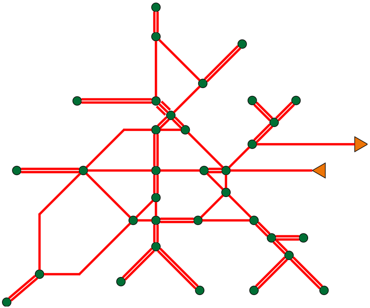
Traffic Optimization:

Optimal Tours in Graphs

Niels Lindner



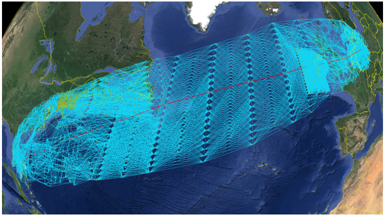
Lecture 1

October 14, 2019

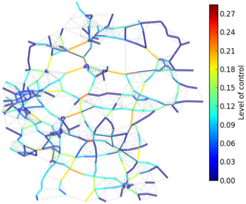
Organization

- **Lectures:**
  Niels Lindner (`lindner@zib.de`)
  Monday, 10-12, A6/SR 009
- **Tutorials:**
  Pedro Maristany de las Casas (`maristany@zib.de`)
  Monday, 12-14, A6/SR 025/026 (**starting from October 21**)
- **Homework:**
  50% for exam admission
  from Monday to Monday
  submission via e-mail or on paper
  groups of max. two students
- **Website:**
  `https://kvv.imp.fu-berlin.de/x/92kN1e` (Whiteboard)

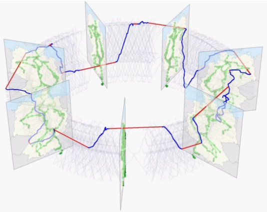
Zuse Institute Berlin



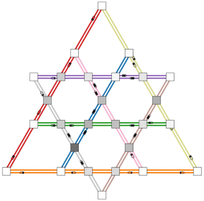
Flight trajectory optimization



Toll control



ICE vehicle rotation



Integrated timetabling and routing

Moreover: Supercomputing, Energy networks, Nanooptics, Bioinformatics, ...

Course Outline

§1 Introduction

S-Bahn challenge, mathematical optimization in public transport

§2 Chinese Postman Problem

Euler tours, shortest paths, perfect matchings, T-joins

§3 Traveling Salesman Problem

Hamiltonian paths, NP-hard optimization problems, approximation algorithms, metric TSP, spanning trees, k-opt moves, asymmetric TSP

§4 Integer Programming

Linear programming, polytopes, cutting planes, IP formulations of TSP

§5 Generalized Routing Problems

Directed Postman, rural Postman, generalized Postman, asymmetric TSP, clustered TSP, generalized TSP

⋮

Chapter 1

Introduction

§1.1 S-Bahn Challenge

Chapter 1

Introduction

§1.2 Mathematical Optimization in Public Transport

Optimal Public Transport

Public transport should be ...

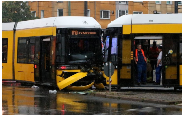
fast

on time

frequent

cheap

reliable



safe

accessible

comfortable

Optimal Public Transport

These goals are conflicting!

Basic Conflict: Passengers vs. Operators

maximum passenger comfort $\leftrightsquigarrow$ minimum operational cost

Examples

low fares	$\leftrightsquigarrow$	high revenues
short intervals	$\leftrightsquigarrow$	few vehicles
high reliability	$\leftrightsquigarrow$	low maintenance cost
punctuality	$\leftrightsquigarrow$	small time supplements
few transfers	$\leftrightsquigarrow$	short lines
flexible disruption handling	$\leftrightsquigarrow$	simple disposition

$\vdots$

Optimal Passenger Journeys

Which connection is the best one?

Bahnhof/Haltestelle	Zeit	Dauer	Umst.	Produkte	Sparangebote	Flexpreis
	Früher				Preis für alle Reisenden inkl. Ermäßigungskarten*	
Berlin Hbf (tief) Frankfurt(Main)Hbf Details einblenden	07:04 10:56	3:52 Rückfahrt hinzufügen	0	ICE	79,90 EUR Zur Angebotsauswahl	129,00 EUR
Berlin Hbf (tief) Frankfurt(Main)Hbf Details einblenden	07:27 11:44	4:17 Rückfahrt hinzufügen	0	ICE	67,90 EUR Zur Angebotsauswahl	129,00 EUR
Berlin Hbf (tief) Frankfurt(Main)Hbf Details einblenden	07:38 11:44	4:06 Rückfahrt hinzufügen	1	ICE	51,90 EUR Zur Angebotsauswahl	129,00 EUR
Details für alle	Später					

bahn.de

No connection is *the* best: W.r.t. the criteria *shortest travel time*, *minimum number of transfers* and *lowest price*, all connections are *Pareto optimal*.

Strategic Planning

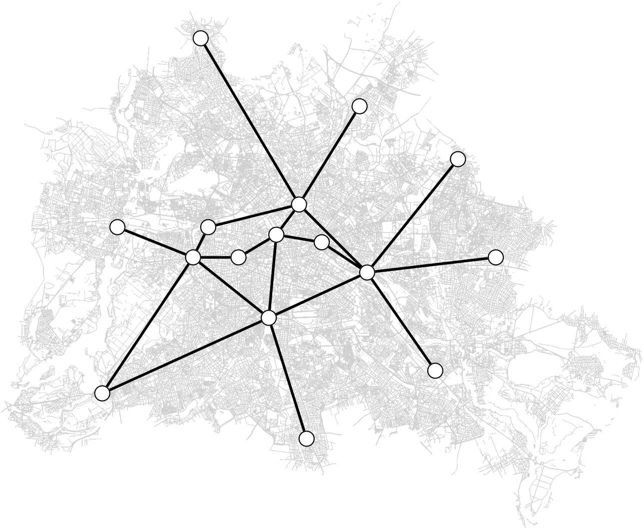
Imagine a city without any public transportation network...

Strategic Planning

Network planning: Locate stops...

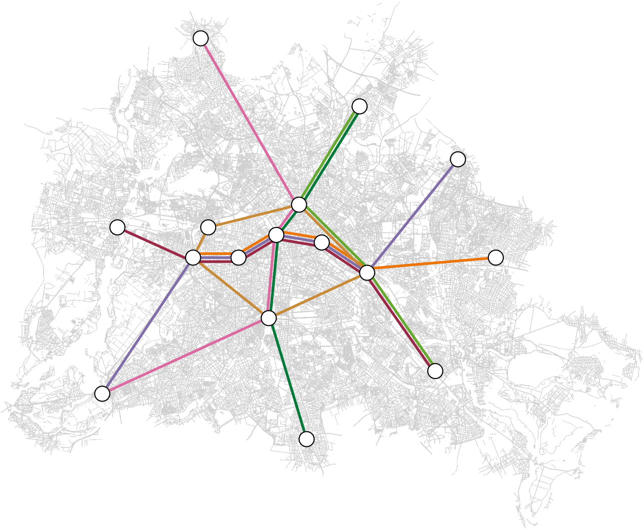
Strategic Planning

Network planning: ... and infrastructure



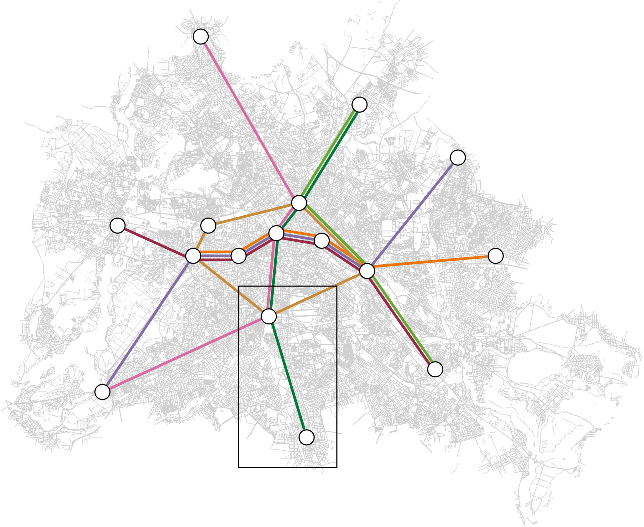
Strategic Planning

Line planning: Lines and their frequencies



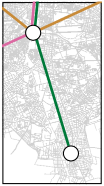
Strategic Planning

Timetabling: Departure and arrival times

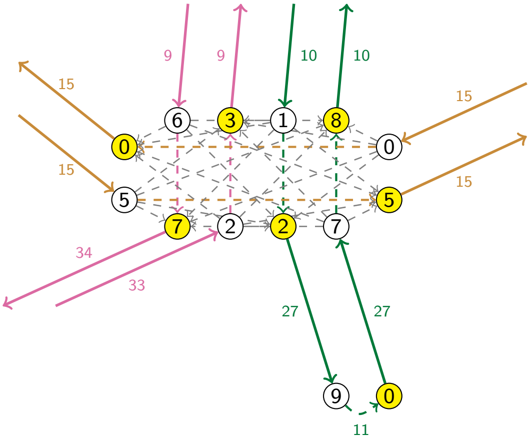


Strategic Planning

Timetabling: Departure and arrival times



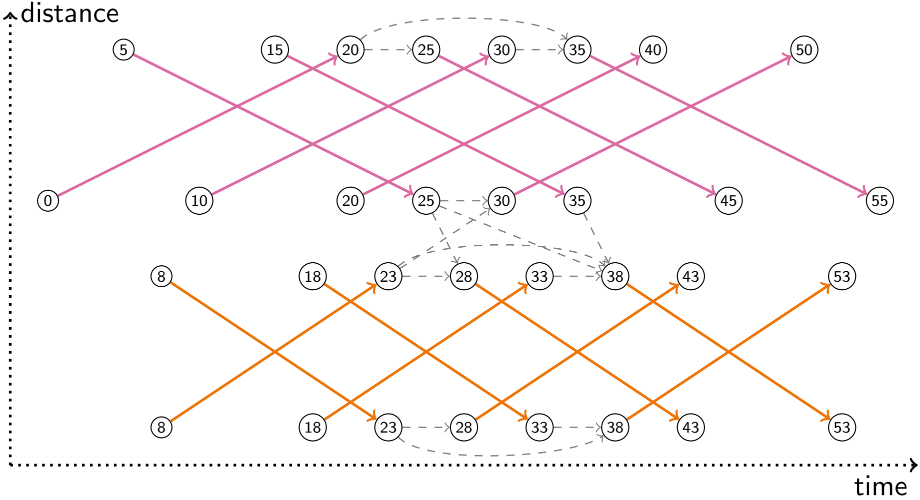
$\rightsquigarrow$



periodic timetable with period time 10

Operational Planning

Vehicle scheduling: Assign vehicles to a sequence of trips



Operational Planning

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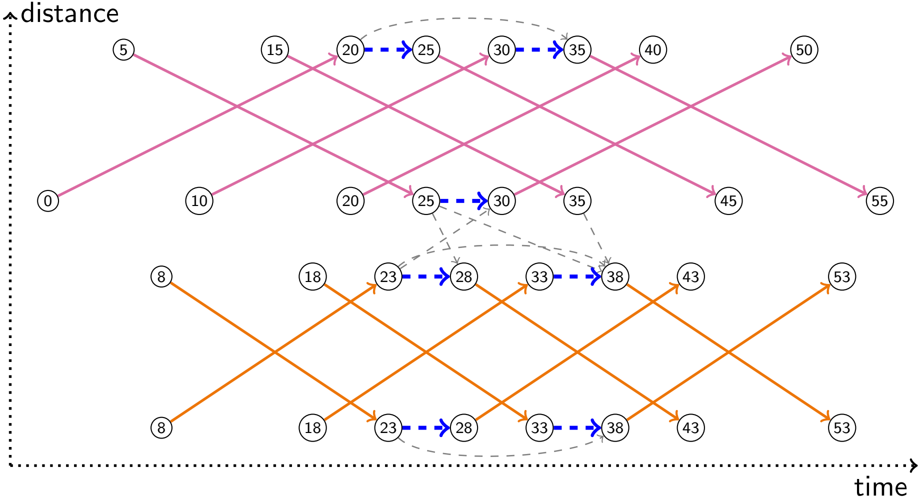
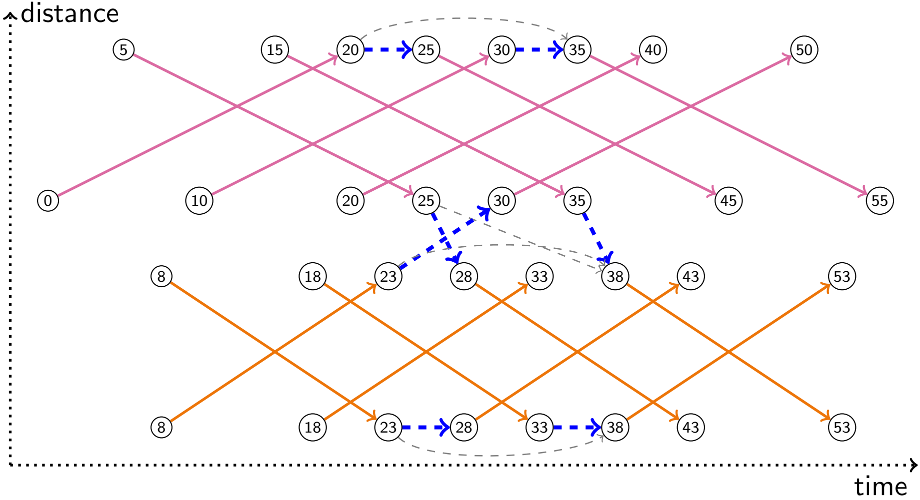


Operational Planning

Vehicle scheduling: Assign vehicles to a sequence of trips



More Optimization Tasks

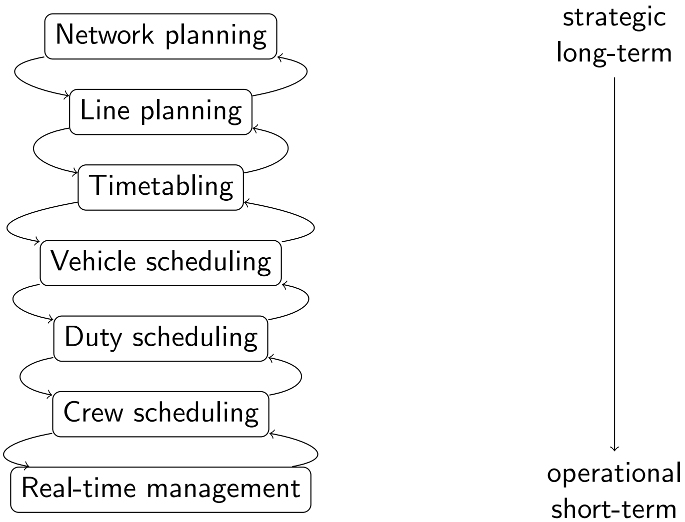
General Tasks

- **Duty scheduling:** group trips to duties
- **Crew scheduling:** assign workers to duties
- **Re-scheduling:** e.g., in case of disruptions
- **Robust scheduling:** for timetables, vehicles and duties
- **Construction site planning**
- **Fare planning**
- **Routing:** passengers, vehicles, inspectors
- ...

Specific Tasks

Special needs of railway systems, air networks, electric vehicles, ...

Public Transport Planning Cycle



Bussieck et al.: Discrete optimization in public rail transport, 1997
Liebchen: Periodic timetable optimization in public transport, 2006

Mathematical Background

Many problems can be formulated as discrete optimization problems:

Public Transport	Discrete Optimization
network planning	Steiner tree, survivable network design
line planning	multi-commodity flow, Knapsack
timetabling	multi-commodity flow, periodic event scheduling
vehicle scheduling	multi-commodity flow, matching
optimal journeys	time-dependent/constrained shortest path

Problem 1: Hardness

Most of these problems are NP-hard. Provided that $P \neq NP$ holds, there are no polynomial-time algorithms providing exact solutions. However, this does not mean that real-world instances cannot be optimized in practice.

Problem 2: Size

Realistic instances are large. Berlin bus scheduling, 1997: 44 bus types, 24'906 trips, 69'700'000 turnarounds. Optimization saved 20% buses.

Success Stories

Mathematical Optimization in Practice

- Line planning: Potsdam (2010), Istanbul (2016), Karlsruhe (2018)
- Timetabling: Germany (DB Fernverkehr, BVG U-Bahn), Netherlands (NS), Switzerland (SBB), Denmark (S-tog Copenhagen)
- Vehicle scheduling: Germany (DB Fernverkehr), France (SNCF)
- Integrated vehicle and duty scheduling: part of IVU.suite
- Disruption management: Netherlands (NS), Norway (Jernbaneverket)
- Optimal passenger journeys: standard

Savings

- Line planning, Karlsruhe: 16% operational costs, 4% transfers
- Timetabling, Berlin U-Bahn: one vehicle
- Vehicle scheduling, Berlin-Spandau: 20% of fleet

Advertisement

Next Lecture on Optimal Tours in Graphs
No big picture, just blackboard mathematics

Next monday (no tutorial today!)
Room: A6/SR 009

Block Seminar on Graph Decompositions
Contents: treewidth, branchwidth, graph partitioning and optimization applications

First meeting: Wednesday, 10 am, ZIB, seminar room 2006

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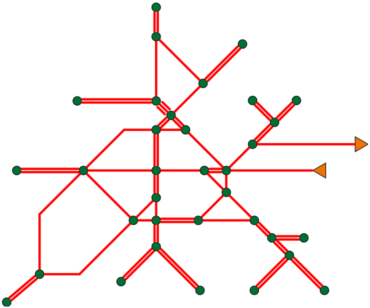

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