Technische Universität Braunschweig

Integration of information and optimization models for routing in city logistics

Dirk Mattfeld and Jan Fabian Ehmke, Shonan Village, 18.12.2012

Challenges for city logistics service providers

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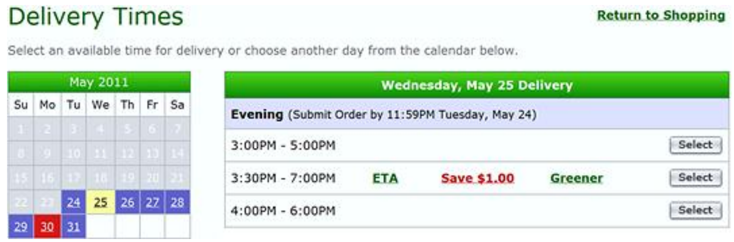
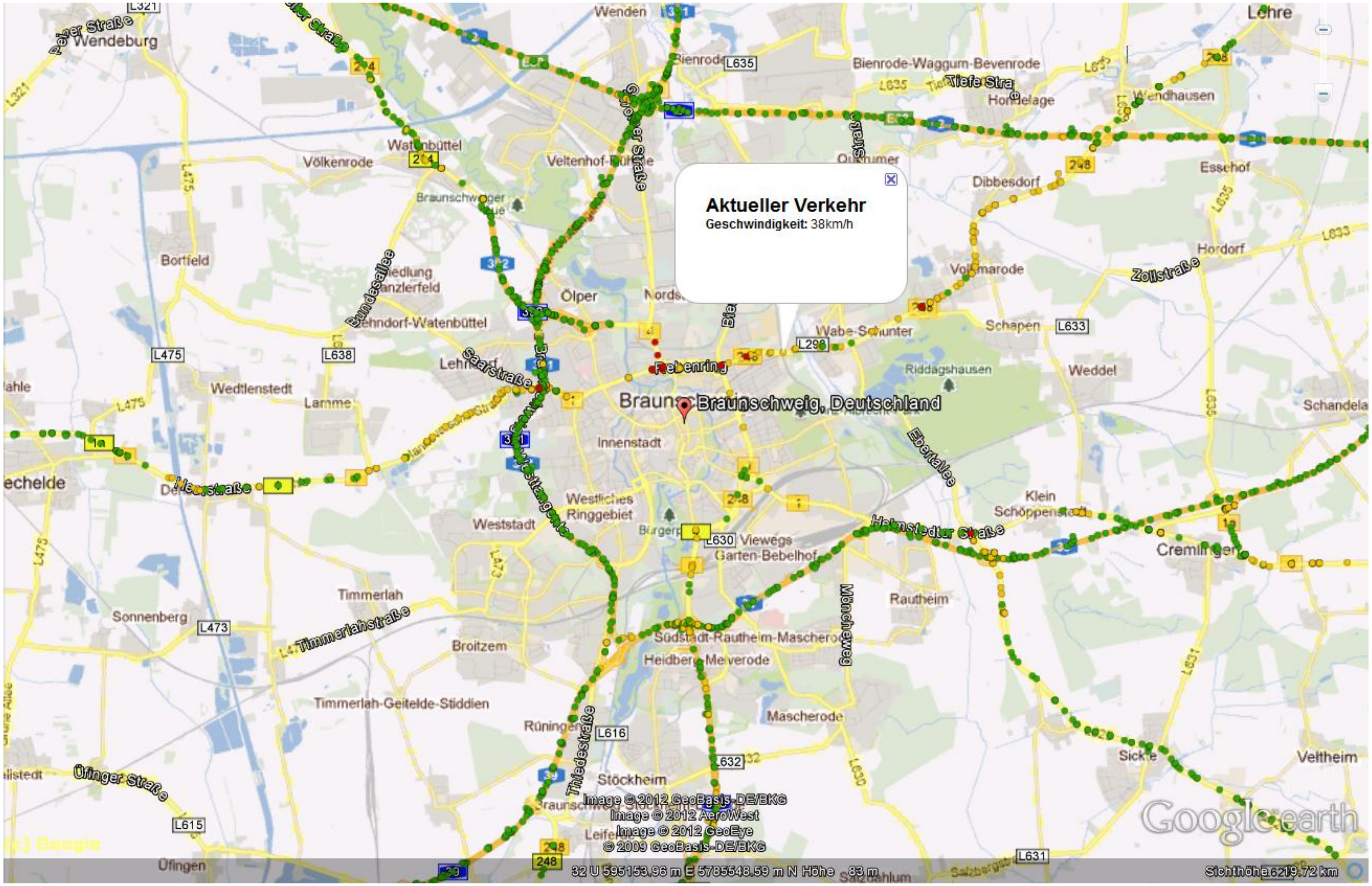


- Increasing importance of online retail and e-commerce
- More complex supply chains require transshipment on time

- Time-varying (and increasing) traffic demand within limited transport infrastructure of conurbations (→ congestion)
- City logistics service providers have to realize more reliable delivery tours considering tight customer time

► Vehicle routing for city logistics applications demands for time-dependent travel times in order to meet increasing customer requirements more efficiently.

What Google does



Agenda

Information models

- Provision of time-dependent travel times
  - Transformation of empirical traffic data by Data Mining
  - Evaluation of time-dependent travel times

Integration

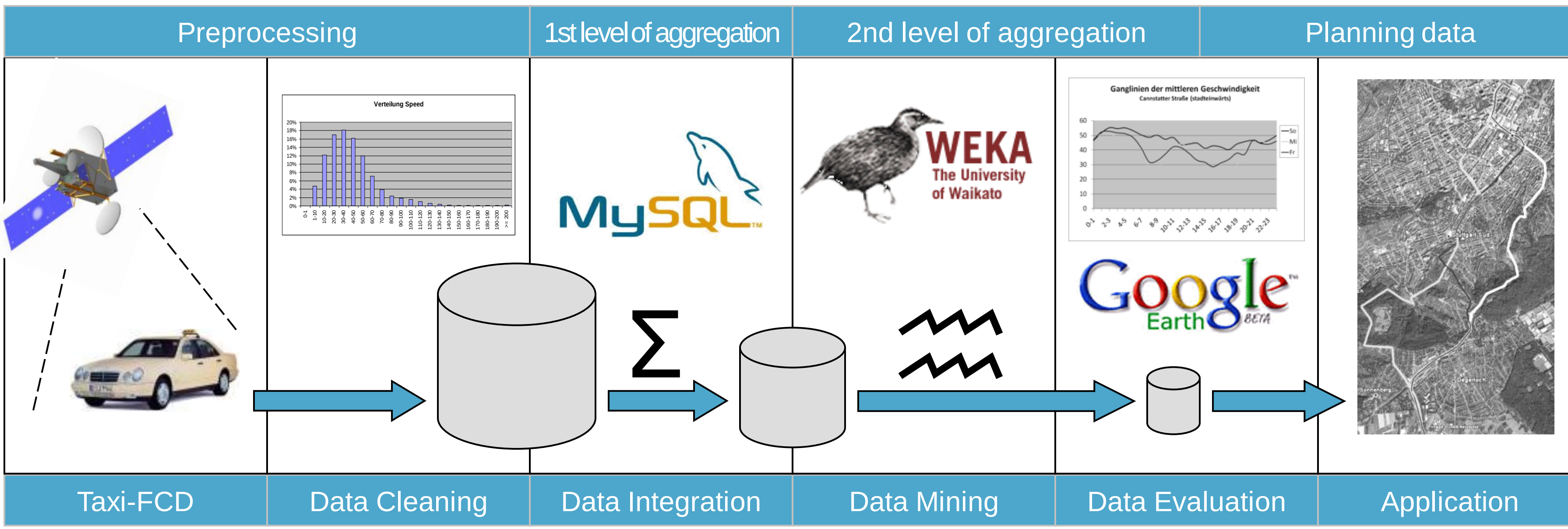
- Integration of time-dependent travel times
  - Modelling of time-dependent networks
  - Calculation of time-dependent shortest paths

Optimization models

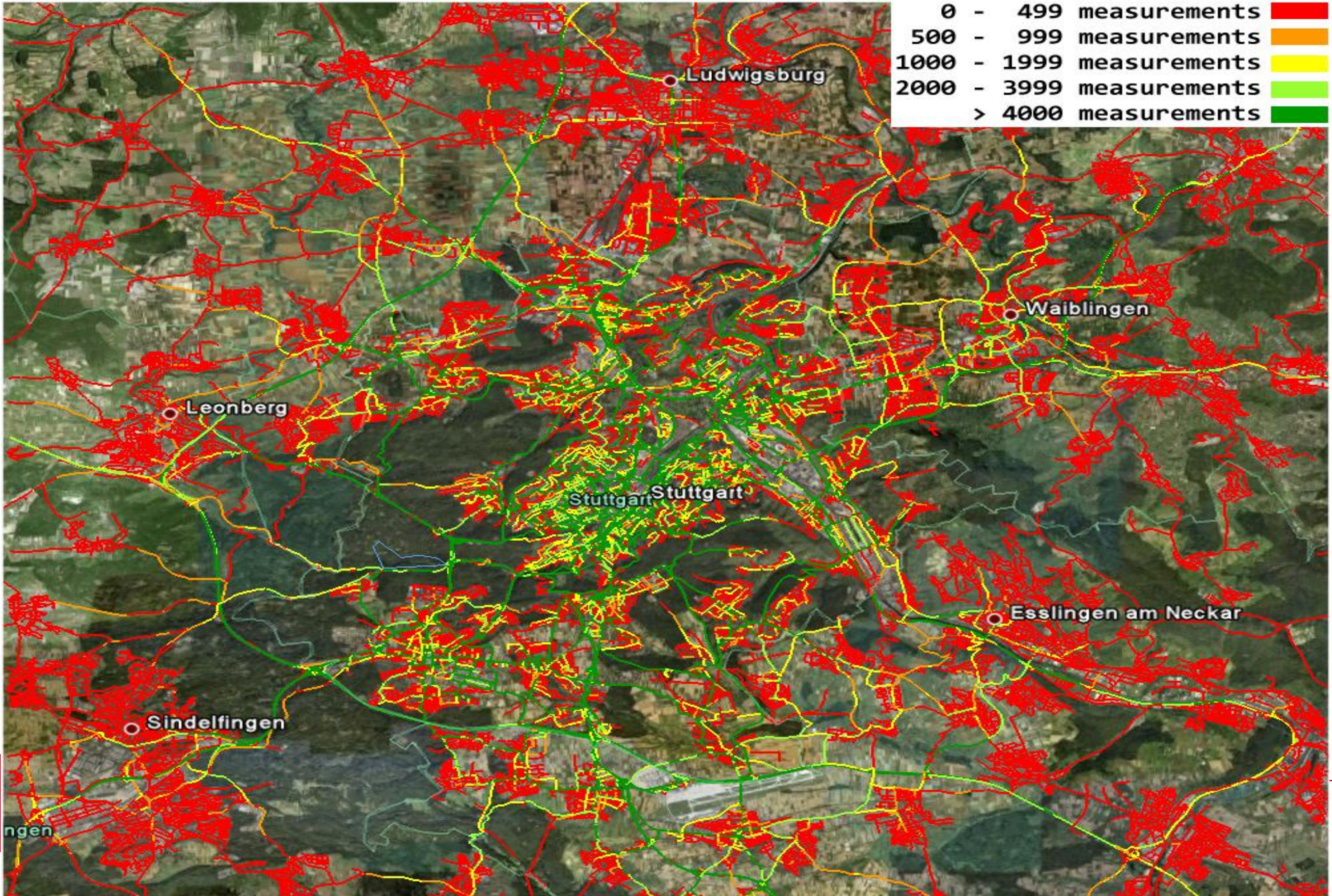
- Design and evaluation of a vehicle routing system
  - Routing of a single vehicle and of a fleet of vehicles
  - Impact of customer time windows

Collection and transformation of empirical traffic data

- Goal: provision of compact, time-dependent travel time data sets
- Aggregation of telematics based traffic data by Data Mining
- Implementation of the Knowledge Discovery Process (Fayyad et al. 1996; Han, Kamber 2000)
- Exemplary analysis of ~230 millions of empirical traffic data (Floating Car Data (FCD), Stuttgart, DLR, 2003-2005)



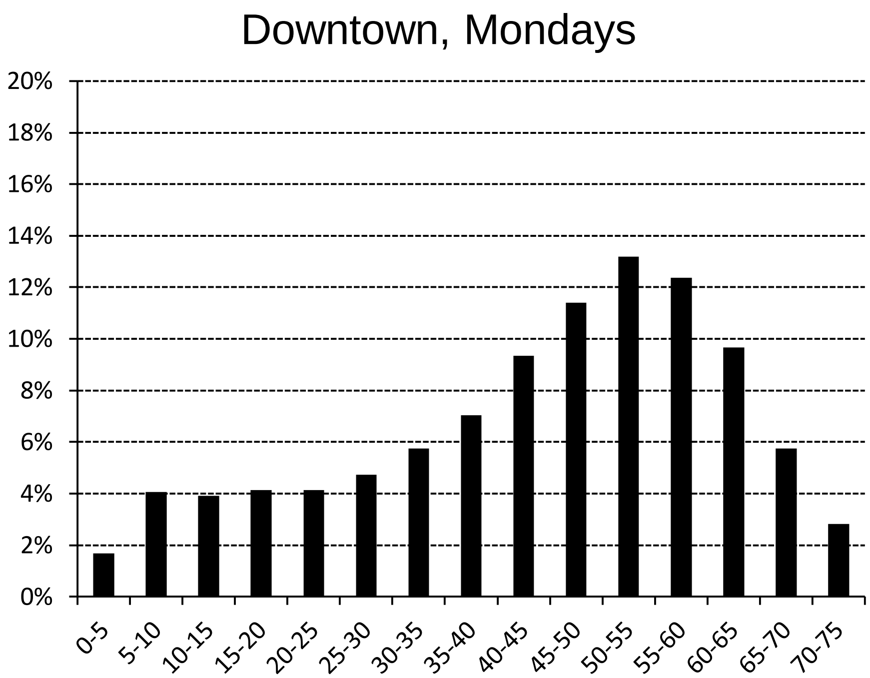
Preprocessing: Spatial distribution of FCD

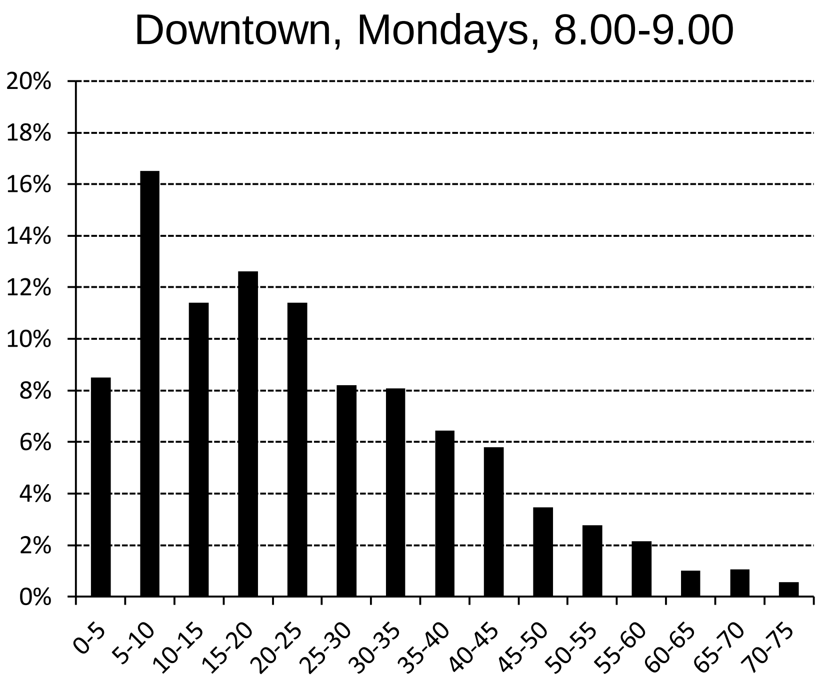


Preprocessing: Distribution of speeds

- Preparing FCD for subsequent analysis by Data Mining procedures
- Handling of incomplete, erroneous FCD measurements

TIME	LINK	SPEED
time of positioning	road segment ID	calculated speed [km/h]
01.08.2003 07:01	54362718	50.73

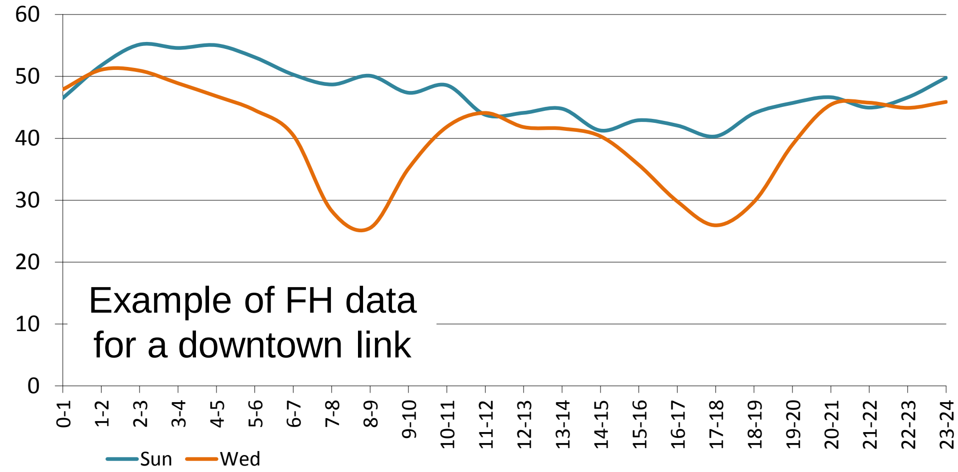




1st and 2nd level of aggregation

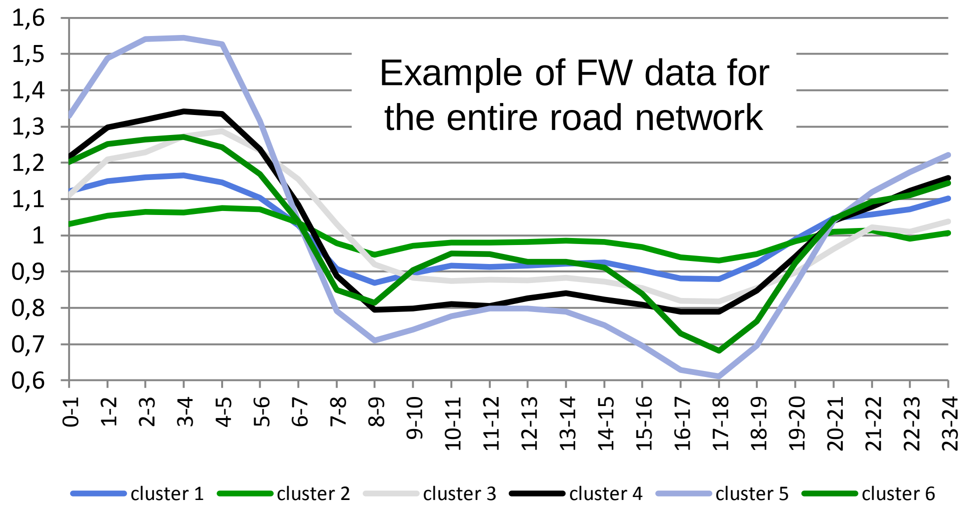
1st level of aggregation

- Empirical traffic data → planning data
- Daily curves are derived from 7x24 average speeds per link
- "FCD Hourly Average" (FH)
- Comprehensive representation of time-dependent travel times



2nd level of aggregation

- Compress planning data without significant loss of planning reliability (→ cluster analysis)
- Speed reduction factors represent deviation from average speed
- "FCD Weighted Average" (FW)
- Compact representation of time-dependent travel times



Results of 2nd level aggregation for a typical weekday

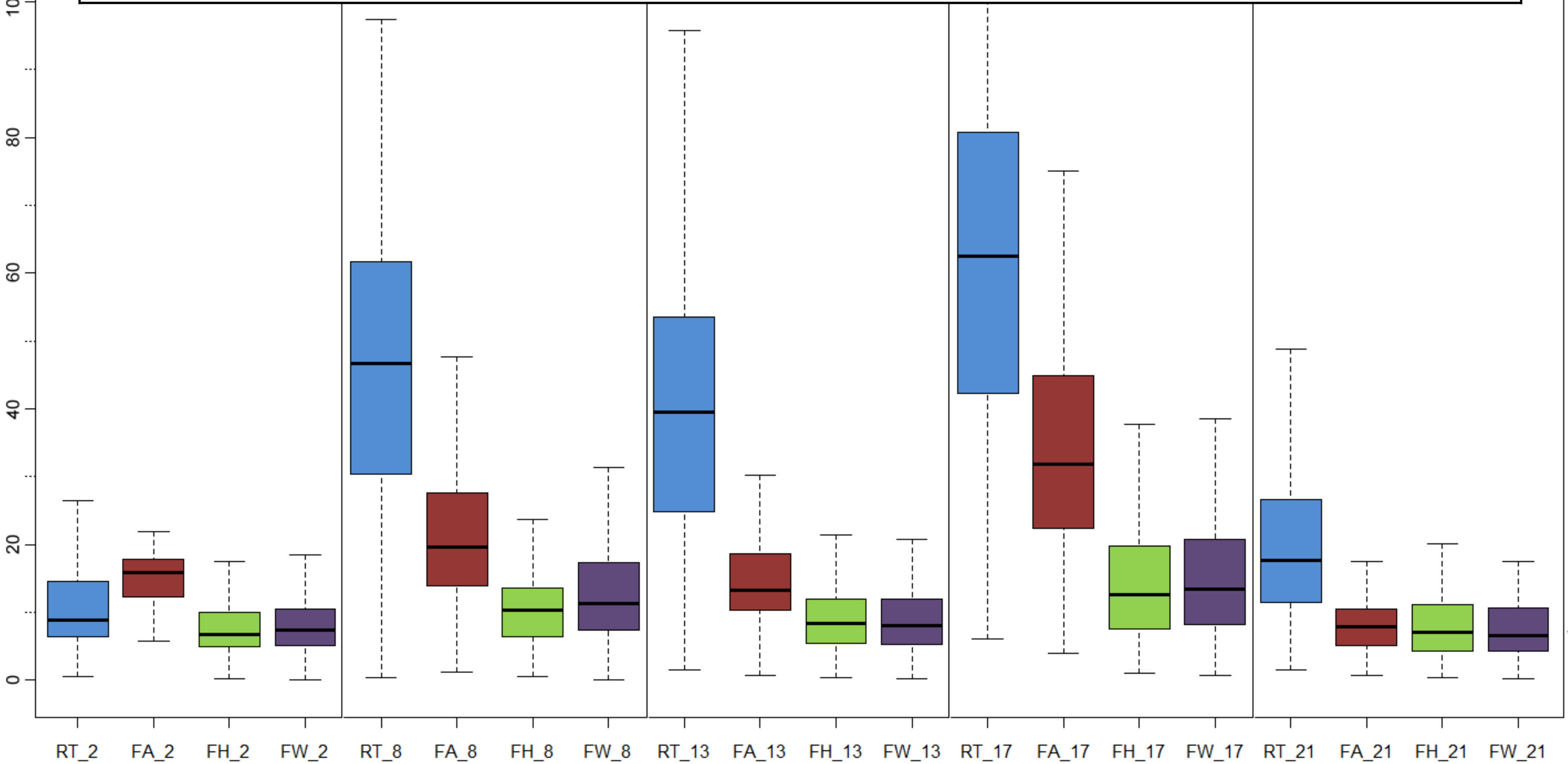
Evaluation of time-dependent travel times (1/2)

- Planning and evaluation of routes
  - Which route is in fact the fastest?
  - Which route leads to the most reliable travel time anticipation?
- Evaluation of planned routes by simulation
  - Realization by recalculation of travel times based on historical FCD
  - Comparison of average deviation between planned and realized travel times
- Experimental setup (3600 routes in total)
  - 3 traveler scenarios (downtown, inner city, outer city, for 100 OD pairs each)
  - 5 traffic scenarios (2x “free flow”, 2x “rush hour”, “average traffic flow”)
  - 4 travel time data sets (digital roadmap, FA, FH, FW)

Evaluation of time-dependent travel times (2/2)

Planning data set	roadmap travel times (RT)	FCD averages (FA)	FCD hourly average[illegible]	FCD weighted [illegible])
[illegible] of	n	d x n	t x d [illegible]	[illegible]d
[illegible]	1	7	16[illegible]	[illegible]

n = number of links, d = number of weekdays, t = number of time bins, k = number of clusters



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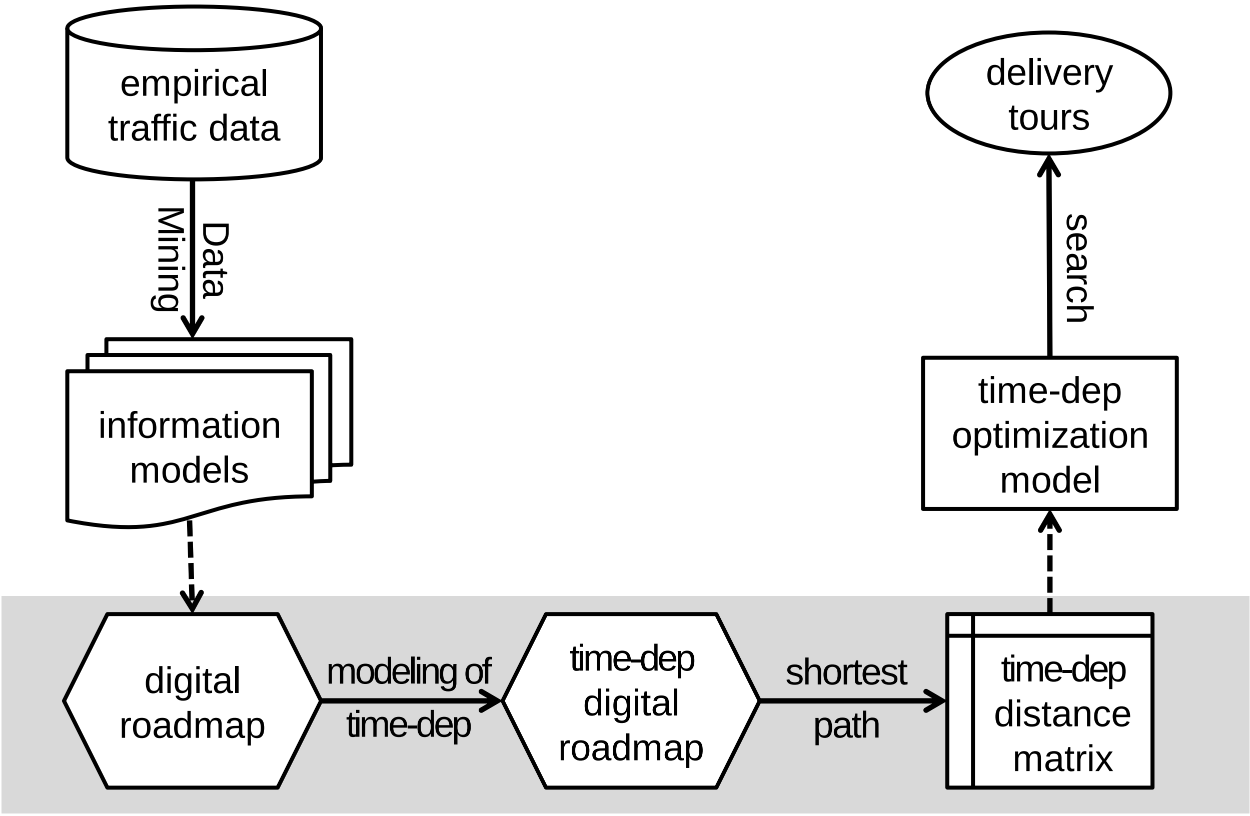
Integration of time-dependent information models

- Time-dependent optimization requires a time-dependent topology of the road network

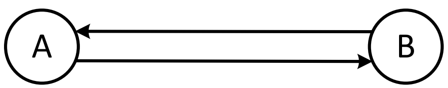


Time-Space Network

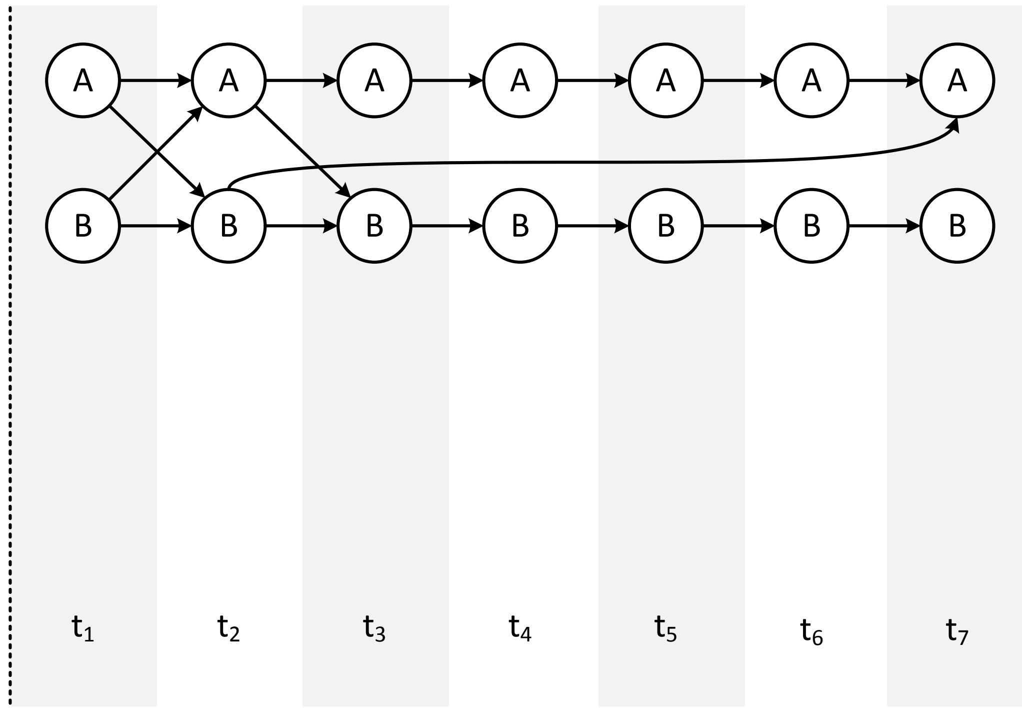
- Travel times depend on departure time on an edge
- Common approach: multiplication of network according to time series

$$V = \{i_h \mid 1 \leq h \leq q\}$$

$$E = \{(i_h, j_k) : (i,j) \in V, t_h + d_{i,j}(t_h) = t_k, 1 \leq h < k \leq q\}$$



$d_{A,B} = \{1,1,-\}$ $d_{B,A} = \{1,5,-\}$



Following Pallottino (1997)

$O(nT) + O(n + mT)$ with n as number of vertices, m as number of edges, T length of time series

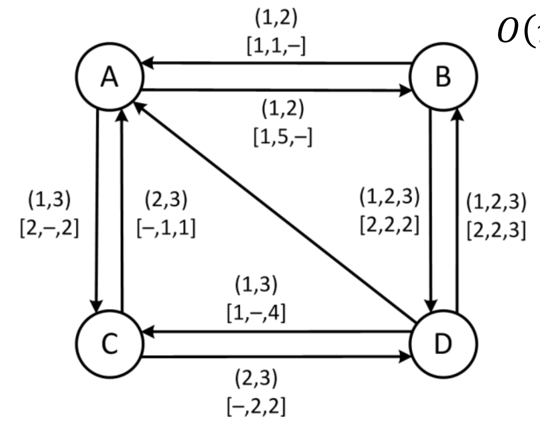
Time-aggregated graph

- Smaller network, but more complex data structures
- Calculation of shortest paths similar to static networks, if FIFO condition is fulfilled

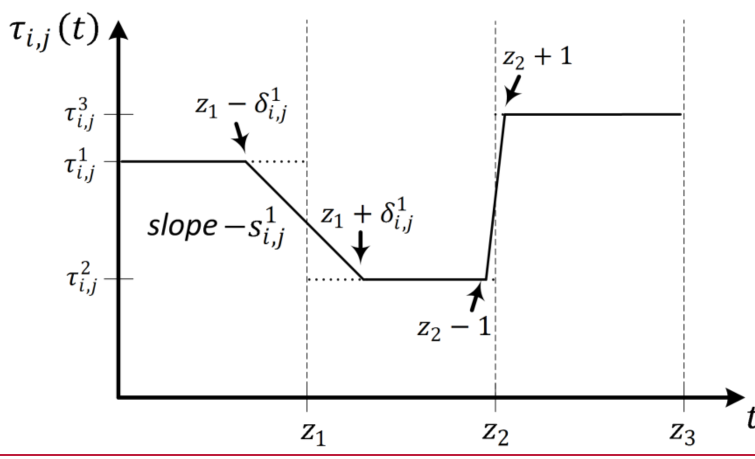
- FIFO condition: vehicles travelling on the same edge must not pass each other
- FIFO graphs ensure that waiting is never beneficial and sub paths of shortest paths again represent shortest paths
- Time-dependent travel times may violate the FIFO condition

- Transformation of FH and FW data into a FIFO consistent, time-aggregated graph

- Calculation of time-dependent distance matrices für vehicle routing procedures



$O(n+m)T$



Adapted from Fleischmann et al. (2004)

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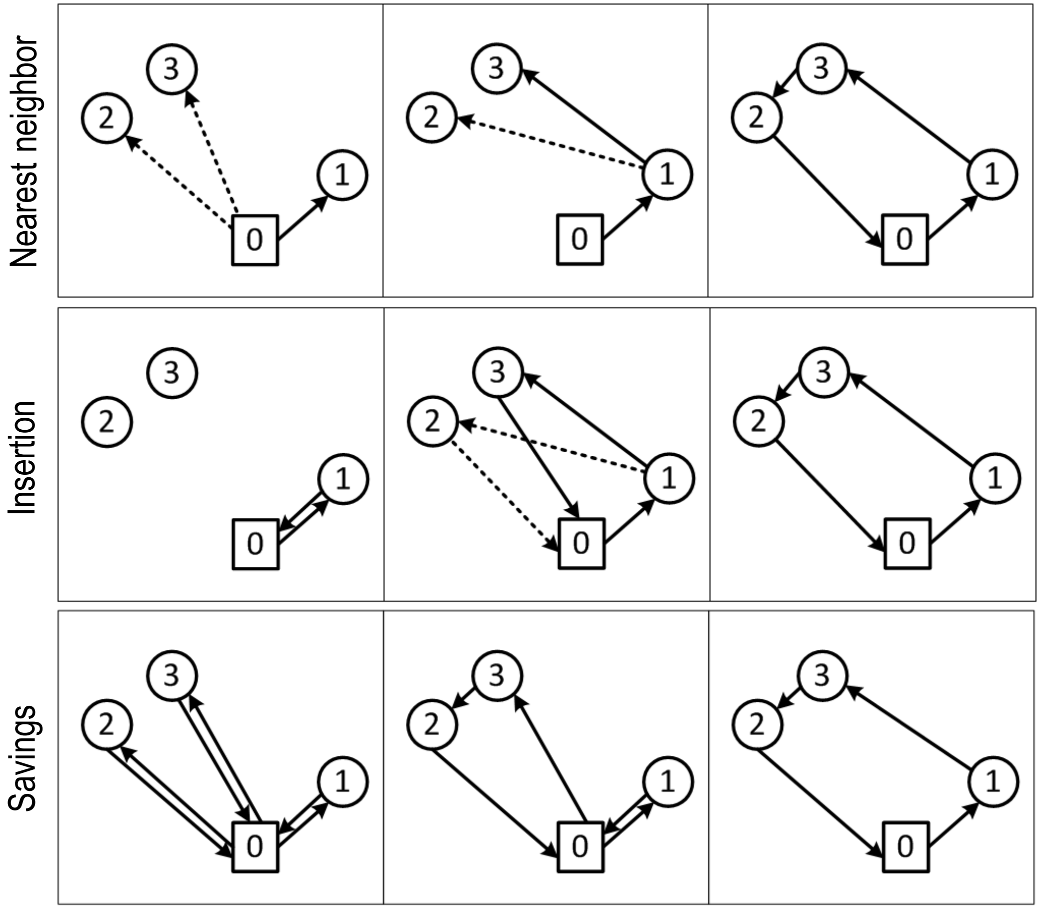
What we are aiming at

Routing of a single vehicle

- Time-Dependent Traveling Salesman Problem (TDTSP):
  determine the optimal order of delivery for a given departure time



- TDNN: Amend that node that can be reached fastest at current departure time
- Simply lookup travel times from time-dependent distance matrix for the current time slice

- TDIH: Complement the tour by that customer that extends the current tour minimally at cost minimal position
- Determination of insertion costs more expensive than in the static case

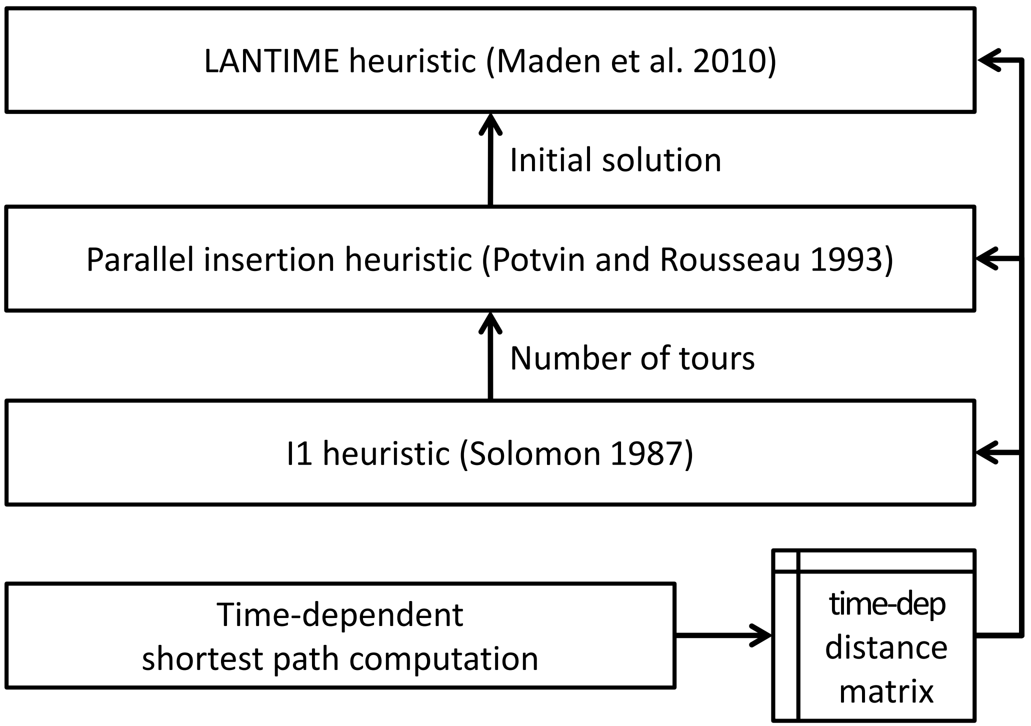
- TDSAV: Serve each customer individually, then merge pendulum tours in order of decreasing savings
- Static calculation of savings is opposed by time-dependent realization

Routing of a fleet of vehicles

- Time-Dependent Vehicle Routing Problem (TDVRP): determine the optimal assignment of customers to vehicles as well as the optimal order of delivery for a given departure time
- Consider customer time windows (→ TDVRPTW)

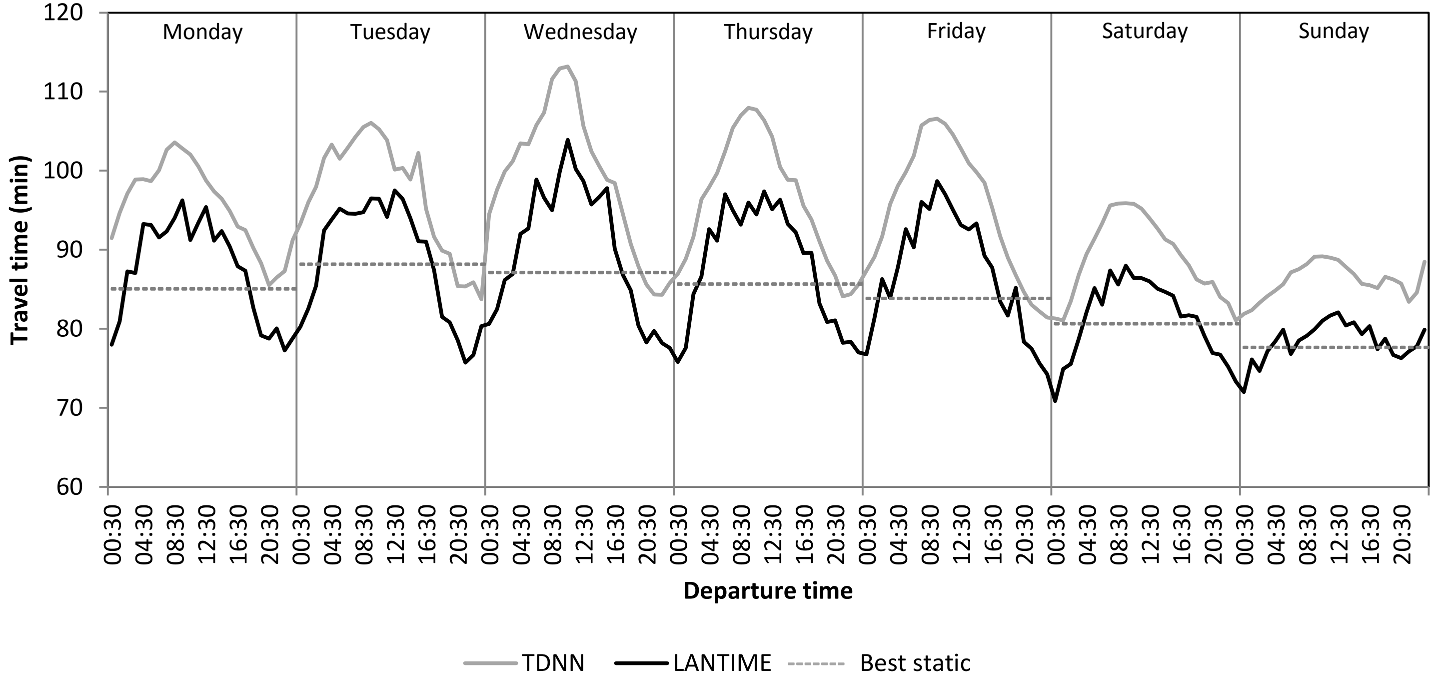
- Implementation of a tabu search heuristic
- Infeasible solutions are permitted temporarily in order to overcome local optima

- Computation of an initial solution by parallel insertion
- Improvement of initial solution by random application of several neighborhood operators



Results of TDTSP calculation

- Exemplary delivery to 40 inner city customers (service time 10 minutes)
- Results for 7x24 departure times from the depot (Mon, 00:30 – Sun, 23:30)



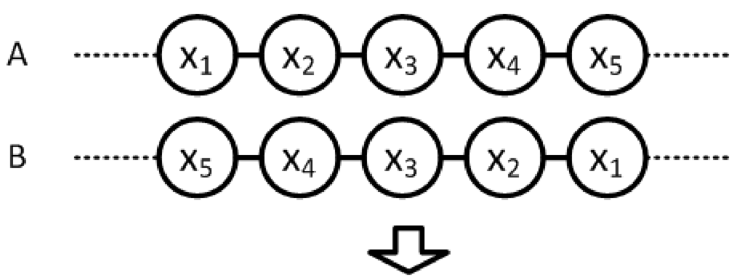
- Overall travel times vary between 70 and 100 minutes
- Tours reflect typical travel times at different times of the day

Impact of time-dependent travel times (1/2)

- What is the impact of time-dependent travel times on the structure of a tour?
- Idea: analyze the structure of temporally consecutive tours by comparison of the order of customers (precedence relations)
- Quantification based on the normalized Hamming distance

$$d_{x,y} = \frac{1}{l}\sum_{i=1}^{l} \text{xor}(x_i, y_i)$$

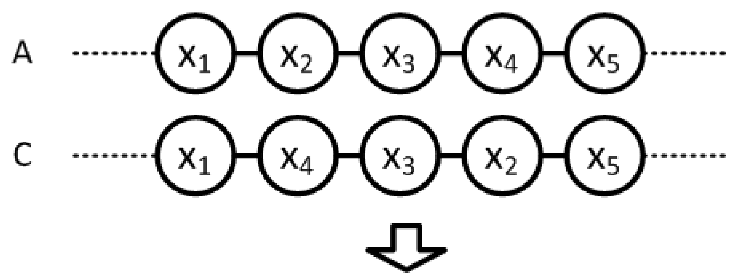
(1)



	$x_1<x_2$	$x_1<x_3$	$x_1<x_4$	$x_1<x_5$	$x_2<x_3$	$x_2<x_4$	$x_2<x_5$	$x_3<x_4$	$x_3<x_5$	$x_4<x_5$
A	0	0	0	0	0	0	0	0	0	0
B	1	1	1	1	1	1	1	1	1	1

$$d_{A,B} = \frac{1}{10}(10) = 1$$

(2)

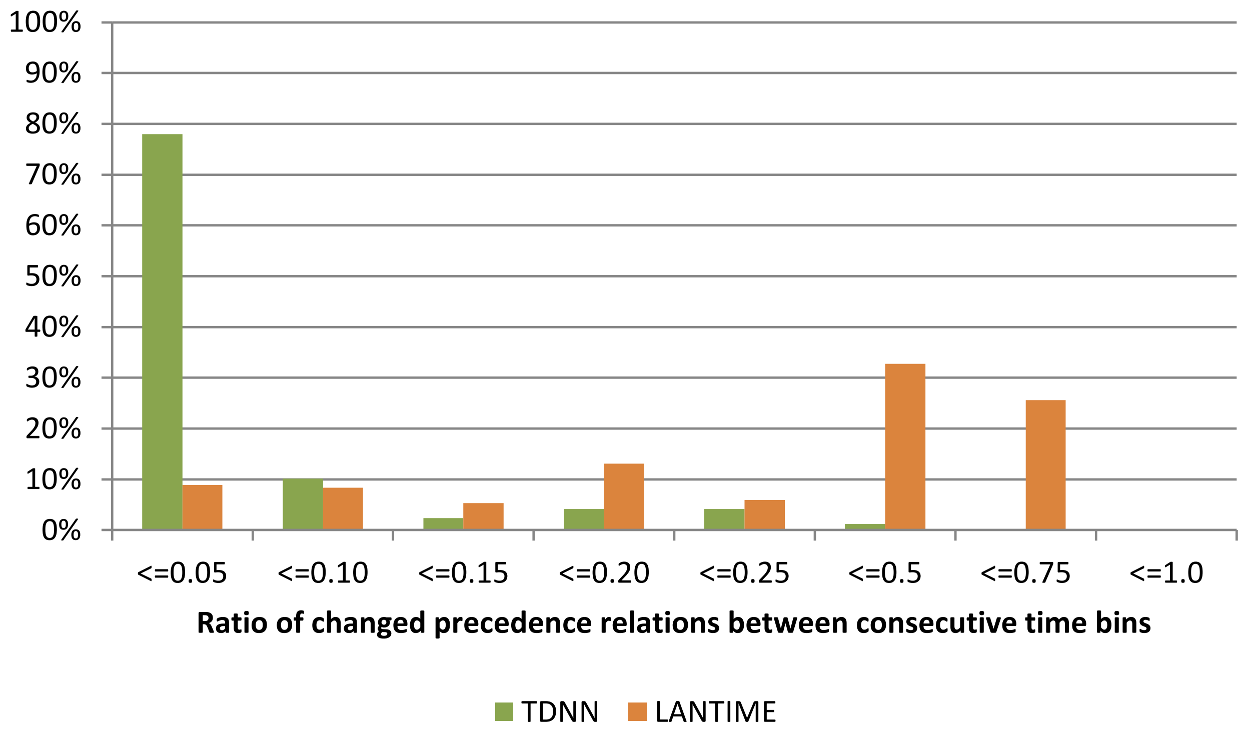


	$x_1<x_2$	$x_1<x_3$	$x_1<x_4$	$x_1<x_5$	$x_2<x_3$	$x_2<x_4$	$x_2<x_5$	$x_3<x_4$	$x_3<x_5$	$x_4<x_5$
A	0	0	0	0	0	0	0	0	0	0
C	0	0	0	0	1	1	0	1	0	0

$$d_{A,C} = \frac{1}{10}(3) = 0.3$$

Impact of time-dependent travel times (2/2)

- Comparison of precedence relations for inner city customers



- Nearest neighbor procedures (TDNN) feature small changes only
- Tabu Search (LANTIME) reacts more sensitively to time-dependent travel times

Impact of customer time windows on TDVRP calculation

- Reliability of customer time windows defines an important part of service quality
- Shorter tours or addition of buffer times may increase service quality, but decrease efficiency

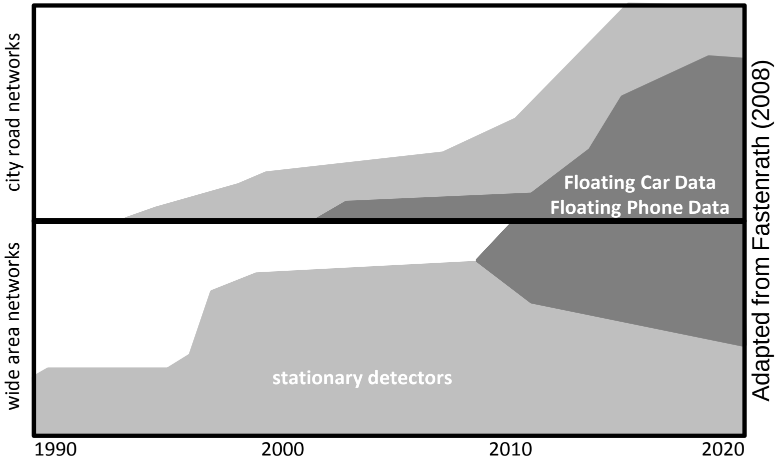
- Exemplary delivery to 100 customers for three exemplary delivery slots with 15 minute delivery time windows
- Comparison of three planning approaches: static (FA), with buffer time (FA+), time-dep. (FW)

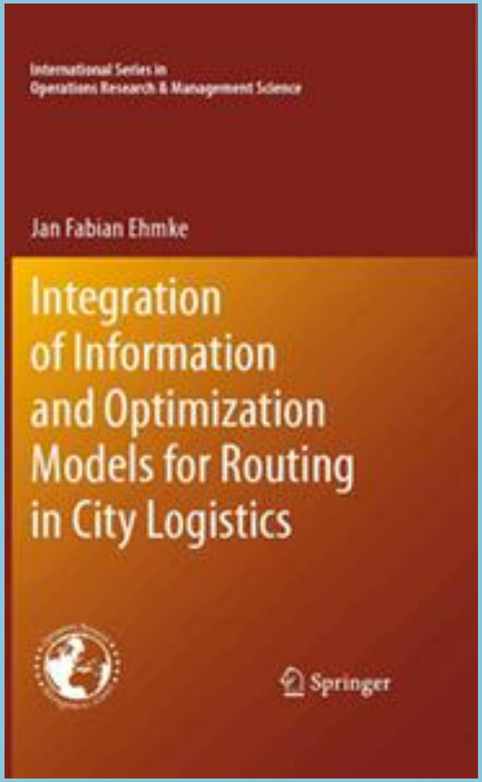
- Buffer times inefficiently utilize transportation resources
- Time-dependent planning may ensure service quality as well as efficiency

Summary and outlook

- Implementation of a planning system for time-dependent vehicle routing in city logistics
- Alignment of recent technology, data analysis and optimization procedures
- Next step: conduct field studies in urban areas (attended home delivery or similar services)

- Data availability will increase (→ Bluetooth, WLAN, Floating Phone Data)
- More efficient network modeling for time-dependent, large area networks
- Consider stochastic information in network modeling
- Improve solution methodology (→ heuristics)





Thank you for your attention!