTEKONS,PF12=TILLEGGSOPP
A F T E N P O S T E N    DISTRIBUSJONSSYSTEM   KOSTNADS- OG TIDSBEREGNING
Rute: 21509 Utg.: M Ukedag: 0 Pr. dato: 221105               Betjenes med: G
 Ant.l0nn:  265 -Ant. abo og andre,     0  -Ant. pressede  Sone: 3  O/U: U
  265 +    0 =  265 a kr.   23,76 +   0 Spes.abo a kr.    0,00   = kr   6296,40
 Avstandsl0nn:   3,3 km a kr.   52,80                            = kr    174,24
 Vintertillegg:  5 mnd. a kr.  291,00 :12                        = kr    121,25
 Sum l0nn                                                  *MIN* = kr   6892,17
  26,00 % tillegg for feriepenger og arb.avgift                  = kr   1791,96
 Sykkelgodtgj.                                                   = kr      0,00
 Transp.godtgj.    3,3 km x 26,00 dager x kr.:    0,00           = kr      0,00
 Transp.strekn.    0,0 km x 26,00 dager x kr.:    0,00           = kr      0,00
 Sum l0nn, sos.kostn. og transp.godtgj.                    *MIN* = kr   8684,13
 Kostnad pr. abonnement pr. måned                                = kr     32,77
1. Klargj0ring f0r start            =       15 min  Dekn.%:   44,69
2. Avstand   3,3 km        a  12,00 =    39,60 min  Beregnet tid  128,13 min.
3.   0 oppg. uten n0kkel   a   0,35 =     0,00 min  Reell    tid  128,13 min.
4.  53 oppg. med n0kkel    a   0,50 =    26,50 min  Beregn. dagl0nn  248,87 kr
5. 206 etasjer             a   0,35 =    72,10 min  Reell   dagl0nn  260,42 kr
6.    0 lev. i enebolig    a   0,15 =     0,00 min  Beregn. timel0nn  116,54 kr
7.  63 lev. i rekkehus     a   0,20 =    12,60 min  Reell   timel0nn  121,95 kr
8.   4 lev. i FK (ute)     a   0,15 =     0,60 min  Timetillegg o/18 ....... kr
9.   0 fellesleveringer    a   0,00 =     0,00 min  Antall husstander    593
Totalt                              =   166,40 min
TB                        A2--Session1   R 4   C 1           3:22p 22/11/05
```


Moduler på rute - Windows Internet Explorer
http://app.di.no/app/Route/ModulesOnRoute.do?action=list&routeId=18924&pendingId=3968
but one
File
Edit
View
Favorites
Tools
Help
Forside - SINTEF
TRANSPORT OPTIMIZATION ...
Moduler på rute
Page
Tools
normal
ortho
hybrid
Slottsparken
Grotten
Slottsplassen
Nisseberget
Abelhaugen
Vår Frelsers gravlund
Æreslunden
Youngstorget
Studenterlunden
Stensberggt
Pilestredet
Karl Johans gt
Hammersborg-Torg
Adresser uten modul
Modul
Vis kun valgt rute
Done
Internet
100%
start
Effekt - Micro...
Moduler på ru...
Workshop inf...
Infoark_innov...
Calculator
Search Results
Microsoft Pow...
BDG_v11.doc ...
Clue
Untitled - Mes...
NO
11:35


Moduler på rute - Windows Internet Explorer
File Edit View Favorites Tools Help
Forside - SINTEF
TRANSPORT OPTIMIZATION ...
Moduler på rute
normal
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hybrid
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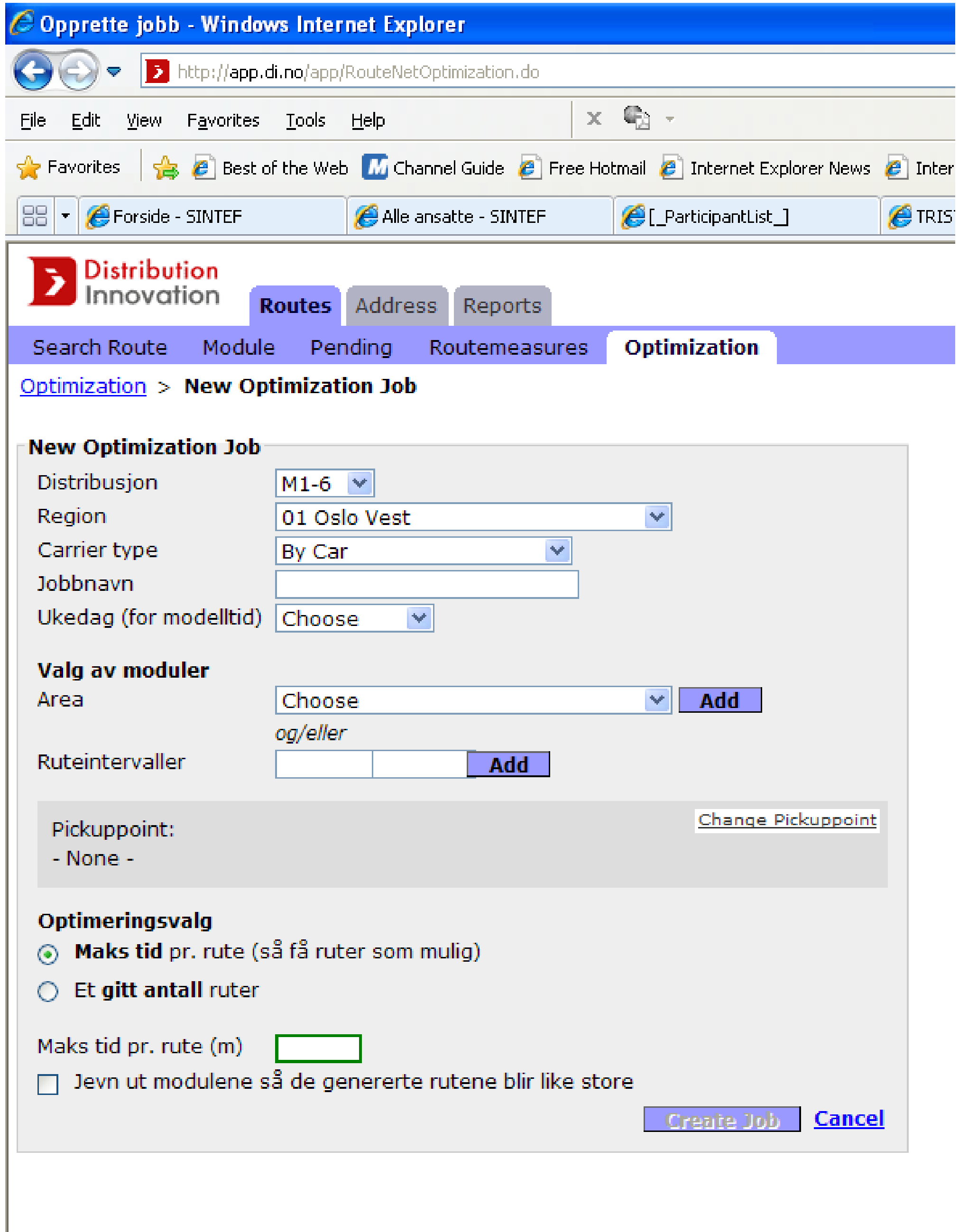
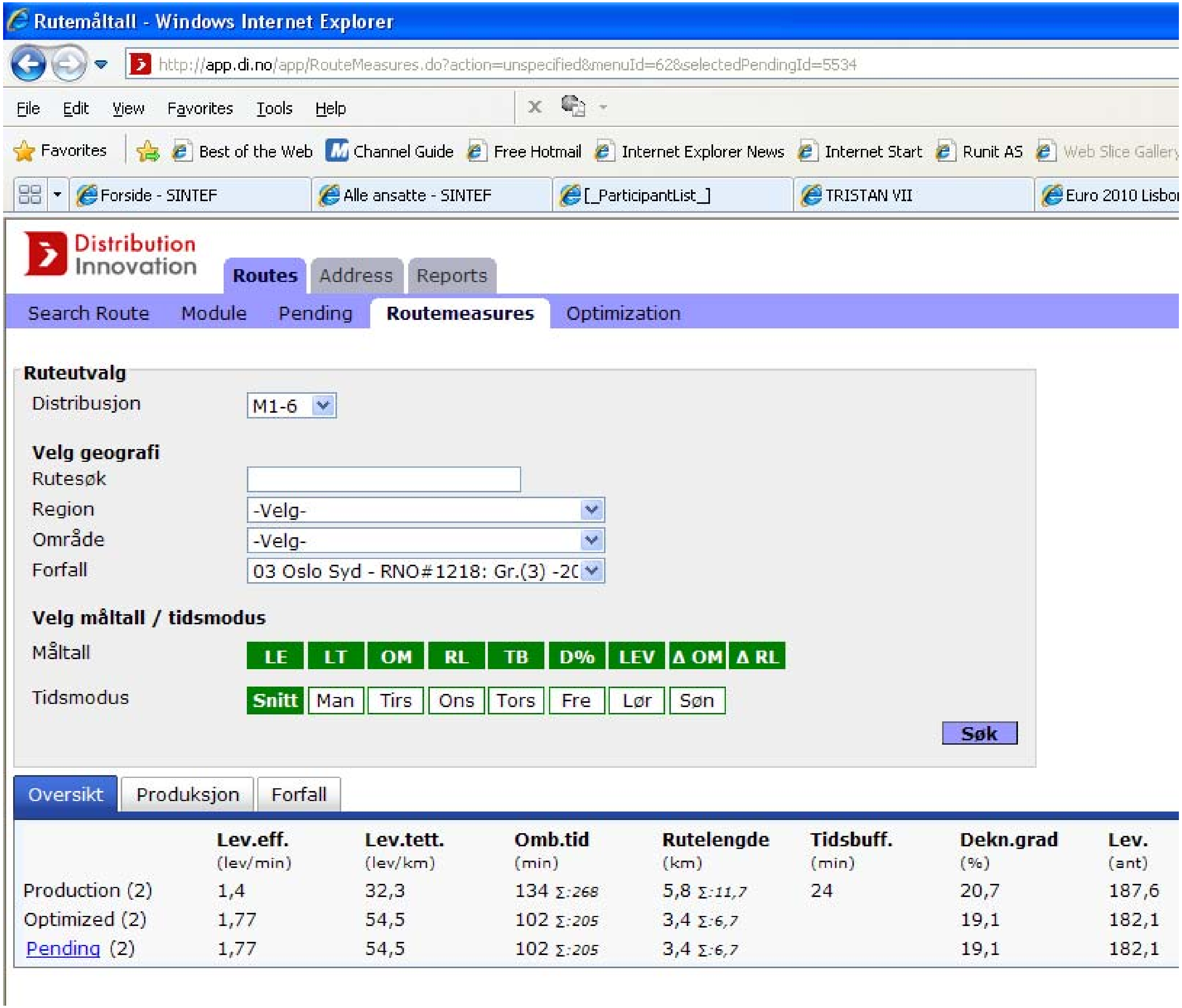
Done
Internet
start


Opprette jobb - Windows Internet Explorer
http://app.di.no/app/RouteNetOptimization.do
File Edit View Favorites Tools Help
Favorites
Best of the Web
Channel Guide
Free Hotmail
Internet Explorer News
Forside - SINTEF
Alle ansatte - SINTEF
[_ParticipantList_]
Distribution Innovation
Routes
Address
Reports
Search Route
Module
Pending
Routemeasures
Optimization
Optimization > New Optimization Job
New Optimization Job
Distribusjon
M1-6
Region
01 Oslo Vest
Carrier type
By Car
Jobbnavn
Ukedag (for modelltid)
Choose
Valg av moduler
Area
Choose
Add
og/eller
Ruteintervaller
Add
Pickuppoint:
- None -
Change Pickuppoint
Optimeringsvalg
Maks tid pr. rute (så få ruter som mulig)
Et gitt antall ruter
Maks tid pr. rute (m)
Jevn ut modulene så de genererte rutene blir like store
Create Job
Cancel


1220
Geografi
02 Oslo Nord, M1-6
Gr.4D2 -20747-751
H/3R/K/J v.3.2
3 ruter (168 moduler)
Optimeringsvalg
By Car
Friday
Hentested angitt
- Lukket rute
- Med hentestedretur
Ant. ruter: 3
Med utjevning
Lagt inn
17:40 (12.03.2010)
Startet 19:00
Ferdig 19:27
Eksportért til forfall
Ant. ruter 3
CPU-tid 27 min
Iterasjoner 674051
1219
Geografi
02 Oslo Nord, M1-6
Gr.4D2 -20747-751
H/3R/K/J v.3.1
3 ruter (168 moduler)
Optimeringsvalg
By Car
Friday
Hentested angitt
- Lukket rute
- Med hentestedretur
Ant. ruter: 3
Med utjevning
Lagt inn
17:40 (12.03.2010)
Startet 18:39
Ferdig 18:59
Eksportért til forfall
Ant. ruter 3
CPU-tid 20 min
Iterasjoner 562608
1218
Geografi
03 Oslo Syd, M1-6
Gr.(3) -20947+949
H/2R/G/J v.3.4
2 ruter (182 moduler)
Optimeringsvalg
By Feet
Friday
Hentested angitt
- Lukket rute
- Med hentestedretur
Ant. ruter: 2
Med utjevning
Lagt inn
17:35 (12.03.2010)
Startet 18:23
Ferdig 18:38
Eksportért til forfall
Ant. ruter 2
CPU-tid 15 min
Iterasjoner 270674
1217
Geografi
03 Oslo Syd, M1-6
Gr.(3) -20947+949
Optimeringsvalg
By Feet
Friday
Lagt inn
17:34 (12.03.2010)
Eksportért til forfall


Rutemåltall - Windows Internet Explorer
http://app.di.no/app/RouteMeasures.do?action=unspecified&menuId=62&selectedPendingId=5534
File Edit View Favorites Tools Help
Favorites
Best of the Web
Channel Guide
Free Hotmail
Internet Explorer News
Internet Start
Runit AS
Web Slice Gallery
Forside - SINTEF
Alle ansatte - SINTEF
[_ParticipantList_]
TRISTAN VII
Euro 2010 Lisbo
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Routes
Address
Reports
Search Route
Module
Pending
Routemeasures
Optimization
Ruteutvalg
Distribusjon
M1-6
Velg geografi
Rutesøk
Region
-Velg-
Område
-Velg-
Forfall
03 Oslo Syd - RNO#1218: Gr.(3) -2(
Velg måltall / tidsmodus
Måltall
LE
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RL
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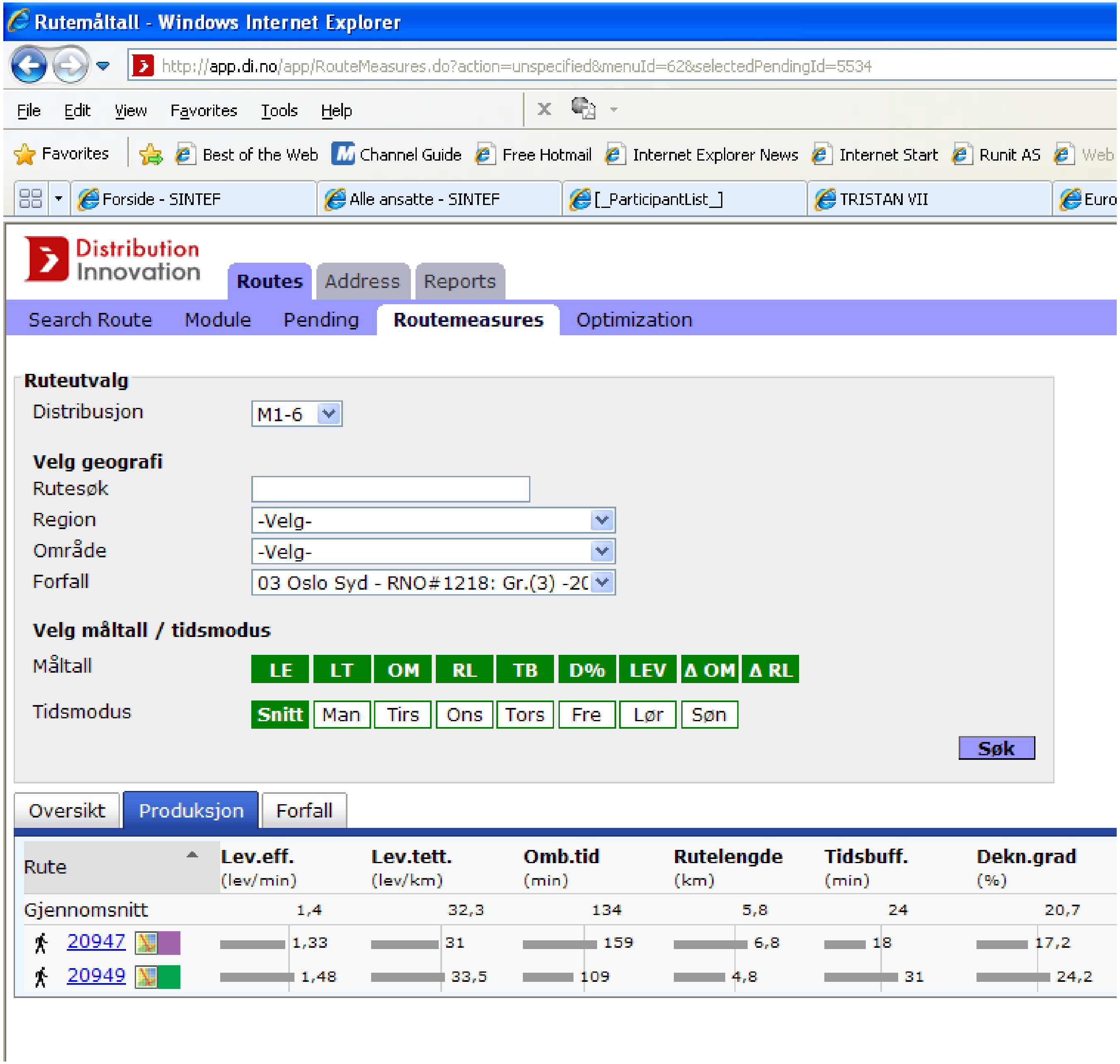
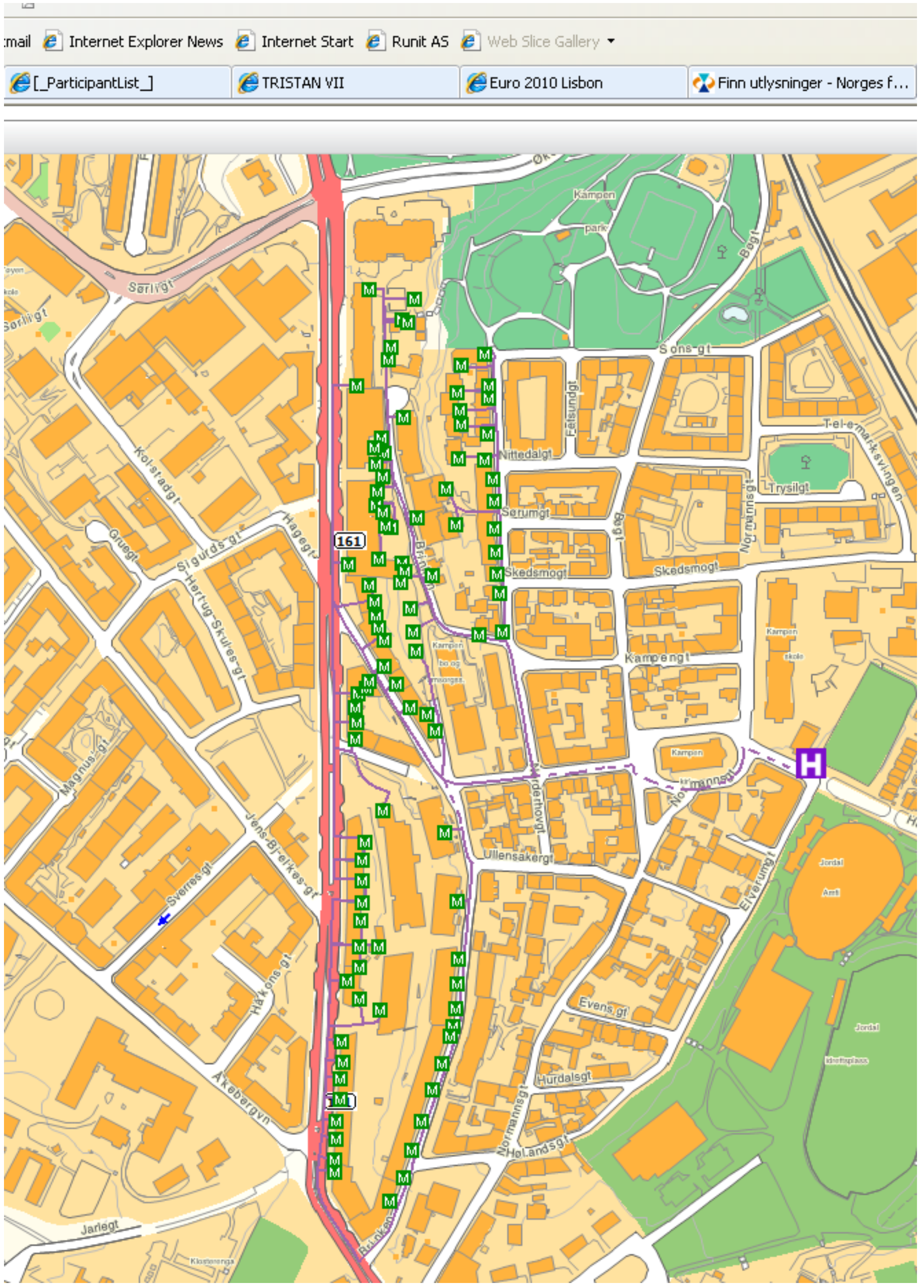
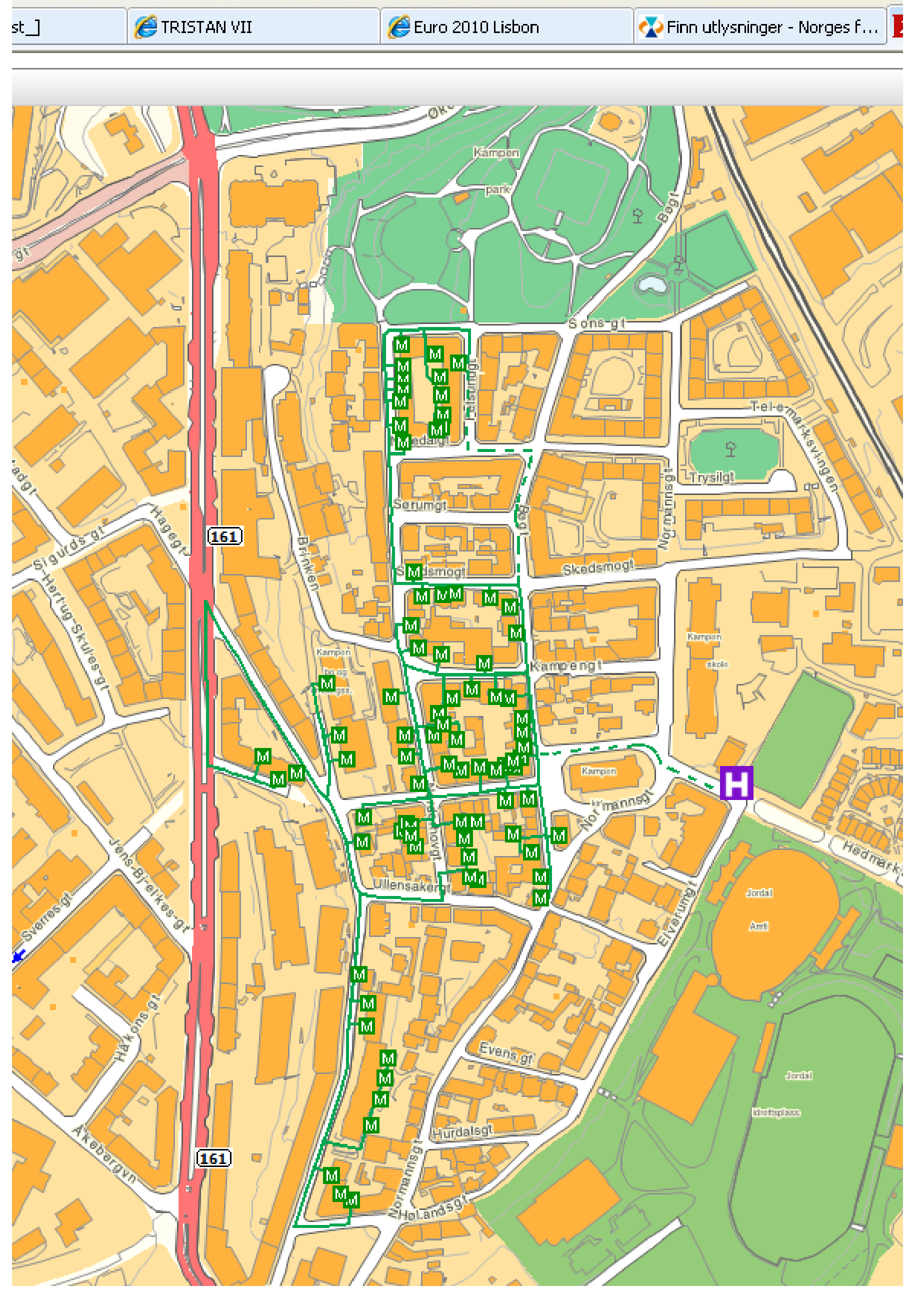
LEV
Δ OM
Δ RL
Tidsmodus
Snitt
Man
Tirs
Ons
Tors
Fre
Lør
Søn
Søk
Oversikt
Produksjon
Forfall
Lev.eff. (lev/min)
Lev.tett. (lev/km)
Omb.tid (min)
Rutelengde (km)
Tidsbuff. (min)
Dekn.grad (%)
Lev. (ant)
Production (2) 1,4 32,3 134 Σ:268 5,8 Σ:11,7 24 20,7 187,6
Optimized (2) 1,77 54,5 102 Σ:205 3,4 Σ:6,7 19,1 182,1
Pending (2) 1,77 54,5 102 Σ:205 3,4 Σ:6,7 19,1 182,1

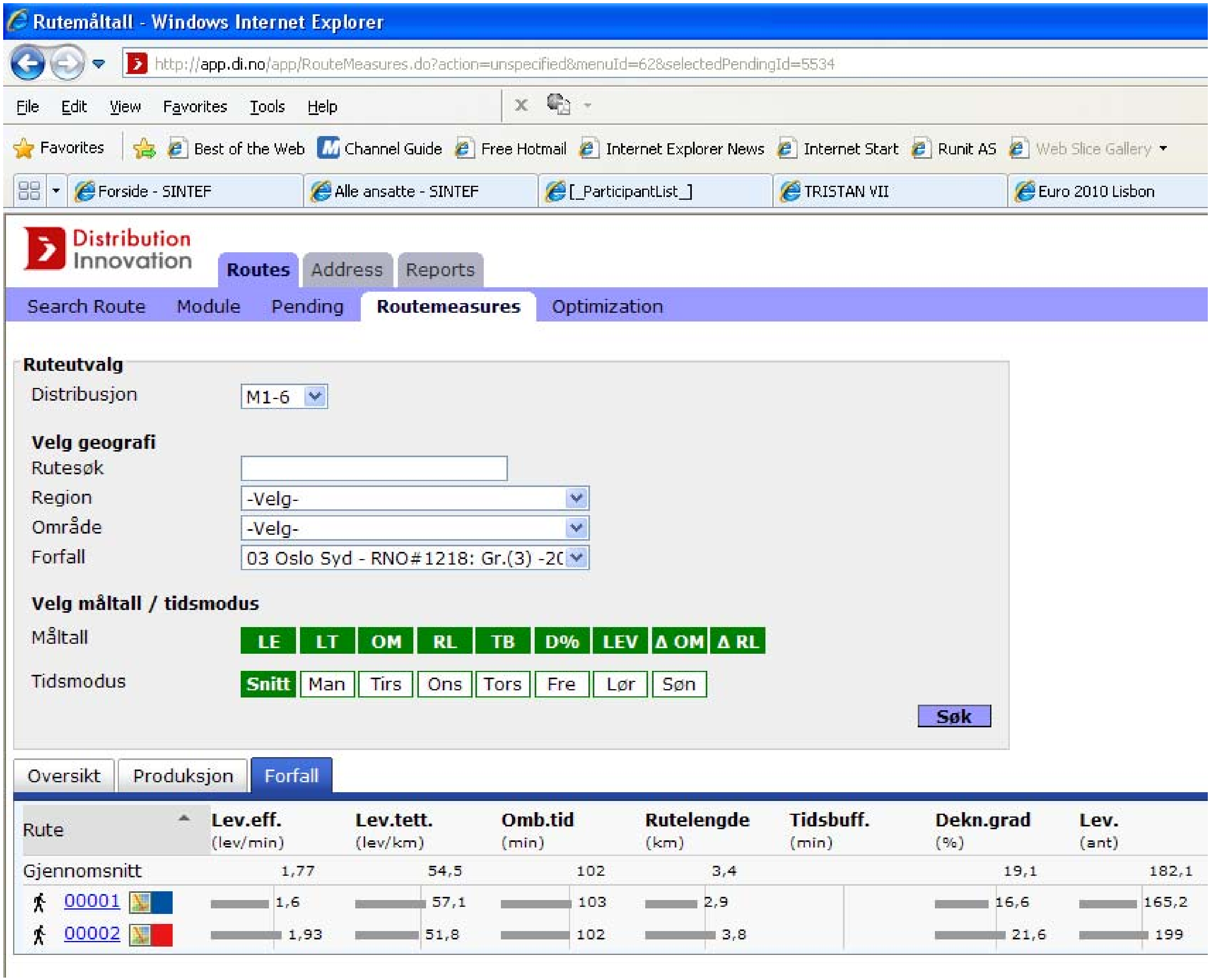

Rutemåltall - Windows Internet Explorer
http://app.di.no/app/RouteMeasures.do?action=unspecified&menuId=62&selectedPendingId=5534
File Edit View Favorites Tools Help
Favorites
Best of the Web
Channel Guide
Free Hotmail
Internet Explorer News
Internet Start
Runit AS
Web
Forside - SINTEF
Alle ansatte - SINTEF
[_ParticipantList_]
TRISTAN VII
Euro
Distribution Innovation
Routes
Address
Reports
Search Route
Module
Pending
Routemeasures
Optimization
Ruteutvalg
Distribusjon
M1-6
Velg geografi
Rutesøk
Region
-Velg-
Område
-Velg-
Forfall
03 Oslo Syd - RNO#1218: Gr.(3) -20
Velg måltall / tidsmodus
Måltall
LE LT OM RL TB D% LEV Δ OM Δ RL
Tidsmodus
Snitt Man Tirs Ons Tors Fre Lør Søn
Søk
Oversikt
Produksjon
Forfall
Rute
Lev.eff. (lev/min)
Lev.tett. (lev/km)
Omb.tid (min)
Rutelengde (km)
Tidsbuff. (min)
Dekn.grad (%)
Gjennomsnitt 1,4 32,3 134 5,8 24 20,7
20947 1,33 31 159 6,8 18 17,2
20949 1,48 33,5 109 4,8 31 24,2



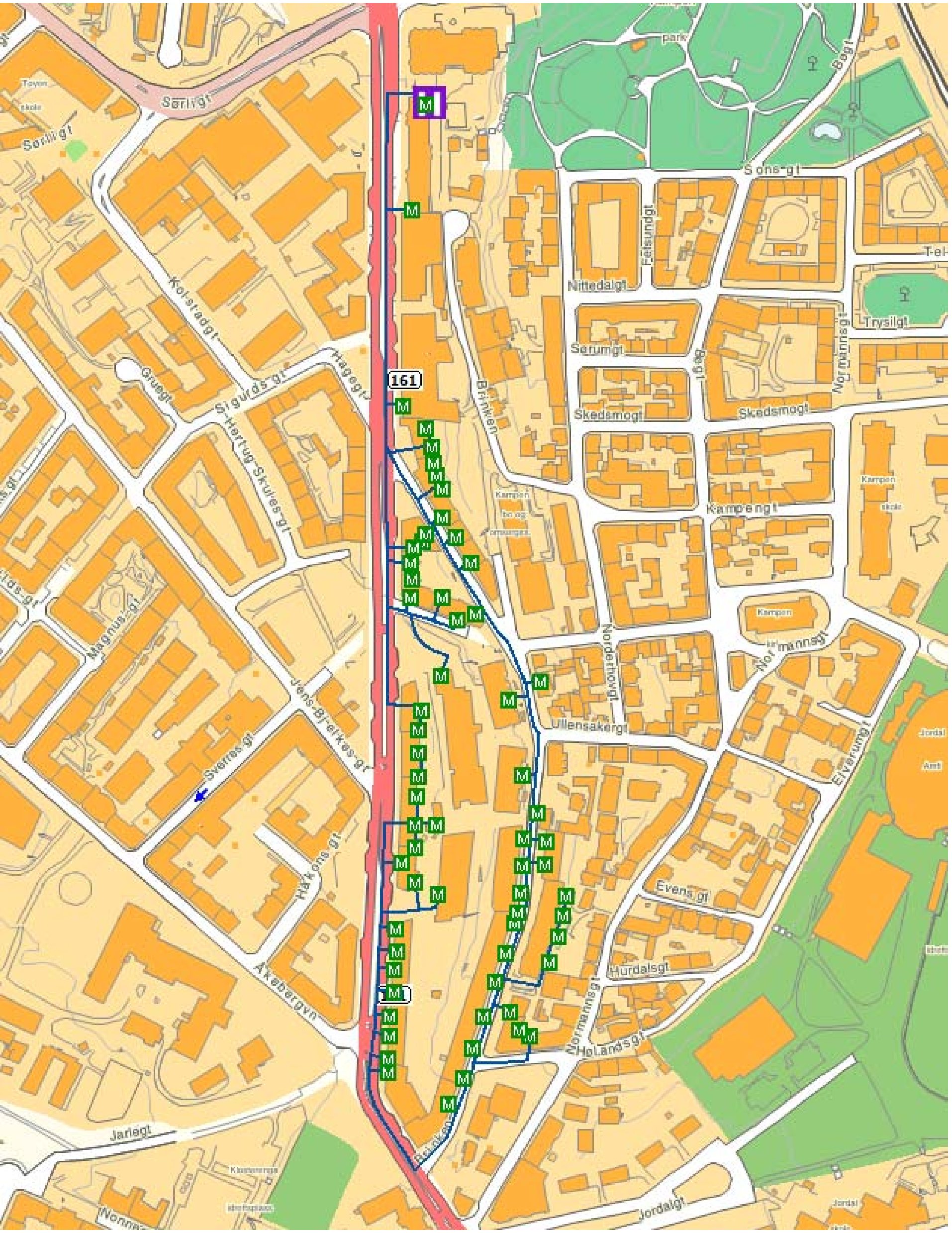
Internet Explorer News
Internet Start
Runit AS
Web Slice Gallery
[_ParticipantList_]
TRISTAN VII
Euro 2010 Lisbon
Finn utlysninger - Norges f...
Kampen
park
Sons gt
Sørligt
Kolstadgt
Grueqt
Sigurds gt
Hagegt
Hertug Skules gt
Magnus gt
Jens Bjelkes gt
Sverres gt
Håkons gt
Akebergvn
Jarlegt
Nittedalgt
Serumgt
Skedsmogt
Kampengt
Normannsgt
Trysilgt
Telemarksvingen
Ullensakergt
Elvarumgt
Evens gt
Hurdalsgt
Holandsgt
161



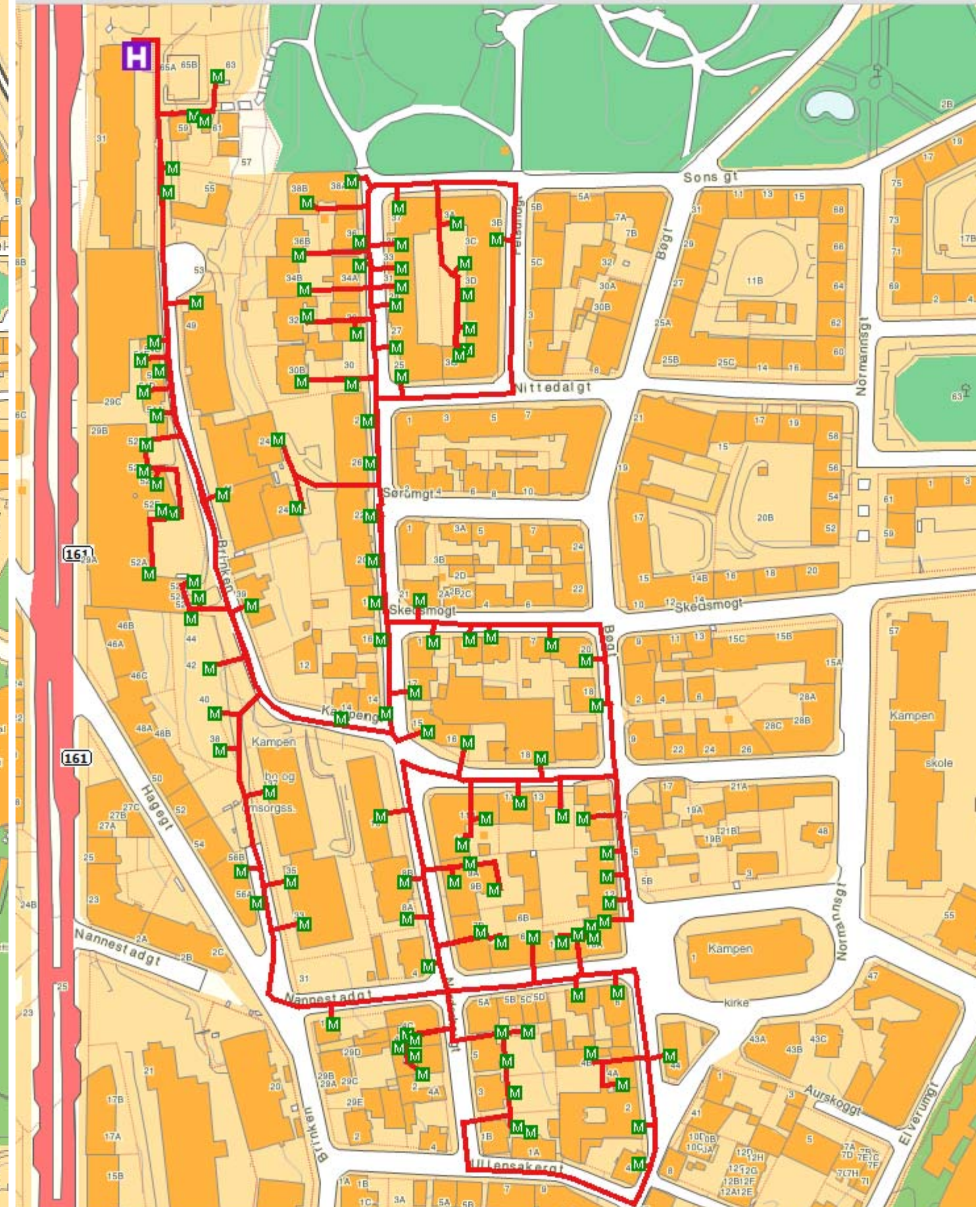
TRISTAN VII
Euro 2010 Lisbon
Finn utlysninger - Norges f...
Kampen
park
Sons gt
Telemarksvingen
Trysilgt
Serumgt
Skedsmogt
Kampengt
Normannsgt
Sigurds gt
Hagegt
Hertug Skules gt
Jens Bjelkes gt
Sverres gt
Håkons gt
Akebergvn
Ullensakergt
Elvarumgt
Evens gt
Hurdalsgt
Holandsgt
Hedmarkgt
161



Rute	Lev.eff. (lev/min)	Lev.tett. (lev/km)	Omb.tid (min)	Rutelengde (km)	Tidsbuff. (min)	Dekn.grad (%)	Lev. (ant)
Gjennomsnitt	1,77	54,5	102	3,4		19,1	182,1
00001	1,6	57,1	103	2,9		16,6	165,2
00002	1,93	51,8	102	3,8		21,6	199



Sørligt
Kolstadgt
Sigurds gt
Hagegt
Hertug Skules gt
Magnus gt
Jens Bjelkes gt
Sverres gt
Håkons gt
Åkebergvn
Jarlegt
161
Brinken
Nittedalgt
Sørumgt
Skedsmogt
Kampengt
Sons gt
Bøgt
Normannsgt
Trysilgt
Ullensakergt
Nordstrandgt
Evens gt
Hurdalsgt
Hollandsgt
Elverumgt
Jordalgt



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Brinken
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Ullensakergt
Aurskoggt
Elverumgt
Kampen
skole
kirke
161

Problem description

- Last mile part of two-echelon distribution
- (Open) DVRP with extensions
- Objectives
  - total duration
  - route balancing
  - clustering, route separation, ”visual beauty”
- Constraints
  - route duration
  - # routes

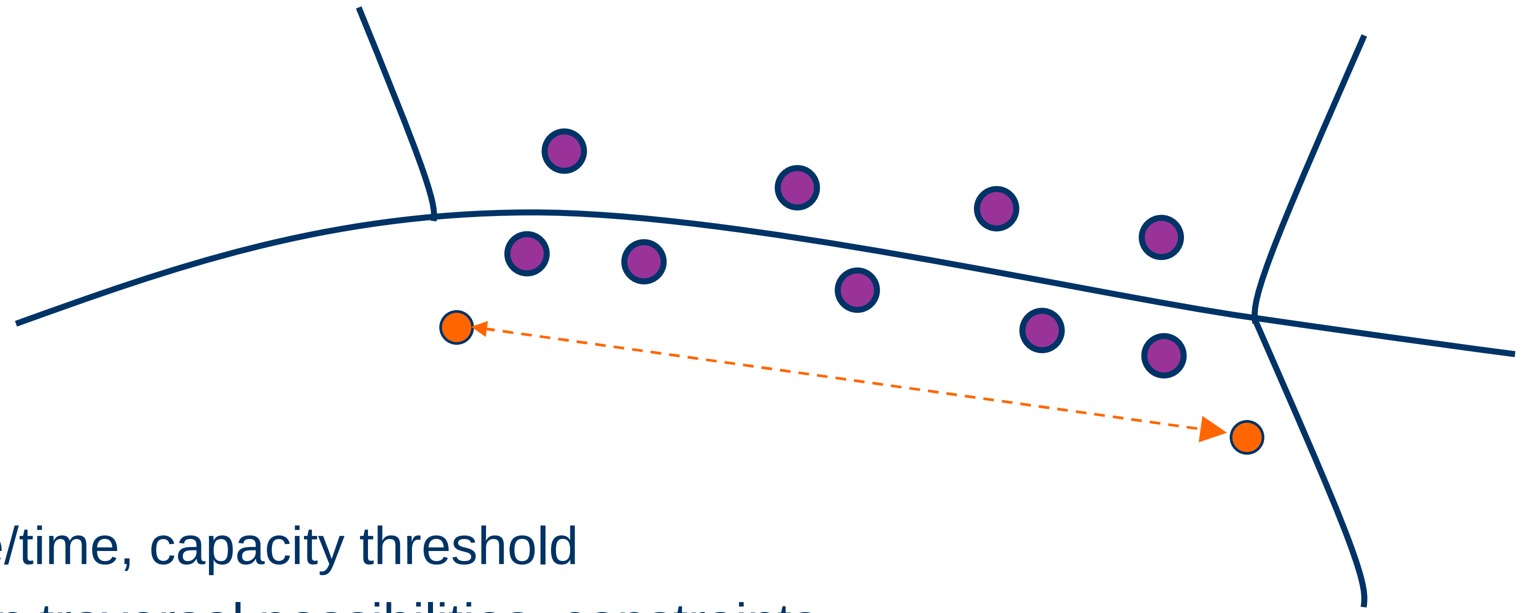
Additional niceties

- Determination of vehicle type (pedestrian, car)
- Combined routes
- Links that may be used by one route only
- ...

Extended problem

- Integrated problem
- Distribution from print shop to subscriber
- Location routing: Determination of pickup points

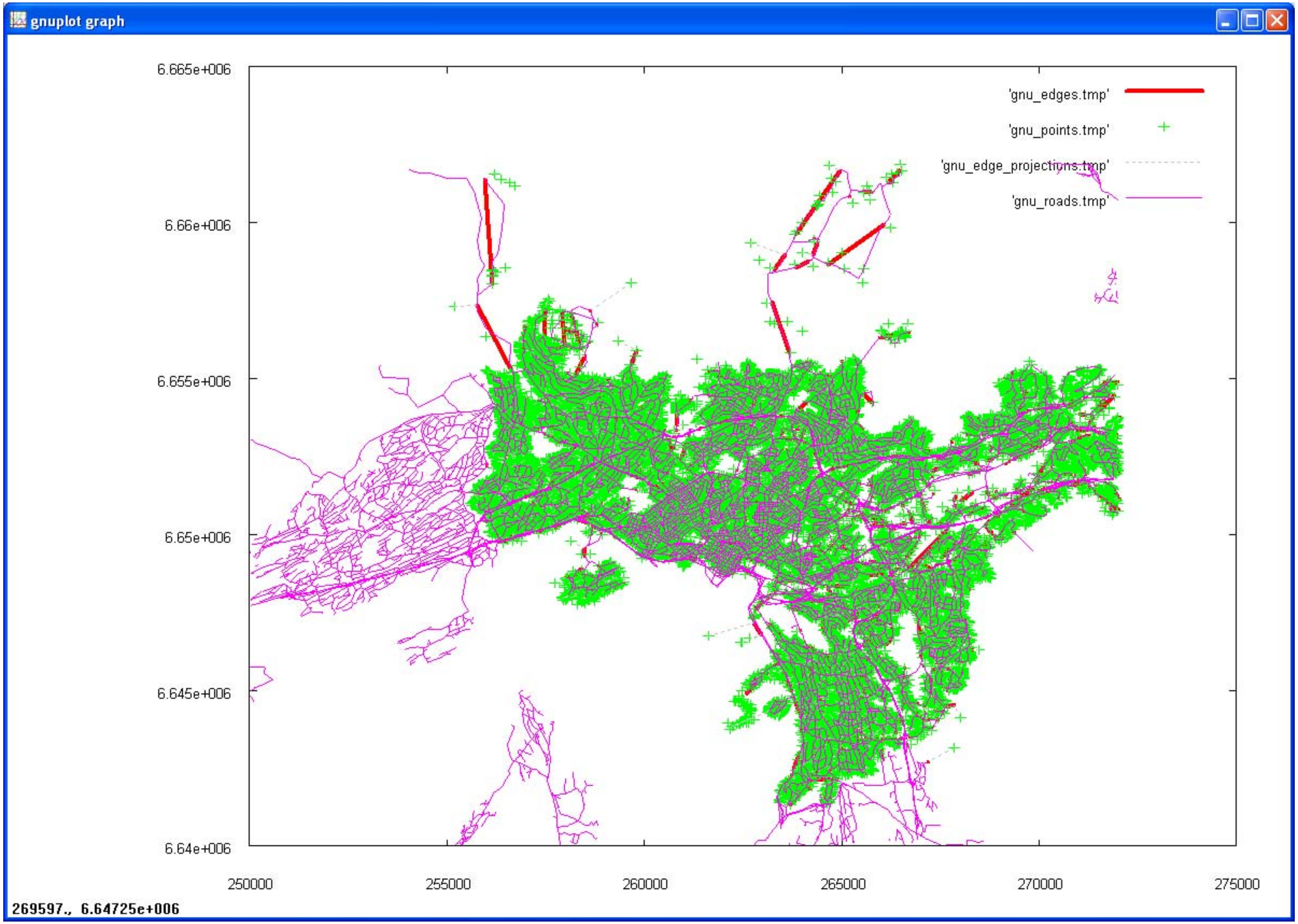
Demand aggregation based on road topology, proximity



- Distance/time, capacity threshold
- Issues on traversal possibilities, constraints
- Typical reduction factor of 5-20
- Needs extention to arc model (Node Edge Arc Routing Problem, NEARP)

Case: Oslo data from Aftenposten

33.200 orders reduced to 5600 aggregates




gnuplot graph
'gnu_edges.tmp'
'gnu_points.tmp'
'gnu_edge_projections.tmp'
'gnu_roads.tmp'
6.6514e+006
6.6512e+006
6.651e+006
6.6508e+006
6.6506e+006
6.6504e+006
6.6502e+006
6.65e+006
6.6498e+006
262400
262600
262800
263000
263200
263400
263600
263800
264000
263275., 6.65038e+006

Decomposition approaches

- Geographical
- Cluster-first route second
  - Capacitated Clustering Problem – with balancing
  - Routing

Outline

- Background and Context
- The Vehicle Routing Problem
- Industrial Aspects
- Spider - A Generic VRP Solver
- Specific cases
- Ongoing and Further Research

Important trends in VRP research

- Richer models, larger instances
- Exact methods
- Self-adaptation
- Hybrid and collaborative methods
- Parallel and heterogeneous computing

Parallel computing

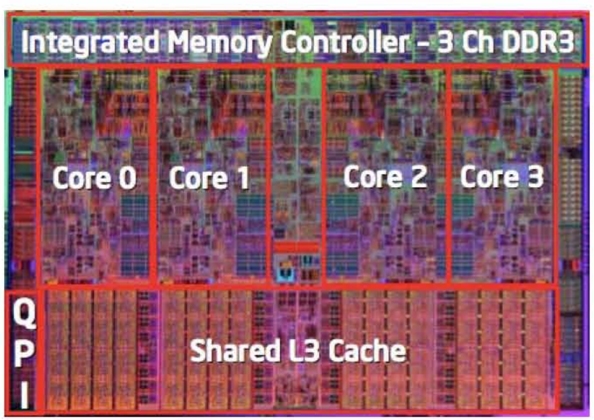
- Some tasks in EA and LS are embarassingly parallel
- ”Simple” parallelization through multi-threading
  - fine-grained to medium level granularity
  - very interesting for routing technology
  - not so interesting for VRP research, no literature
- More interesting parallelization
  - Coarse-grained, asynchronous
  - Multi-search
  - Collaborative search
  - Parallel multi-level
- Recent review by Crainic, 80 references
- Additional 30 papers
- Heterogeneous computing not really investigated

Parallel and heterogeneous computing

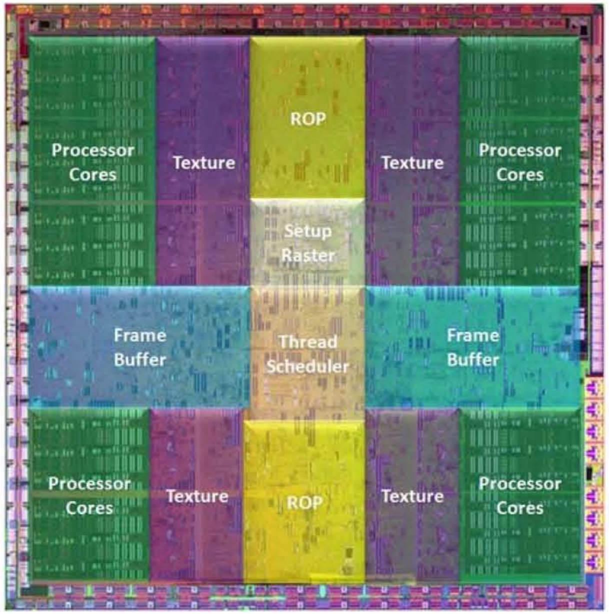
- CPU Clock frequency has stagnated
  (The Beach Law does not hold anymore ...)
- Moore's Law still valid
- Multi-core and heterogeneous commodity computers
- Fine-grained and coarse-grained parallelism

Heterogeneous Computer

- A *heterogeneous computer* is a tightly coupled system of processing units with distinct characteristics.
- A modern desktop or laptop computer is an example of such a system, as most systems include both a task-parallel, multi-core CPU and one or more data-parallel processors in the form of programmable graphics processing units(GPUs).



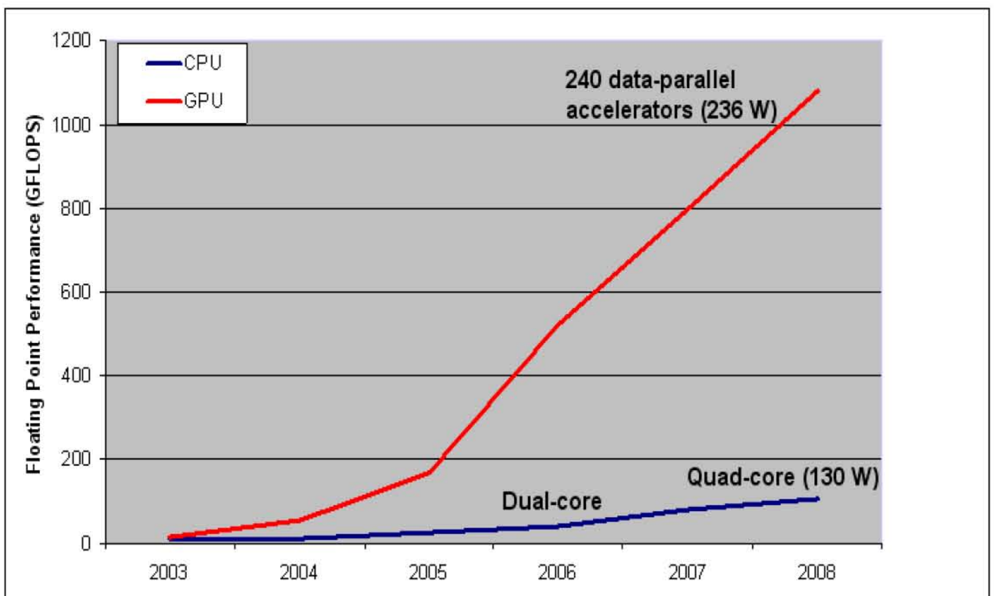
CPU (Intel Nehalem)



GPU (NVIDIA GeForce 280)

Graphics Processing Unit (GPU)

- Background: Game industry
- Massive parallel architecture (>500 cores per chip)
- Typically 10-50 times speedup compared to CPU applications



NVIDIA Fermi GPU

- 3 billion transistors
- 512 cores
- Up to 1 Terabyte of GPU memory
- 1.5 Teraflops performance
- 40 nm manufacturing process

NVIDIA GTX 480

The Collab project

- ”Iteration level” parallelization of Spider
- Experimental VRP Solver
- http://www.sintef.no/Projectweb/Collab/

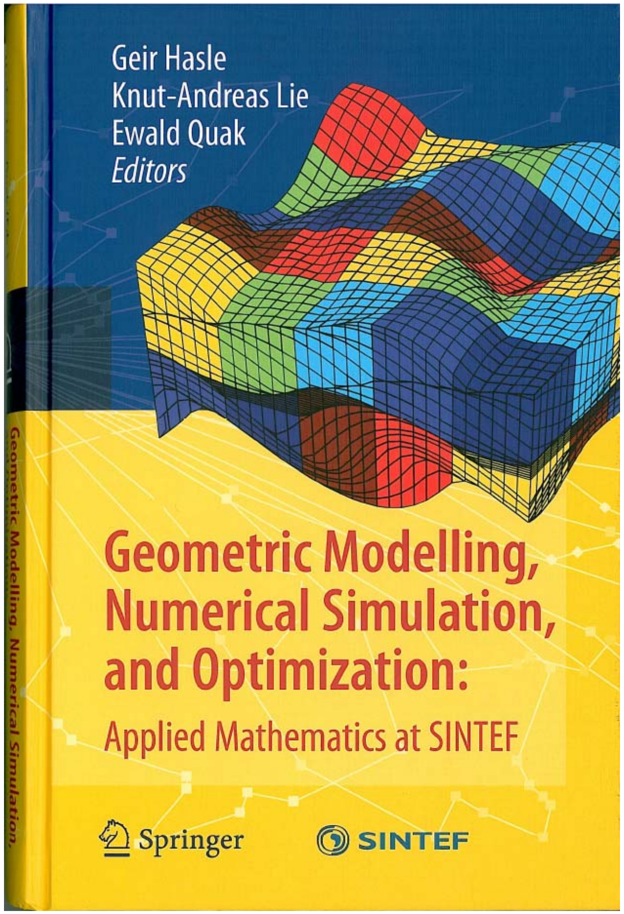
- Special session ”**Metaheuristics on graphics hardware**” under the META’10 conference in Djerba Island, October 28-30 2010, deadline May 15 http://www2.lifl.fr/META10/

Summary

- The Vehicle Routing Problem is a key to efficient transportation
- The VRP is a very hard optimization problem
- Thousands of VRP papers, mostly generic, idealized
- OR success story, tool industry
- Industry needs rich models, powerful algorithms
- Still challenges, VRP research has never been more active
- Generic VRP Solver SPIDER
  - rich, generic model
  - resolution algorithm based on metaheuristics
  - results

- Still a lot of work to be done ...

Geir Hasle and Oddvar Kloster: *Industrial Vehicle Routing*.
Chapter (pp 397-435) in
Hasle, Geir; Lie, Knut-Andreas; Quak, Ewald (Eds.)
Geometric Modelling, Numerical Simulation, and Optimization:
Applied Mathematics at SINTEF
2007, XI, 558 p. 162 illus., 59 in color., Hardcover. ISBN: 978-3-540-68782-5
http://www.springer.com/



Special Issue Transportation Science

- Advances in Vehicle Routing
- TRISTAN VII, Tromsø, Norway June 20-25 2010
- Guest editors
  - Marielle Christiansen
  - Arne Løkketangen
  - Geir Hasle
- Deadline October 15, 2010

- See May issue of Transportation Science for call

Vehicle Routing in Practice

Geir Hasle
SINTEF ICT, Oslo, Norway

XVIII EWGLA

Naples, Italy April 28-30 2010