Transportation Planning in Supply Chains

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Outline

- Motivation
- Transportation planning tasks
- Focus: Vehicle Routing
- Decision Support Technology
- Challenges

Main messages

- Transportation is an important part of the supply chain
- Complex decision problems at multiple levels
- Improvement potential through better co-ordination
- Need for decision-support technology
- Technology implemented at an increasing rate
- Still many challenges
- More research and technology development needed

Efficient transportation is important

- Norway: 16.900 companies (EU 1/2 million)
- Annual turnover 44 billion NOK (EU 1.200 billion)
- Transportation some 10-15 % of GNP in western countries
- ”Lastebilundersøkelsen”, Statistics Norway (2002)
  - 12,7 billion ton kilometers
  - 31,2 million trips - 18,1 million with load
  - Total capacity utilization 46,7 %
  - Capacity utilization with load: 63 %
- Huge volumes, important to society and businesses
- Small relative improvements may give huge effects
  - economy
  - environment
  - customer service

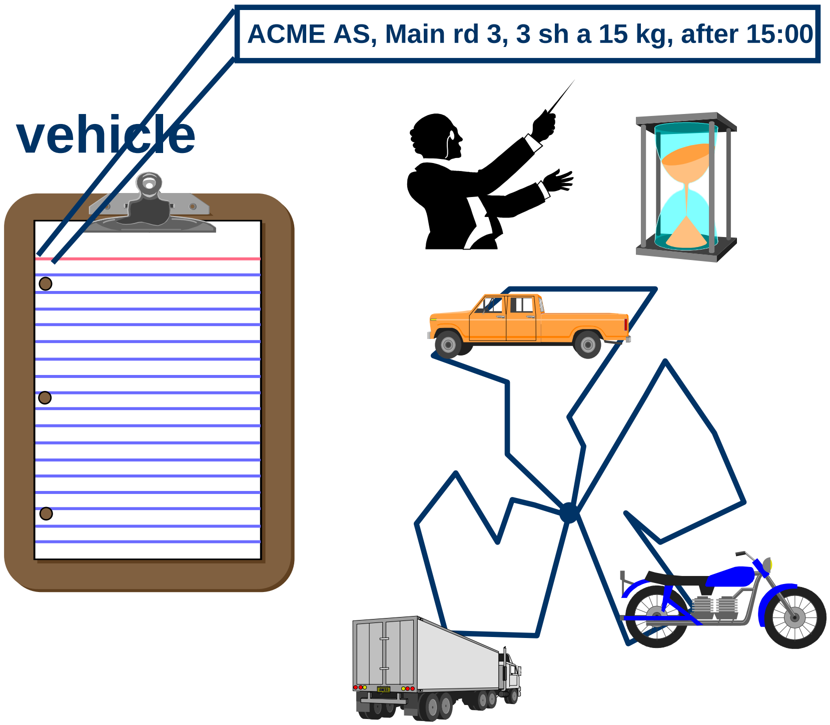
Challenges

- Lack of efficiency - uncoordinated, unnecessary driving
- Customer service, punctuality, short lead times
- Increased dynamics - need for increased reactivity
- Today: Manual planning predominates
  - complex
  - time consuming
  - first feasible solution
  - route revision may take years, MNOK
- Remedies
  - structural changes
  - co-ordination

- Potential for improvement: efficiency, customer service, reactivity
- Need for “coordination technology” – decision support systems

Tasks in transportation management

- (Re)configuration of transportation network
- Fleet dimensioning
- Route design and fleet management, vehicle routing
  - Allocation of order to vehicle
  - Sequencing of stops in a tour
- Distance / time / cost from A to B?



Transportation Management

- Strategic, tactical, operative, dynamic (real-time) decisions
- Often complex, several causes
  - Information availability
  - Uncertainty, dynamics
  - Management policies, practical limitations
  - Computational complexity
  - Response times
- Often need for tools
  - Distribution network design
  - Fleet dimensioning
  - Route design, real-time routing
  - Interaction human planners – system
- Tools are implemented at an increasing rate
  - Awareness
- Challenges

Tools in transport management
- prerequisites for positive effects

- Solve the right problem
- Information availability, quality
- User acceptance
- User interface
- User training
- Organizational changes
- SW Integration
- Underlying solution methods

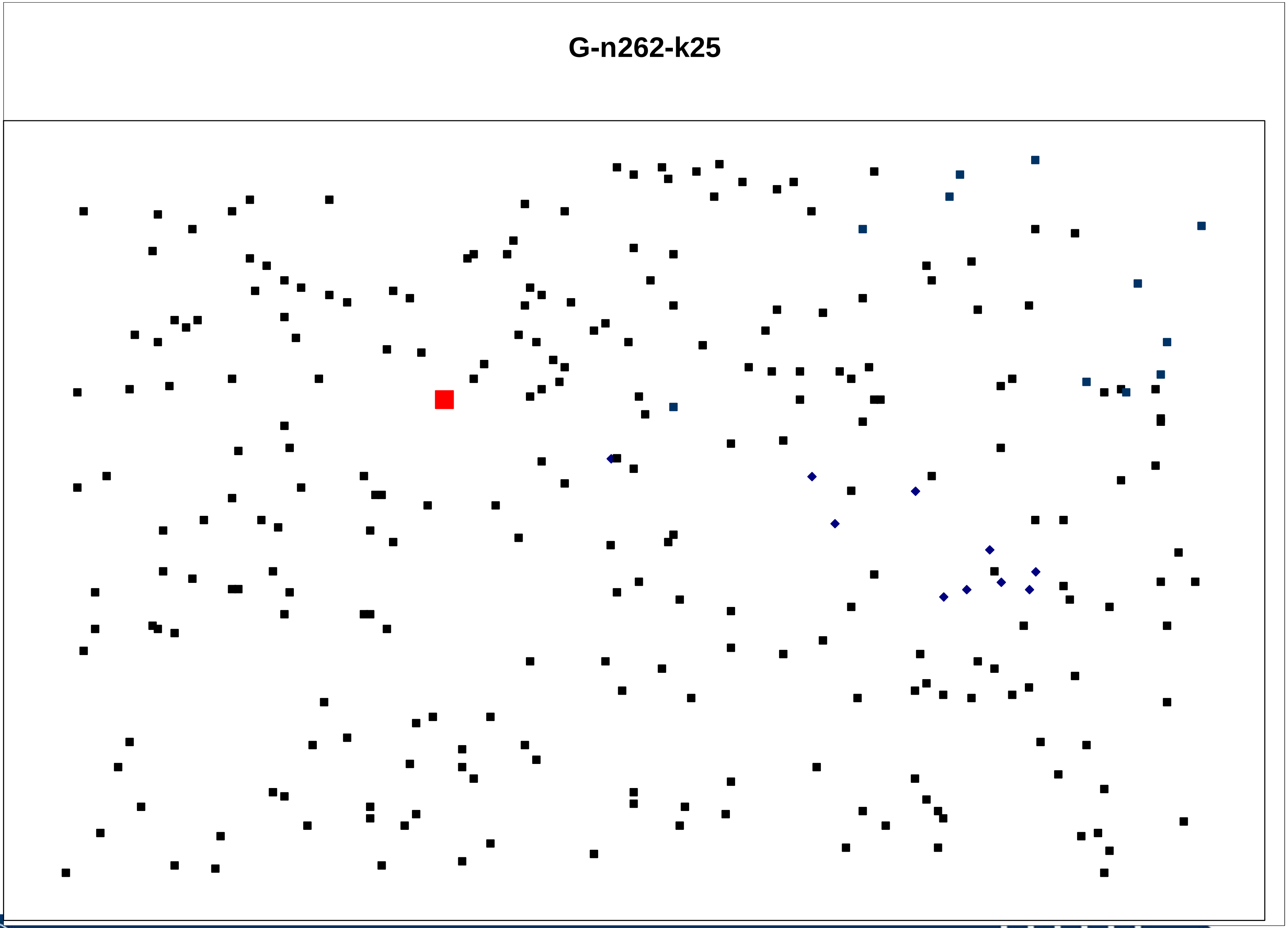
Mathematical formulation of optimal route design (with time windows, VRPTW)

minimize $\sum_{k\in V}\sum_{(i,j)\in A} c_{ij}x_{ij}^{k}$		(1)	minimize transport costs

subject to:

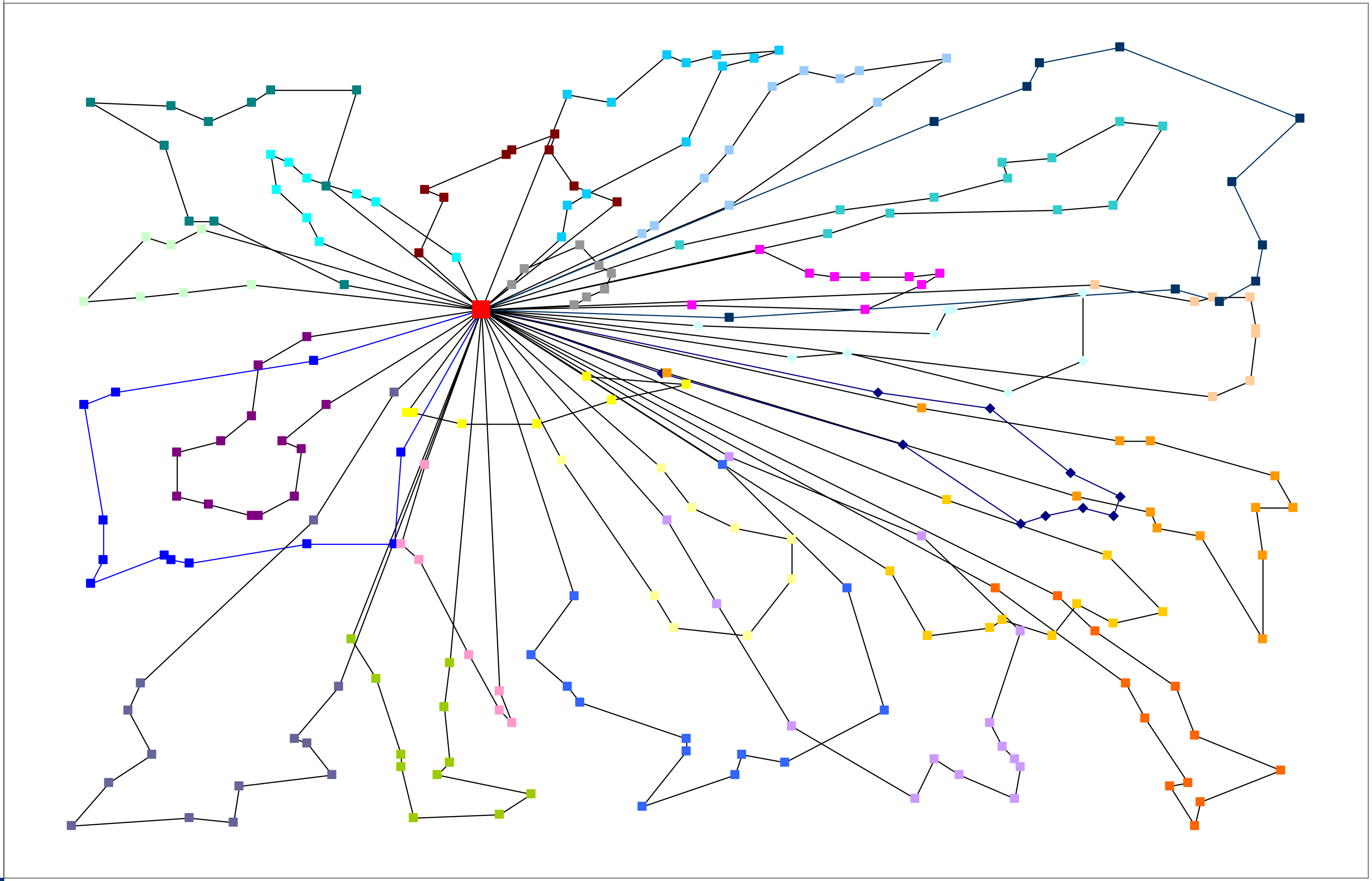
$\sum_{k\in V}\sum_{j\in N} x_{ij}^{k} = 1,$	$\forall i \in C$	(2)	each customer served
$\sum_{i\in C} d_i \sum_{j\in N} x_{ij}^{k} \le q,$	$\forall k \in V$	(3)	vehicle capacity constraint
$\sum_{j\in N} x_{0j}^{k} = 1,$	$\forall k \in V$	(4)	k tours out of depot
$\sum_{i\in N} x_{ih}^{k} - \sum_{j\in N} x_{hj}^{k} = 0,$	$\forall h \in C,\ \forall k \in V$	(5)	flow conservation at customer
$\sum_{i\in N} x_{i,n+1}^{k} = 1,$	$\forall k \in V$	(6)	k tours into depot
$x_{ij}^{k}(s_i^{k} + t_{ij} - s_j^{k}) \le 0,$	$\forall (i,j) \in A,\ \forall k \in V$	(7)	sequence, travel time
$a_i \le s_i^{k} \le b_i,$	$\forall i \in N,\ \forall k \in V$	(8)	time window at customer
$x_{ij}^{k} \in \{0,1\},$	$\forall (i,j) \in A,\ \forall k \in V$	(9)	vehicle k travels from i to j

VRP Instance



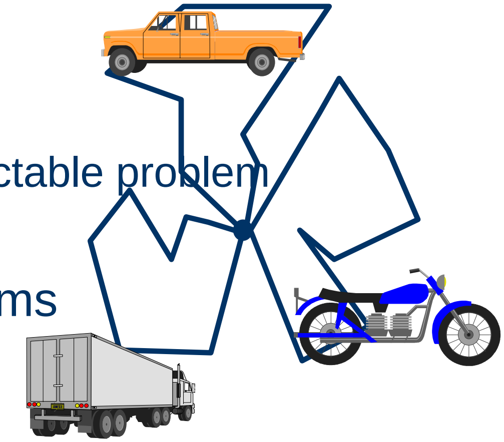
VRP Solution – Routing Plan

G-n262-k25: 5685 vs. 6119, 5767 CPU s



Some problems are harder than others
- computationally

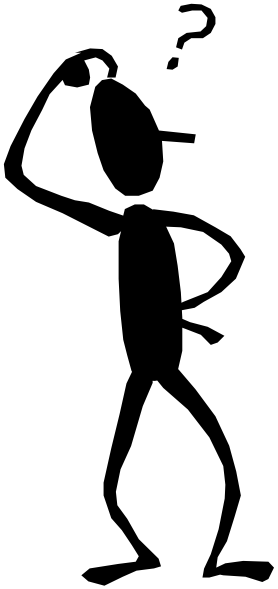
- Best route from A to B in a road network (NAF, Visveg, Michelin, ...)
  - Shortest Path Computing time depends on size of network
  - Polynomial growth, computationally tractable problem
  - Challenges: Information quality, very large road networks
  - Speed information, time-varying speeds, ...
- Find the best sequence of multiple stops in a tour
  - Traveling salesman problem, TSP
  - Computing time depends on number of stops
  - Computing time grows ”exponentially”, computationally intractable problem
  - Depends on solving many SPP
- Design routing plan for vehicles and transportation problems
  - Vehicle Routing Plan (VRP)
  - Generalization of TSP
  - Computing time grows ”exponentially”, computationally intractable problem
  - Depends on solving many SPP



Some Major Variants of the VRP

- Pickups, deliveries, pickup and delivery
- Spit deliveries allowed?
- Single depot / multiple depots
- Fleet homogeneous or not
- Fleet to be determined or not
- Capacity dimensions
- Time windows
  - none, single, multiple
  - hard or soft
- Periodic orders
- Orders on points or on arcs
- Inventory routing
- Transport modality, type of goods

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

Real-life Applications need Rich Models

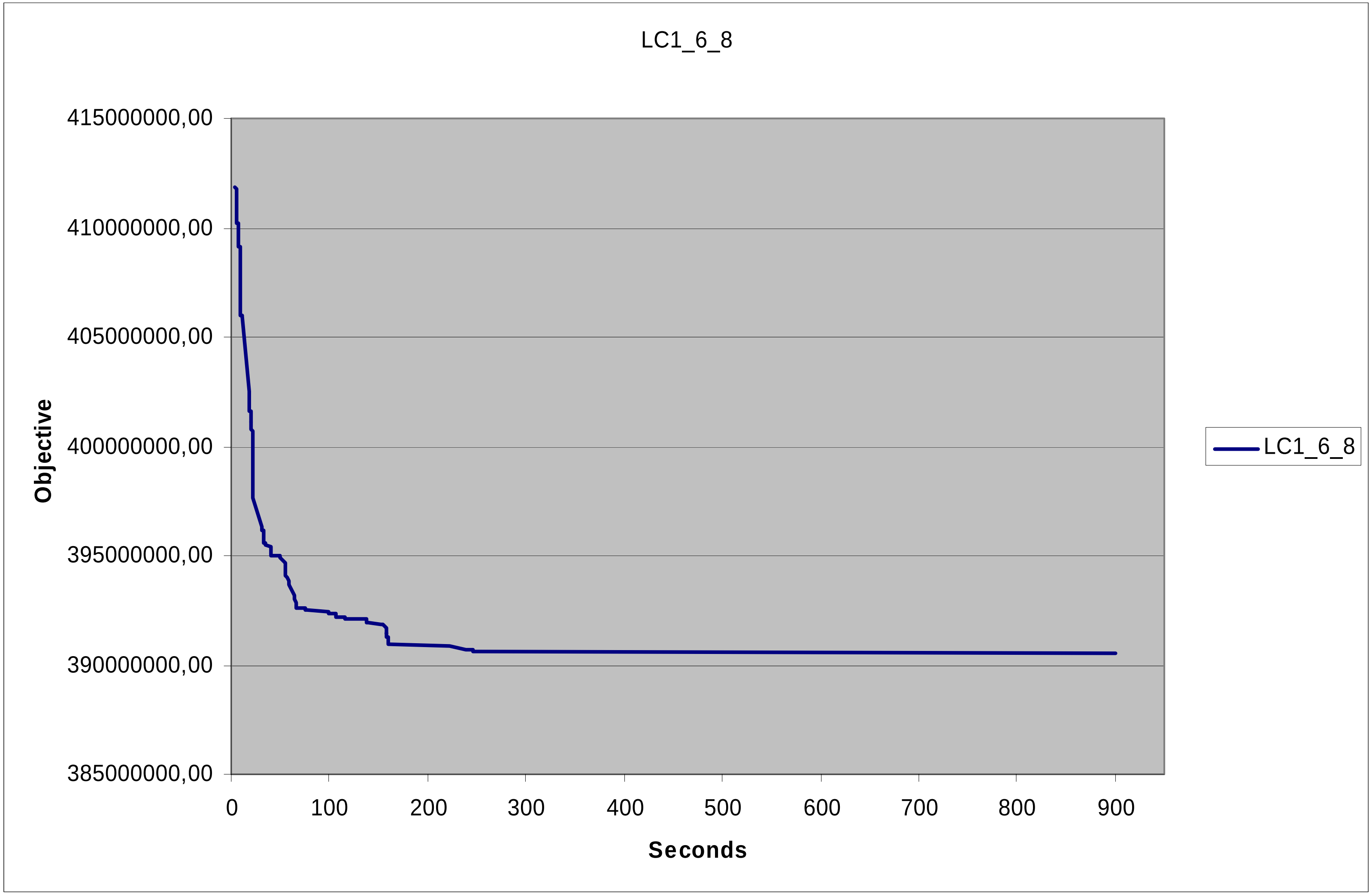
- Types of Operation, Services
  - multiple depots
  - mix of pickup and delivery
  - order splitting
  - arc routing
- Constraints
  - capacity
  - time windows
  - precedences
  - incompatibilities
  - driving time restrictions
- Objective
  - multiple components
  - soft constraints
- Uncertainty, dynamics
- Extensions in the literature address aspects

State-of-the-art: Exact methods

- Basic VRP with Capacity Constraints
  - Solves instances up to 50 orders
- VRP with time windows (VRPTW)
  - Finding a feasible solution is computationally intractable
  - Solves instances up to 100 orders

- For most applications (and generic tools) we have to use approximation methods that cannot give strong guarantees
- The VRP has not yet been solved
- ... and will not be solved in the foreseeable future
- development of better VRP algorithms has industrial impact

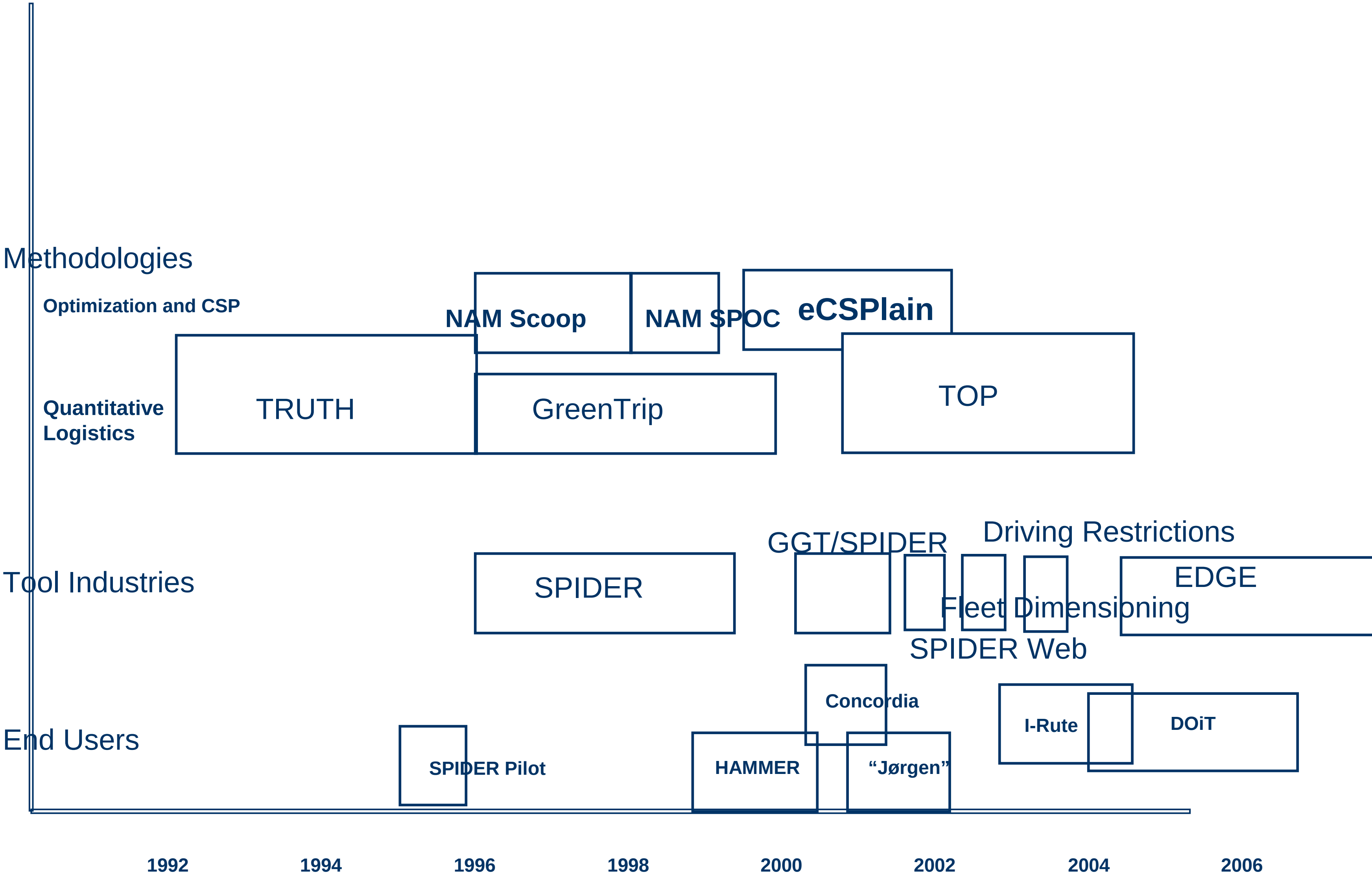
Goal: Good solutions, in due time



Approaches

- Conventional Approach in OR
  - Extensions studied in isolation
  - Taxonomy of VRPs
  - Successful
    - Increased Understanding
    - High-performance, algorithmic approaches
    - Robustness?
- Complementary Approach
  - Generic, rich model
  - Uniform algorithmic approach
  - Robustness
  - Industrial impact
- Cross-fertilization

VRP etc. Research @ SINTEF



The SINTEF Generic VRP Solver - SPIDER

- Designed to be widely applicable
- Based on generic, rich model
  - order types
  - various constraints
  - cost components
  - capacity dimensions
  - driver regulations
- Predictive route planning
- Plan repair, reactive planning
- Robust anytime algorithms
- Uniform algorithmic approach
- Scalability

- Commercialized
- Framework for VRP research

Optimization approach

- Heuristic, does not guarantee optimal solutions
- Good solutions in reasonable time
- Same machinery for all problems
  - Generate initial solution with fast heuristics
  - improve by local modifications
  - restart
- How good is this?
- Assessment through testing
  - Industrial problems
  - Standard benchmarks from scientific literature
  - ”World Champoinship in Vehicle Routing”

Computational experiments **PDPTW**
http://www.top.sintef.no/

- 354 standard test instances: 100 – 1.000 orders
- June 2003: SINTEF has produced best known solution on 273
- Today:

Author	100	200	400	600	800	1000	Total
Li & Lim	41	15	6	3	0	2	67
SINTEF	13	12	5	4	9	37	80
BVH	2	8	8	3	4	13	38
TS	0	1	2	0	0	6	9
SR	0	24	39	50	47	-	160
Total	**56**	**60**	**60**	**60**	**60**	**58**	**354**

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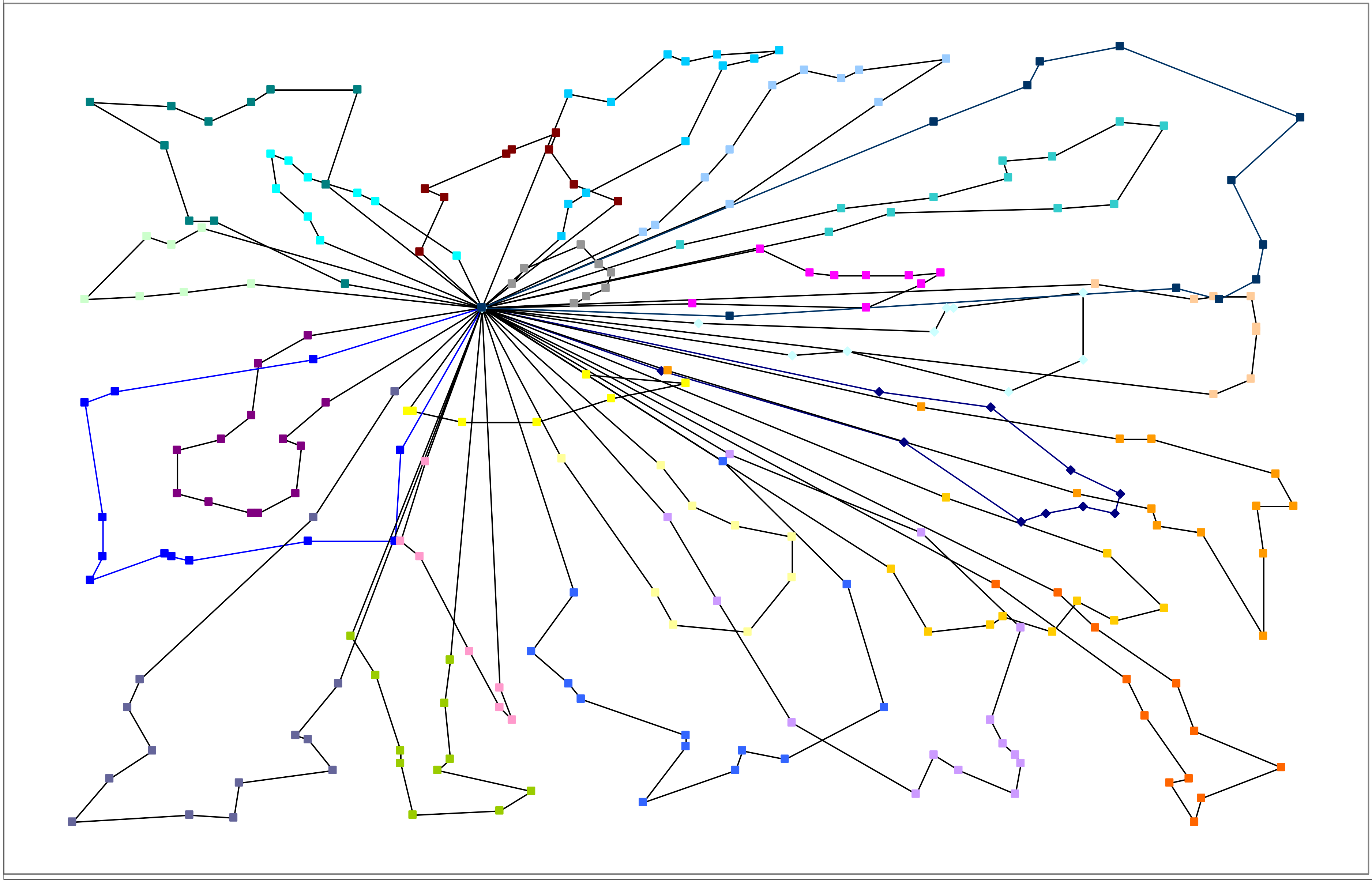
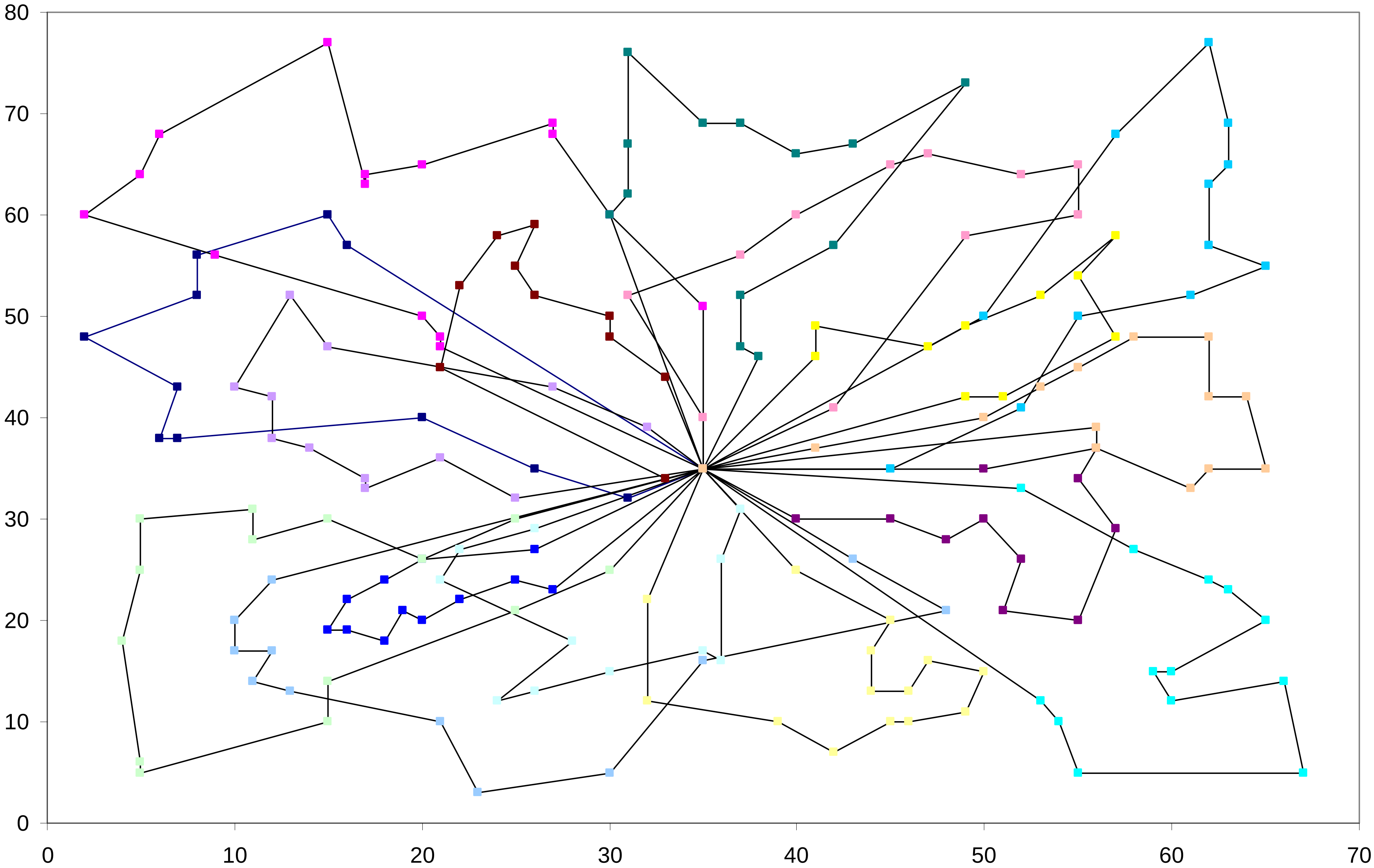
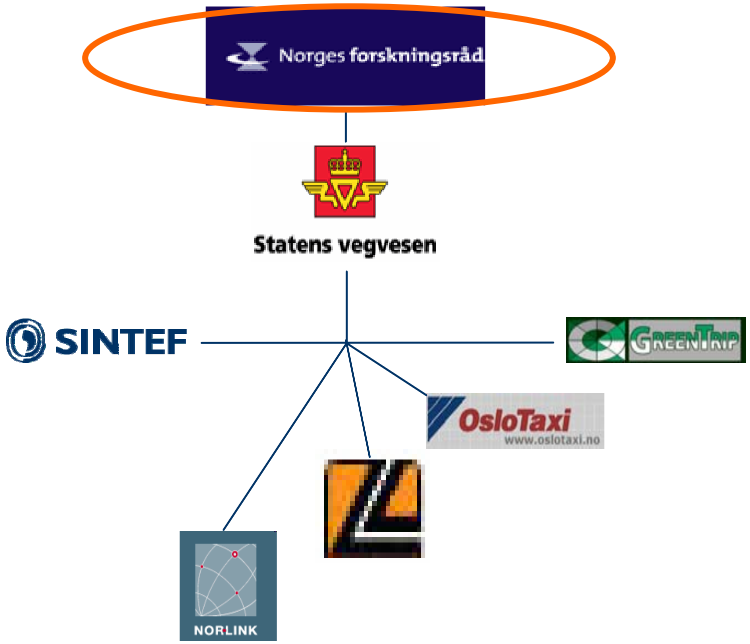


M-n200-k16: First known feasible solution



Ongoing work at SINTEF

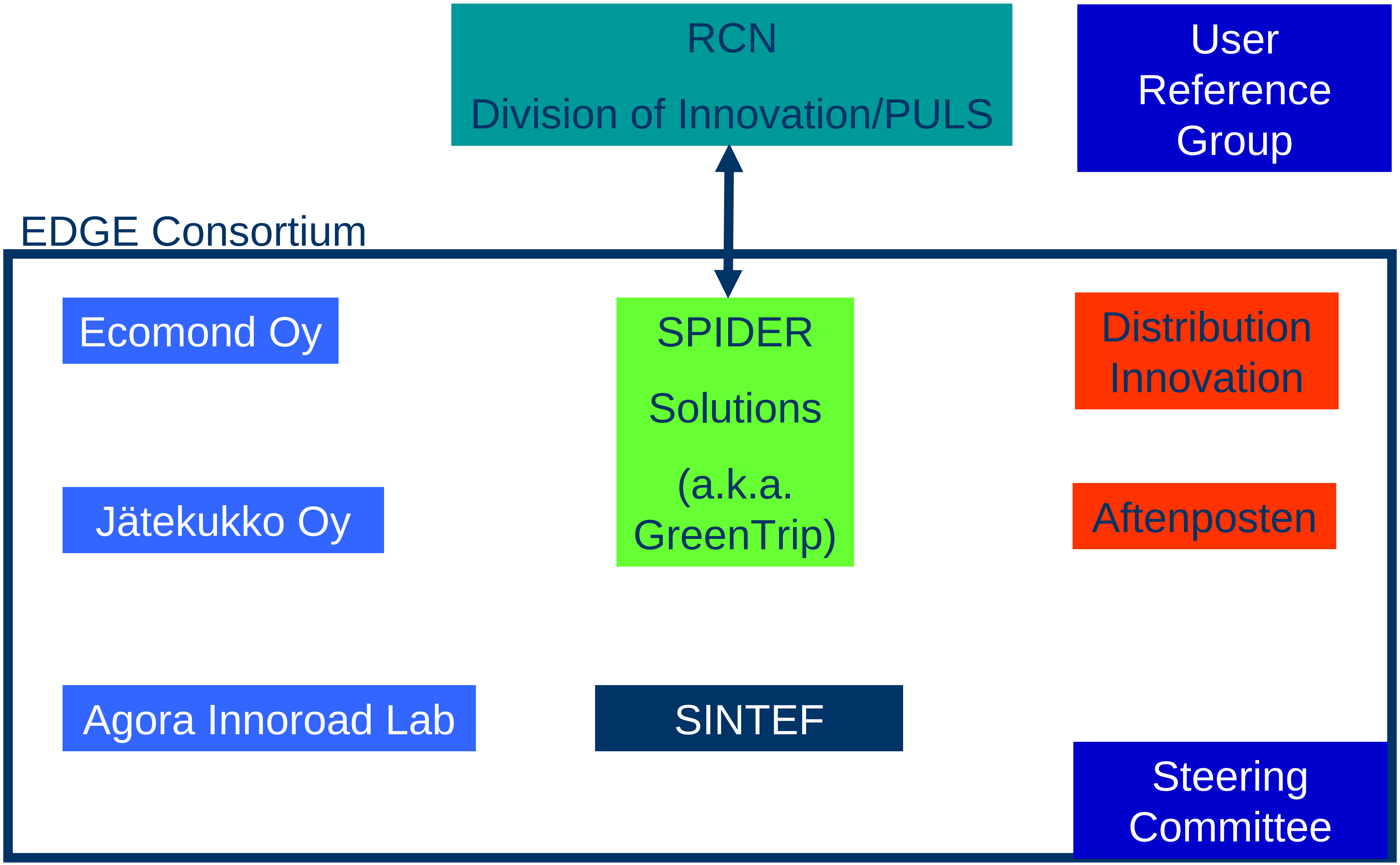
- Stochastic and dynamic routing (DOiT project 2004-2007)
  - including uncertainty in the model
  - dynamic revision
    - new orders
    - delays
    - new information on quantities
    - traffic conditions
- Huge scale routing problems (EDGE project 2005-2008)
  - integration transportation control tech / routing tech
  - efficient acquisition of basic information
  - plan management
  - VRP resolution



DOiT

- Innovation project partly financed by Research Council of Norway
- Totale kostnader ~16 MNOK
- 2004 – 2007

EDGE – Project Organization



Main messages

- Transportation is an important part of the supply chain
- Complex decision problems at multiple levels
- Improvement potential through better co-ordination
- Need for decision-support technology
- Technology implemented at an increasing rate – with success
- Still many challenges
  - stochastic and dynamic models
  - huge-scale instances
  - integrated models
- Calls for collaboration in the RTD supply chain
  - academia
  - applied research
  - tool vendors
  - industry
- Road may be short from basic research to industrial gains

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