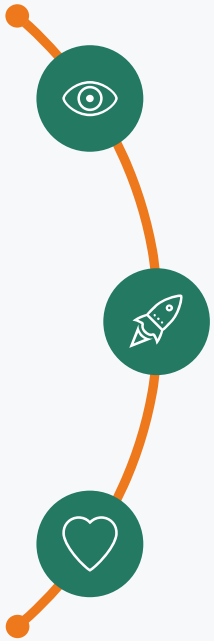
EPG® Ehrhardt Partner Group

Smarter Connected Logistics™

Innovative Route Planning – Reducing your vehicle fleet, transport costs and CO2 emissions

AGENDA



SHORT INTRODUCTION

HOW INNOVATIVE ROUTES ARE CREATED – MATHEMATICAL FOUNDATIONS

WHAT IS THE ESSENTIAL VALUE FOR OUR USERS

ESSENTIAL FACTORS OF INNOVATIVE ROUTE PLANNING

time-dependent travel times

overlapping districts

traffic patterns

contraction hierarchies

street network

GREENPLAN‘S VALUE TO CUSTOMERS

Lower transport cost

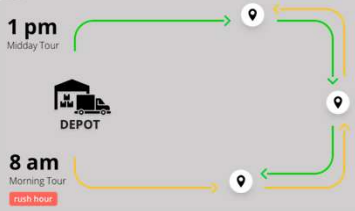
Less vehicles on the road, less kilometers driven, less operational costs, less CO2 emissions (8 to 20 %)

HOW
Calculation with fully dynamic routes (without districts) as well as **overlapping districts**.

Higher punctuality

Precise ETAs and more on-time deliveries, leading to happier customers and happier drivers

HOW
Consideration of predicted traffic flows in 5 minute intervals already in the calculation of the routes



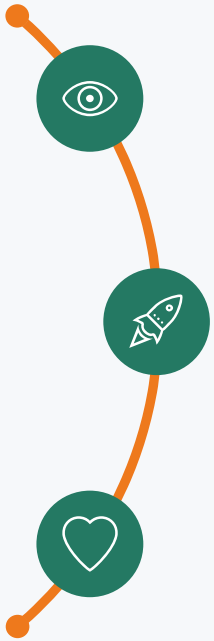
Full adaptability

Tailormade route planning setup considering all special requirements

HOW
Sophisticated business rules engine and flexible modelling capabilities allow for a digital twin of your operations.

“Finally, I have all the freedom needed to improve my route planning.”

AGENDA



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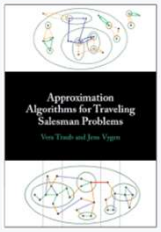
WHAT IS THE ESSENTIAL VALUE FOR OUR USERS

OUR PARTNERSHIP WITH UNI BONN

- **35-year cooperation with IBM**
- Since 2016: **Deutsche Post DHL / Greenplan**
- Agile young team of experts, professional **software development**
- Innovative **algorithms**, successful implementation

Research

- Leading in cutting-edge research
- Publishing actively in top venues

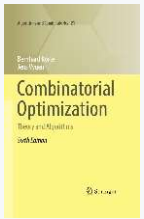


Research Institute for Discrete Mathematics

UNIVERSITÄT BONN

Industrial Collaborations

Teaching



- Excellent students from the top German math department

THE BONNTOUR TEAM AT UNIVERSITÄT BONN

Stephan Held

Vera Traub

Jens Vygen

Jannis Blauth

Dirk Müller

Martin Nägele

Luisa Puhlmann

Manuel Christalla

Lorenzo Conti

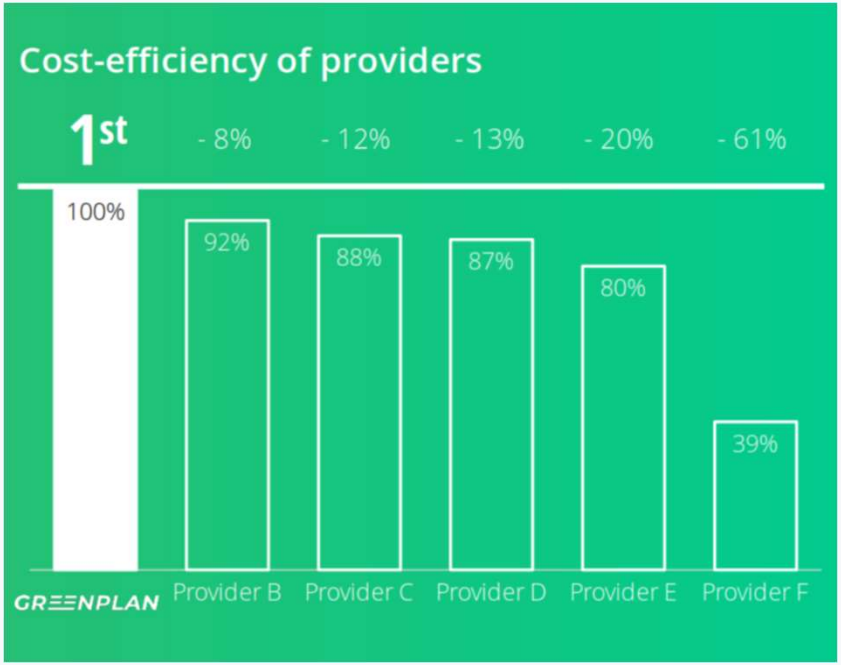
Daniel Ebert

Paula Heinz

Richard Ueltzen

SOME SUCCESS STORIES

- **Best paper awards** for better algorithms
  - SODA 2018 – Traveling Salesman Problem [Traub, Vygen]
  - IPCO 2021 – Capacitated Vehicle Routing [Blauth, Traub, Vygen]
- Winner of the **Amazon Last Mile Routing Challenge** 2021 [Held, Helsgaun, Cook]
- **Maryam Mirzakhani New Frontiers Prize** 2023 [Traub]
- **Heinz Maier-Leibnitz Prize** 2023 [Traub]
- **Winner of several industrial benchmarks**
  - e.g., 8 % better than the second ranked with Greenplan …



THE PROBLEM SOLVED BY BONNTOUR, THE GREENPLAN ALGORITHM

Road Network

Shipments

- pickup and delivery options, possibly with alternatives
- time windows
- sizes (volumes, weight, …)
- dropping penalties
- lateness penalties

Vehicles

- capacities
- availability
- fixed costs and km costs
- dimensions and total gross weight
- optional start- and end addresses
- working hours and (time-dependent) costs
- work break rules
- reach
- sorting requirements (e.g. LIFO)
- parking time

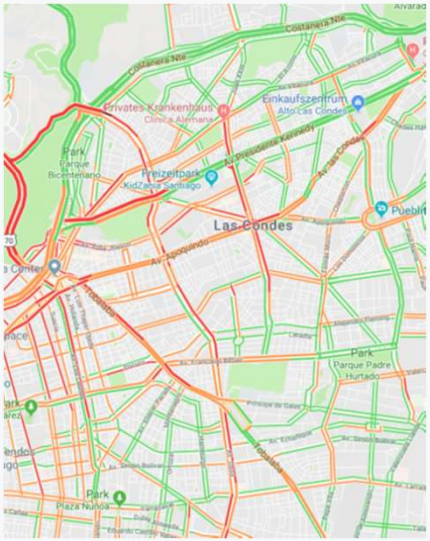
Tour plan

Satisfy all constraints and minimize total costs

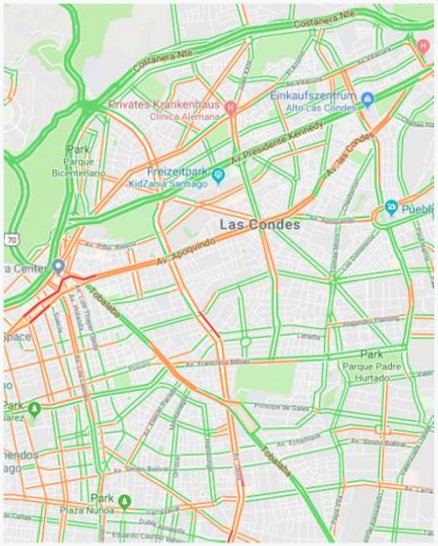
For each tour:

- pickup/delivery action sequence
- schedule
- work breaks

TRAVEL TIMES VARY!



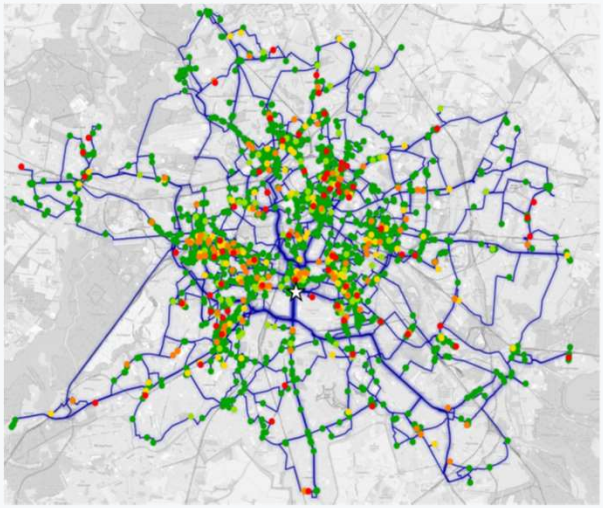
9 am



11 am

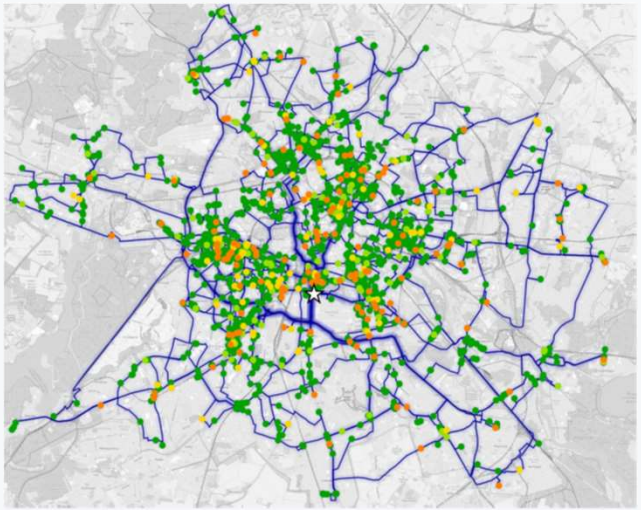
- Approximating time-dependent travel times through constant travel times comes at considerable losses!
- **Different paths** can be optimal at different times of the day!

BETTER TOURS WITH TIME-DEPENDENT TRAVEL TIMES



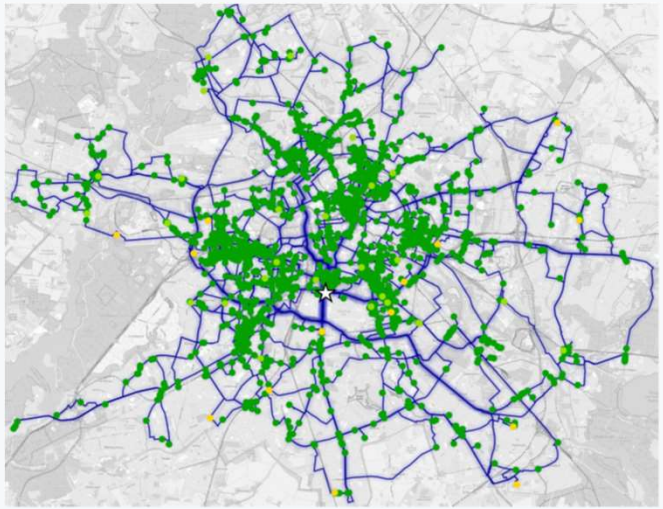
constant avg. travel times

28 tours, cost = 8859



time-dependent travel times

28 tours, cost = 8850



time-dependent travel times & lateness penalties

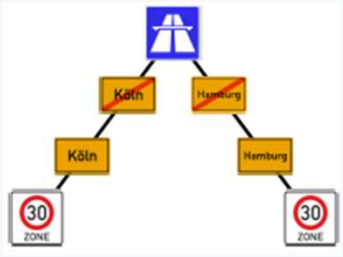
29 tours, cost = 9149

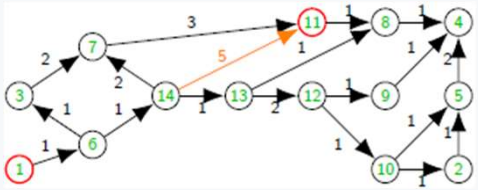
[J. Blauth, S. Held, D. Müller, N. Schlomberg, V. Traub, T. Tröbst, J. Vygen: Vehicle routing with time-dependent travel times: Theory, practice and benchmarks. arXiv:2205.0089]

MODELING A ROAD NETWORK AS A GRAPH

route in the network ←→ Path in the graph

ROAD NETWORK PRE-PROCESSING: CONTRACTION HIERARCHIES





- Idea: exploit that fastest paths typically consist of one segment going up in road importance, and another going down

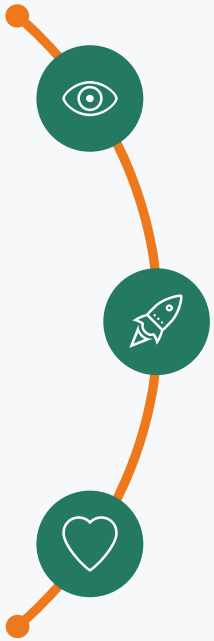
- Can we assign **levels** to the vertices of our road graph such that we can guarantee to find an optimum path consisting of one up and one down part, for all origin/destination pairs and all departure times

contraction hierarchy = a graph with that property, including (time-dependent) travel time data for each edge

- Yes, if we add **shortcut edges**

A contraction hierarchy for Germany for one vehicle class can be stored in 4 GB and reconstructed within ~30 seconds from disk.
Then **one million** travel time functions can be computed in **less than a minute**

AGENDA



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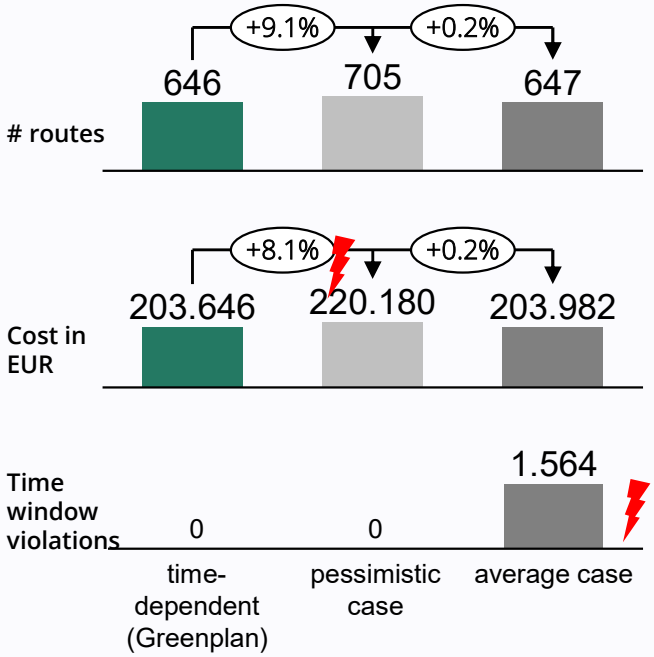
Value of time-of-day dependent driving times: best efficiency while maintaining high quality

- **Scientific study comparing Greenplan's USP (driving time-dependent calculation) with standard approaches**

Study basis: 10 major cities (e.g. New York, Berlin, Nairobi), map material from OpenStreetMap, and speed data/ driving times from Uber for all Mondays from 06.01 - 09.03.2020

Calculations performed with time-of-day dependent driving times (like Greenplan) and with fixed driving times

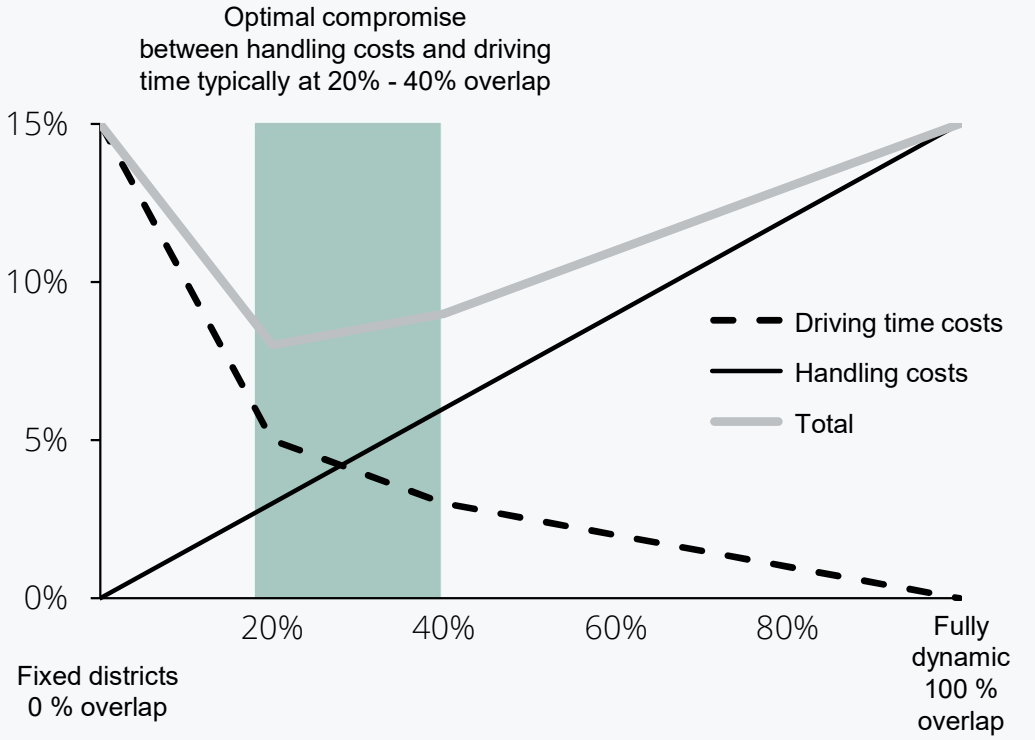

Vehicle Routing with Time-Dependent Travel Times: Theory, Practice, and Benchmarks



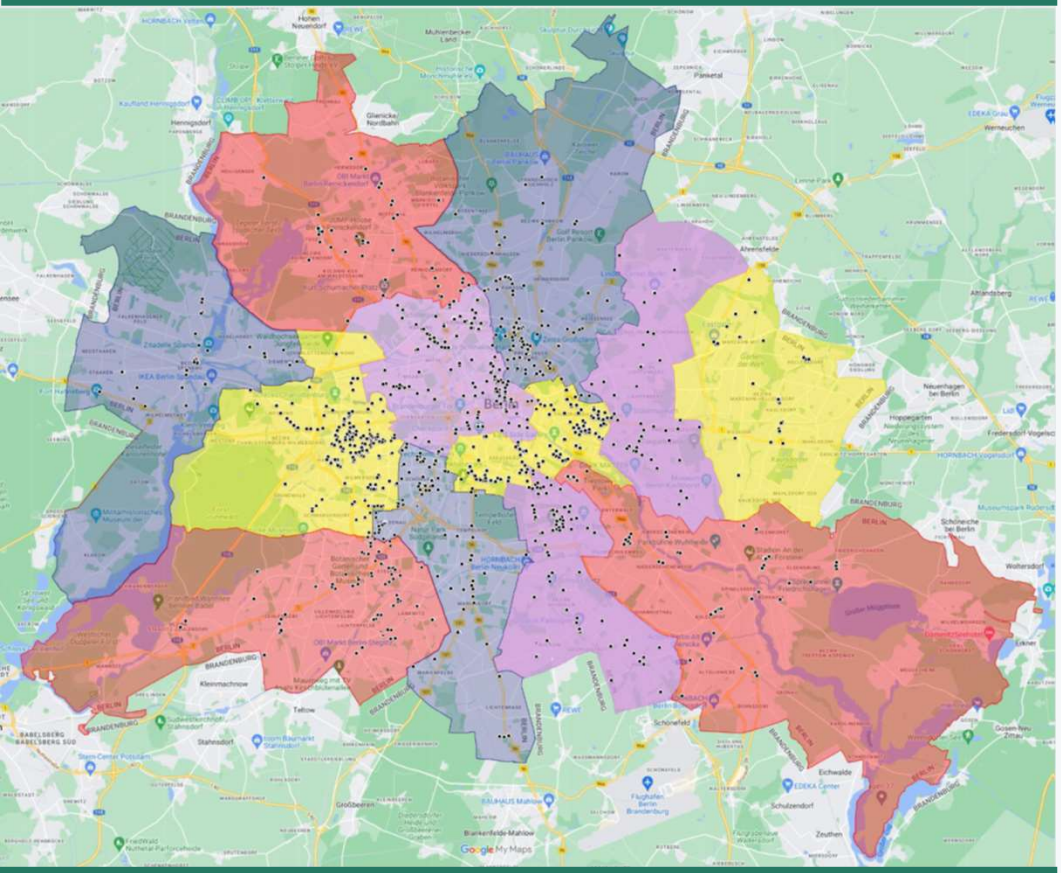
Calculating with time-of-day dependent driving times leads to the best routes; calculating with fixed driving times leads to either more costs (efficiency) or higher unpunctuality (quality).

Link to scientific study „Vehicle Routing with Time-Dependent Travel Times: Theory, Practice, and Benchmarks": https://arxiv.org/abs/2205.00889

VALUE OF OVERLAPPING DISTRICTS: MANAGING THE TRADE-OFF BETWEEN HANDLING & DRIVING TIMES



- Fixed districts means low handling costs but high driving costs
- Fully dynamic means low driving time costs but often high handling costs
- Reason is the increased complexity for drivers to handle a new unknown adress
- Overlapping districts as solution of this trade off
- Hard or soft district overlap depends on customer needs



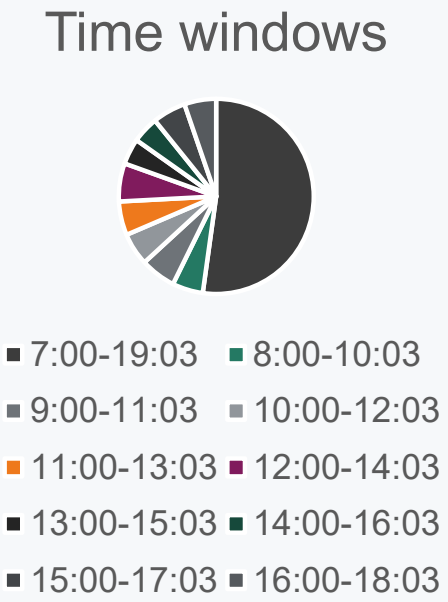
VALUE OF OVERLAPPING DISTRICTS: THE BERLIN CASE

- Sampled 1.000 arbitrary shipments in Berlin
- One depot, 12 vehicles max cap 100, different time windows of 2 hours

- 12 city districts of Berlin serve as delivery districts:
  - Mitte, Pankow, Friedrichshain-Kreuzberg, Charlottenburg-Wilmersdorf, Neukölln, Lichtenberg, Marzahn-Hellersdorf, Reinickendorf, Spandau, Steglitz-Zehlendorf, Tempelhof-Schöneberg, Treptow-Kopenick

ASSUMPTIONS

- Only deliveries
- One depot
  - Open 06:00 – 18:00
  - Return by 20:00
- 12 vehicles
  - One vehicle type (Van)
- Visit time of 1 minute at each address
- Max. working time: 12h
  - No breaks
- Capacity: Maximum 100 shipments per tour



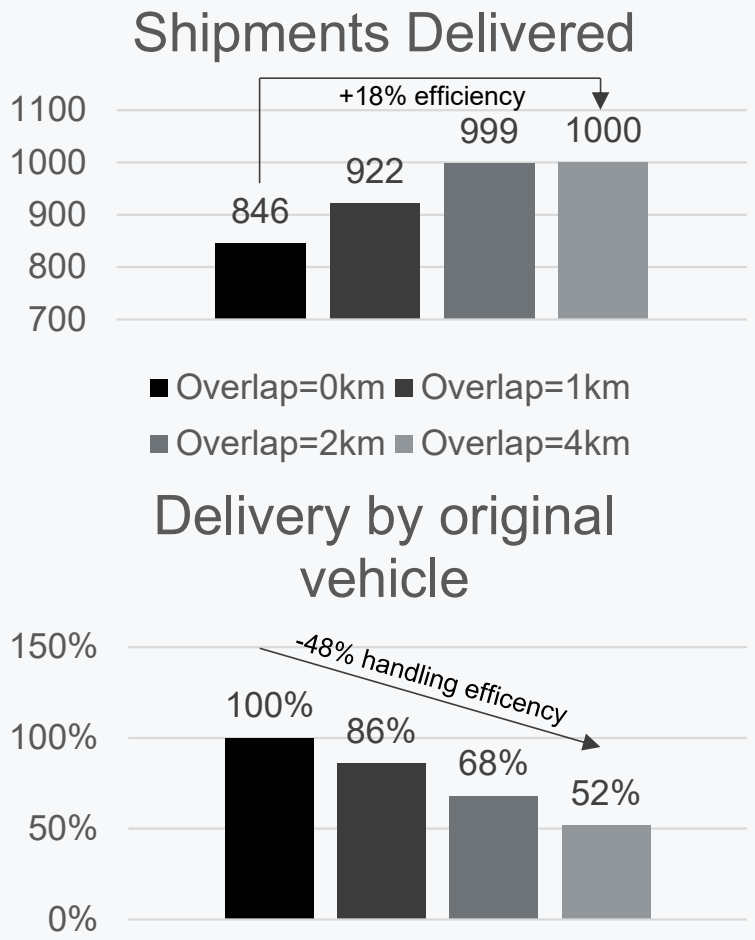
HARD OVERLAP

What happens, if we blow up the districts?

WITHOUT OVERLAP, IT IS IMPOSSIBLE TO HANDLE THE UNBALANCED LOAD

WITH JUST 2KM OF OVERLAP, ALMOST ALL SHIPMENTS CAN BE DELIVERED

AT THE SAME TIME , VOLATILITY AND THEREOF HANDLING TIME INCREASE



SOFT OVERLAPPING DISTRICTS FOR INCREASE OF STABILITY

Volatility effects like increased handling times can be simulated via penalties.
What if we allow exchange of shipments between districts (shipment specific) but penalize the volatility effect?

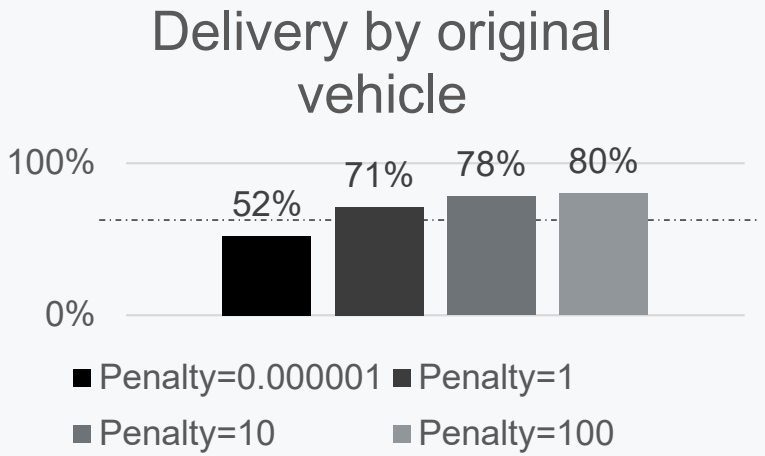
SOFT OVERLAP

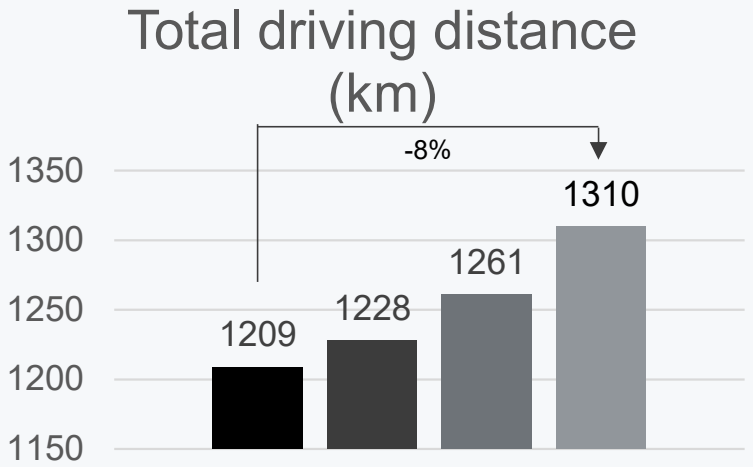
What happens at 4km overlap with different penalties?

PRIMARY GOAL OF DELIVERING ALL SHIPMENTS ALWAYS ACHIEVED

STABILITY INCREASES HEAVILY WITH PENALTIES

THIS EFFICIENCY PLUS COMES (ONLY) WITH MINIMIZED NEGATIVE EFFECTS OF INCREASED WORKING TIMES AND DRIVING DISTANCE





GREENPLAN PROPOSES TO USE HARD AND SOFT CONSTRAINTS TO ACHIEVE BEST TRADE-OFF BETWEEN DRIVING EFFICIENCY AND ADRESS STABILITY (HANDLING TIMES)

EPG'S SOLUTION FOR ROUTE OPTIMIZATION: GREENPLAN

Developed in Germany

- From one of the world's top-selling logistics companies - DHL
- In partnership with one of the world's leading universities for discrete mathematics (top 3 ranking) – University of Bonn

Industry-leading approach

- **Integration** of **traffic data** into route optimisation
- **Overlapping districts**

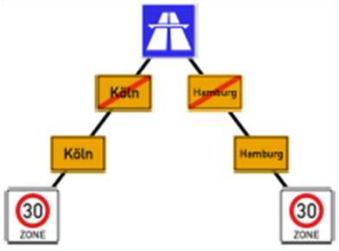
→ Higher delivery reliability (on-time)
→ Lower transportation cost
→ Happy drivers, dispatchers and customers

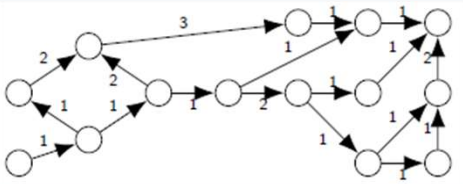
Continuously awarded

- Winner **Amazon Last Mile Challenge**
- Included in **Gartner's Vehicle Routing and Scheduling Report 2023**
- Best product **LogiMAT 2023**
- Winner **PostEurop Innovation Award**

BACKUPS

ROAD NETWORK PRE-PROCESSING: CONTRACTION HIERARCHIES





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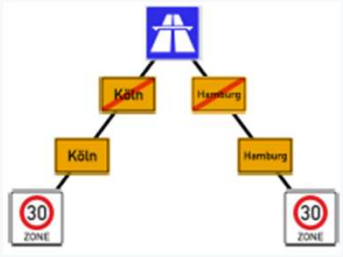

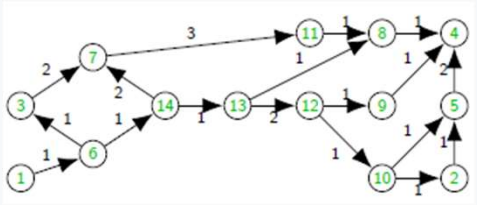

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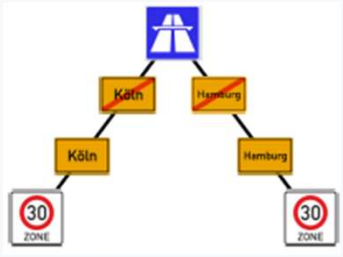

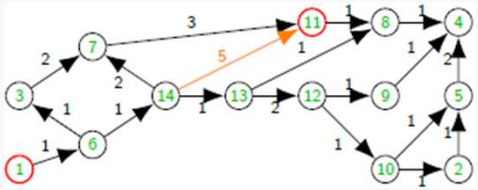

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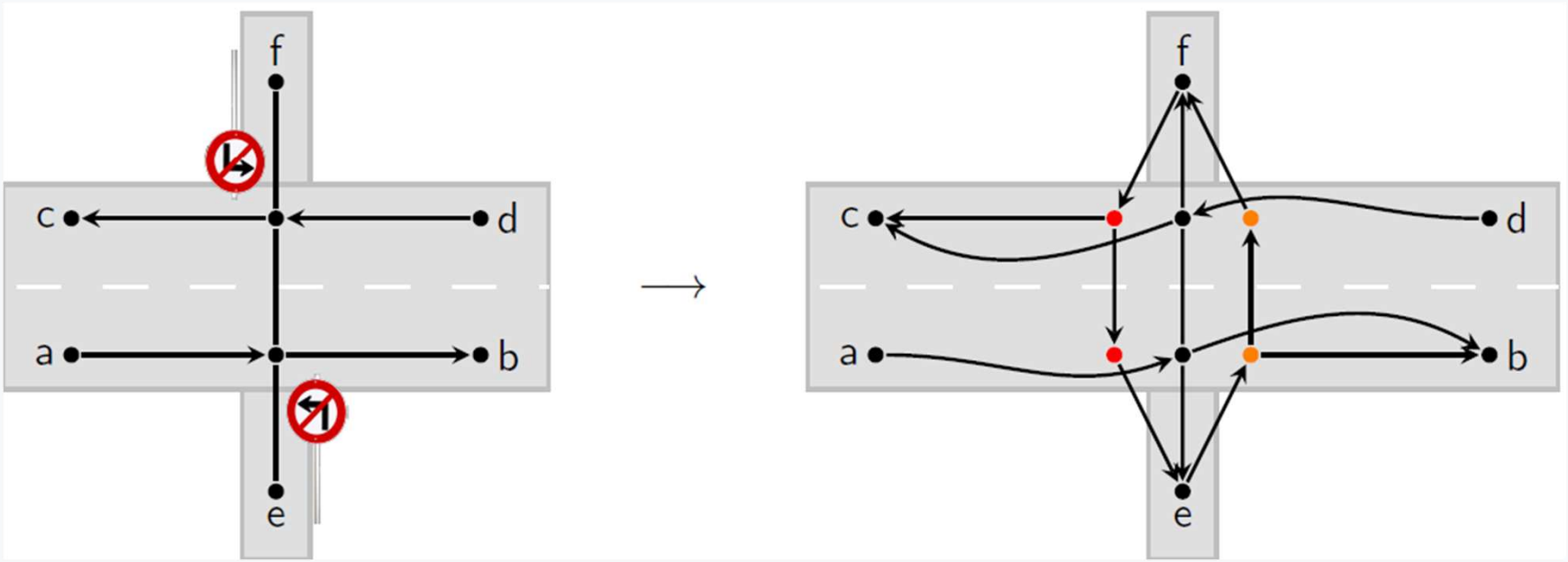
- Yes, if we add **shortcut edges**

MODELING RESTRICTIONS

- **Example:** Forbid left turns when entering a major road.



- Similarly for forbidden U-turns
- A variation allows for budgeting extra time for allowed left- or U-turns
- Restrictions can be time-dependent, which fits naturally into our model