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Optimizing logistic networks and traffic flows

– a rail freight example –

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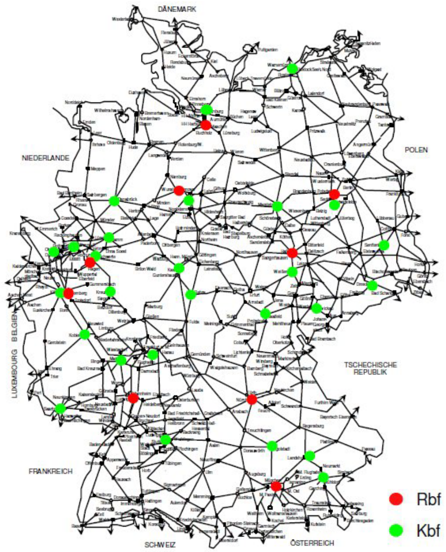
Prof. Dr.-Ing. Uwe Clausen, Director
Institute for Transport Logistics, TU Dortmund University of Technology
Fraunhofer-Institute for Material Flow and Logistics (IML)

Dipl.-Math. Robert Voll
Institute for Transport Logistics, TU Dortmund University of Technology

itl Institut für Transportlogistik

Fraunhofer IML



- topic: wagonload traffic (WLT)
- production form in railway freight traffic
- several OD-requests in railway network
- problem: only a few (mostly 1-5) wagons on each relation
- direct transport not economic
- solution: consolidation of routes
- trains can be decoupled and rearranged in reclassification yards

Introduction

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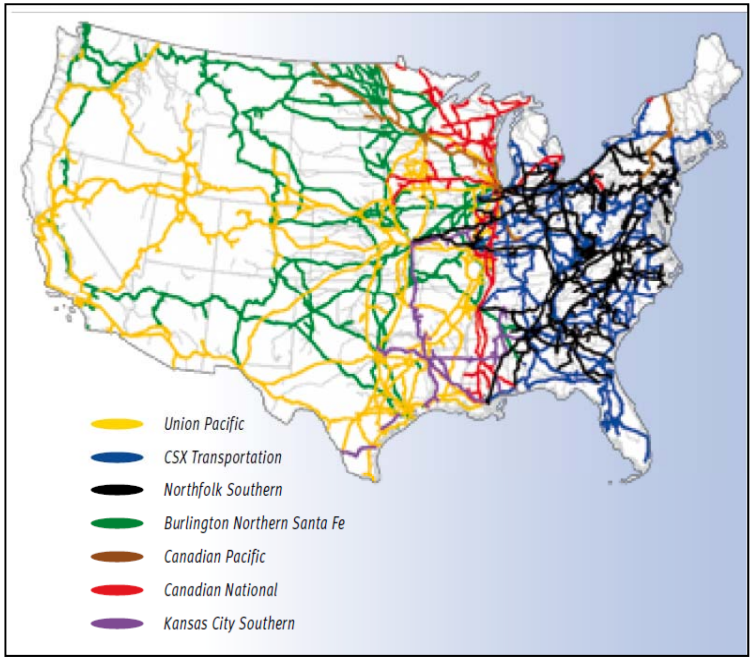

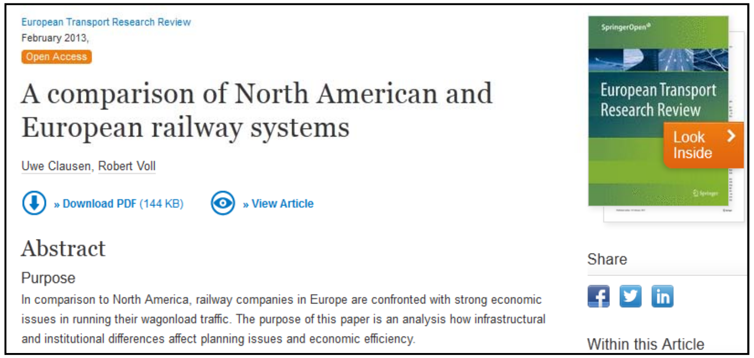
European Transport Research Review
February 2013,
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A comparison of North American and European railway systems

Uwe Clausen, Robert Voll

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Abstract

Purpose

In comparison to North America, railway companies in Europe are confronted with strong economic issues in running their wagonload traffic. The purpose of this paper is an analysis how infrastructural and institutional differences affect planning issues and economic efficiency.

European Transport Research Review

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Within this Article

- how to route each wagon to minimize total costs?
- what is the best sequence of yards for each wagon?
- multicommodity flow problem with network design aspects
- known as *Railroad Blocking Problem* (RBP)
- very long trains in USA (> 1600 m) due to
  1. large distances
  2. ownership structure of railways
  3. freight traffic more important than passenger traffic

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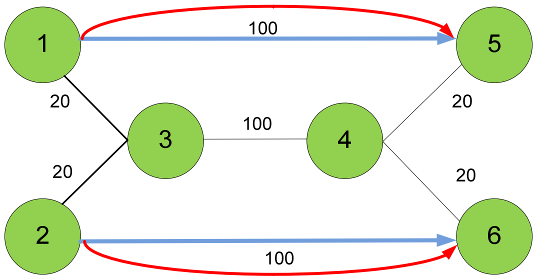
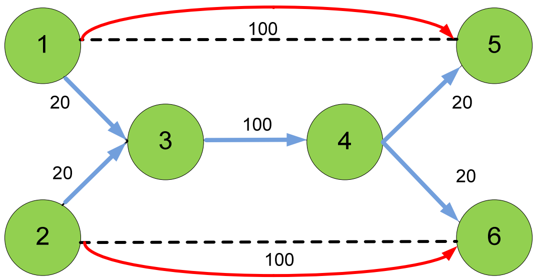
Institut für Transportlogistik Prof. Dr.-Ing. Uwe Clausen minimize wagonkm



minimize trainkm



- Germany: passenger and freight traffic on the same infrastructure
- train lengths restricted (< 700m)
- train lengths have consequences
- two points of view on transportation costs:
- in USA: Focus on wagonkm (also common in literature)
- in Germany: trainkm more important
- completely different optimal solutions
- trainkm induce consolidation effect

Modelling Aspects: Robustness

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demand in WLT changing every day

* provided by Deutsche Bahn

- demands in WLT very volatile
- optimizing on mean values not reasonable
- include multiple demand scenarios
- find one routing plan for all scenarios

Sets

$\mathcal{N}$	nodes
$\mathcal{D}$	scenarios
$\mathcal{K}(d)$	active Relations in scenario d

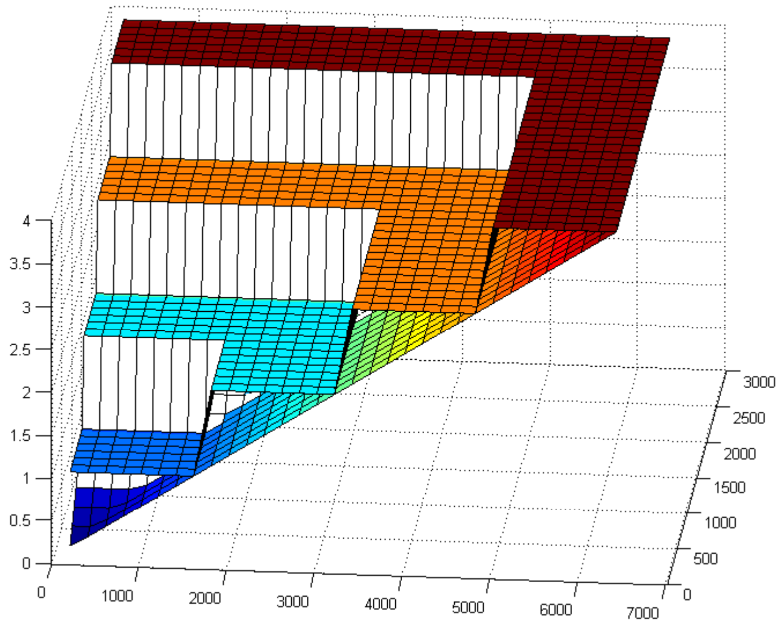
Decision Variables

x_{ij}^k	$= \begin{cases} 1, & \text{if relation } k \text{ uses arc } (i,j) \\ 0, & \text{otherwise} \end{cases}$
n_{ij}	number of trains using arc (i,j)

Parameters

$c_{ij} \in \mathbb{R}^{\|\mathcal{N}\| \times \|\mathcal{N}\|}$	costs per train on arc (i,j)
$U_i \in \mathbb{R}$	classification costs for one wagon in node i
$l_d^k \in \mathbb{R}^{\|\mathcal{K}\|}$	aggregated length of the wagons on relation k in interval d
$w_d^k \in \mathbb{R}^{\|\mathcal{K}\|}$	aggregated weight of the wagons on relation k in interval d
$v_d^k \in \mathbb{R}^{\|\mathcal{K}\|}$	aggregated number of wagons on relation k in interval d
$R_i \in \mathbb{N}^{\|\mathcal{N}\|}$	number of trains which can be classified at i in one time period
$S_k \in \mathbb{N}_0^{\|\mathcal{K}\|}$	upper limit on reclassifications for relation k
Balance(i,k) $\in \{-1, 0, 1\}$	$= \begin{cases} 1, & \text{if i is origin of relation k} \\ -1, & \text{if i is destination of relation k} \\ 0, & \text{otherwise} \end{cases}$

min	$\sum_{(i,j)\in\mathcal{M}} [c_{ij}n_{ij} + \sum_k U_i(\sum_d v_d^k)x_{ij}^k]$		minimize train + reclassification costs
$s.t.$	$\sum_{j\in\mathcal{N}} x_{ij}^k - x_{ji}^k = Balance(i,k)$	$\forall i \in \mathcal{N}\ \forall k \in \mathcal{K}$	flow conservation
	$\sum_{k\in\mathcal{K}(d)} l_k^d x_{ij}^k \leq 700 n_{ij}$	$\forall (i,j) \in \mathcal{M}\ \forall d \in \mathcal{D}$	length restriction
	$\sum_{k\in\mathcal{K}(d)} w_k^d x_{ij}^k \leq 1600 n_{ij}$	$\forall (i,j) \in \mathcal{M}\ \forall d \in \mathcal{D}$	weight restriction
	$\sum_{j\in\mathcal{N}} n_{ij} \leq R_i$	$\forall i \in N$	yard capacity, measured in outgoing trains
	$\sum_{(i,j)\in\mathcal{M}} x_{ij}^k \leq S_k$	$\forall k \in \mathcal{K}$	reclassification limit per wagon
	$x_{ij}^k \in \{0,1\}$	$\forall (i,j) \in \mathcal{M}\ \forall k \in \mathcal{K}$	integrality
	$n_{ij} \in \mathbb{N}$	$\forall (i,j) \in \mathcal{M}$	



number of trains on arc
depending on
aggregated weight and length

- real-world: ˜160 nodes, ˜5000 relations
- ˜20 nodes, ˜100 relations
  not solvable for CPLEX in 24h
- NP-complete (reductable to
  integer multicommodity flow problem)
- LP-relaxation is very weak
  (due to polyhedral structure)
- LP neglects consolidation effect
- common exact methods fail
- heuristic approach reasonable

Heuristic solution

- improvement heuristic
- combination of local search and exact method (matheuristic)
- given a feasible solution $(\widehat{x}, \widehat{n})$ (construction difficult)
- simple idea: Choose a certain number of relations and reroute them optimally (e.g., CPLEX)
- adaptive choice of relations to avoid local minima (Variable neighborhood search)

Iteration step (simplified):

compute the mean value of the unused capacities on (i, j) of all scenarios

$$\overline{u(i,j)} = \sum_{d \in \mathcal{D}} \frac{u(i,j,d)}{|\mathcal{D}|}$$

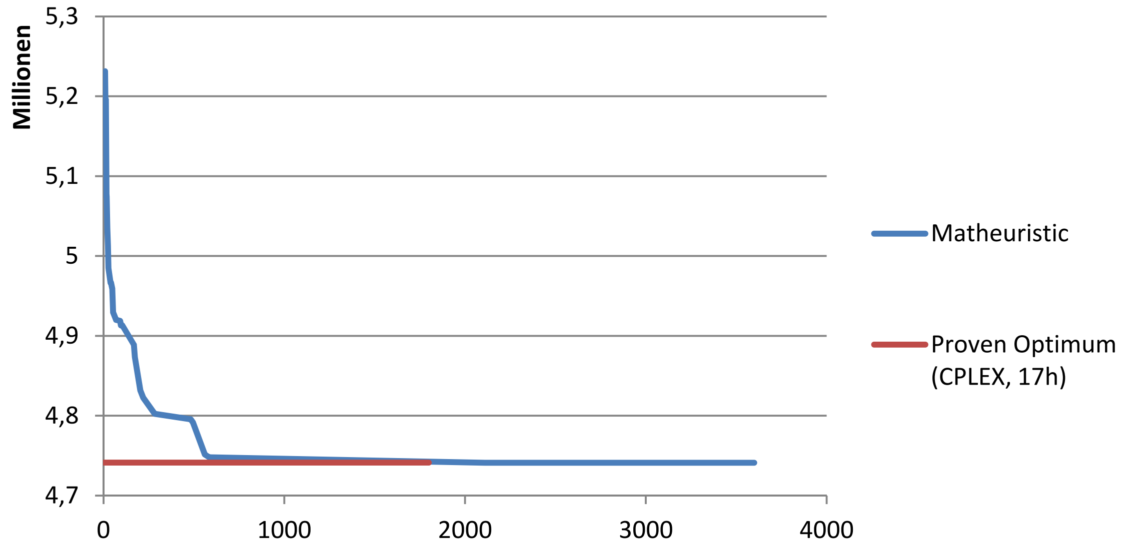
Define set of selected relations $\mathcal{F} = \emptyset$
while $|\mathcal{F}| < \mu$

a. Find arc (i', j') with the highest mean unused capacity $\overline{u(i', j')}$
b. Add relations traversing (i', j') to the set of selected paths F

Find optimal rerouting for all $k \in \mathcal{F}$ with exact algorithm (e.g. CPLEX)

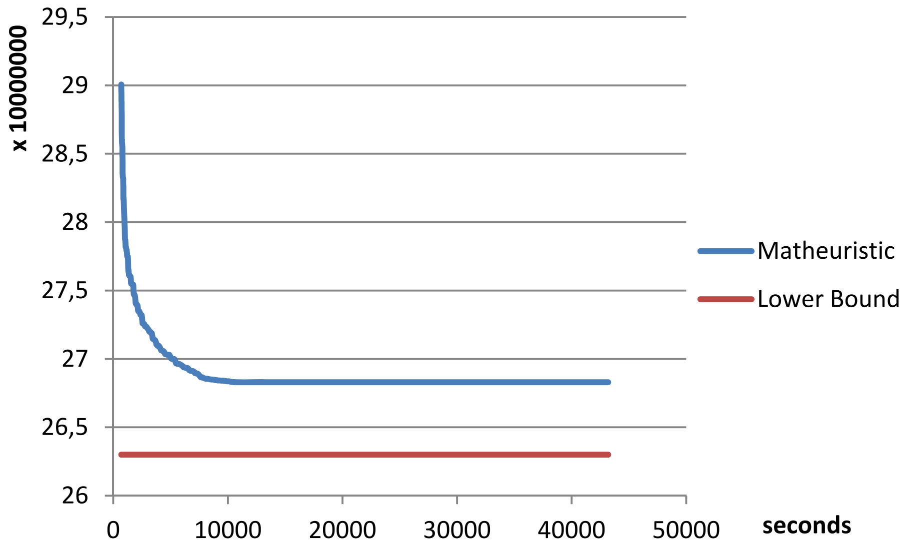
Redefine incumbent solution $(\widehat{x}, \widehat{n})$

- finds optimal solution (proven by CPLEX) for toy instances (e.g. 30 nodes, 65 relation, 10 days) in short time
- for larger instances, the optimum is unknown

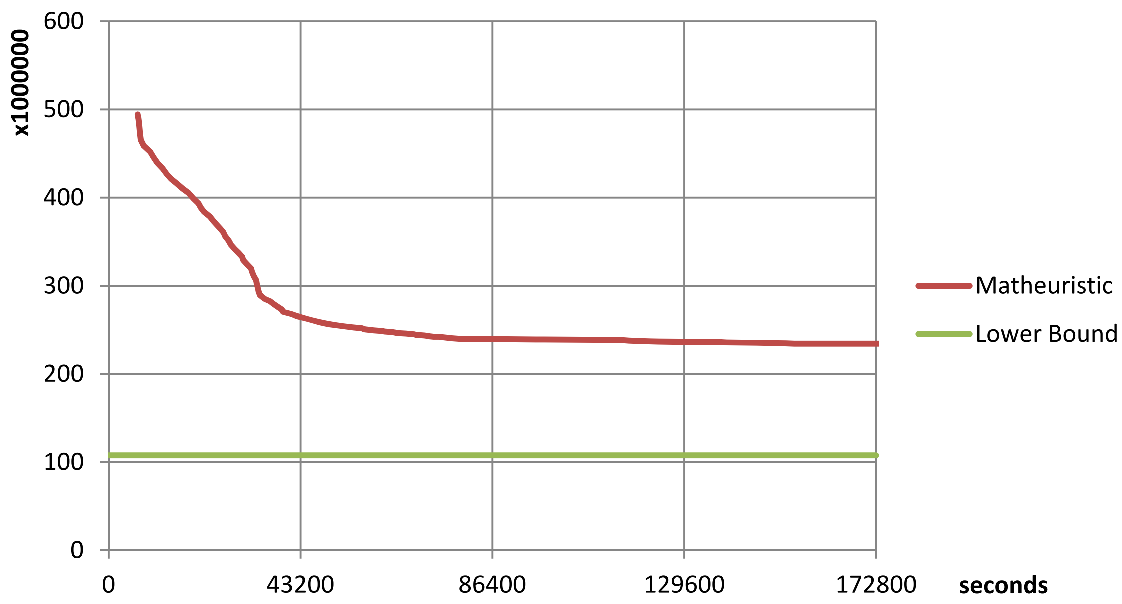


Results of the Matheuristic

- finds feasible solution for real-world instance (partial network of Germany :107 nodes, 1584 relation, 10 days) in 12h
- Gap $< 2\%$
- objective function value remains static after a while

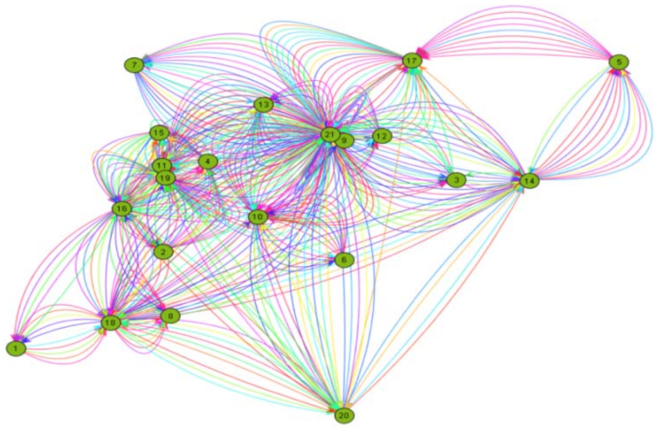


- finds feasible solution for real-world instance (107 nodes, 5673 relation, 10 days) in 24-48h
- Gap > 50% but lower bound is really very weak
- solution is assumed to be much better



Summary

- real-world consolidation problem from railway freight traffic
- two main characteristics: consolidation and robustness
- large-scaled optimization problem with weak LP-relaxation
- meta-/matheuristic approach finds feasible solutions
- estimation of quality difficult due to weak LB
- implementation into Deutsche Bahn systems will begin in the next months



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Thank you !

Prof. Dr.-Ing. Uwe Clausen

Faculty of Mechanical Engineering – Institute of Transport Logistics, TU Dortmund

Phone: +49 231 755 6335
E-Mail: clausen@itl.mb.tu-dortmund.de
Homepage: http:// www.itl.tu-dortmund.de

Director, Fraunhofer-Institute for
Material Flow & Logistics (IML) Dortmund
Chairman, Fraunhofer Transport Alliance, Germany

Phone: +49 231 97 43 400
Email: Uwe.Clausen@iml.fraunhofer.de
Homepage: http://www.iml.fraunhofer.de

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