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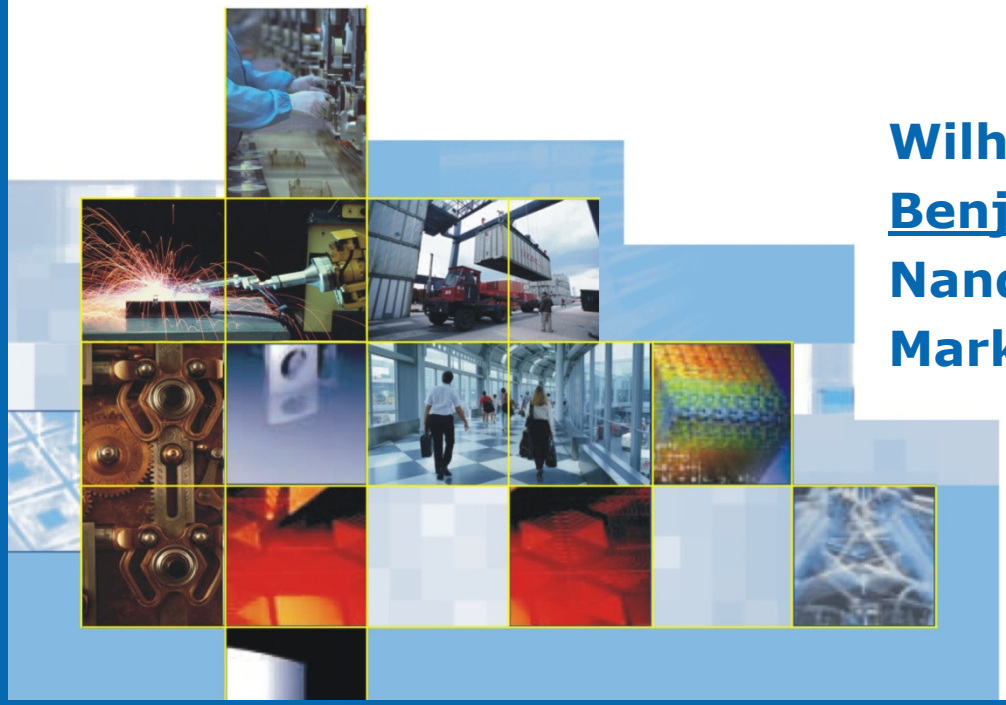
Aspects of Agent Based Planning in the Demand Driven Railcab Scenario



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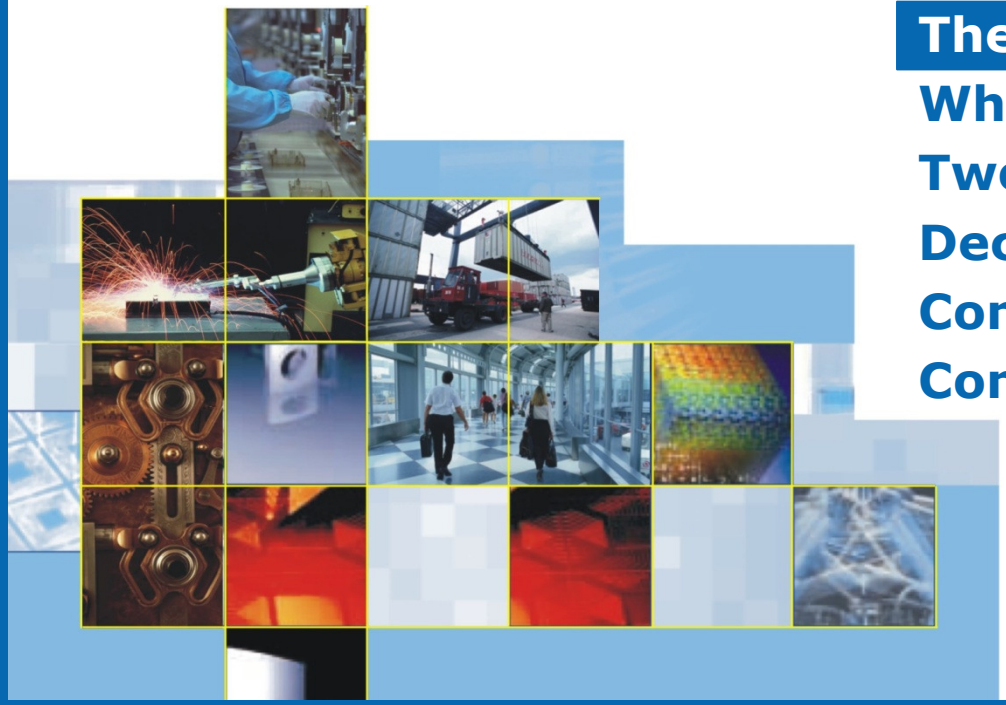

The Railcab Scenario

Why Agent based?

Two-Phase Planning Approach

Decentralised Optimization

Consideration of Uncertain Travel Time

Conclusion

Railcab

Introduction

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Test vehicle on scale 1:2.5

Test track at Paderborn

The Railcab Concept

- … uses small and flexible shuttles instead of large train units
- … combines the effectiveness of railway traffic and the flexibility and individuality of road traffic
- … is demand driven, no fixed schedules exist
- … realises short travel time by high average speed instead of high maximum speed
- … therefore reduces the number of stops on an individual trip
- … the lower maximum speed reduces the energy consumption
- ... is able to form convoys for even more energy effectiveness

Railcab

Example

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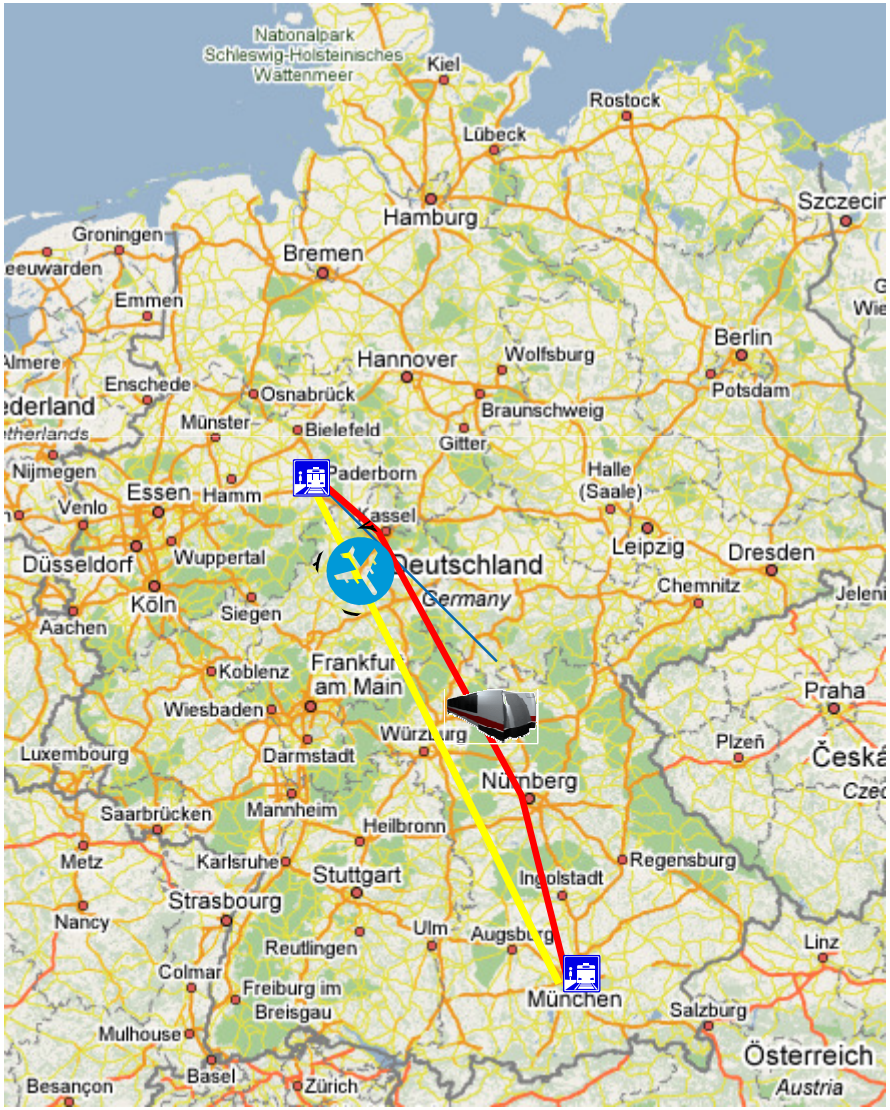

Comparison of two trips:

- Passenger wishes to travel from Paderborn to Munich
- Distance is about 540 km
- Passenger orders shuttle:
  - desired start time: ~10:00
  - desired arrival time: ~14:00

- Railcab offers the following trip:
  - start time: 9:50 (Centre of Paderborn)
  - arrival time: 13:20 (Centre of Munich)
  - two stops to pick up additional passengers

- Same trip by plane:
  - to the Airport 9:35
  - check-in: 9:55 (Paderborn Airport)
  - departure: 10:55 (Paderborn Airport)
  - arrival: 13:20 (Airport Franz-Josef-Strauss)
  - arrival: 14:05 (Centre of Munich)

Railcab

The Logistical Problem

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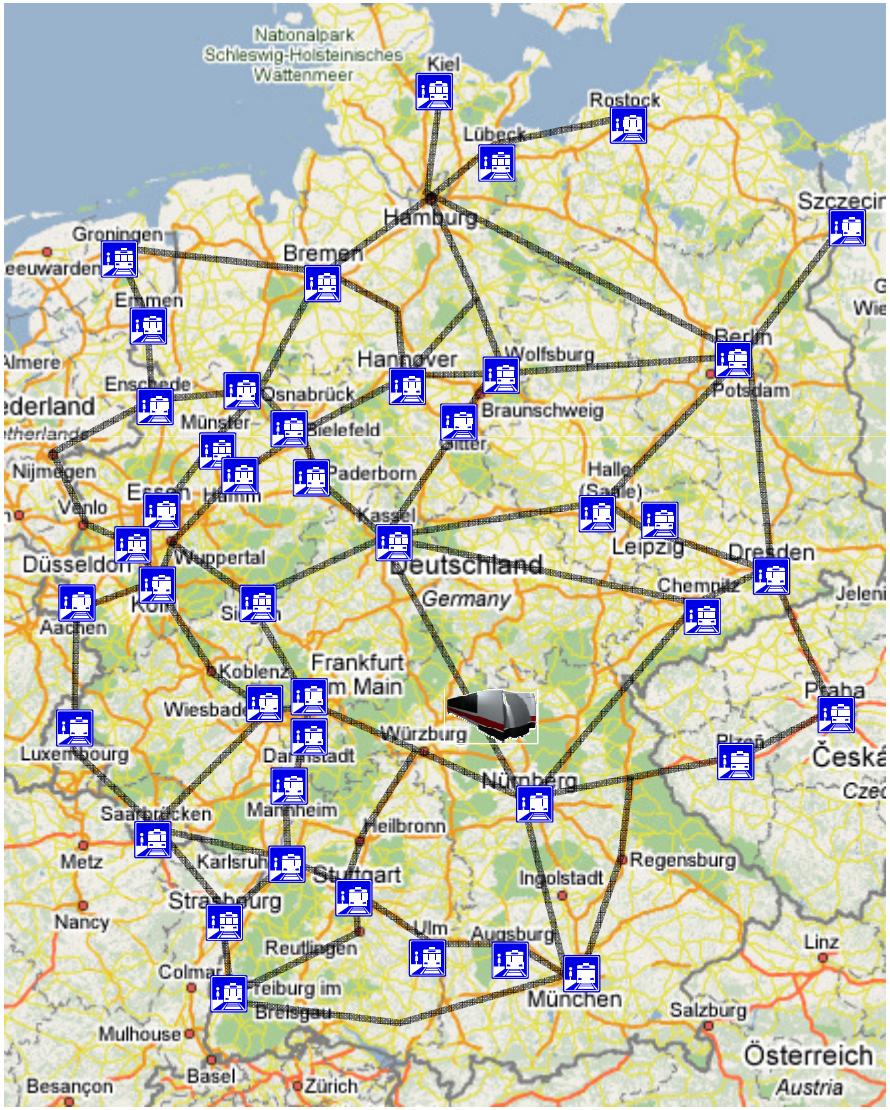

The Planning Problem defined by Railcab

- … is a Pick-Up-And Delivery-Problem-With-Time-Windows (PDPWTW)
- … new transport order appear constantly
- … thus is an online version

- … has special properties:
  - … utilization of tracks
  - … capacities of stations
  - … possibility of forming convoys

- Simplified objective functions can be given by:

  - For a single shuttle i

$$cost_i = \sum_{t=1}^{n} c_t + e_t \cdot ec_t + \sum_{st=1}^{m} c_{st} \cdot (departure_{st} - arrival_{st})$$

  - A global objective Function

$$cost_g = \sum_{sh=1}^{o} cost_{sh}$$

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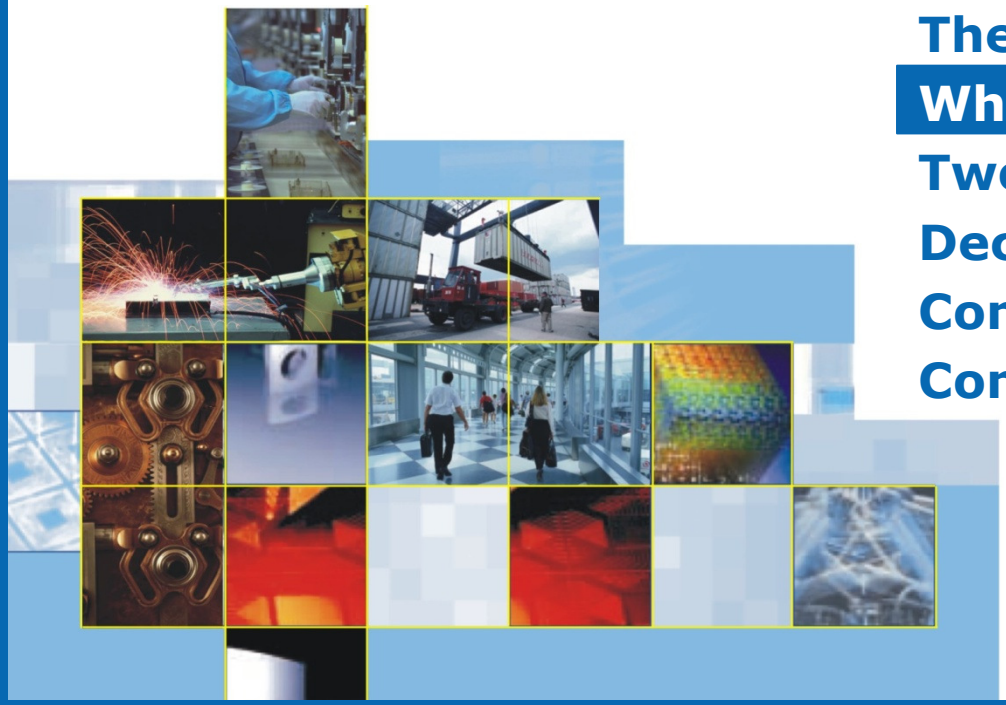
Aspects of Agent Based Planing in the Demand Driven Railcab Scenario



Motivation for Agent Based Planning

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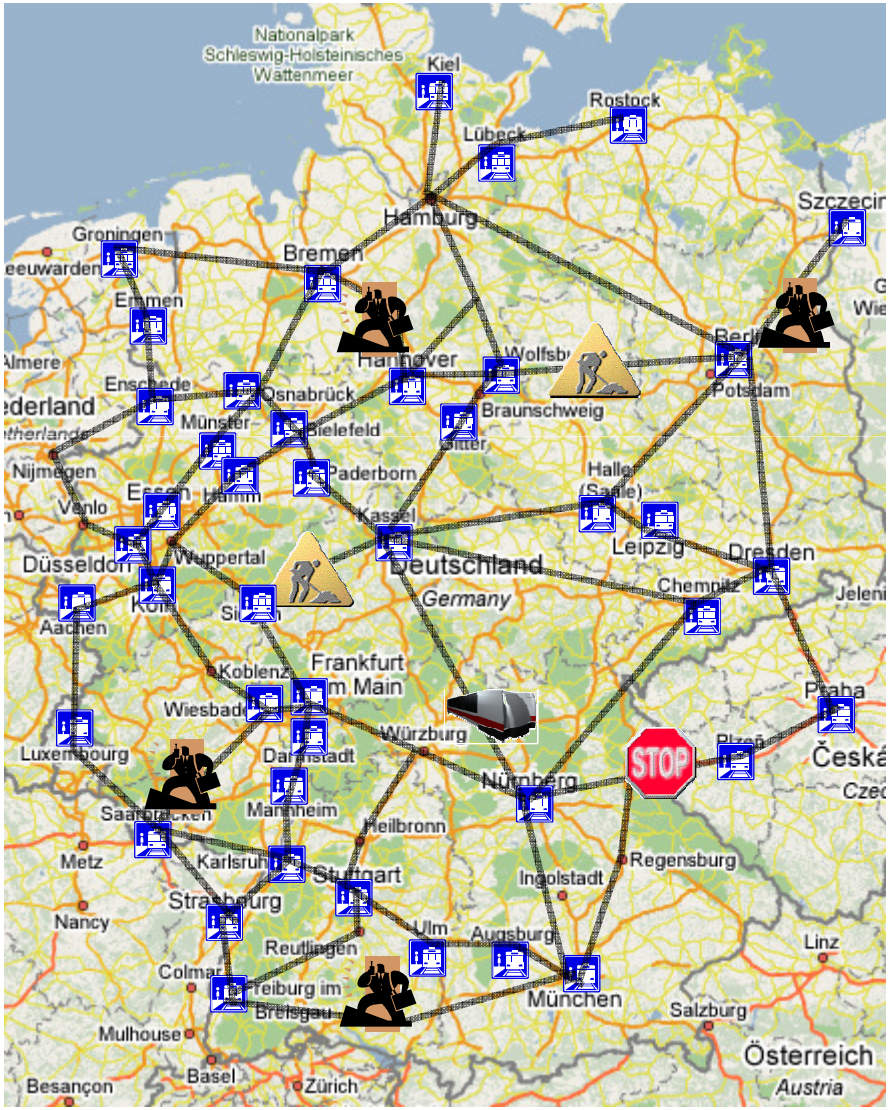

Centralized Planning is not appropriate because:

- … the scheduling is a complex and dynamic problem
- … the system encompasses a large number of objects
  - … shuttles
  - … tracks, switches & stations
  - … passengers & goods
- … the system is subject to frequent changes
  - … new transport orders appear
  - … disturbances occur
- … fast and reliable communication is necessary for centralized planning in such an environment

Agent based planning is more appropriate because:

- … it is able to use local information for local decision making
- … a multi agent system can be adapted to the problem structure

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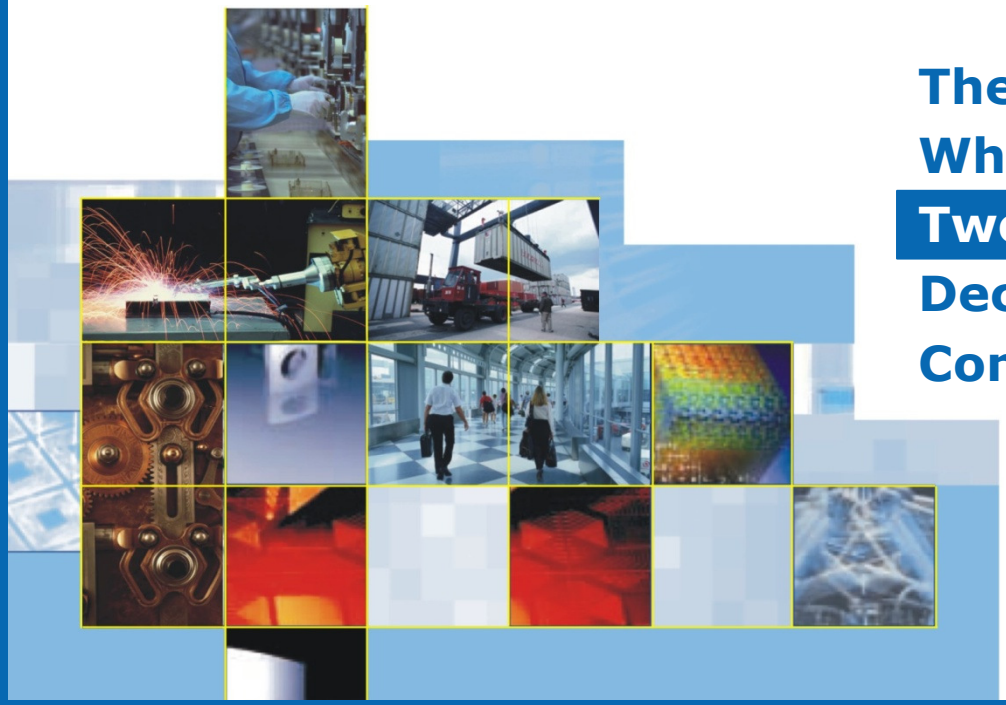

The Railcab Scenario
Why Agent based?
Two-Phase Planning Approach
Decentralised Optimization
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Two Phase Planning Approach
Introduction

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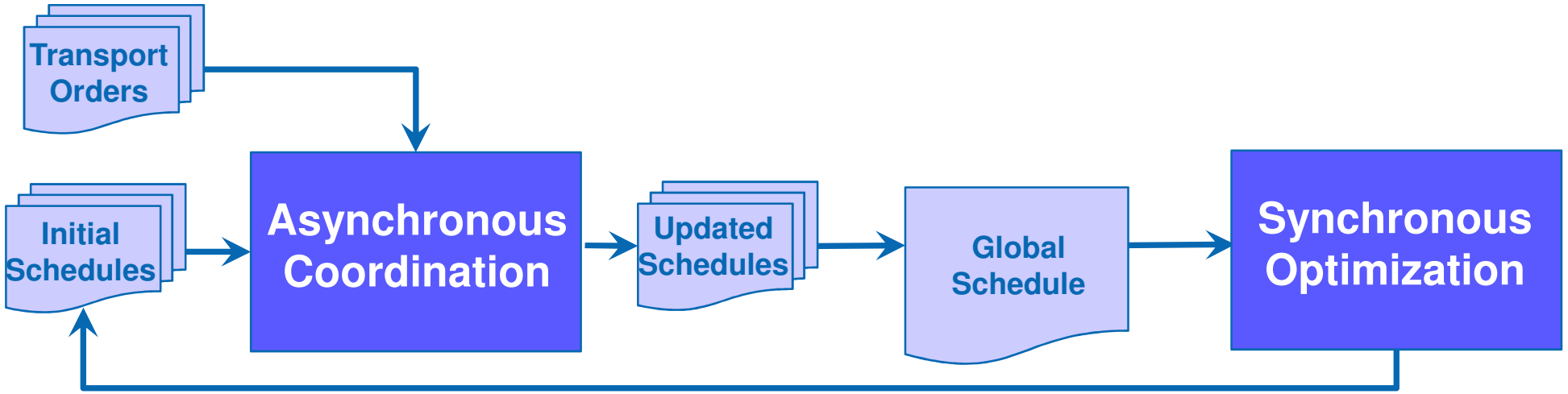
First Version of the Railcab MAS:

- Provides fast and reliable answers to transport orders and low transportation costs
- Implements the cooperative planning paradigm Generalized Partial Global Planning (GPGP)
- In GPGP each agents constructs an individual plan to achieve it‘s objectives
- Afterwards plans are exchanged in order to improve the coordination
- The two phase planning approach uses global synchronization



Two Phase Planning Approach
Asynchronous Coordination

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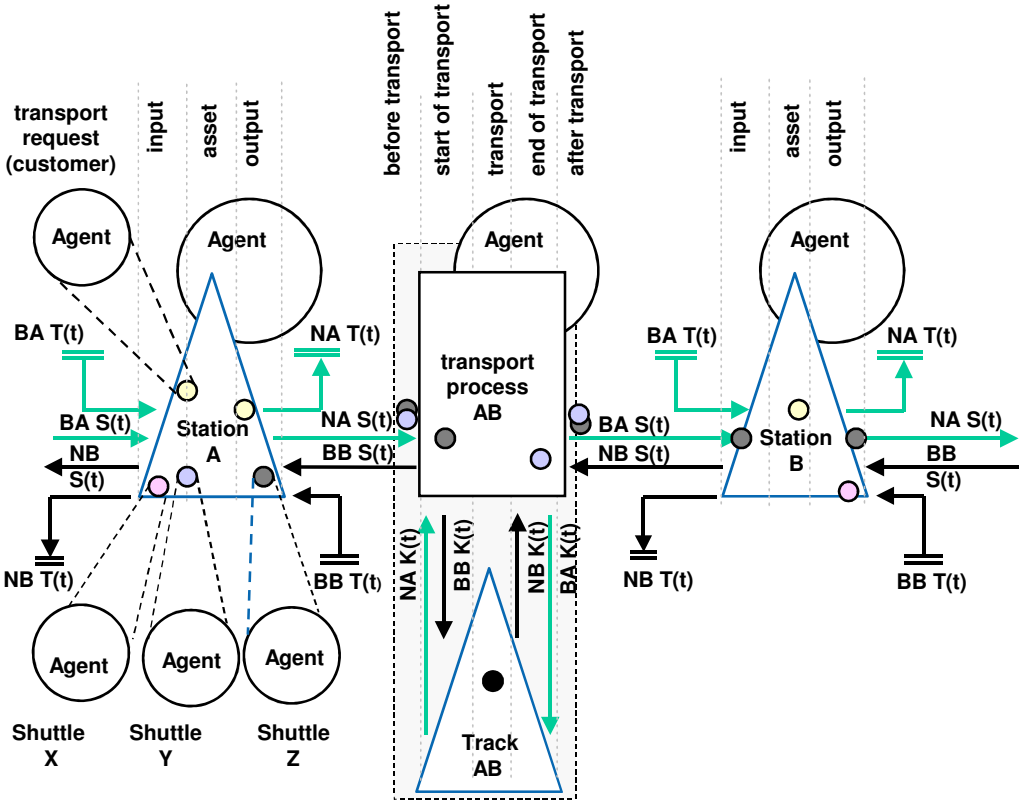
Initial Planning Process:

- Provides a feasible transportation schedule
- Considers all possible resource conflicts
- One agent assigned to each relevant entity
  - Track Agents
  - Station Agents
  - Shuttle Agents
  - Client Agents
- Relationships and interactions systemized by a state transition net profile called MFERT
- Asynchronous communication allows massive parallelism
- System is able to answer several transport requests at the same time within seconds



Two Phase Planning Approach
Synchronous Coordination

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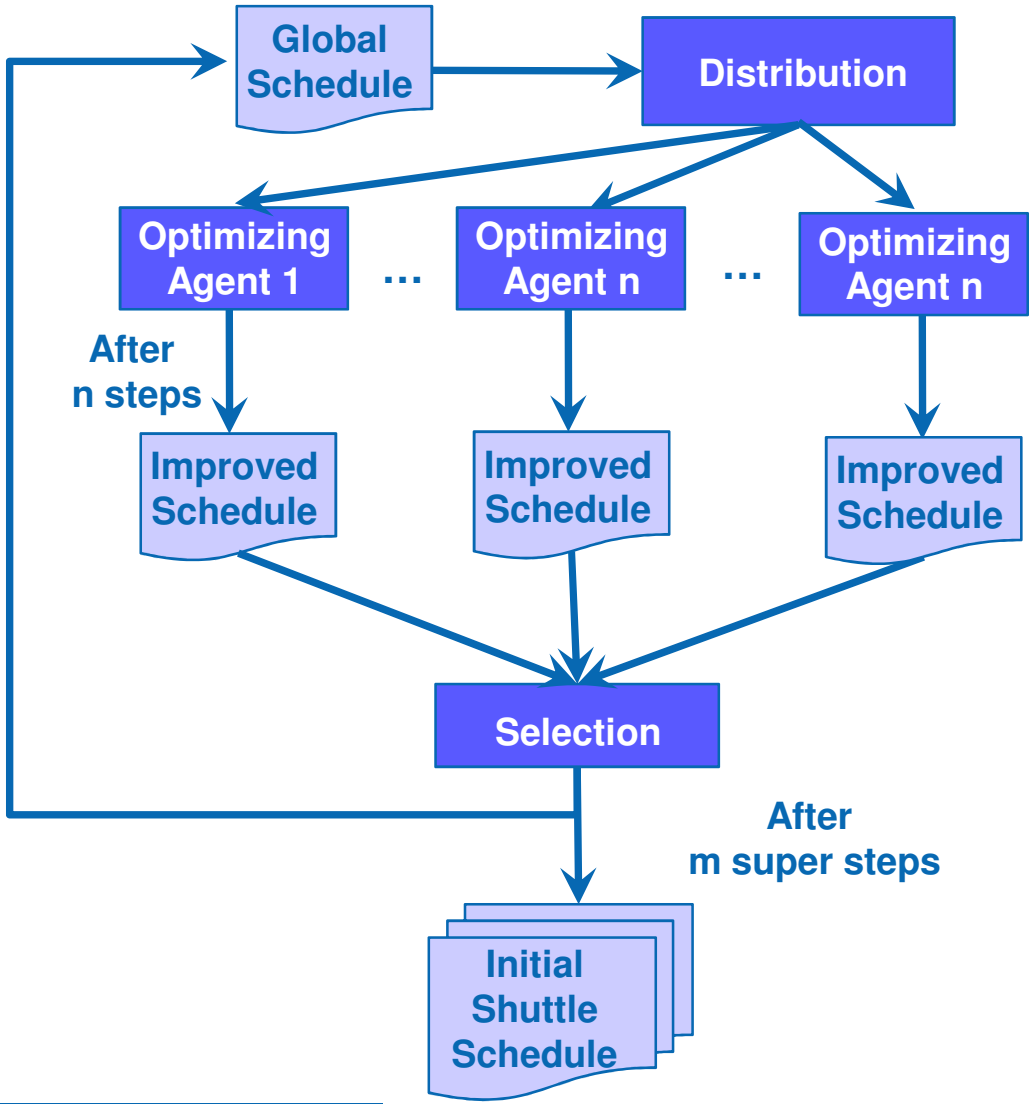
Optimization Process:

- In the second phase the initial plan is optimized
- A parallel heuristic procedure is used (taboo search)
- Synchronously communicating agents are used
- Synchronization of local schedules in fixed time steps
- The currently best solution is used for further optimization
- The procedure is able to realize a decrease in cost of 30%
- Both phases are performed alternating



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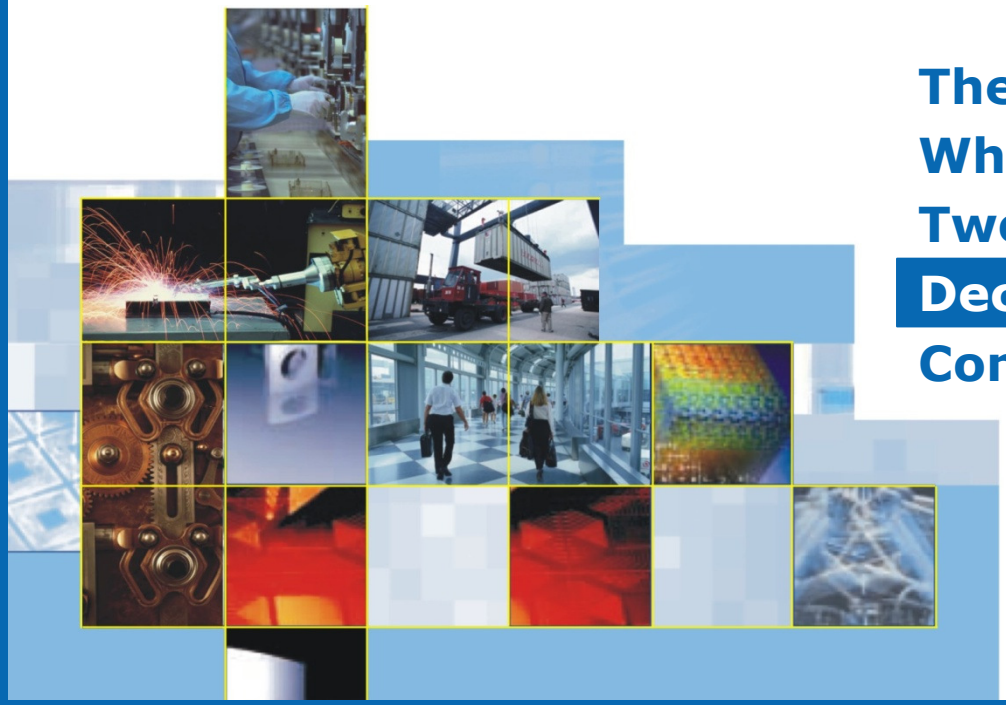
Aspects of Agent Based Planing in the Demand Driven Railcab Scenario



The Railcab Scenario
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Decentralized Optimization
Motivation

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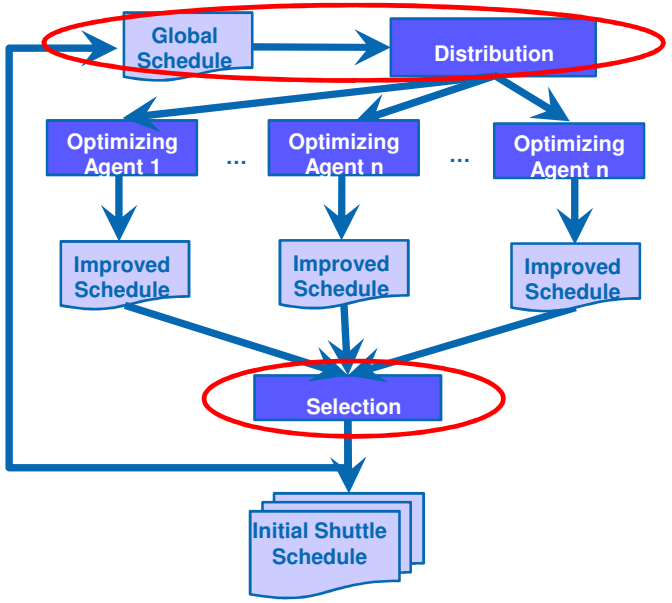
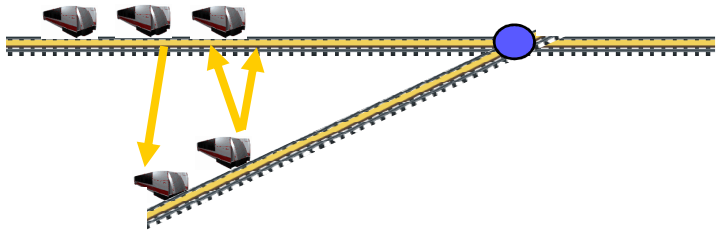
The first version had a critical short coming:

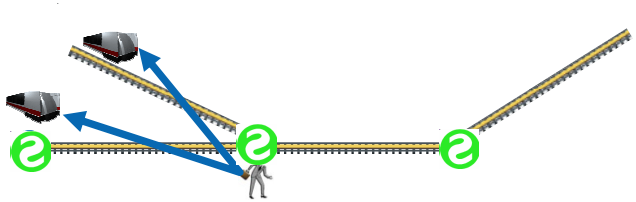
- The synchronous optimization is still a centralized approach
- Thus all the weaknesses persist
- Free exchange of information is not always possible
- Agents can act for different principal, e.g. different forwarding companies



Thus we were looking for decentralised optimization:

- There are two possible coordinating actions in Railcab:
  - job swapping
  - convoy formation
- Both coordinating actions require identification of partners
- Realization of coordinating actions is subject to negotiations





Decentralized Optimization
Job Swapping

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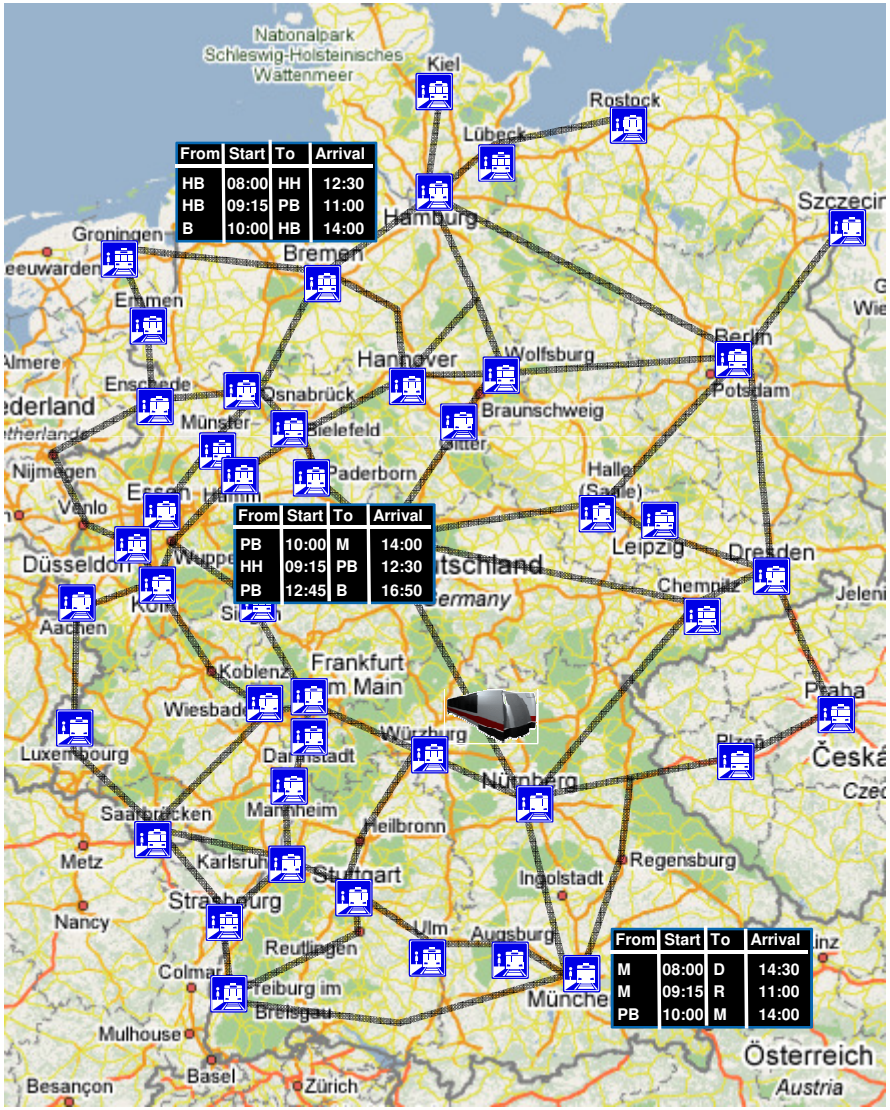

Basic Idea of Job Swapping:

- In decentralized job swapping each agent analyzes it's local plan constantly
- It looks for jobs that cause inappropriate costs
- Theses jobs are advertised for bids of other shuttles

Implementation of Job Swapping:

- A combination of middle agents and Contract-Net-Protocol is used
- Agent advertise jobs on a distributed black board architecture
- Potential job swappings are identified by looking up black boards

Decentralized Optimization
Job Swapping

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Implementation of Job Swapping:

- When agents are interested in taking an advertised job they contact the offering job
- The profitability of transferring the job is checked again
- If it is still profitable to transfer the job, the offering agent sends an CfP to the interested agents
- Interested agents reply with proposal

Results of Job Swapping:

- in experiments job swapping was able to reduce the track utilization costs by 15% in average
- Job Swapping benefits extensively of long time windows

Decentralized Optimization
Convoy Formation

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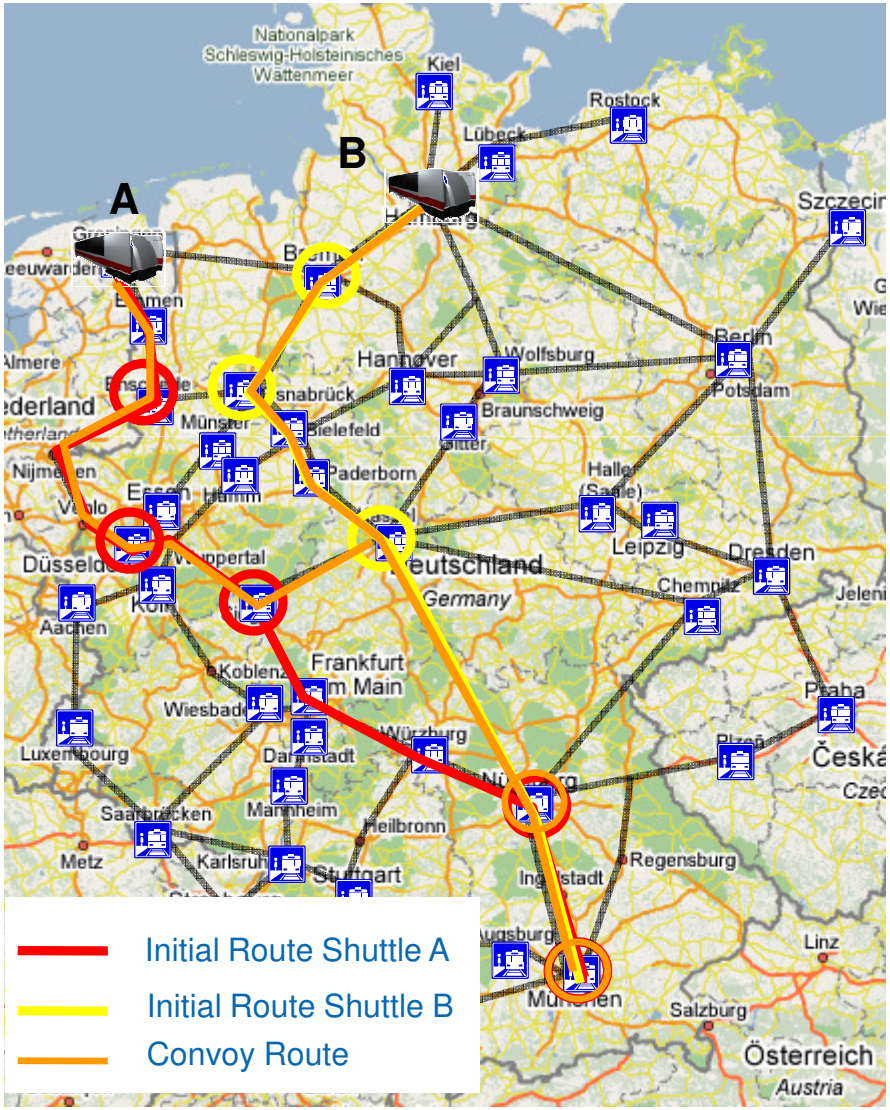

Purpose of Convoy Formation

- Shuttle can reduce their energy consumption by travelling in convoys
- Convoy Formation joins shuttle route where appropriate
- Savings must countervail possible detours
- Convoy formation is a problem of high complexity
- Thus, it is necessary to keep problem size small

Implementation of Convoy Formation

- Convoy Formation is split into three phases:
  - Search for convoy partners
  - Filtering and clustering of convoy partners
  - Distributed convoy planning

Decentralized Optimization
Convoy Formation

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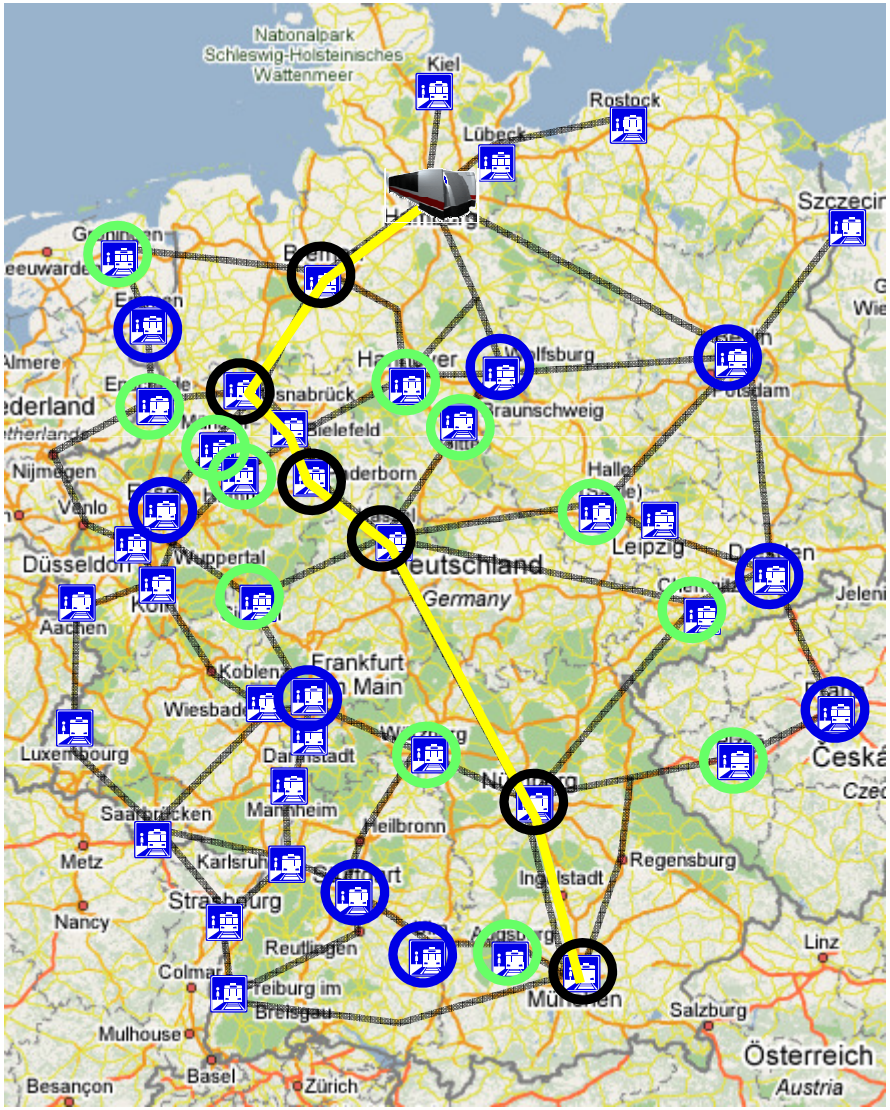

Search for Convoy Partners

- Proper identification of partners reduces the complexity of the convoy formation
- The matchmaking is initiated by shuttle agents
- The actual search is performed distributed by the station agents
- Search is performed along the shuttles route with a limited search depth:

$$depth(st) = \begin{cases} 0, \textit{ if st is queried by shuttle agent} \\ d(st') + 1, \textit{ if st is queried by station st'} \end{cases}$$

stations with depth 0

stations with depth 1

stations with depth 2

Decentralized Optimization
Convoy Formation

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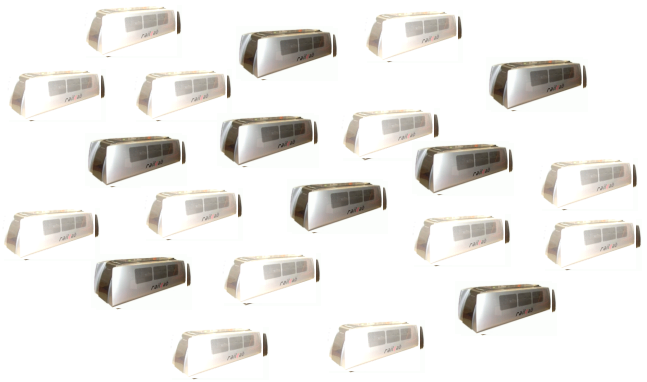

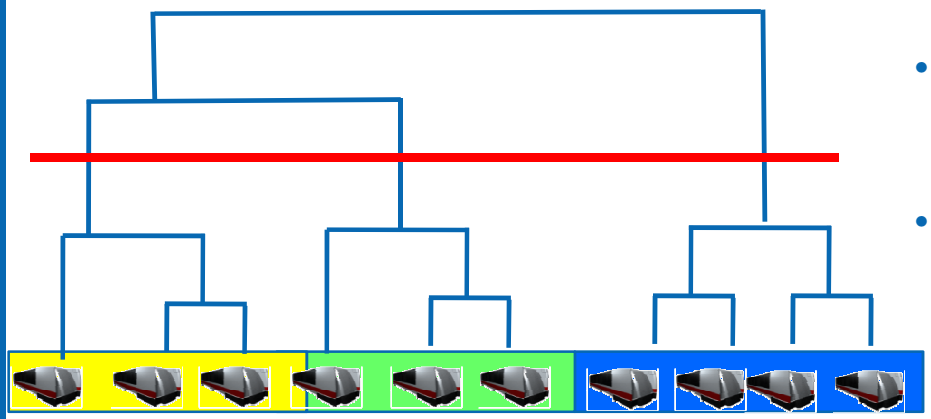

Filtering

- … improves the efficiency of multiagent planning
- … reduces the problem size for clustering/route planning
- … criteria are arrival/departure time and direction of travel

Clustering

- … identifies groups of shuttles which may constitute a good convoy
- … criteria are :
  - similarity of pick-up and delivery stations and times
  - planned travel speed
  - internal energy balance
  - braking distance
  - …

Decentralized Optimization
Convoy Formation

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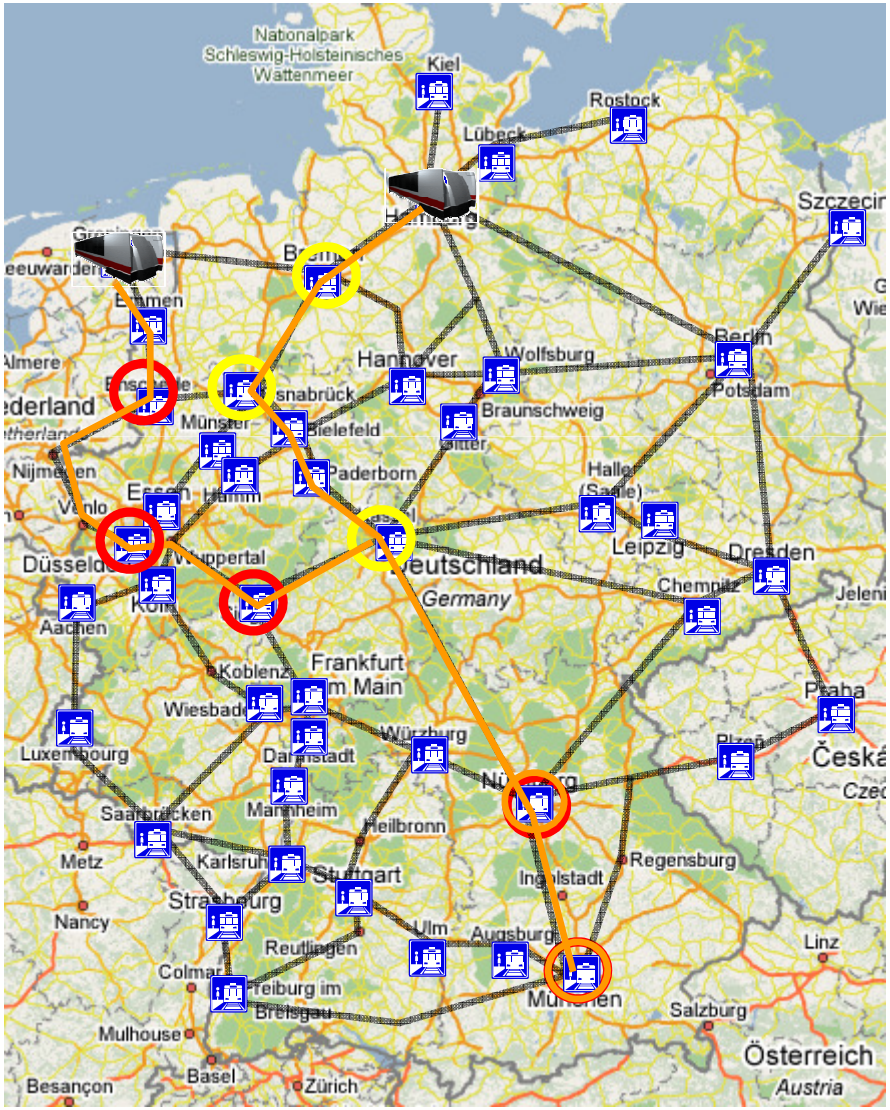

Results of an early version:

- Formation of convoys can reduce the overall costs
- Clustering and filtering can be used to identify potential convoys
- Overall costs where decreased by 1%
- Simple route planning was used, causing heavy detours

Current development:

- PDTW-Algorithms are modified to implement a better convoy routing with less detours
- Clustering and filtering are enhanced by more criteria

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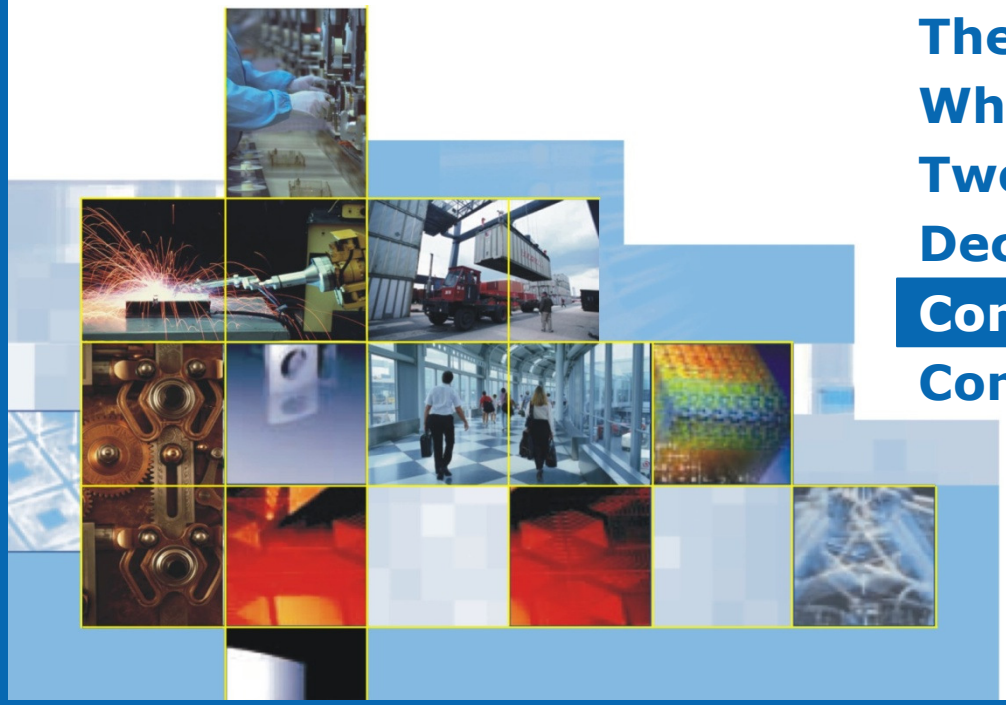

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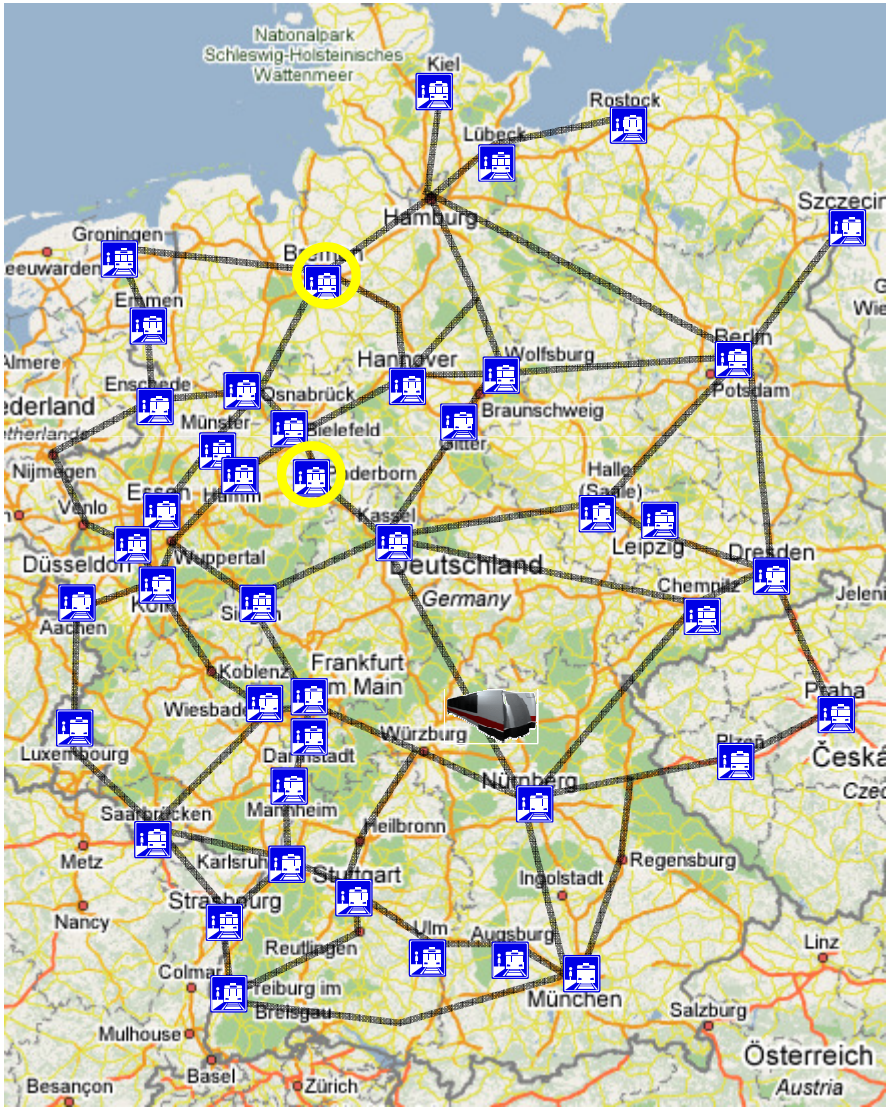

The Shortest Path Problem in Railcab

- Given a transport order with start s and destination d a shuttle agent has to find the best way from s to d
- Usually travel times are considered as constant
- But travel times depend on external influences:
  - leaves on rails
  - slow shuttles
  - delays in station caused by events
- Better results can be achieved if travel times are estimated depending on these external influences
- The Paradigm of Bayesian Thinking says that we can estimate variables like travel time by partial knowledge of the influences and their conditional probability distribution

Consideration of Uncertain Travel Time
Modelling Probabilistic Shortest Path Problem

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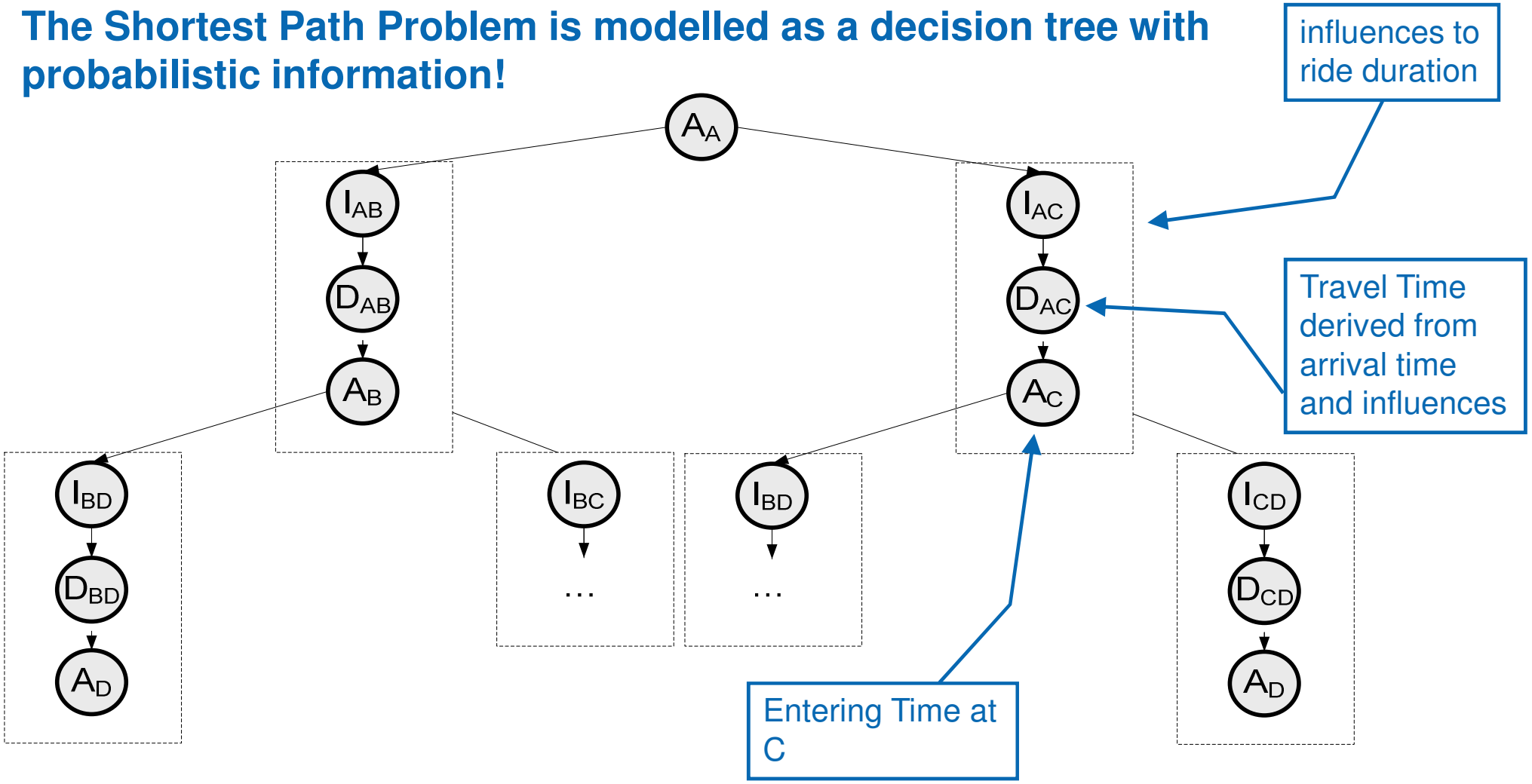
The Shortest Path Problem is modelled as a decision tree with probabilistic information!



Consideration of Uncertain Travel Time
Modelling Probabilistic Shortest Path Problem

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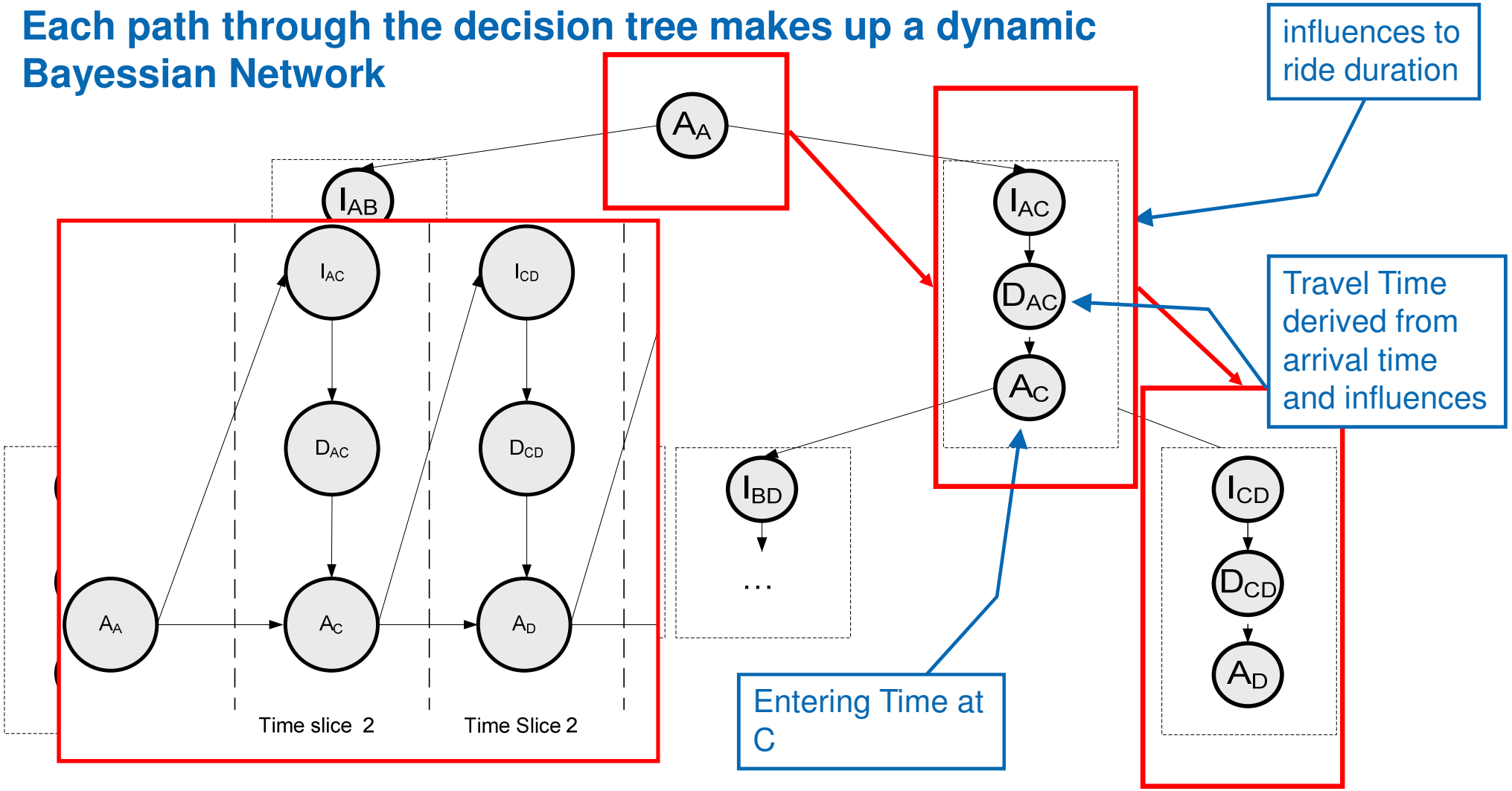
Each path through the decision tree makes up a dynamic Bayessian Network



Consideration of Uncertain Travel Time
Modelling Probabilistic Shortest Path Problem

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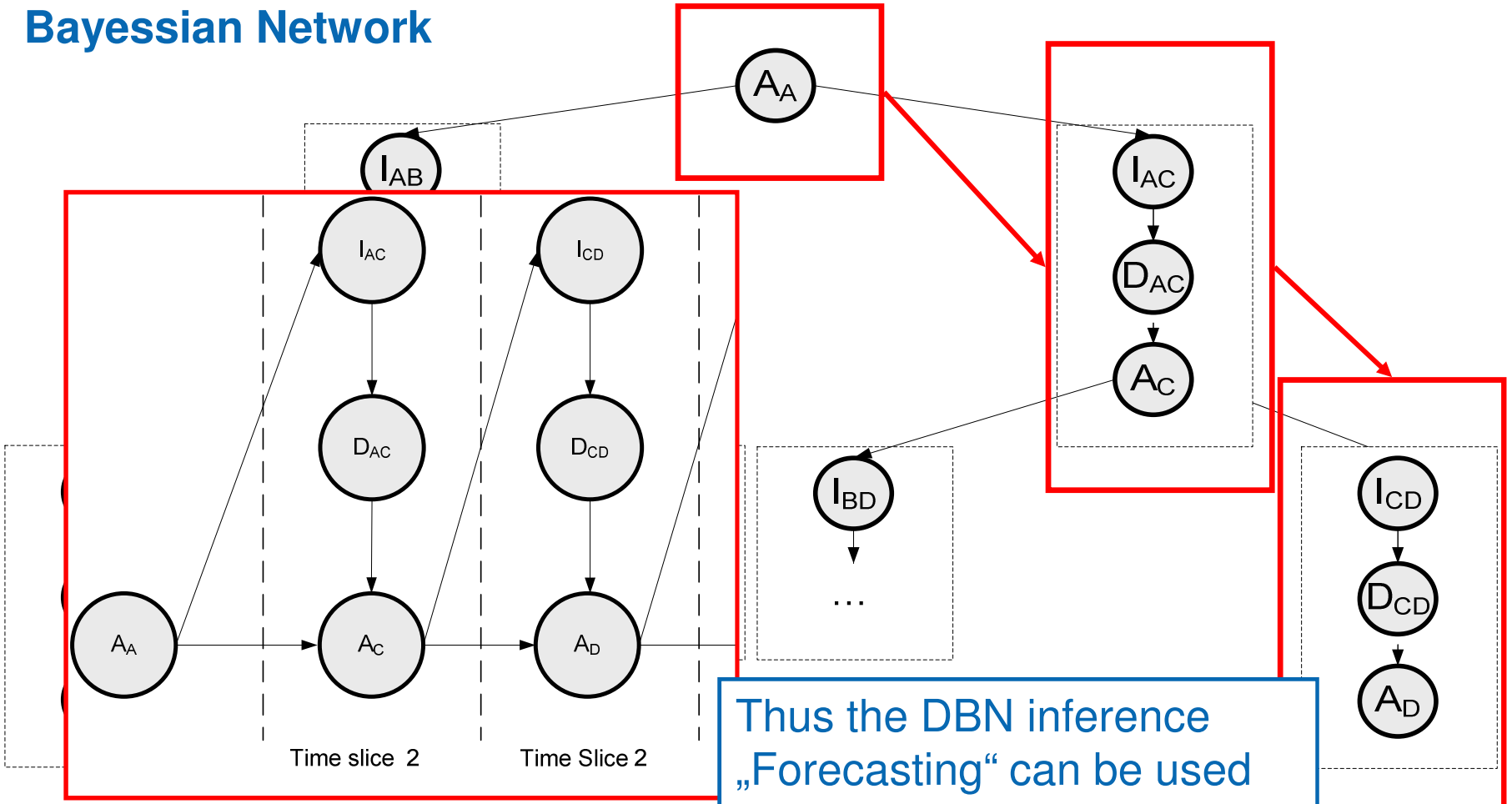

Thus the DBN inference „Forecasting“ can be used to estimate future travel time

Consideration of Uncertain Travel Time
Modelling the Time Slices

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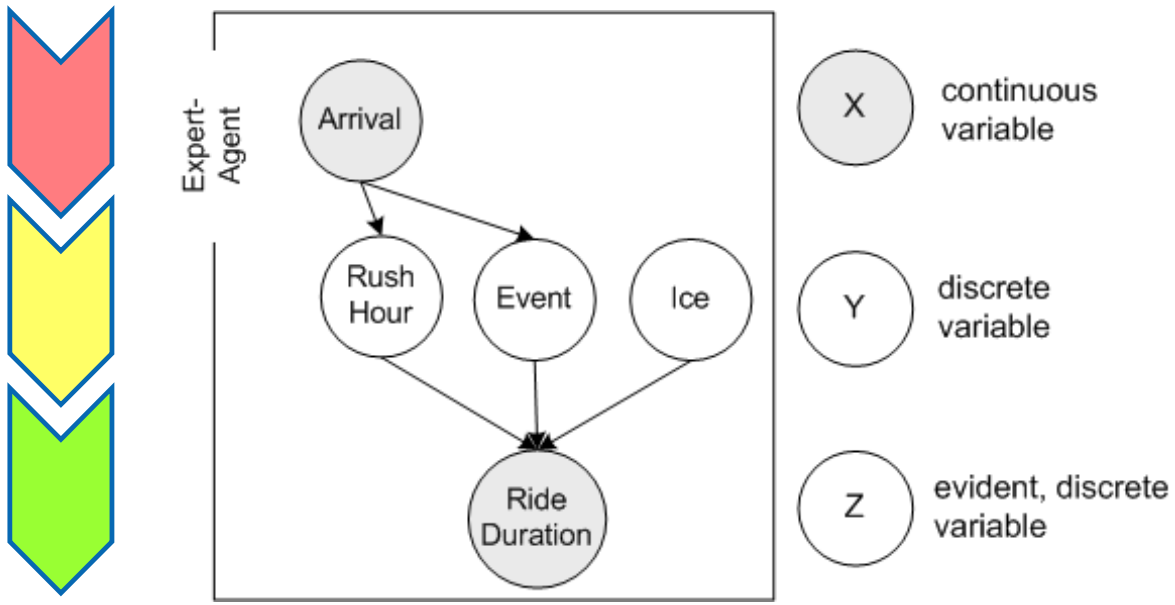
- To construct the decision tree, for each link in the network, the following inference process has to be performed:

Arrival Time → **External influences** → **Ride Duration**

- It is performed by expert agents assigned to tracks and stations, using such a Bayesian Network:



Consideration of Uncertain Travel Time
Interaction of Shuttle and Expert Agents

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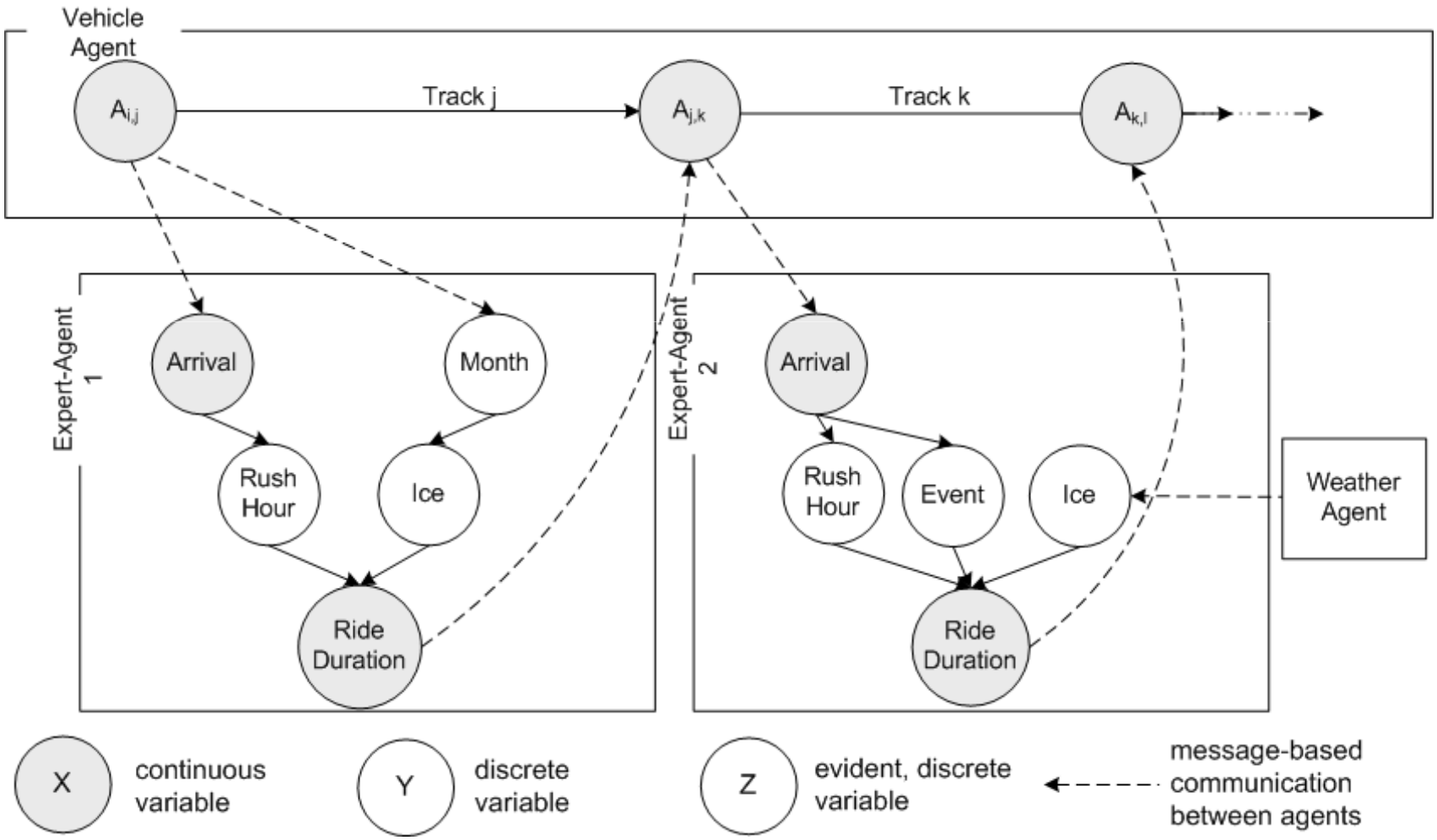
By querying expert agents, vehicle agents construct their individual DBN:



Consideration of Uncertain Travel Time

Results: Quality of Forecasts

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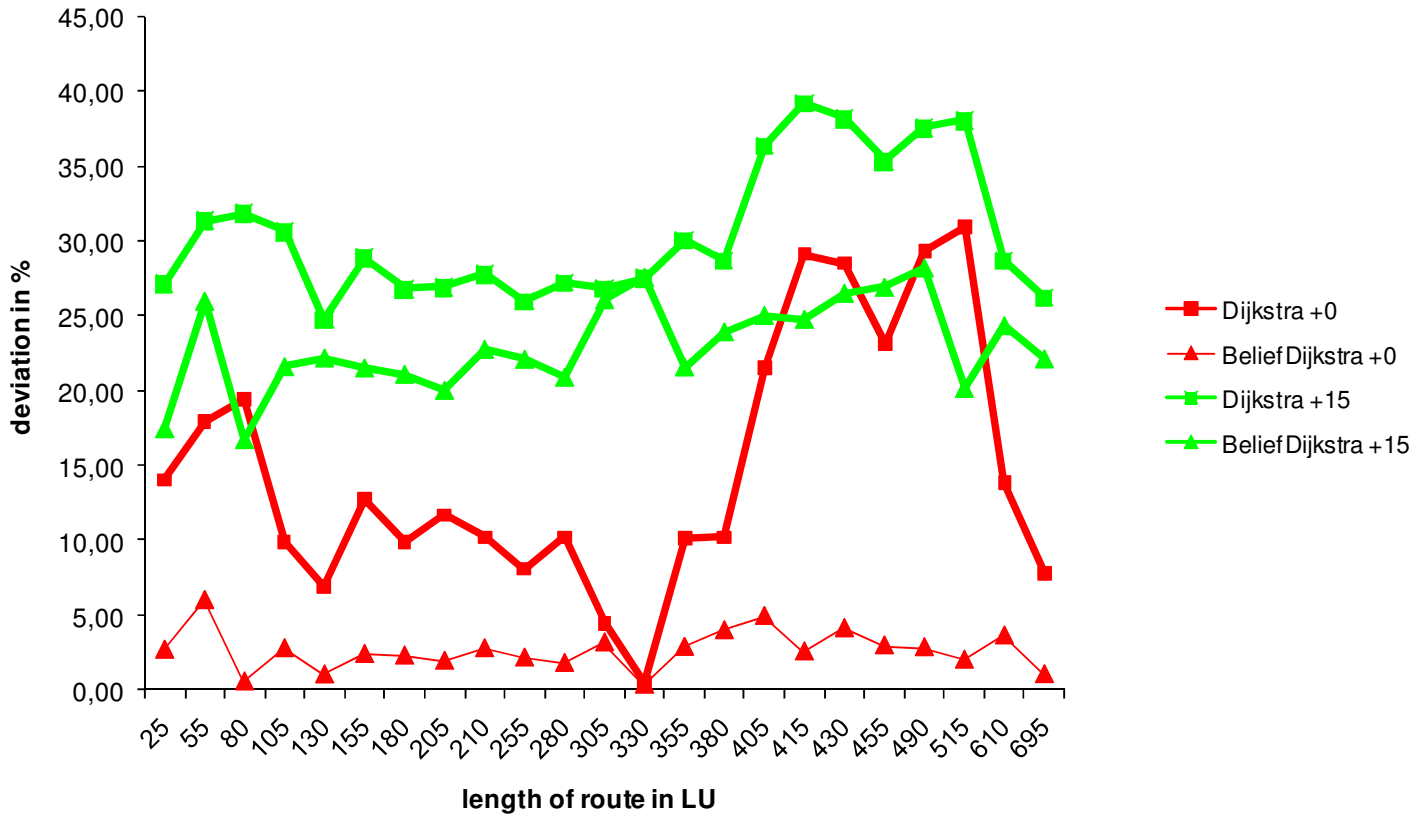

The new Shortest Path methods (Belief Dijkstra) provided more realiable information about travel time even when the Parameters of the probability distribution within the expert agents and used during Simulation differed by 15%!

Consideration of Uncertain Travel Time

Results: Shorter Travel Times

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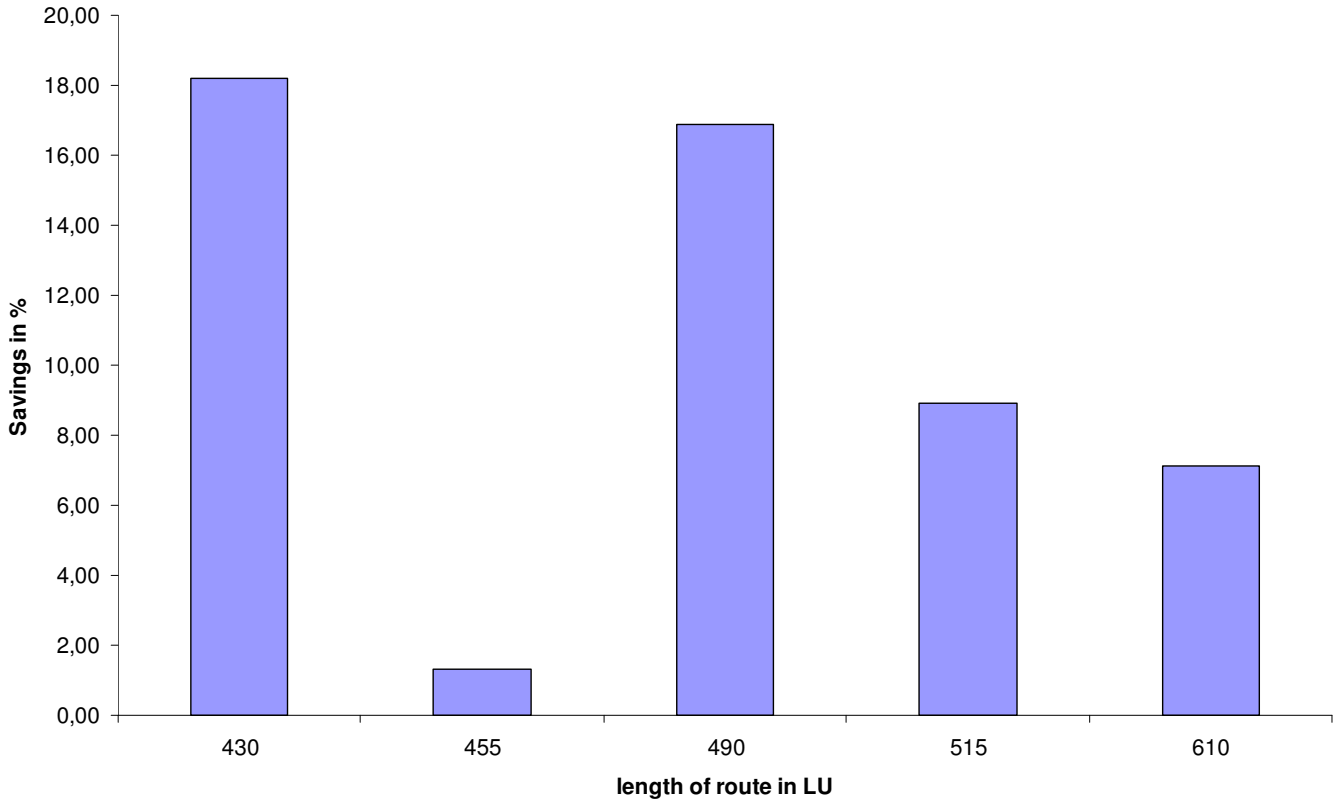

In all cases where the Belief Dijkstra and classical Dijksta resulted in different routes, the Belief Dijkstra resulted during simulation in shorter average travel times

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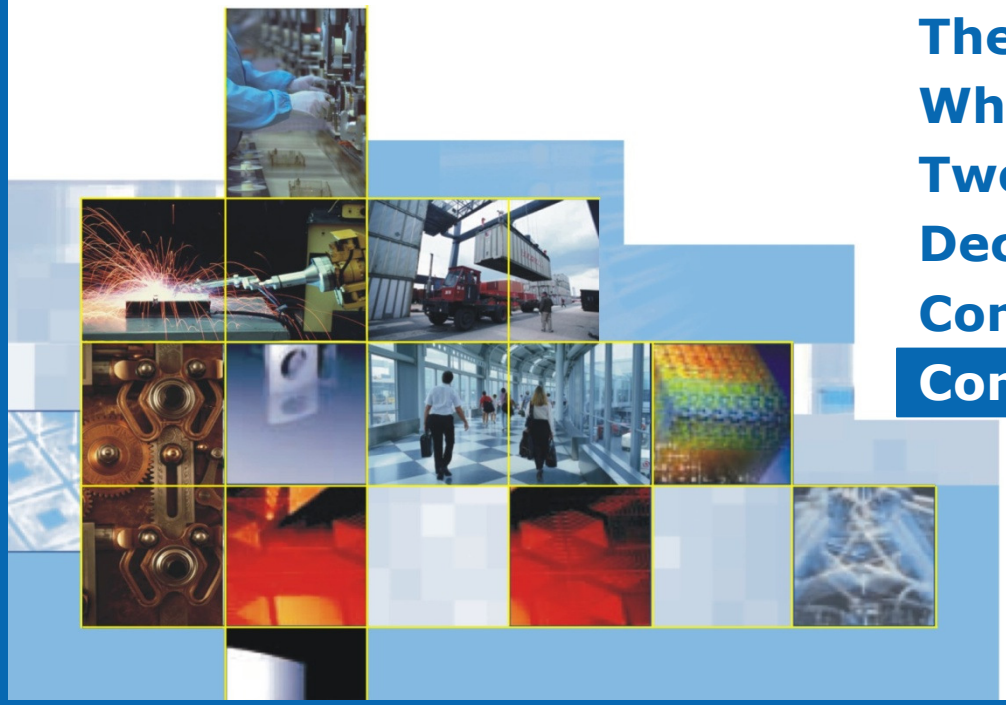

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Test vehicle on scale 1:2.5

Test track at Paderborn

- Safety issues are considered by a formal modelling of resources and interactions in the transportation system
- A state-transition net is used for implicit synchronization of shuttles
- Centralized and decentralized optimization methods suitable for different application scenario were introduced
- A new concept for path planning in dynamic and probabilistic environment was introduced
- Further research will focus on the last aspect

Conclusion

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Test vehicle on scale 1:2.5

Test track at Paderborn

- We presented a MAS for planning and optimizing a rail-bound transportation system
- Different aspects of demand driven railway concepts are reflected in the development process of the MAS:
  - Safety critical coordination of shuttles
  - Potentially competing forwarding companies
  - External influences on travel times

Thank you for your attention!

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