Robustness in Rail Operations

RobustRailS

QAMPO

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RobustRailS DTU

AGENDA

1. Introduction
2. Overview of RobustRailS (by prof. David Pisinger)
3. Integrated Rolling Stock Scheduling
4. Train Speed Advisory System
5. Conclusions (by prof. David Pisinger)

Introduction

ROBUSTRAILS

Can we get the trains to run on time?

Robustness in **Rail**way Operation**S**

- Large interdisciplinary project
  - DTU Management
  - DTU Transport
  - DTU Compute
  - DTU Fotonik
- Industrial Partners
- Research Partners

- Attract more passengers
- More robust systems

RobustRailS

Founded by The Danish Council for Strategic Research

DSB banedanmark Trafikstyrelsen Danish Transport Authority Universität Bremen

QAMPO

by professor David Pisinger

OVERVIEW

Rolling Stock Scheduling

ROLLING STOCK SCHEDULING

The Basics

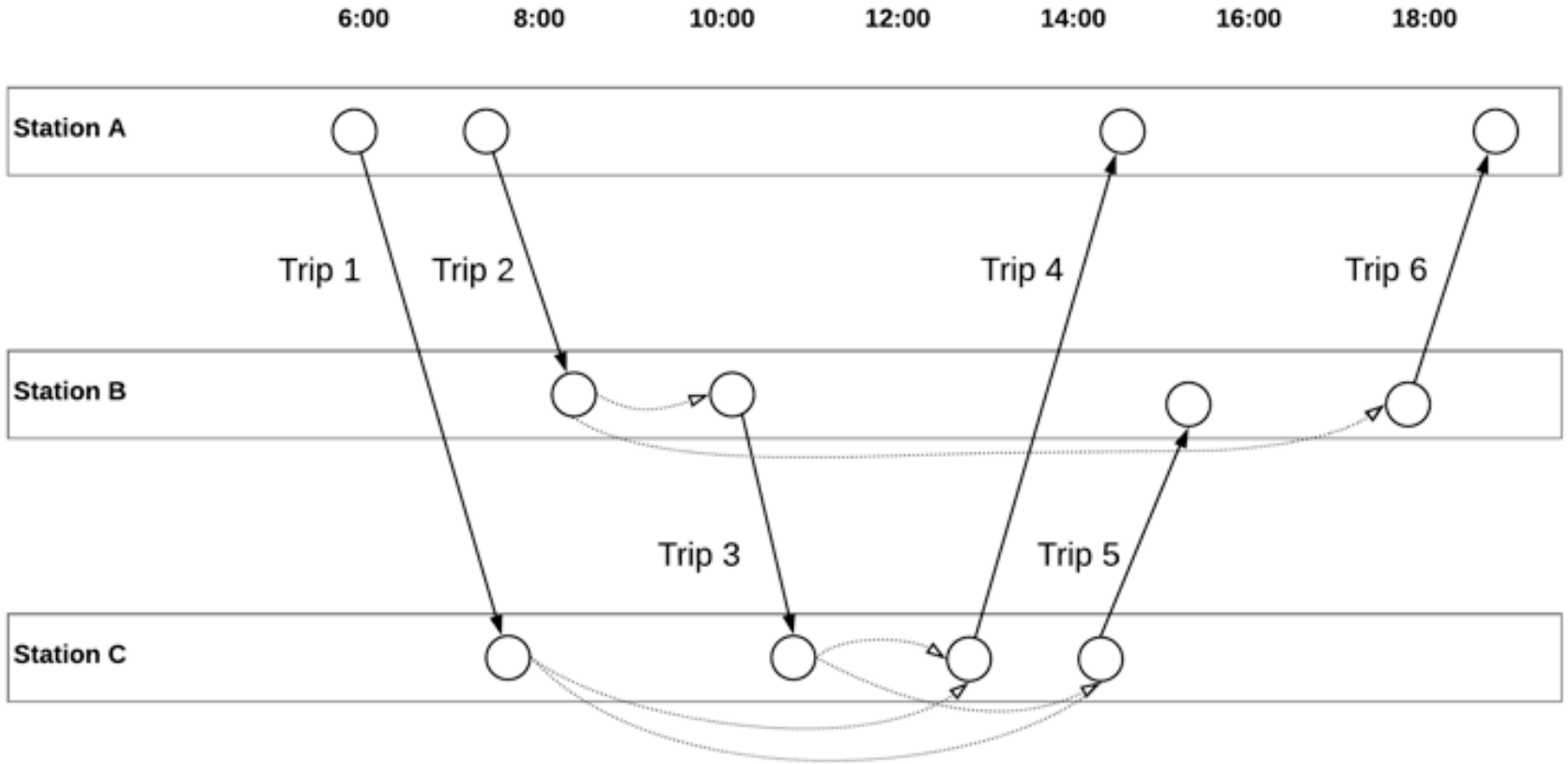
- Fleet management
  - Train composition
  - Inventory
  - Passenger demand
  - Maintenance
  - Parking
- Algorithmic support

REACTIVE ROBUSTNESS

- Proactive robustness
  - Resource slack
  - Buffers
  - Redundancy

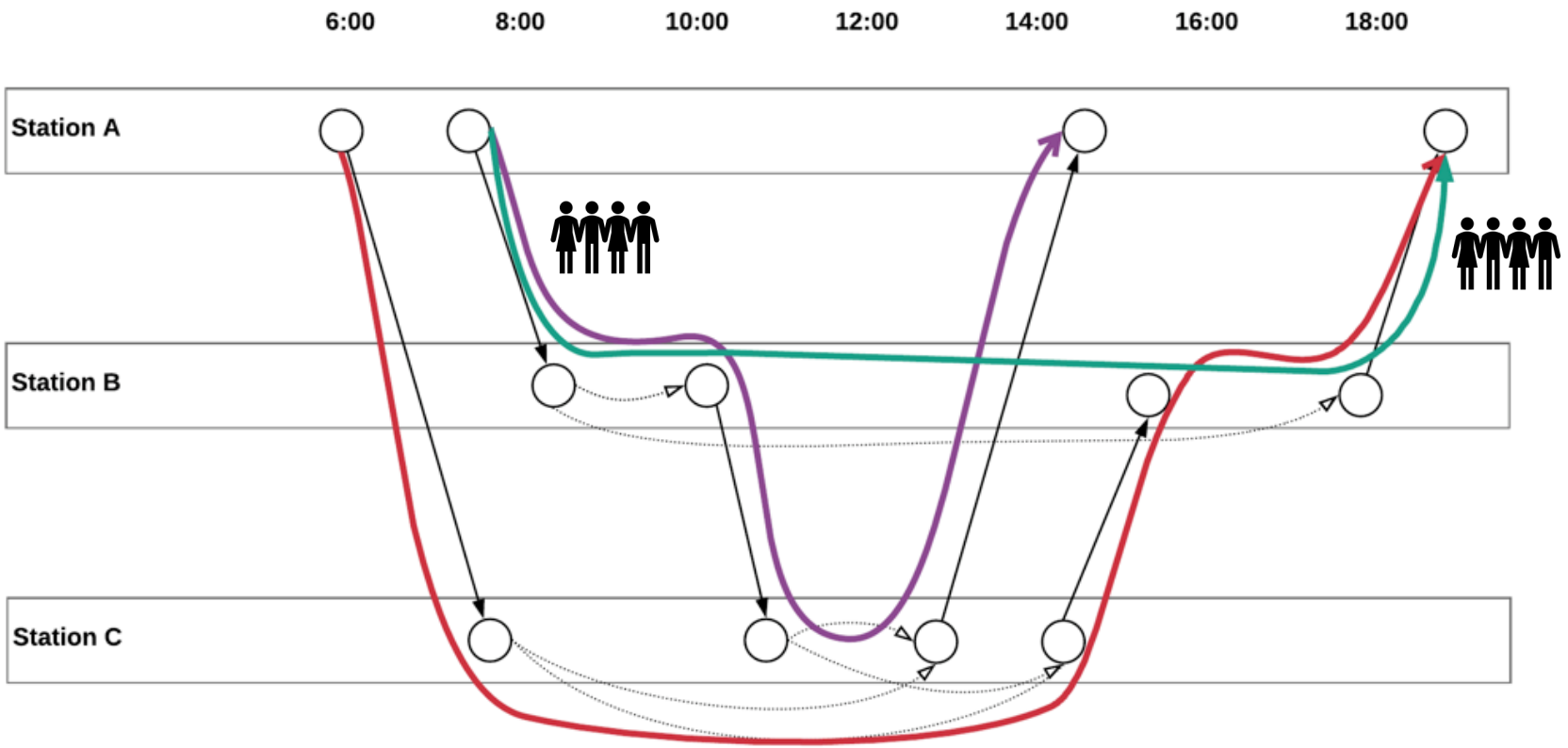
- Reactive robustness
  - Recoverability
  - Ability to re-plan efficiently
  - Holistic model

AN EXAMPLE



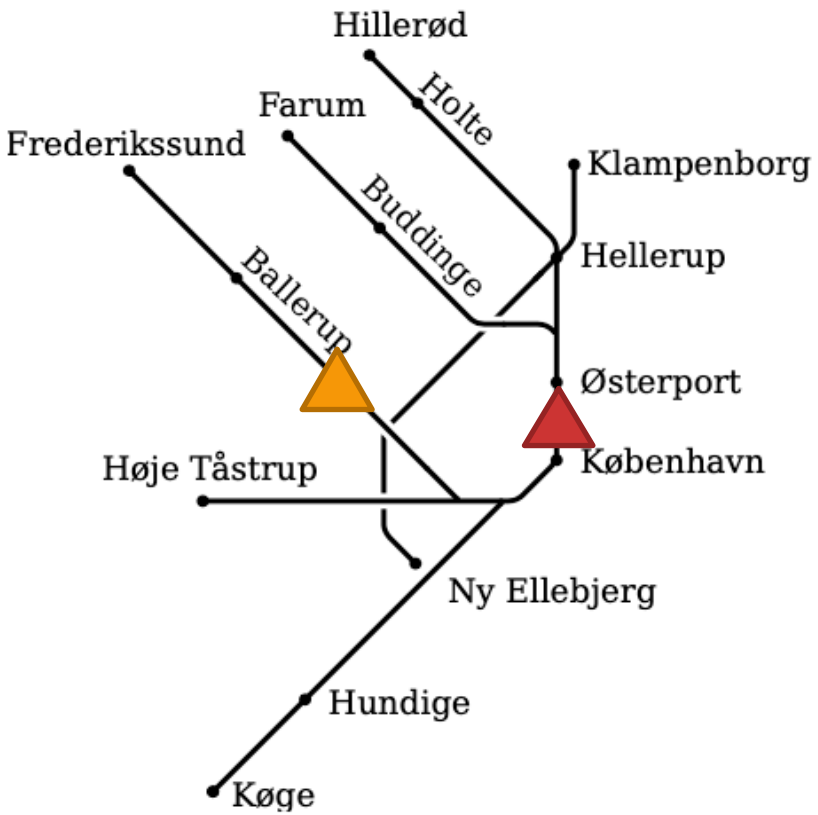
Time-space diagram

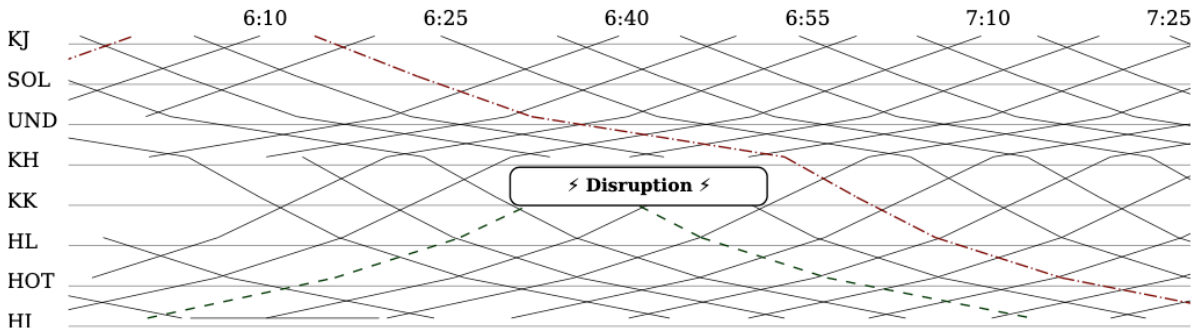
AN EXAMPLE SOLUTION



Time-space diagram

DISRUPTION CASES





Scenario #1 - Leg Segment	
Contingency Plan	A.3.10 (Val - Fs)
Description	One track is blocked on one of the fingers
Cancelled lines	H
Turned lines	C1
Unchanged	A1, A2, B1, B2, Bx, C2, E1, E2

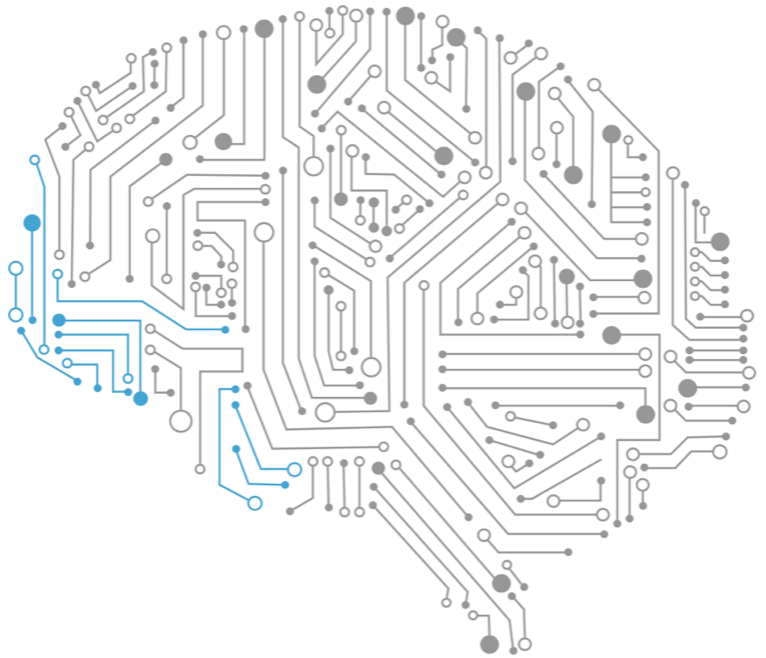
Scenario #2 - Central Segment	
Contingency Plan	A.0.16 (Kh - Kk)
Description	One track is blocked in the central segment
Cancelled lines	A2, B2, Bx, C1, E2, H
Turned lines	A1, B1, C2, A1, C1
Unchanged	E1

DISRUPTION CASES

	Disruption	#	Time	Cols	Quality				
					Gap	Root	Cover	Seat	Mileage
Fri	9:00-10:00	836	11	4 096	0.3%	15.1%	99.8%	98.9%	122.4%
Fri	9:00-13:00	782	18	6 068	0.5%	14.7%	99.8%	98.7%	119.4%
Fri	11:00-12:00	713	8	3 051	0.6%	16.7%	99.8%	98.9%	122.1%
Fri	11:00-15:00	657	10	3 939	0.2%	14.8%	99.7%	98.4%	117.5%
Fri	15:00-16:00	468	6	2 379	0.3%	2.1%	99.6%	97.2%	113.8%
Fri	15:00-19:00	402	5	1 727	0.0%	1.9%	99.8%	98.4%	115.3%
Mon	9:00-10:00	820	13	4 129	0.4%	2.7%	99.8%	98.4%	121.6%
Mon	9:00-13:00	766	14	5 827	0.1%	2.5%	99.8%	98.8%	118.3%
Mon	11:00-12:00	697	10	3 665	0.5%	16.5%	99.8%	98.8%	122.4%
Mon	11:00-15:00	641	8	4 066	0.2%	14.3%	99.7%	98.4%	118.6%
Mon	15:00-16:00	451	6	2 239	0.0%	1.5%	99.6%	97.5%	119.1%
Mon	15:00-19:00	385	6	2 053	0.2%	1.9%	99.8%	97.2%	118.2%

CONTRIBUTION

- Prototype
- Re-scheduling
- Benchmark
  - Fast response
  - Good quality
- Integrated approach



- Reactive Robustness

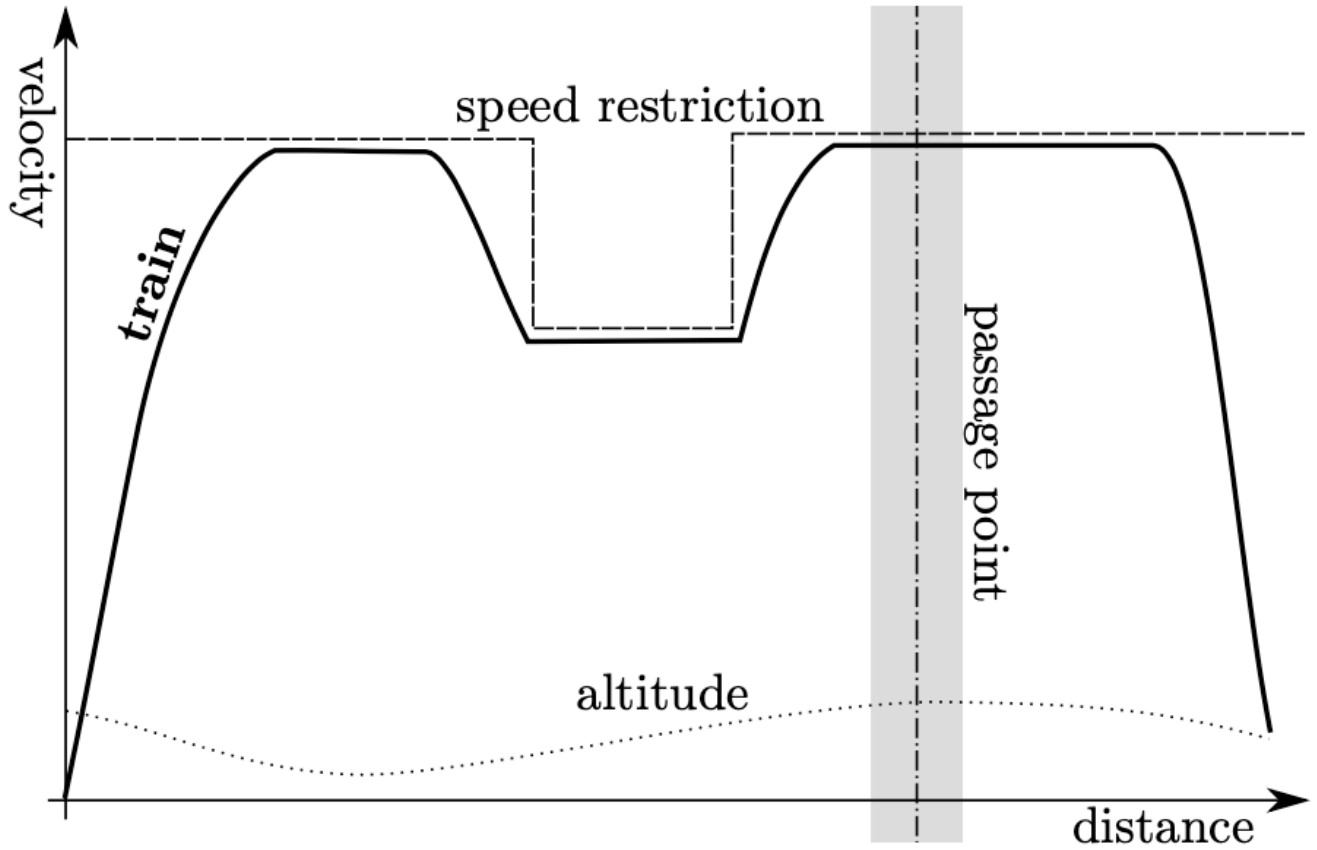
Train Speed Advisory System

TRAIN SPEED PROFILE CALCULATION

The basics

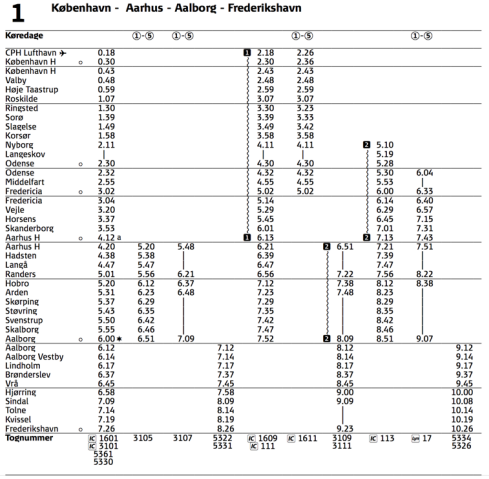
- Possible actions
  - Accelerate
  - Cruise
  - Break
  - Coast

- Minimum time
- Buffer
- Energy consumption?



REACTIVE ROBUSTNESS

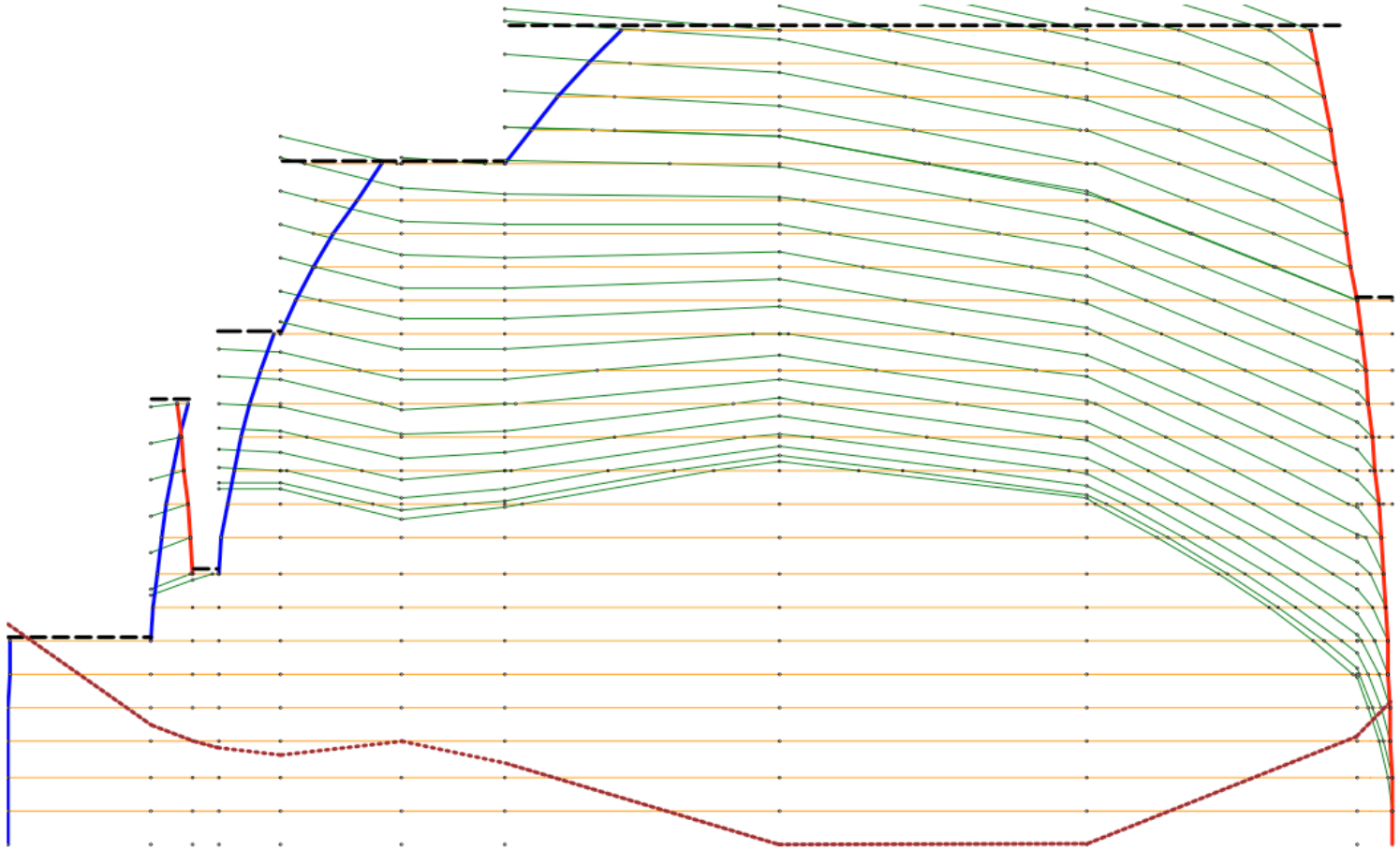
- Proactive
  - Timetable planning
    - Minimal time
    - Buffer time
- Reactive
  - In-cab recommendation
  - Unforeseen events
  - Avoiding potential problems



1 **København - Aarhus - Aalborg - Frederikshavn**

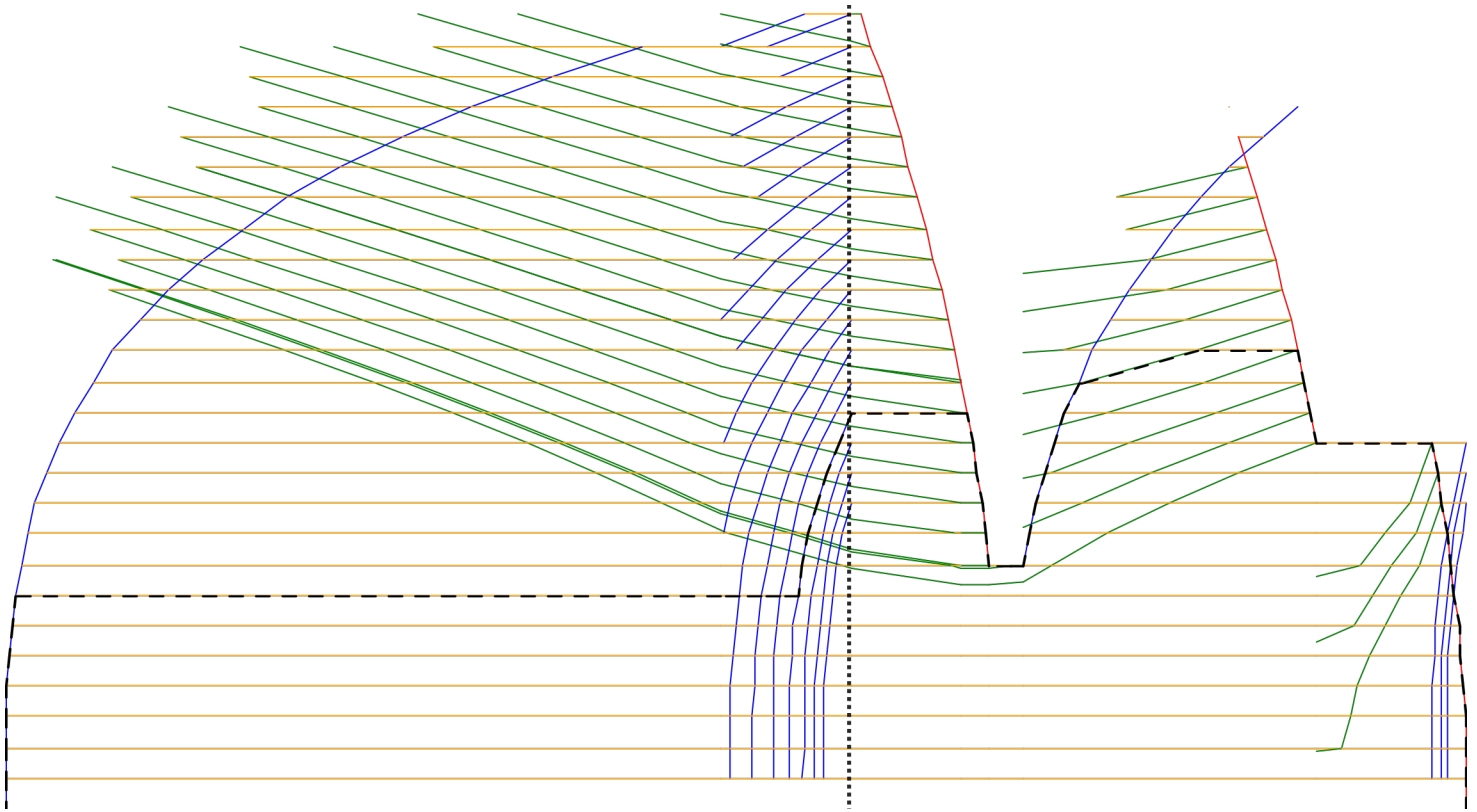
Køredage			①-⑤	①-⑤			①-⑤				①-⑤		
CPH Lufthavn ✈		0.18				1	2.18	2.26					
København H	○	0.30					2.30	2.36					
København H		0.43					2.43	2.43					
Valby		0.48					2.48	2.48					
Høje Taastrup		0.59					2.59	2.59					
Roskilde		1.07					3.07	3.07					
Ringsted		1.30					3.30	3.23					
Sorø		1.39					3.39	3.33					
Slagelse		1.49					3.49	3.42					
Korsør		1.58					3.58	3.58					
Nyborg		2.11					4.11	4.11		2	5.10		
Langeskov		|				|	|			5.19		
Odense	○	2.30					4.30	4.30			5.28		
Odense		2.32					4.32	4.32			5.30	6.04	
Middelfart		2.55					4.55	4.55			5.53	|	
Fredericia	○	3.02					5.02	5.02			6.00	6.33	
Fredericia		3.04					5.14				6.14	6.40	
Vejle		3.20					5.29				6.29	6.57	
Horsens		3.37					5.45				6.45	7.15	
Skanderborg		3.53					6.01				7.01	7.31	
Aarhus H	○	4.12 a				1	6.13			2	7.13	7.43	
Aarhus H		4.20	5.20	5.48			6.21		2 6.51		7.21	7.51	
Hadsten		4.38	5.38	|			6.39		|		7.39	|	
Langå		4.47	5.47	|			6.47		|		7.47	|	
Randers		5.01	5.56	6.21			6.56		7.22		7.56	8.22	
Hobro		5.20	6.12	6.37			7.12		7.38		8.12	8.38	
Arden		5.31	6.23	6.48			7.23		7.48		8.23	|	
Skørping		5.37	6.29	|			7.29		|		8.29	|	
Støvring		5.43	6.35	|			7.35		|		8.35	|	
Svenstrup		5.50	6.42	|			7.42		|		8.42	|	
Skalborg		5.55	6.46	|			7.47		|		8.46	|	
Aalborg	○	6.00 ●	6.51	7.09			7.52		2 8.09		8.51	9.07	
Aalborg		6.12			7.12				8.12				9.12
Aalborg Vestby		6.14			7.14				8.14				9.14
Lindholm		6.17			7.17				8.17				9.17
Brønderslev		6.37			7.37				8.37				9.37
Vrå		6.45			7.45				8.45				9.45
Hjørring		6.58			7.58				9.00				10.00
Sindal		7.09			8.09				9.09				10.08
Tolne		7.14			8.14				|				10.14
Kvissel		7.19			8.19				|				10.19
Frederikshavn	○	7.26			8.26				9.23				10.26
Tognummer		IC 1601 IC 3101 5361 5330	3105	3107	5522 5531	IC 1609 IC 111	IC 1611		3109 3111		IC 113	bus 17	5334 5526

AN EXAMPLE



AN EXAMPLE

With a passagepoint



ALGORITHM BENCHMARKS

					FP		LSA			Heuristic			
Case	Reg.	Vertices	Edges	Labels	Cost	Time	Sav	Arr.	Time	Sav	Arr.	Δ
A00	9	246	259	160	22.6	20	31.3%	-4.8	19	29.5%	1.6	1.8%
A01	26	1 122	1 606	1 490	31.9	118	16.8%	-6.7	10	13.7%	1.3	3.1%
A02	21	906	1 245	3 012	29.8	77	19.0%	-6.5	25	18.6%	1.8	0.4%
A03	17	664	866	1 237	22.6	68	17.5%	-6.3	13	17.5%	-1.0	-0.0%
A04	15	431	490	1 650	24.6	58	43.7%	5.1	3	39.3%	0.5	4.4%
A05	19	714	875	4 184	33.8	97	32.0%	-2.2	20	27.5%	1.0	4.5%
A07	5	350	488	405	27.1	15	34.9%	-3.8	84	35.6%	1.1	-0.7%
A08	3	357	511	409	33.6	15	37.1%	-5.2	36	44.3%	-0.2	-7.3%
A09	7	382	517	47	33.9	41	2.8%	-6.7	0	0.0%	-4.0	2.8%
A10	5	259	295	233	37.3	18	37.4%	-4.7	33	38.3%	0.3	-0.9%
A11	4	356	485	594	34.0	32	29.9%	-4.6	31	30.0%	0.0	-0.2%
A12	7	629	1 049	695	20.1	57	32.3%	-1.3	17	32.2%	-1.9	0.1%
A13	10	392	491	1 106	39.4	40	17.9%	-5.4	23	16.9%	-0.6	1.0%
A14	11	572	736	378	18.0	41	50.8%	-2.8	84	49.3%	1.5	1.5%
A16	3	43	40	54	12.6	6	83.8%	45.1	7	71.8%	-0.7	12.0%
Avg							32.5%			31.0%		1.5%
B00	61	5 756	8 900	112 756	46.2	1 248	50.6%	-4.5	23	38.9%	0.3	11.7%
B01	22	3 124	5 169	55 264	43.2	499	36.3%	-5.2	23	35.5%	0.9	0.8%
B02	14	2 156	3 310	60 223	44.0	426	46.1%	-5.3	86	41.4%	1.1	4.7%
B03	7	1 579	2 562	11 110	56.4	130	44.2%	-5.4	38	42.6%	1.8	1.6%
B04	7	1 040	1 508	4 181	52.3	49	42.8%	-4.0	27	42.4%	0.4	0.4%
B05	9	1 985	3 241	22 633	51.0	183	55.3%	-5.6	42	53.2%	-0.8	2.1%
B06	21	3 492	5 999	84 476	42.9	635	37.8%	-4.7	41	36.6%	-1.1	1.2%
B07	13	1 930	3 067	12 277	52.8	143	60.3%	-5.0	46	59.9%	-1.5	0.4%
B08	23	2 039	2 873	42 344	47.5	314	71.0%	-5.0	64	70.3%	1.7	0.7%
Avg							49.4%			46.7%		2.6%
C00	23	2 053	3 100	22 360	49.3	208	53.1%	-4.8	54	52.3%	-1.0	0.9%
C01	12	2 023	3 303	10 577	59.6	201	50.2%	-5.2	37	49.5%	-0.8	0.7%
C02	24	2 738	4 159	25 868	45.5	342	41.1%	-4.5	24	37.4%	-0.7	3.7%
C03	12	1 921	3 028	13 074	52.4	163	47.3%	-5.3	33	45.2%	1.7	2.0%
C04	7	1 088	1 608	2 854	50.3	51	44.3%	-4.6	30	43.3%	1.7	1.0%
C05	7	2 014	3 504	26 599	46.3	220	55.3%	-6.4	29	53.4%	1.3	1.9%
C06	13	1 643	2 404	6 311	44.9	160	35.0%	-5.6	22	39.5%	-1.5	-4.5%
C07	25	2 857	4 434	35 412	44.1	395	34.6%	-5.3	41	33.7%	0.9	0.9%
C08	57	5 842	9 356	93 436	38.1	1 143	35.7%	-5.7	36	35.2%	1.5	0.6%
Avg							44.1%			43.3%		0.8%

CONTRIBUTION

- Prototype
- Benchmarks
  - Fast response
  - Good quality
- Passage points

- Reactive Robustness

by professor David Pisinger

CONCLUSIONS

Signature Rail - User Conference

Questions and Comments

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