Hochschule Offenburg
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WHITESTEIN Technologies

Applications of Multi-Agent Systems in Logistics

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Overview

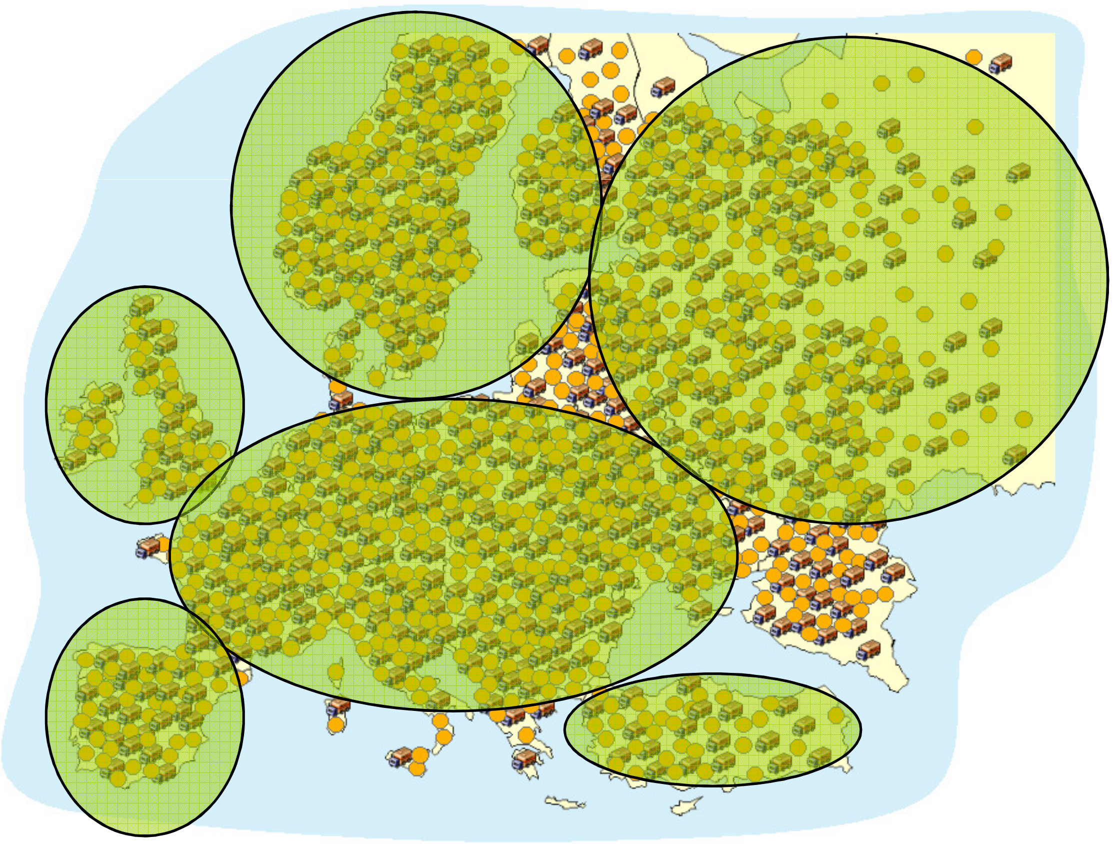
- Transportation Domain
- Agent-Based Optimization
  - Agent-Design
  - Allocation
  - Reallocation
  - User-Interaction
- Optimization Results
- Conclusion

Freight Logistics

- Task: Create a plan to transport all orders
- Challenges
  - Complexity
    - Mergers
    - Higher volumes
    - Constraints
  - Dynamics
    - Ever shorter notice in advance
    - Unforeseen events
    - User interaction

Freight Logistics

- Today's Solution
  - Division into (regional) businesses
- Problems
  - Visibility
  - Communication
  - Missed synergetic effects



Spot-Market

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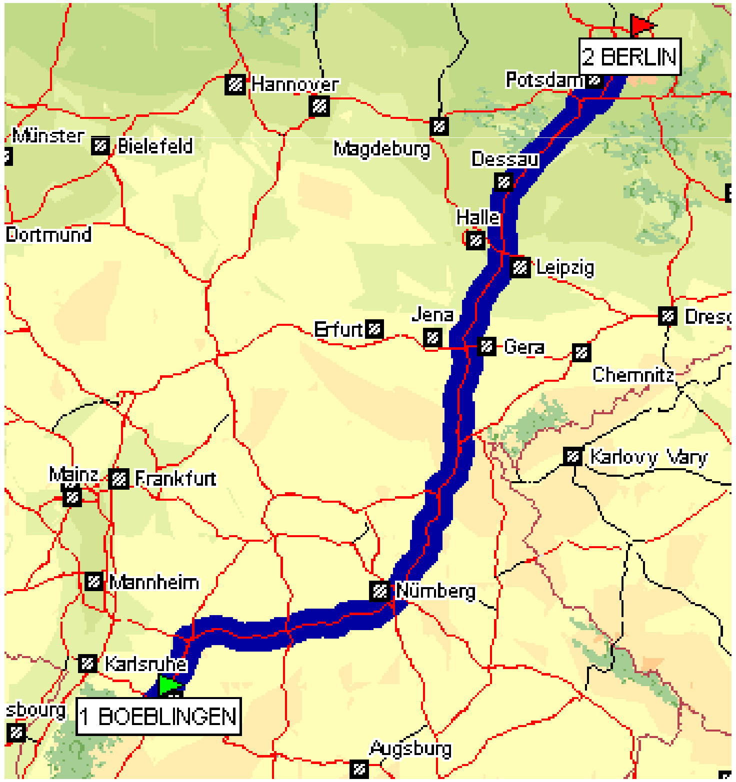
- Trucks are ordered on the Spot-Market just in time
  - Assumption: truck is always available everywhere
  - We do not have to care for successor routes
- Dispatchers have to find a truck for each route (by phone)
- System has to suggest the routes
- Objective
  - Minimum cost
- Pickup and delivery has to obey
  - Load constraints
  - Time constraints

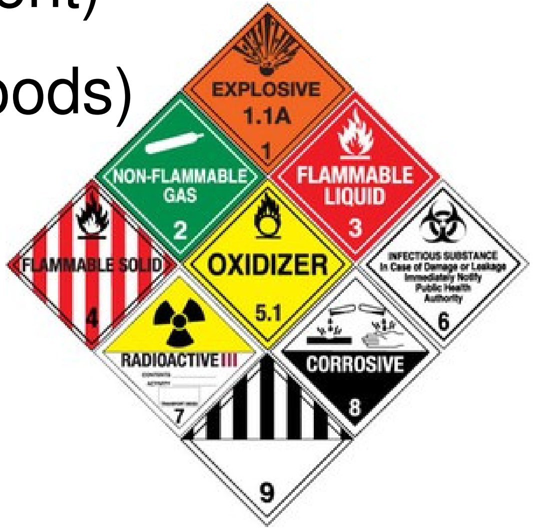
Cost Calculation

- Spot-Market
  - Variable costs depending on
    - Distance
    - Load
    - Relation (Start – Destination)
    - Discount
  - Minimum costs



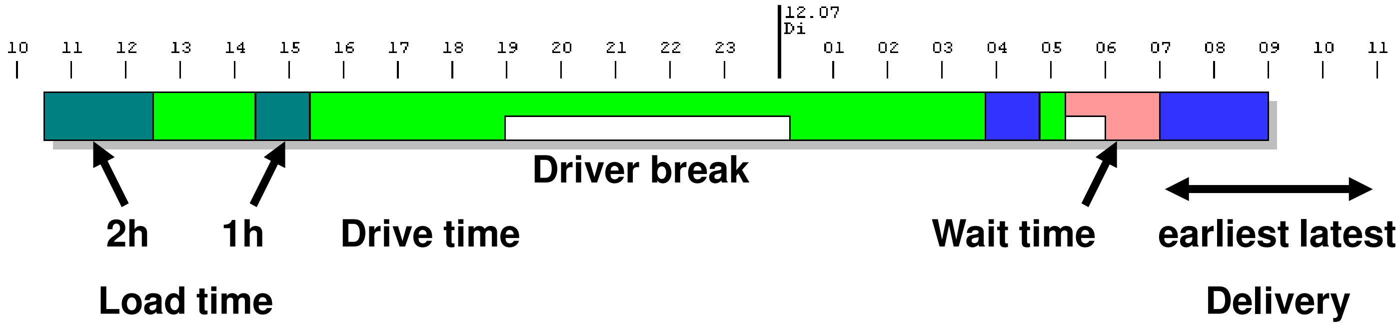
Load Constraints

- ❒ Precedence (pickup before delivery)
- ❒ Pairing (pickup and delivery by the same truck)
- ❒ LIFO (last in first out loading of orders)
- ❒ Capacity limitation (dependent on truck type)
- ❒ Weight limitation (dependent on truck type)
- ❒ Order – truck compatibility (Type, Equipment)
- ❒ Order – order compatibility (Dangerous goods)



Time Constraints

- Order dependent load and unload durations
- Earliest and latest pickup (Soft constraints)
- Earliest and latest delivery (Soft constraints)
- Opening hours for pickup and delivery
- Legal drive time restrictions
- Lead time for ordering spot market trucks
- Maximum Tour duration



Traditional Optimization (top-down)

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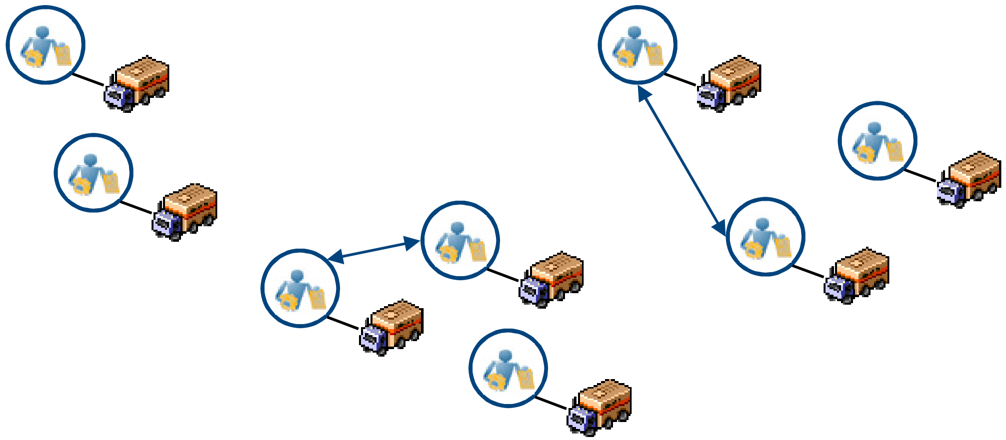
- Batch optimizers using Linear Programming
- Complexity
  - Not able to deal with number of orders and trucks of big logistics companies
  - Harder to model and change constraints
- Dynamics
  - Need to know all orders in advance
  - Batch optimization, no real-time capabilities, no user interaction
- Advantages
  - Closer to optimum (for those domains they are able to solve and if time allows)

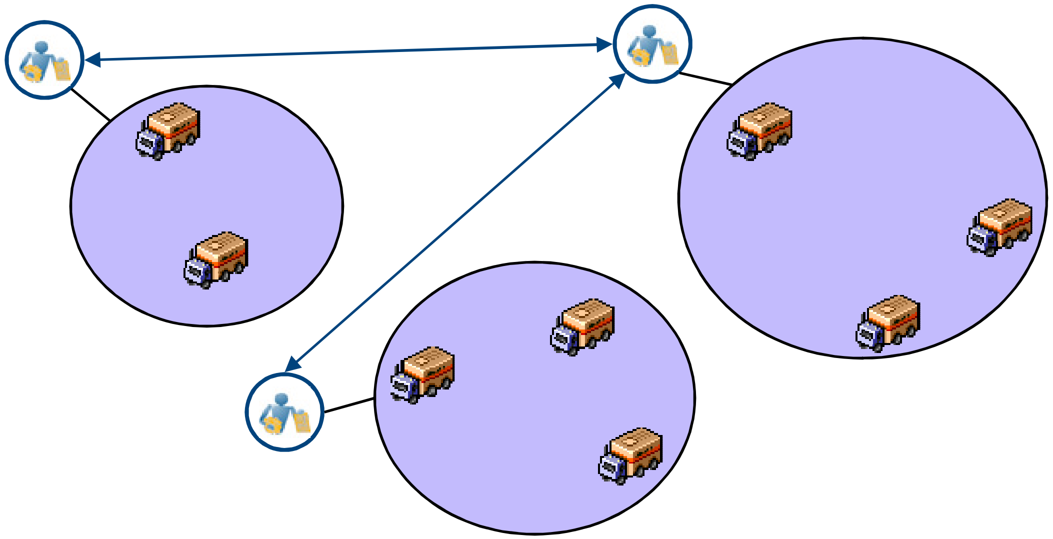
Agent Design

- Each truck is represented by an autonomous agent
  - Maximal scalability
  - Overhead (messaging, memory, other resources)



Agent Design

- Regional cluster of trucks represented by an agent
  - Agents use almost same solution generation and optimization
- Solution generation
  - Start in the most promising cluster
- Optimization
  - Exchange request for tours running across multiple clusters



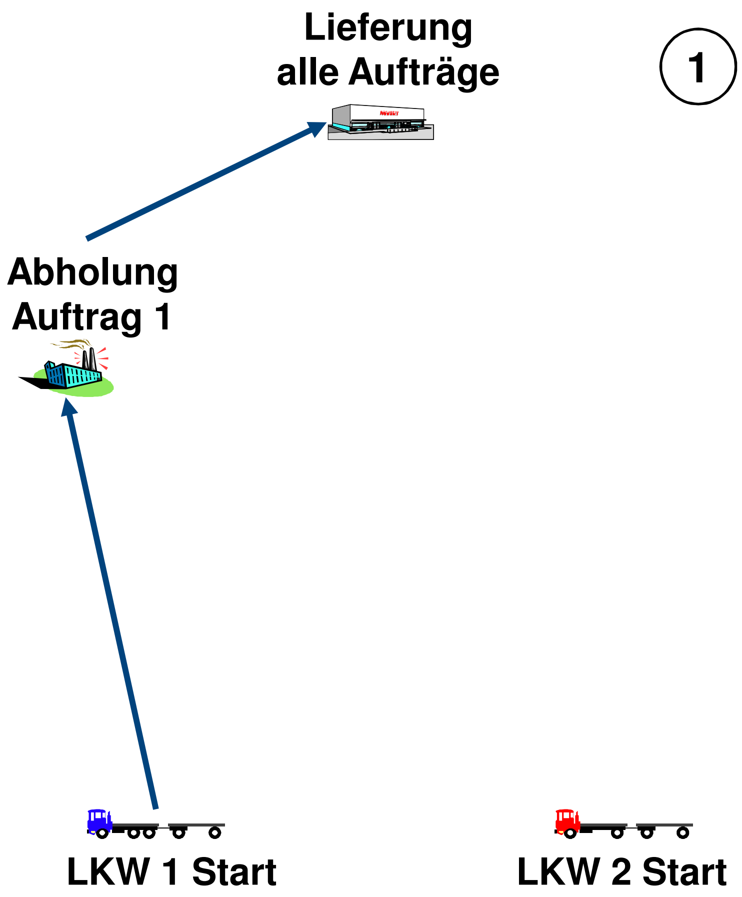
Allocation

Contract Net

- Coordinator agent asks each truck agent for a quote
- Each truck able to transport the order sends back a bid representing the cost increase when transporting the order
- Coordinator awards order to lowest bidding agent

Example

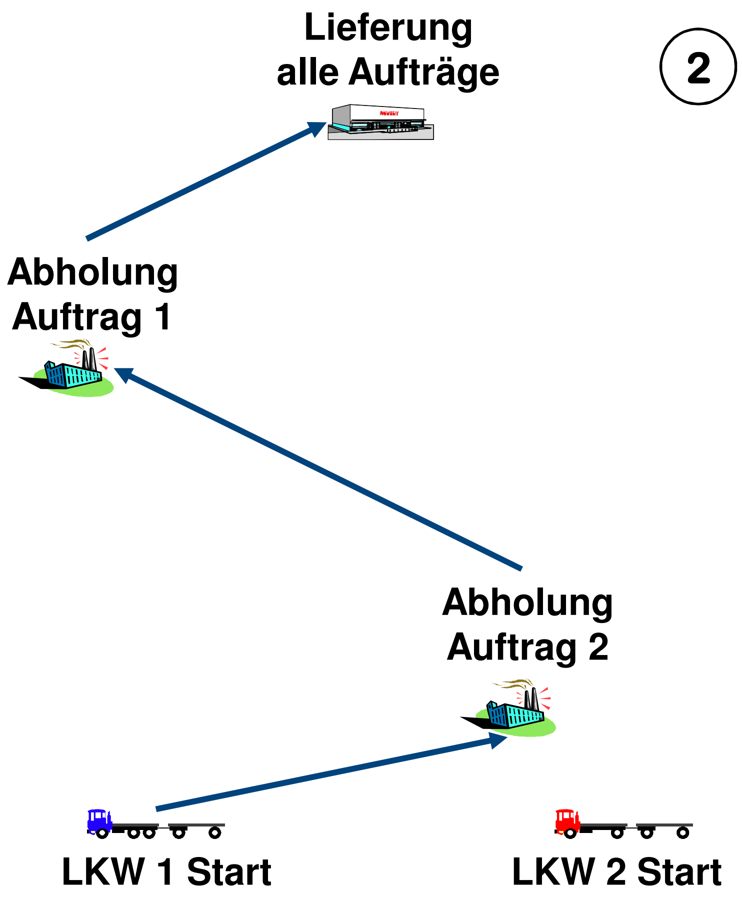
- Order1 is assigned to truck1, it is closer to the pickup location



Allocation

❒ Example

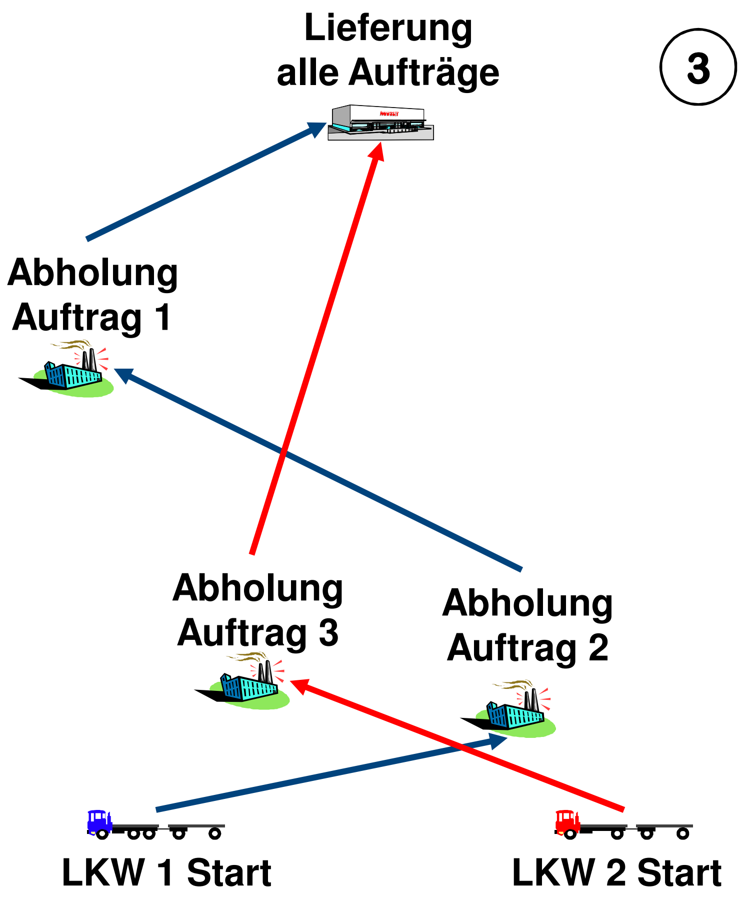
- Order2 is also assigned to truck1
- Additional distance for truck1 is less than additional distance for truck2
- truck1 is now fully loaded when order2 and order1 are picked up



Allocation

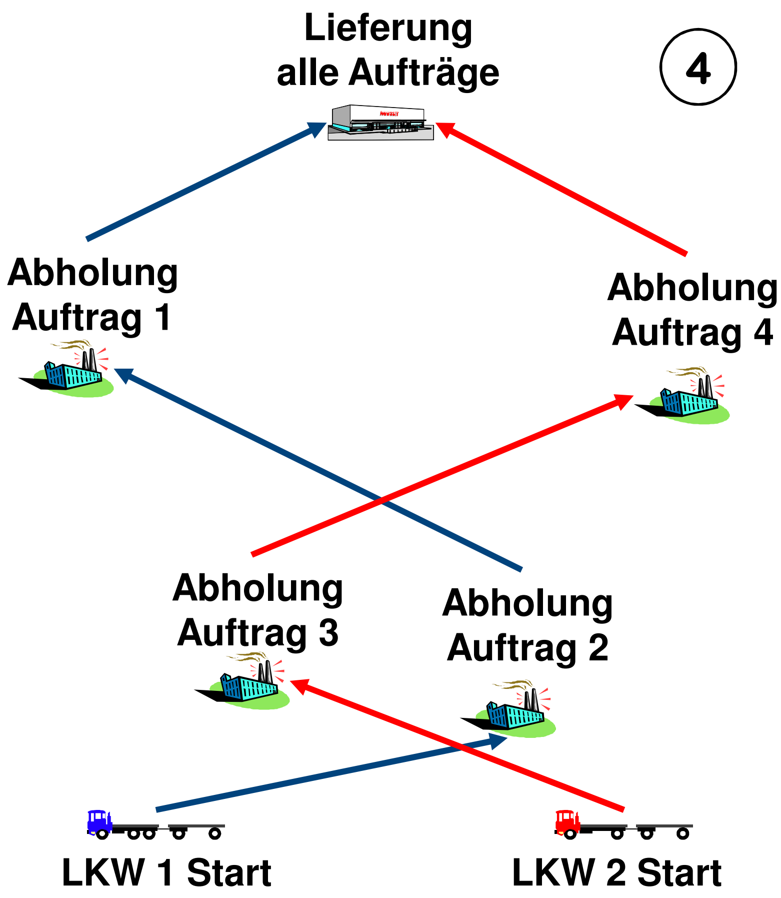
❒ Example

- Order3 is assigned to truck2
- truck1 does not bid, because
  - it is overloaded when picking it up together with order1 and order2
  - it is late at pickup location of order2 when picking it up before picking up order1 and order2
  - it is late at pickup location of order3 when picking it up after delivering order1 and order2



Allocation

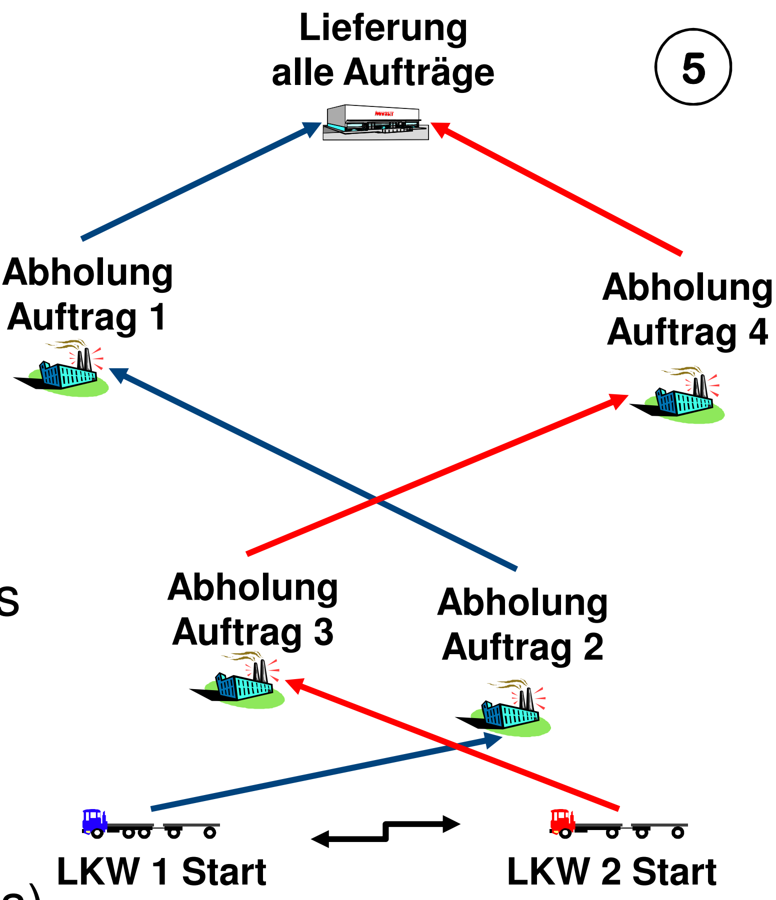
- Example
  - Order4 is also assigned to truck2
- Optimality
  - Contract net protocol produces sub-optimal results
  - Quality depends on the order in which transport orders arrive



Reallocation

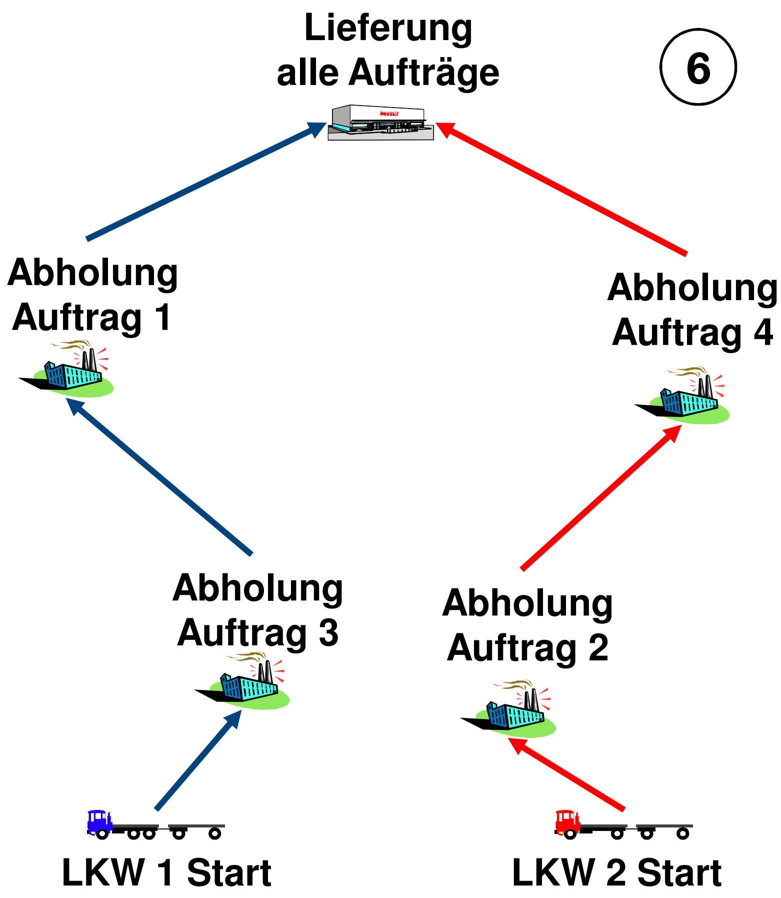
❒ Mutual negotiation

- Agent with changed route sends request for checking order exchanges to other agents
- Other agent checks potential and sends back request for order exchange if exchange creates a better solution
- Agent accepts if exchange creates a better solution
- Better solution
  - win-win for inter-company systems (self-interested agents)
  - win-loose for intra-company systems if win > loose



Reallocation

- Example
  - agent2 sends agent1 request for checking order exchanges
  - agent1 sends back request for exchanging order2 and order3 to save costs
  - agent2 accepts exchange, because it also saves costs
- b-cyclic k-transfer
  - b: number of involved trucks
  - k: number of involved orders
- Distributed Hill-climbing



User Interaction

- Agents and Users have to work together
- Performance
  - Users expect feedback within seconds (real-time optimization)
- Control
  - Full control to agents
    - Not feasible (can not know all constraints, spot market, ..)
  - Full control to dispatchers (all the time)
    - Slows down the system
  - Solution: different phases with handover of control

User Interaction

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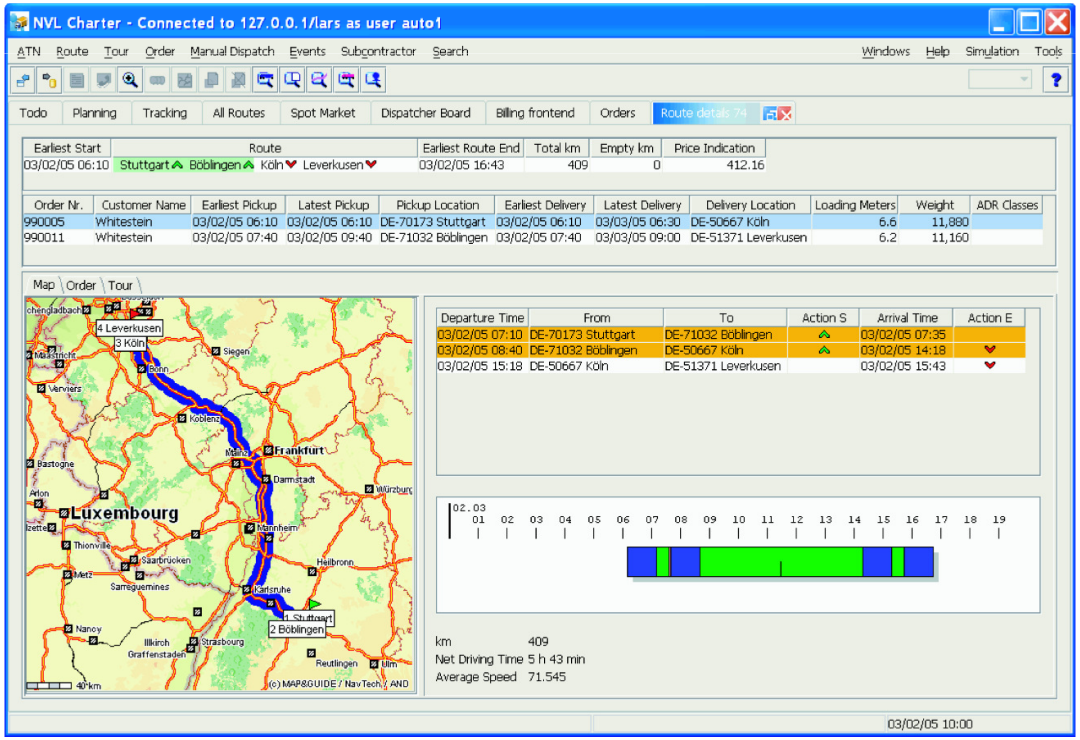
❐ Planning phase

- Until n hours before route starts
- Trucks under full control of the agents
- Allocation and Reallocation without restrictions
- Dispatcher observes



User Interaction

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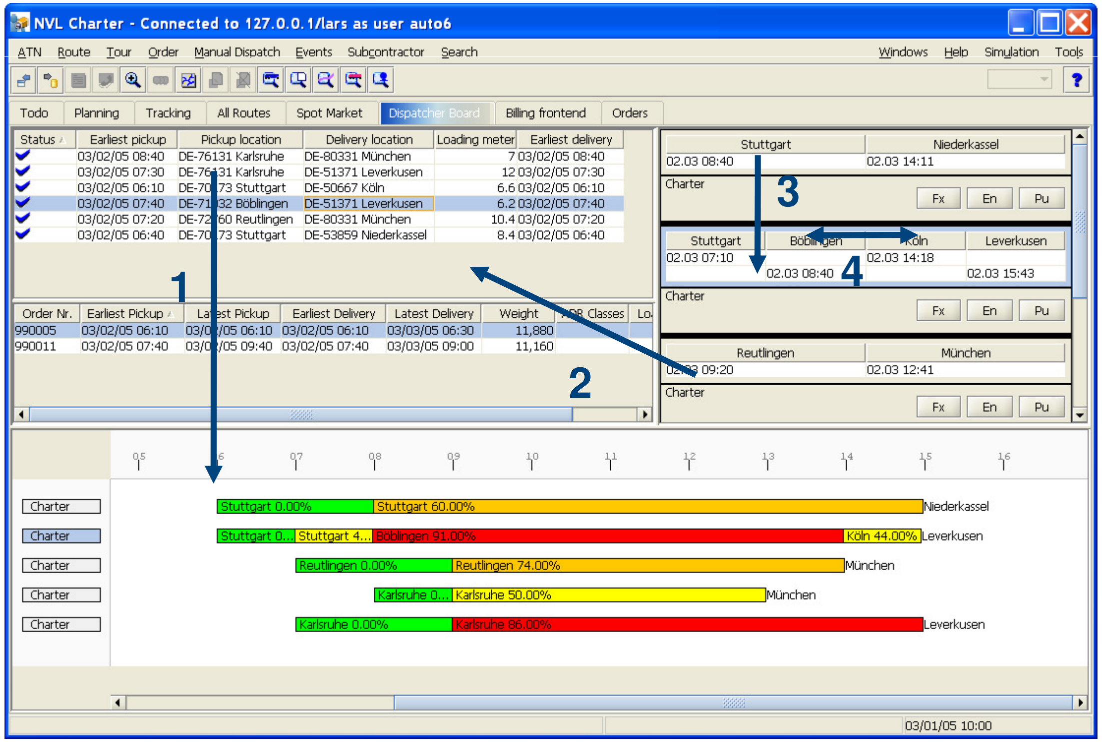
❐ Todo phase

- Trucks under control of agents, but dispatcher can take over
- Find alternatives to transport an order
- Add (1), Remove (2) or exchange (3) orders
- Change schedule (4)
- Agents may not change manually edited routes
- Dispatchers may violate some constraints



User Interaction

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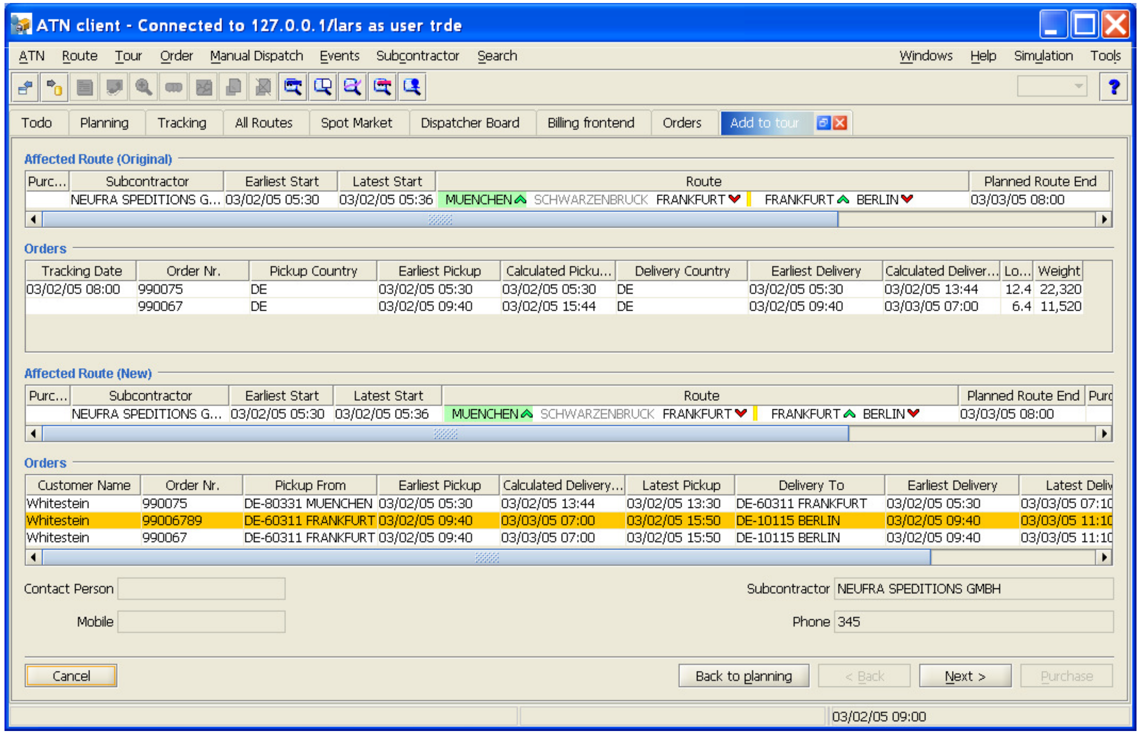
❐ Tracking phase

- Trucks under full control of dispatcher
- Agents can make suggestions to add orders
- Telematics system keeps schedule updated
- Reactive alerting
- Proactive alerting



Overview

- Case study with 3500 real orders
- Objectives
  - Reduce cost
  - Reduce distance
- Measures to ensure comparability with manual solution
  - Same geo-coding
  - Same cost parameterization
  - No soft time constraints
  - Result checked by dispatchers

Solution Quality

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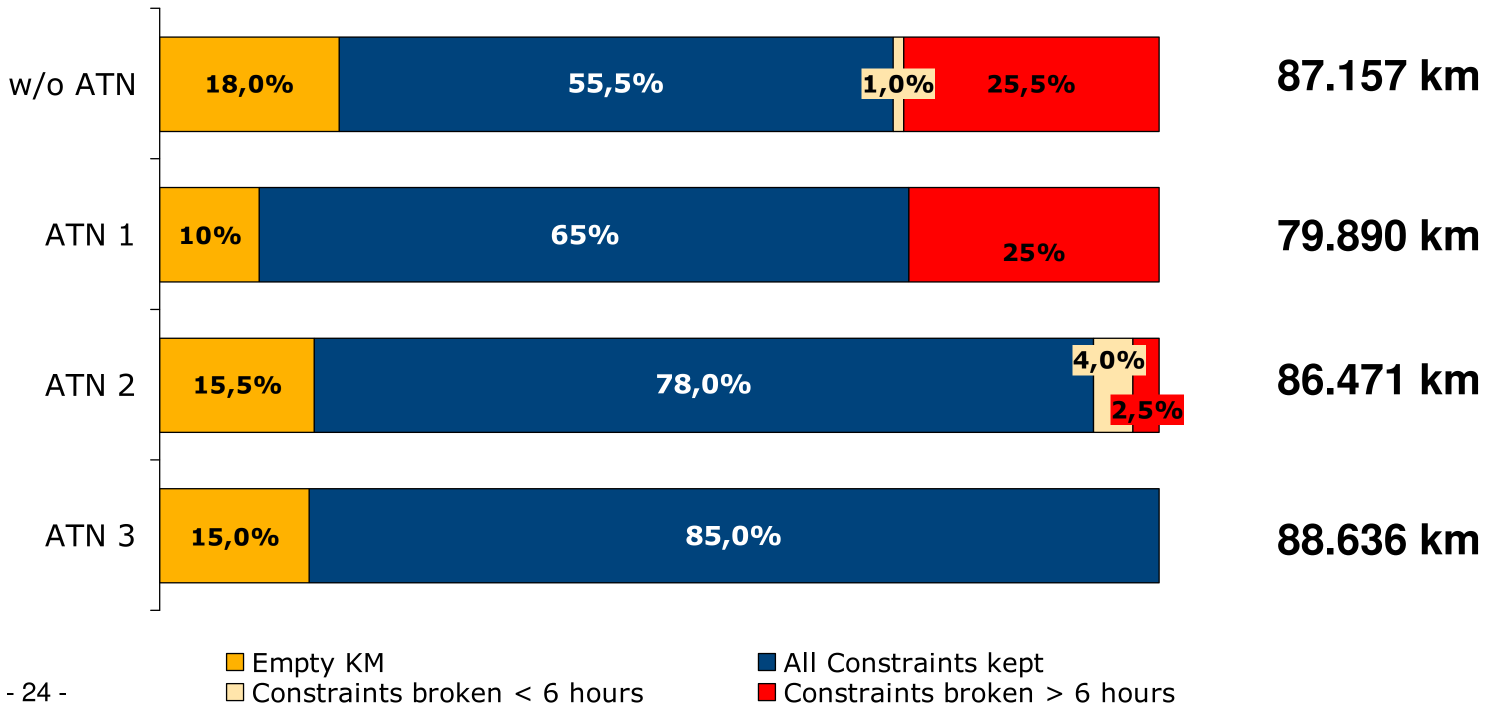
- Comparison to manual dispatching plan

Objective	Reduce Cost	Reduce Distance
Cost	**11.7%**	not comparable
Kilometer	**4.2%**	13.4%
Vehicles	**25.5%**	40.4%

- Cost savings
  - 4.2% by reducing driven kilometers
  - 2.2% by increasing cost-saving tramp routes (reuse of trucks)
  - 5.3% by hiring trucks in cheaper regions

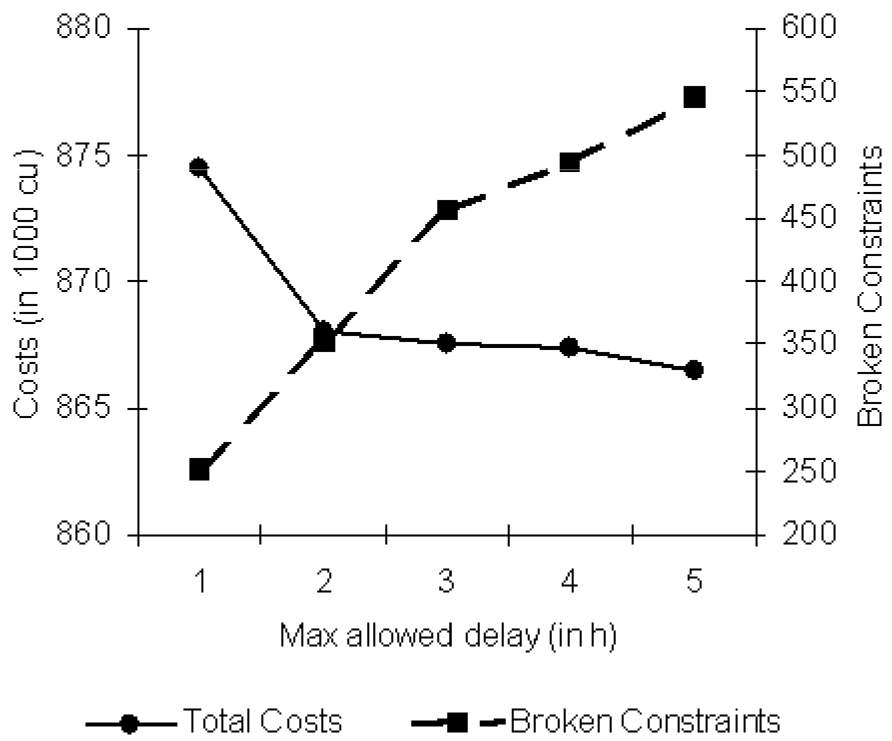
Solution Quality

- w/o ATN: Dispatchers (manual) solution
- ATN 1: Significant reduction of driven kilometers at same service level
- ATN 2: Reduced kilometers with significant higher service level
- ATN 3: Minimal additional kilometers while meeting all restrictions



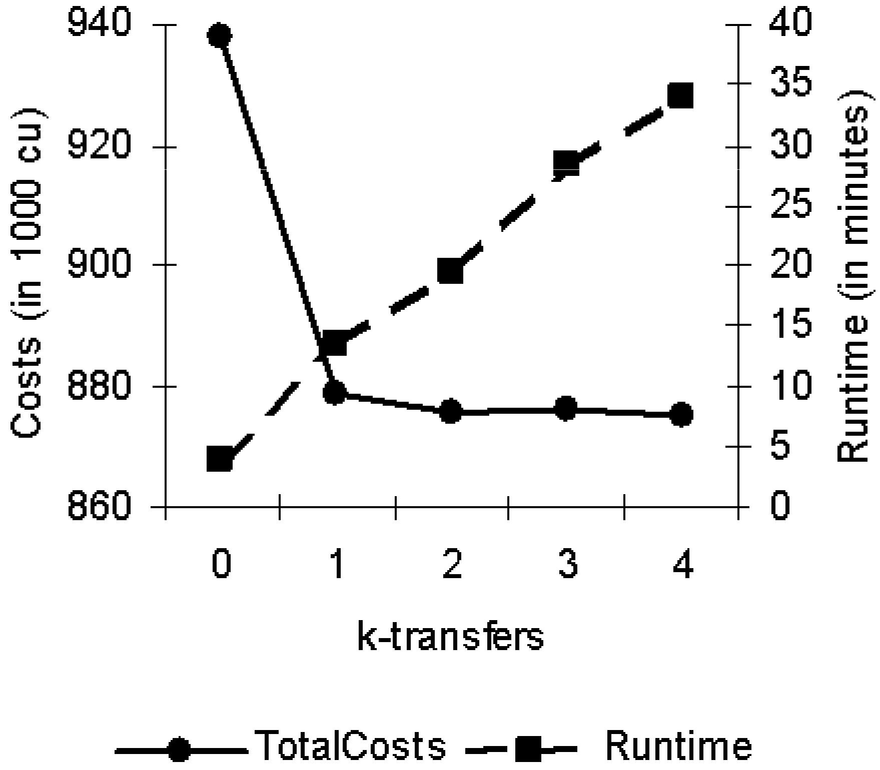
Soft Time Windows

- Optimization results with increased soft time windows



k-transfers

- Optimization results with increasing k (number of orders exchanged)



Clustering

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- Cluster sizes can be varied
- Compared 4 clusters against 1 on a 4 CPU machine

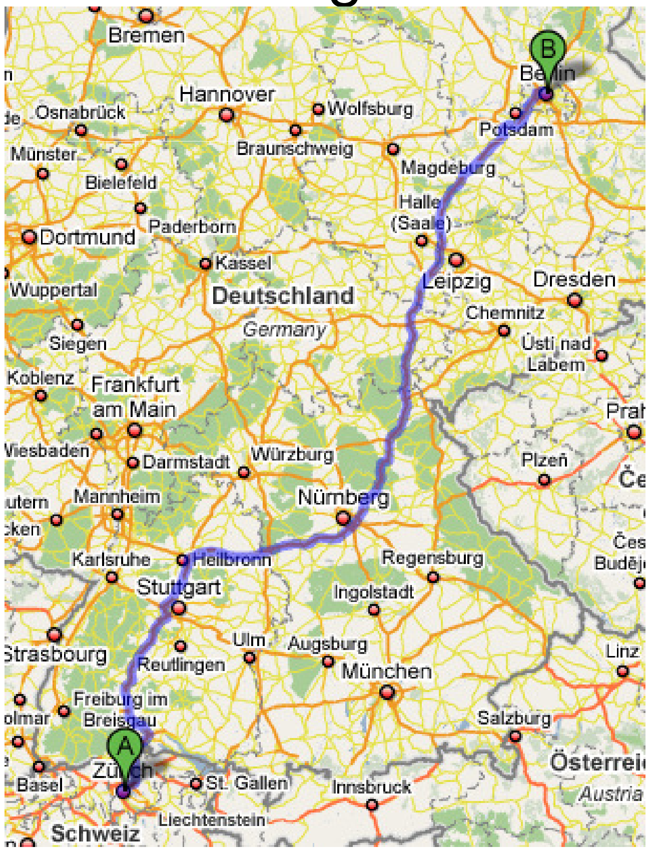
	4 Clusters compared to 1
Cost	**+1.2%**
Runtime	**11%**

- Cost
  - Higher costs due to distribution of trucks into clusters
- Runtime
  - Factor 3 by having computation distributed to 4 CPUs
  - Factor 3 by having less trucks in one cluster

Tracking Feedback

- It is common to have feedback at pickup/delivery locations
- Truck positions are not known in between
- Knowing the position more precisely has advantages
  - Can suggest to add very short time notice orders
  - May detect late trucks earlier and replan
  - May make use of truck ahead of schedule

	Real time tracking
Cost	**-3%**



Software Agents

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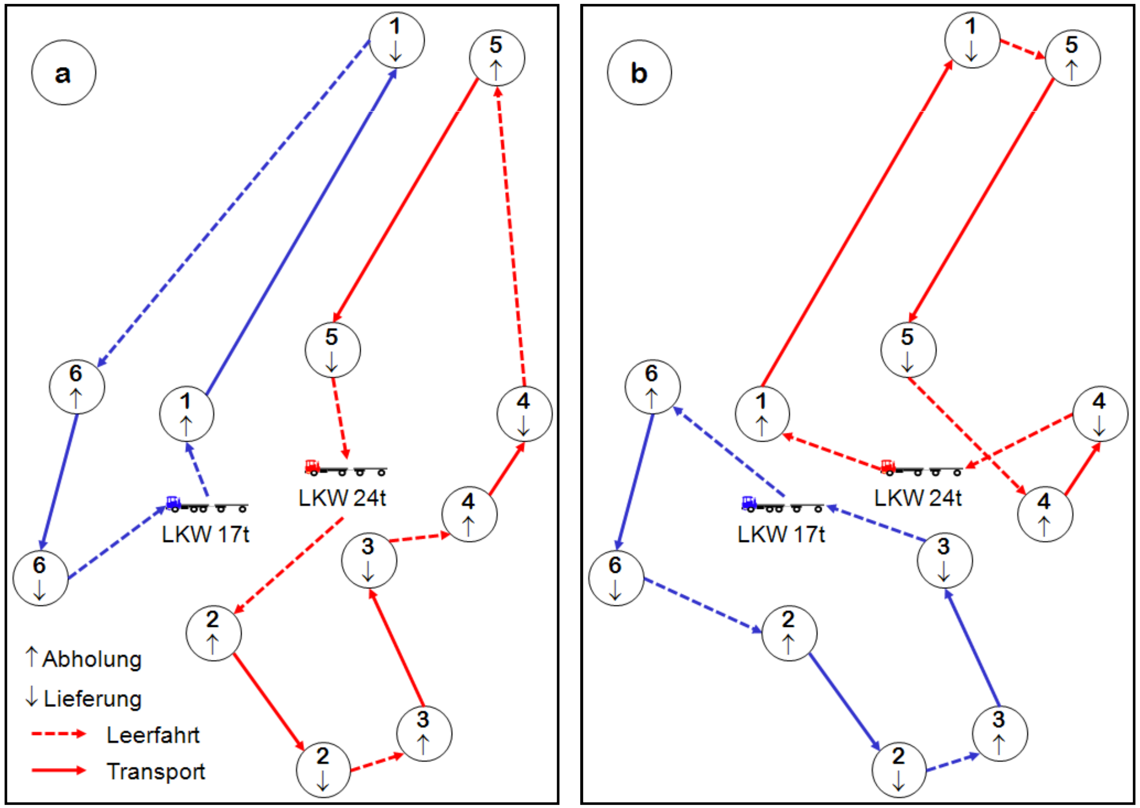
- Help our customers to reduce their costs
- Support the dispatchers in working in a
  - Complex,
  - Distributed and
  - Dynamic domain
- Help us to sell ATN
- Accounted for roughly 10% of the effort to create the system (assuming having an agent runtime available)

Questions?

Thank you for your attention!

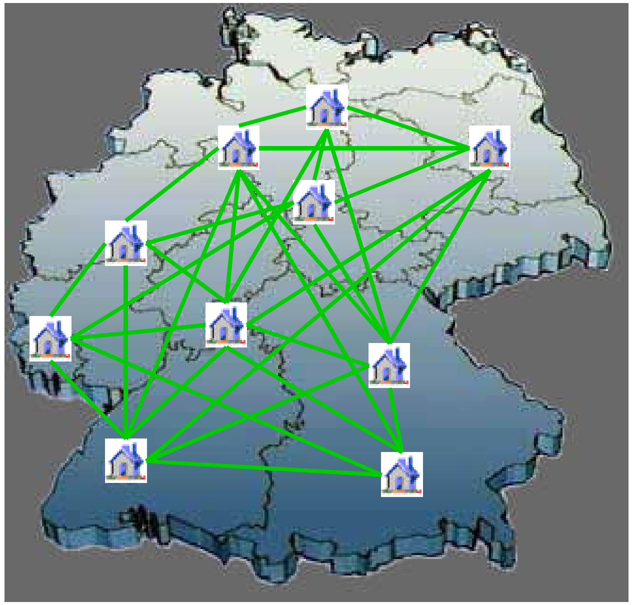
Heterogeneous Vehicles (FTL)

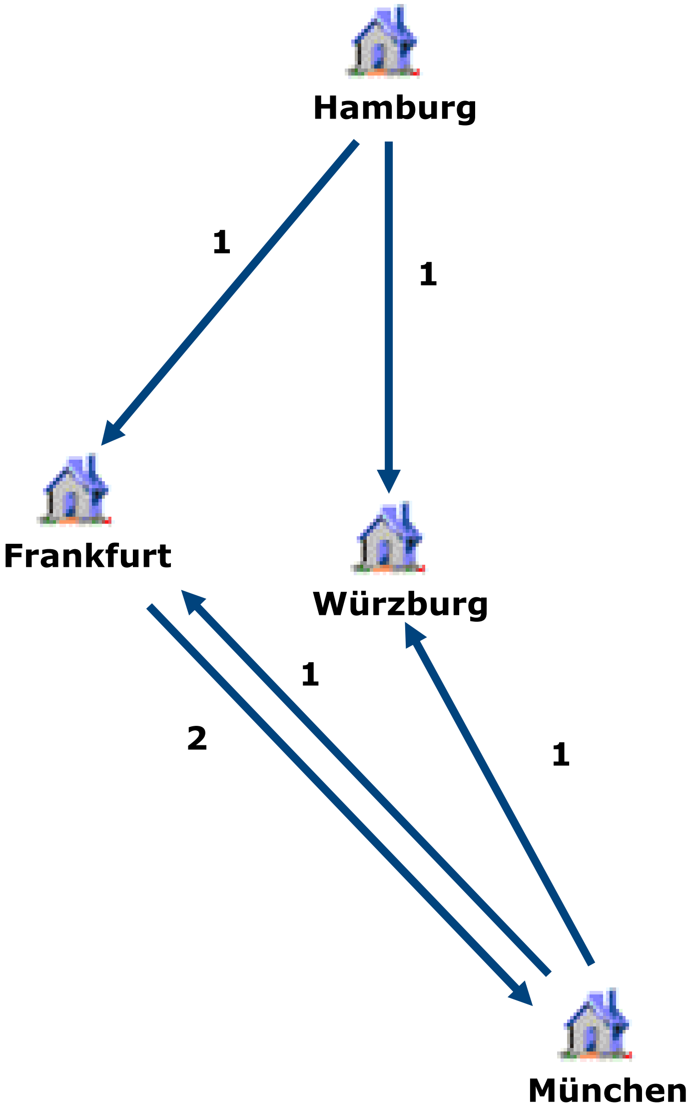
- Decision for which truck to choose matters
- Example
  - Order5 (24 tons) can not be transported by truck 17t
  - Routes in a have too many empty km
  - Simple Reallocation does not work



Network Optimization

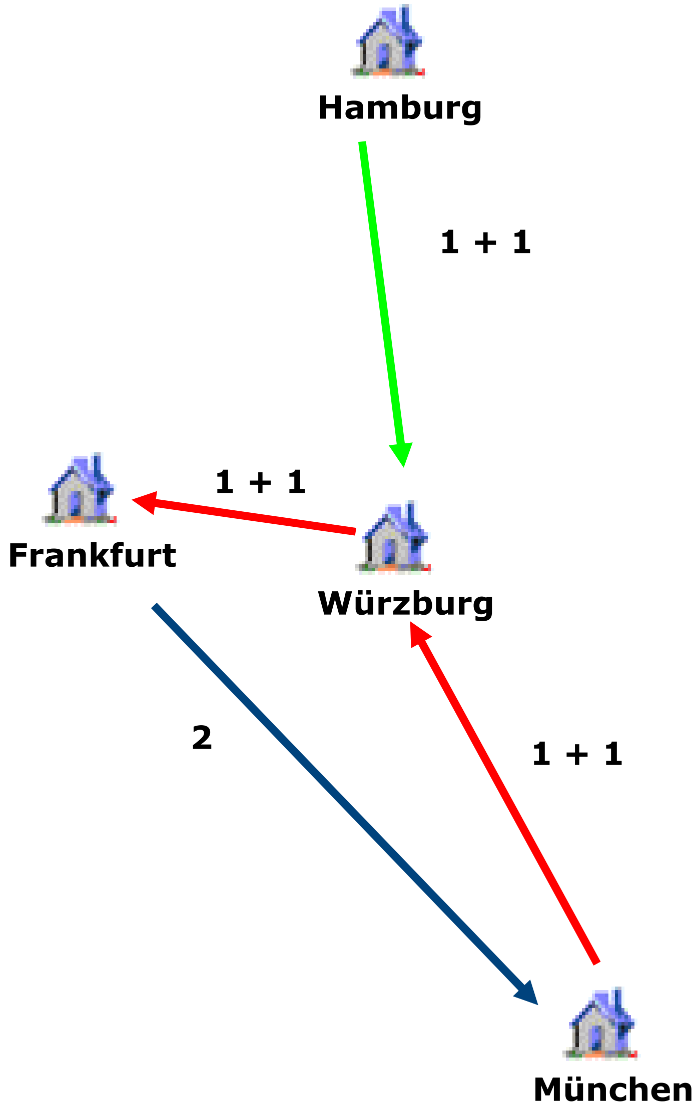
- Transport orders between network of hubs
- Orders may be relayed at hubs
- Create a transport plan for all relations between hubs





Network Optimization

- Distance optimal solution
  - 352 km
  - 3 trucks
- How does a cost optimal solution look like?
  - Distance costs
  - Fix costs for trucks
  - Costs for drivers not at home



Network Optimization

- Setup
  - 175 orders
  - 33 hubs
  - 16 paths on average per relation for each order
  - 61233 order kilometers

Approach	Result (avg) (km)	Result (best) (km)	Runtime (avg) (sec)	Result (best known)
Hill Climbing	33288	33288	9	30657
Tabu Search	32647	32647	60	32051
Simulated Annealing	28502	28325	65	28325
Genetic Algorithm	30684	30114	61	28180