ETH zürich

Disruptions in railway networks

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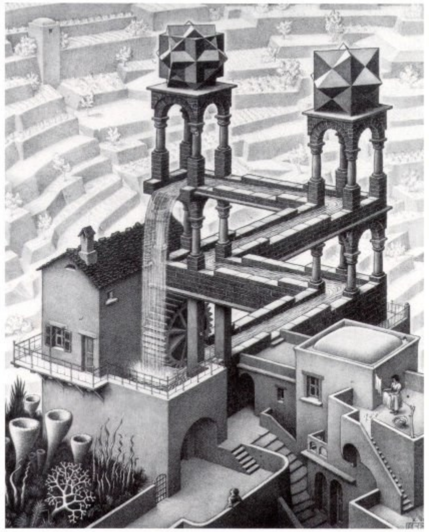
Those slides

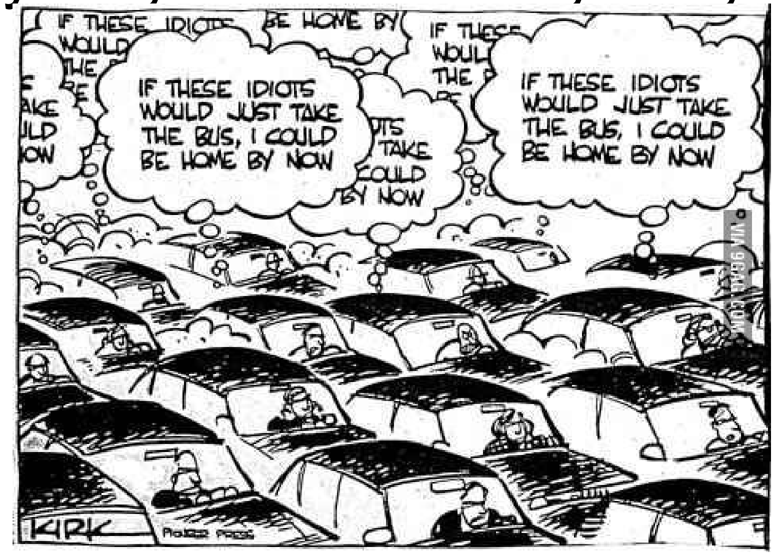
- Background on scheduling / routing
- Bad models
- Refreshing positive results from reality
- Interactions
- Understanding more about demand



Background on scheduling / routing: why railway transport is peculiar

Routing /scheduling: Interesting instances

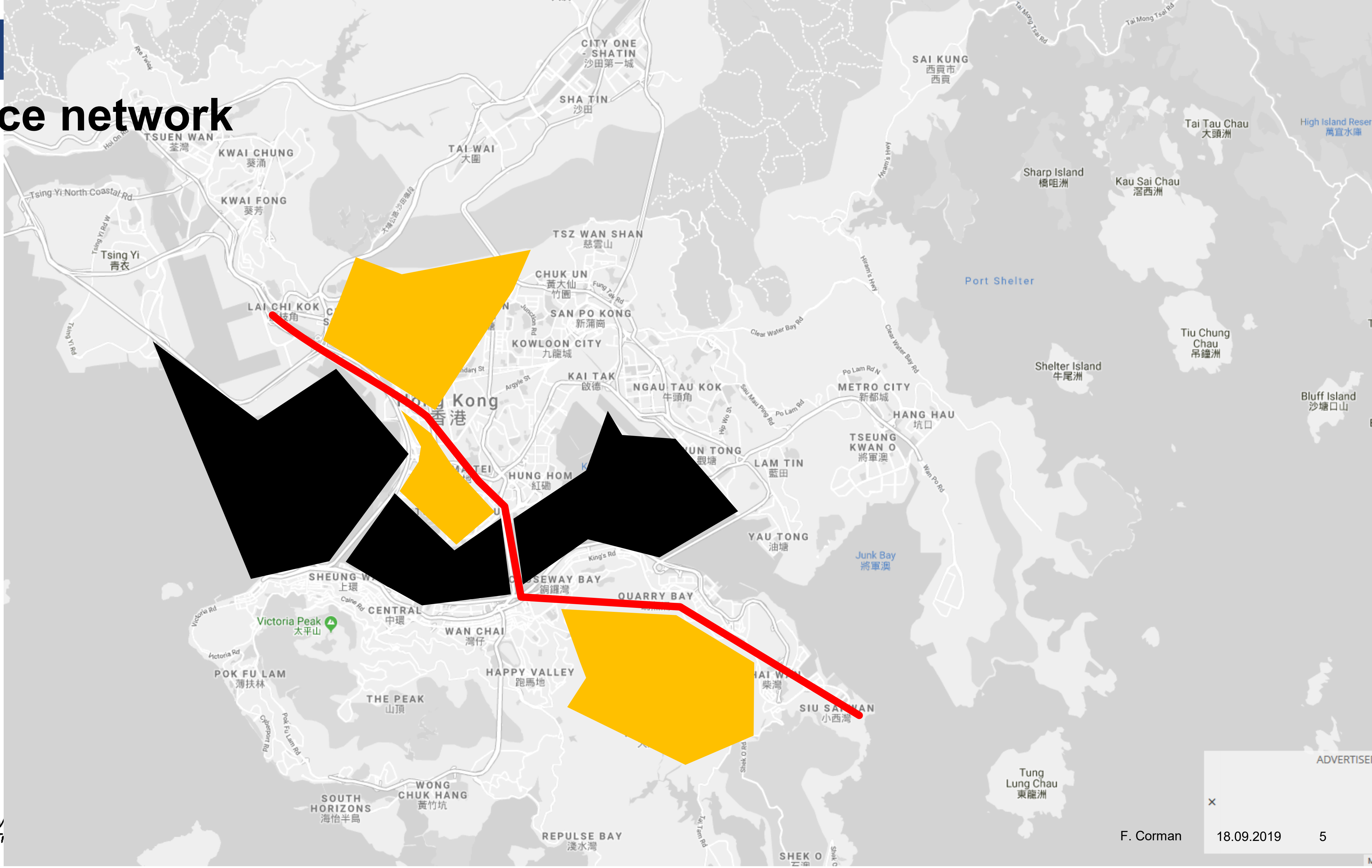
- When things are constant, and nobody influences anybody else: relatively easy
- In reality, there is some influence



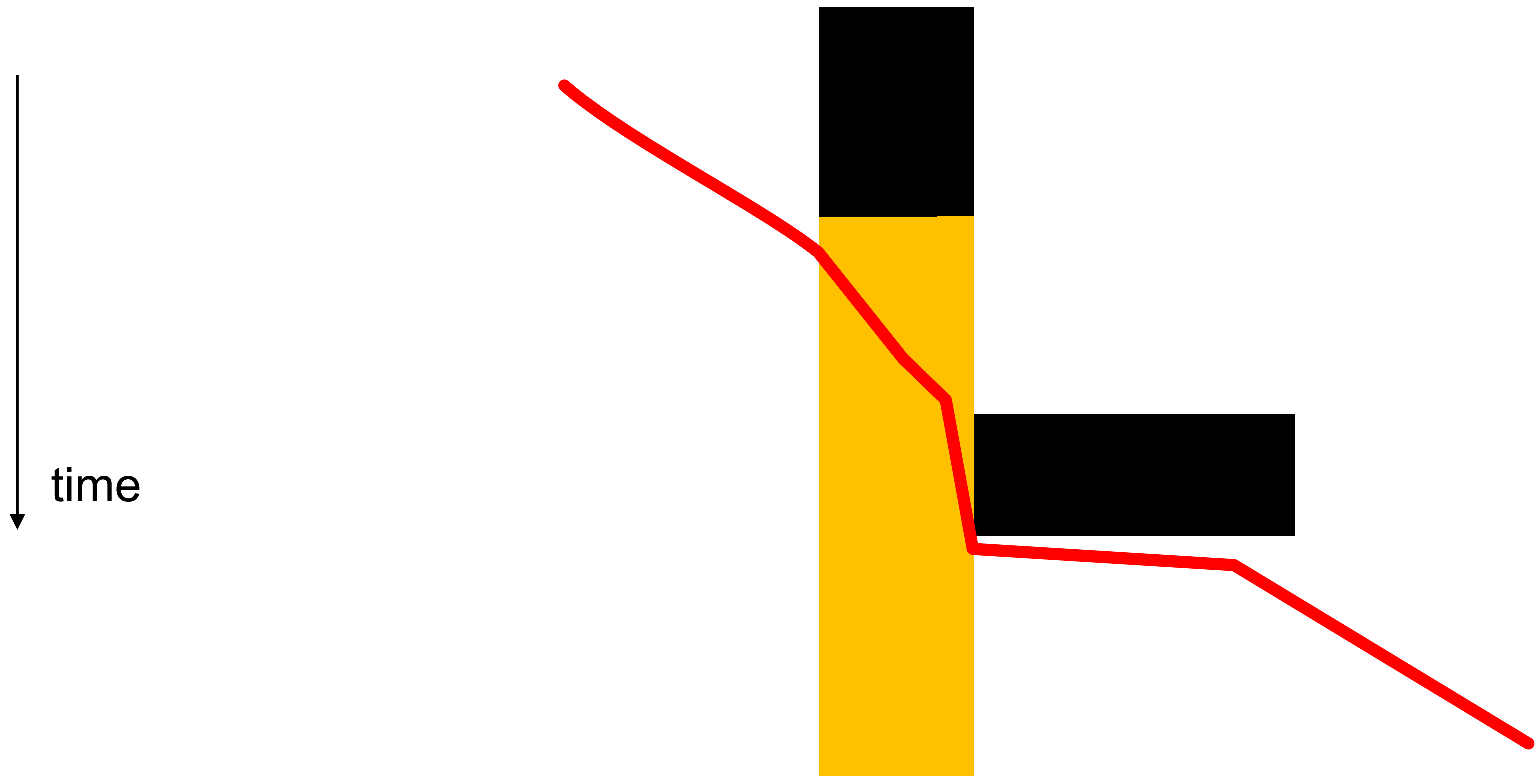
- Routing in time and space models explicitly changes over time

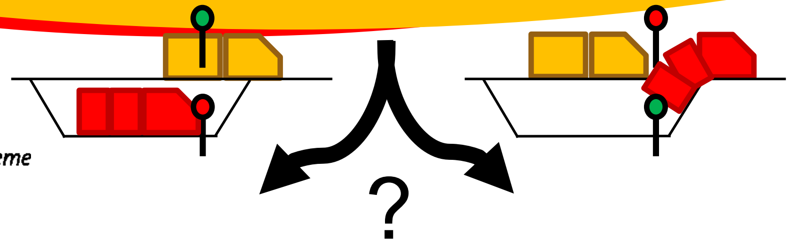
- Interesting case: When capacity of links or intersections is limited
- Opportunity: When vehicles/people can be “controlled”
- Issues: when things “interact“

A space network



An extended time space network

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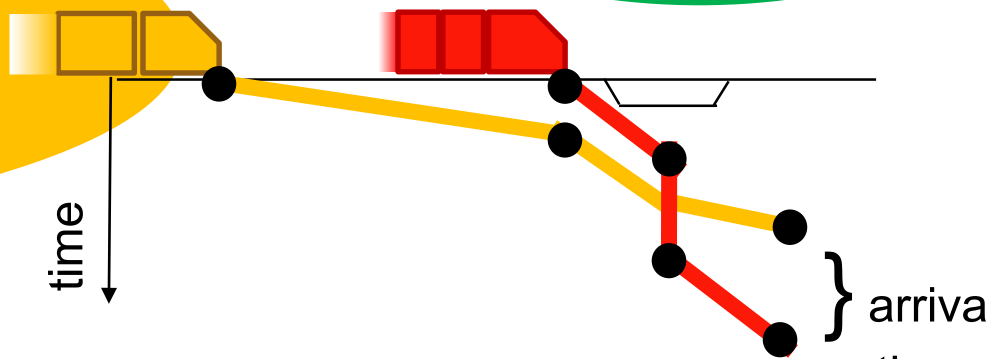
time
} arrival
time

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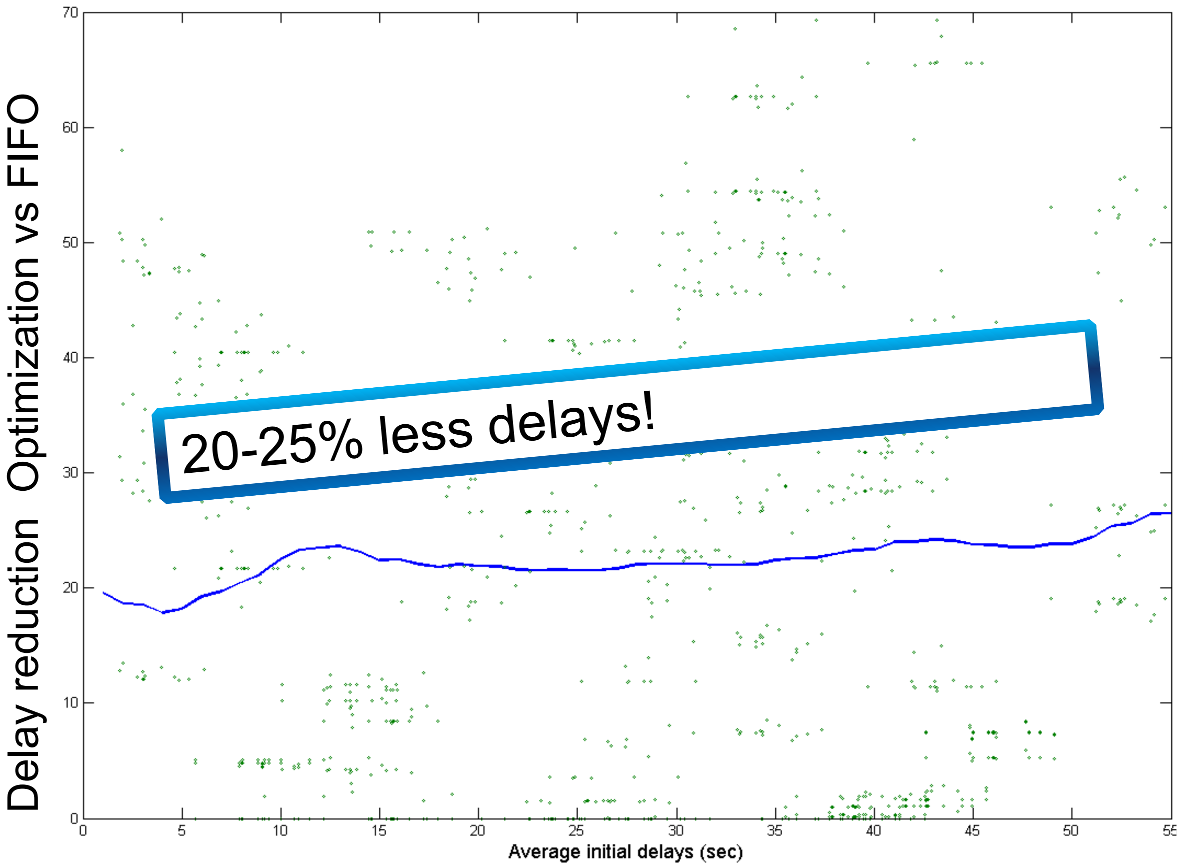
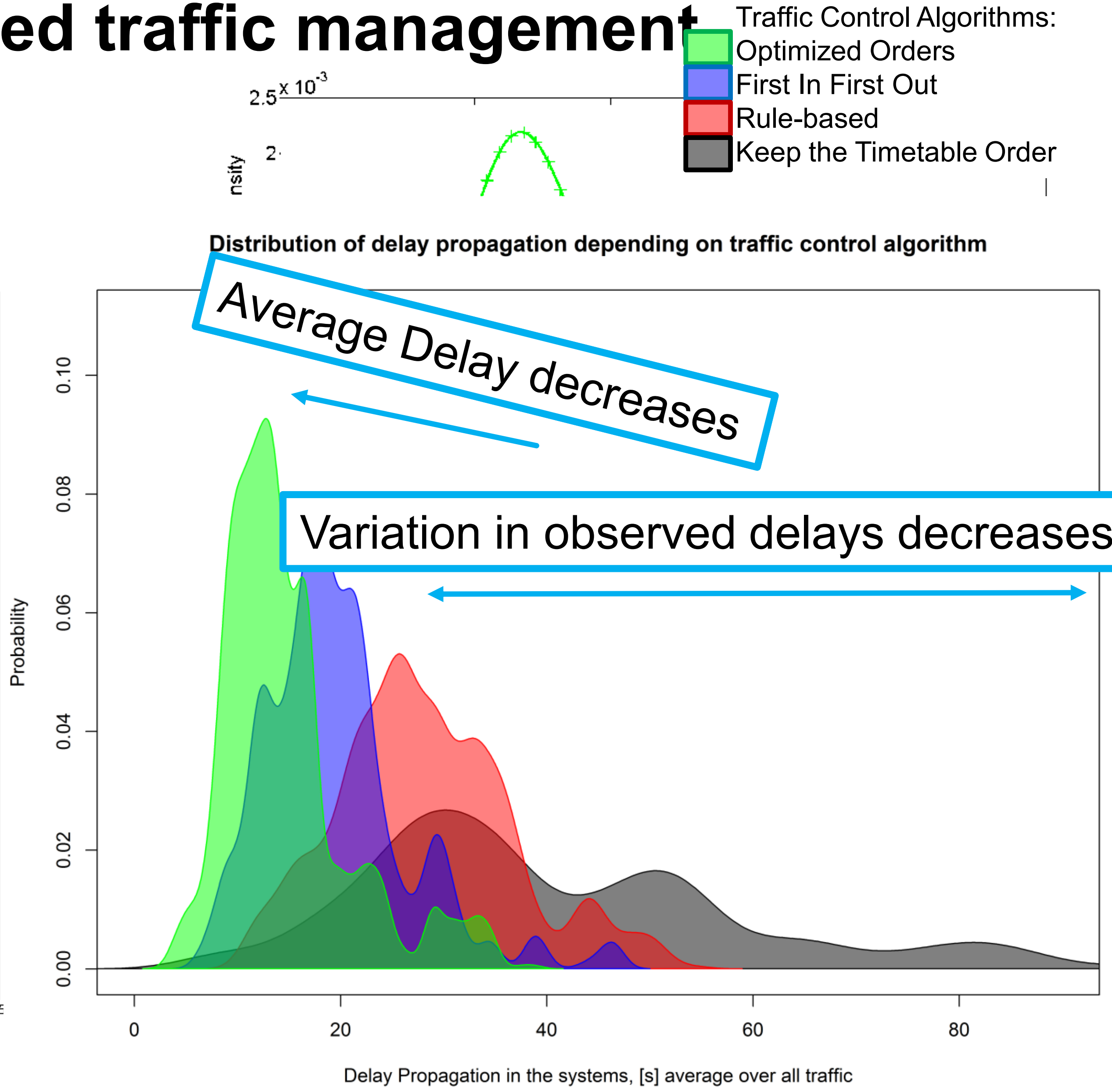
Delay minimization via optimized traffic management

2700 block sections,
150 trains / h



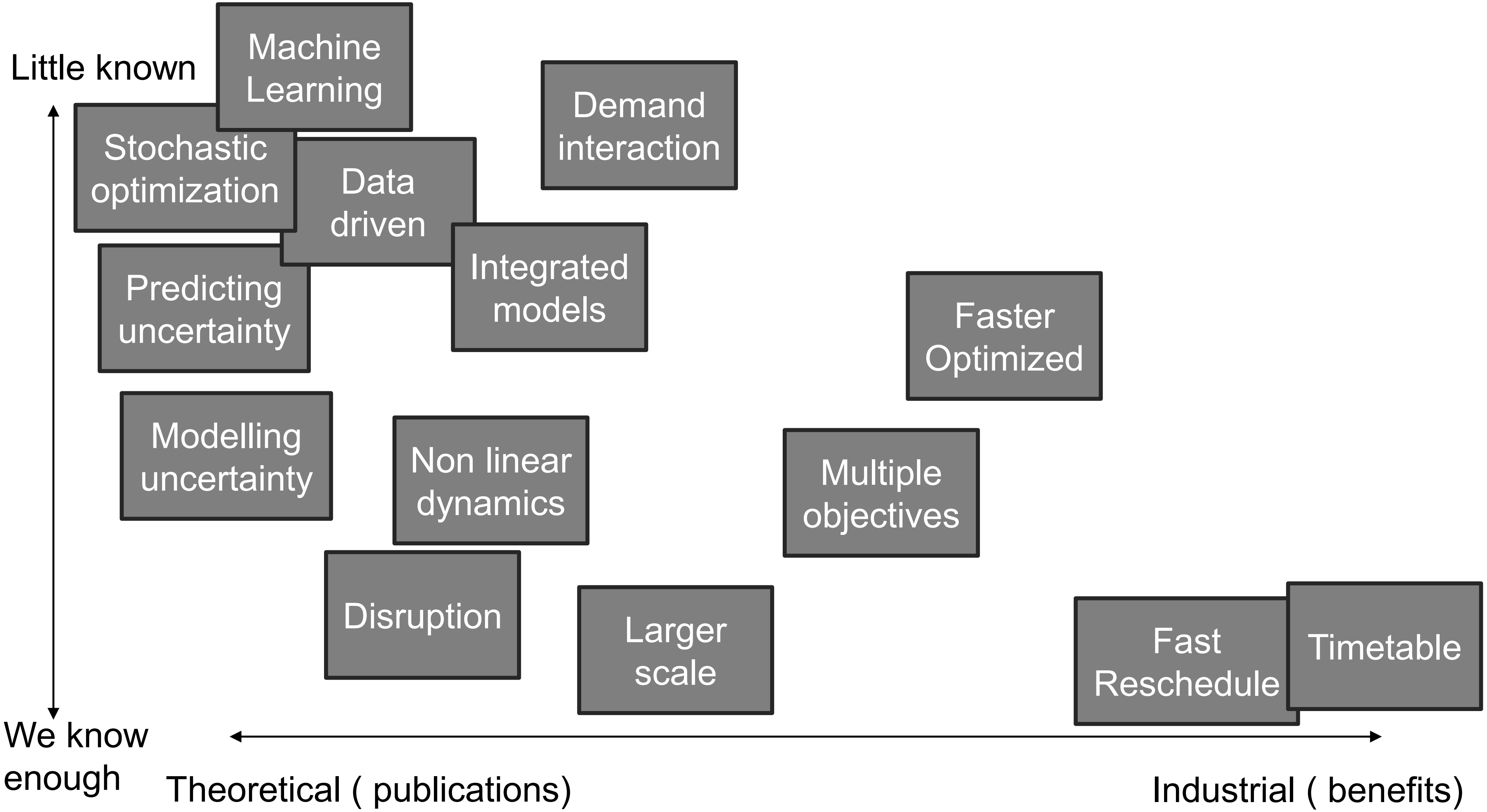


Corman D'Ariano Pacciarelli Pranzo , TR-B, TR-

State of the art in railway traffic control

- Hundreds of trains can be modelled
- For a time horizon of one hour or so
- Orders, routes and times optimally decided
- Limited inclusion of non linear effects -
  speed variations as function of the orders chosen
  passenger loads

Railway traffic management (incomplete, incorrect graph)

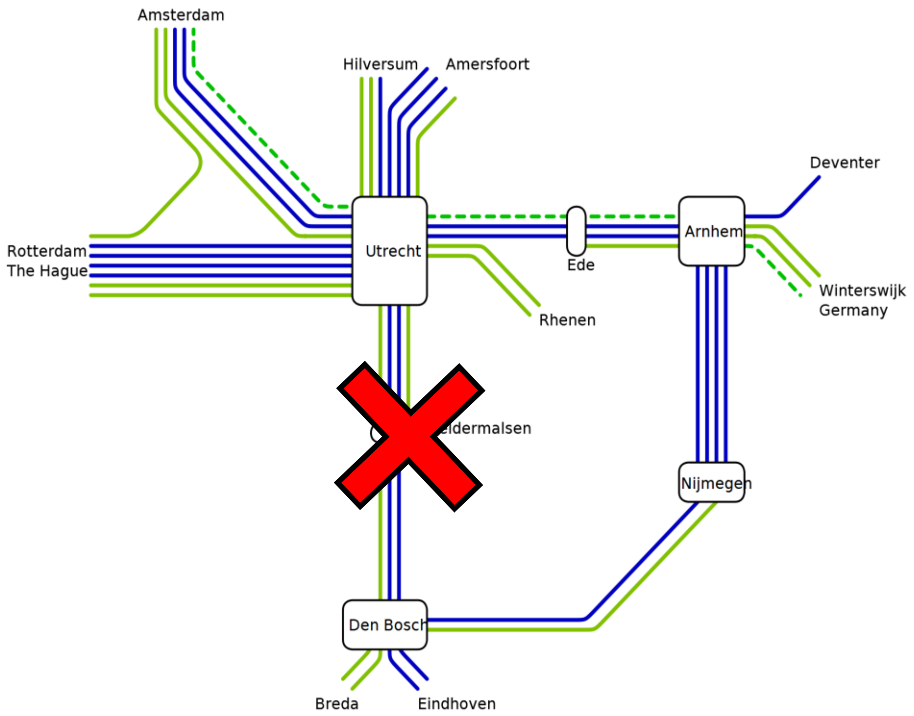


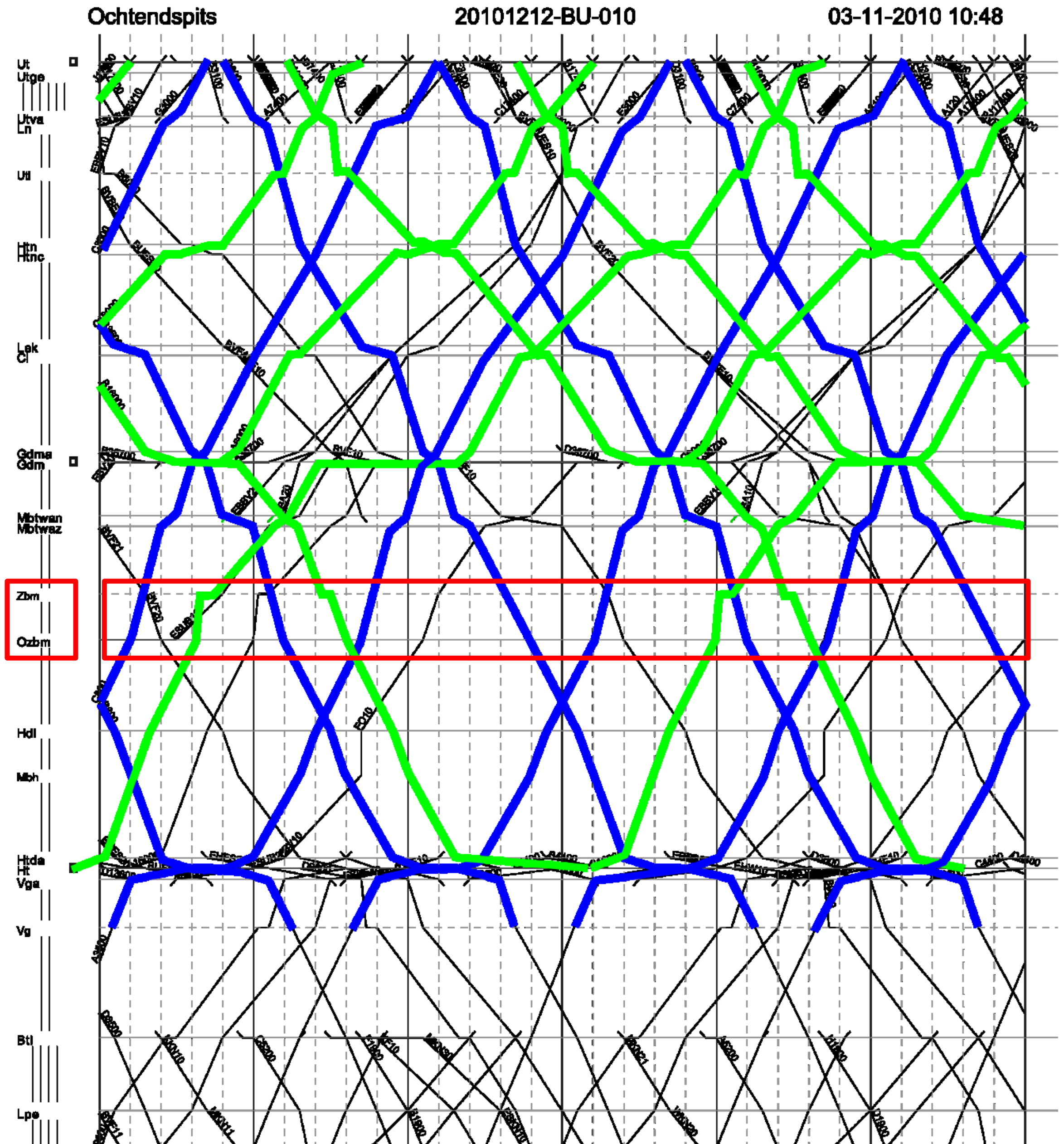
Bad Models:
How railway traffic control models apply to disruptions

F Corman, Assessment of advanced dispatching measures for recovering disrupted railway situations. Transportation Research Record

Prorail

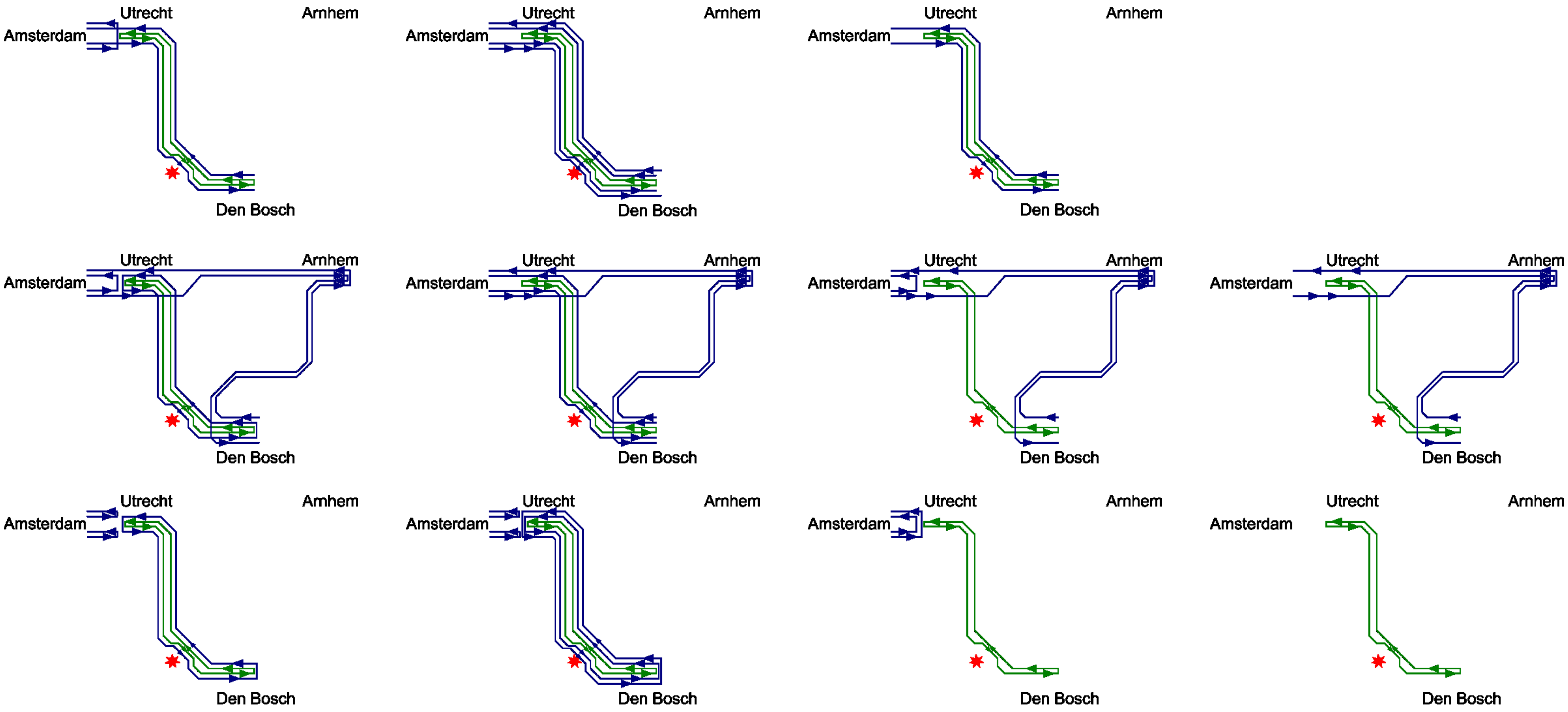
Disruption situation





Situation → Resolution → Disposition

A lot of resolution scenarios



A lot of performance indicators

Alternative	Gener Traveltime Ht→Aco	Freq Services Ht→Aco	Freq Services Ht→Ut	Gener TravelTime Ht→Ut	Gener Traveltime Ut→Aco	Freq Services Ut→Aco	Gener TravelTime Aco→Ut	Freq Services Aco→Ut	Gener Traveltime Aco→Ht	Freq Services Aco→Ht	Gener Traveltime Aco→Ht	Freq Services Aco→Ht
12_0_0	3765	6.5	4040	8	2144	15	2398	6.5	4455	4.5	3423	11.5
12+shuttle_0_0	3714	5	4057	8	3179	15	2518	6.5	7697	3.5	4010	12.5
8_4_0	3854	6.5	3844	6.5	3216	14.5	2104	6	5215	4	4704	11
8+shuttle_4_0	3839	3.5	3821	6.5	4333	15.5	2187	6	9358	2.5	5164	12.5
8 _0_4	3735	3.5	4326	5.5	3010	8.5	3153	3	5502	2	3660	7
8 _0_4+shuttle	3708	3.5	4326	5.5	2653	12	2440	6.5	6545	3.5	4028	9
8+shuttle_0_4+shuttle	3723	3.5	4592	5.5	2929	12	2518	6.5	7826	2.5	4248	8.5
4_4_4	3744	1.5	5055	3.5	5014	8.5	3390	2	7175	0.5	4370	4.5
4_4_4+shuttle	3719	1.5	5055	3.5	3828	12.5	2187	6	8194	1	4706	5.5
4_0_8	4000	0	4000	2	4000	0	4000	0	4000	0	5000	1.5
4_0_8+shuttle	3750	1	5471	2	2424	9	2518	6.5	8776	1.5	5592	4.5
TIMETABLE REF	3672	7	3589	8	2840	14	2540	6.5	4294	4.5	3228	11.5

A lot of performance indicators

Alternative	Average Total Delay (s)	Max Total Delay (s)	Average Consecutive Delay (s)	Max Consecutive Delay (s)	Punctuality 5 min (% of running trains)	Canceled trains (absolute number)	Capacity occupation, Ht←→Ut	Extra Units compared to plan
12_0_0	43.8998	510	21.2463	510	94.73684	0	1.231	0
12+shuttle_0_0	43.258	510	21.0339	510	95.83333	0	1.242	8
8_4_0	98.8813	1739	67.4402	1206	88.88889	0	1.143	4
8+shuttle_4_0	96.73	1739	65.6454	1206	89.16667	0	1.154	8
8_0_4	37.2391	510	14.6082	510	97.22222	4	0.959	-4
8 _0_4+shuttle	37.1944	510	14.4421	510	97.2973	4	0.948	0
8+shuttle_0_4+shuttle	36.7468	510	14.2366	510	96.49123	4	0.948	4
4_4_4	56.6107	1739	24.9972	1206	92.79279	4	0.948	0
4_4_4+shuttle	56.818	1739	25.2173	1206	92.98246	4	0.948	4
4_0_8	28.668	510	6.70236	510	100	8	0.959	-4
4_0_8+shuttle	29.3327	510	6.78802	510	100	8	0.959	0
TIMETABLE REF	26.8934	510	5.81801	510	100	0		0

Comparing them

?

Alternative	Average Total Delay (s)	Max Total Delay (s)	Average Consecutive Delay (s)	Max Consecutive Delay (s)	Punctuality 5 min (% of running trains)	Canceled trains (absolute number)	Capacity occupation, Ht←→Ut	Extra Units compared to plan	Gener Traveltime Ht→Aco	Freq Services Ht→Aco	Freq Services Ht→Ut	Gener TravelTime Ht→Ut	Gener Traveltime Ut→Aco	Freq Services Ut→Aco	Gener TravelTime Aco→Ut	Freq Services Aco→Ut	Gener Traveltime Aco→Ht	Freq Services Aco→Ht	Gener Traveltime Aco→Ht	Freq Services Aco→Ht
12_0_0	43.8998	510	21.2463	510	94.73684	0	1.231	0	3765	6.5	4040	8	2144	15	2398	6.5	4455	4.5	3423	11.5
12+shuttle_0_0	43.258	510	21.0339	510	95.83333	0	1.242	8	3714	5	4057	8	3179	15	2518	6.5	7697	3.5	4010	12.5
8_4_0	98.8813	1739	67.4402	1206	88.88889	0	1.143	4	3854	6.5	3844	6.5	3216	14.5	2104	6	5215	4	4704	11
8+shuttle_4_0	96.73	1739	65.6454	1206	89.16667	0	1.154	8	3839	3.5	3821	6.5	4333	15.5	2187	6	9358	2.5	5164	12.5
8_0_4	37.2391	510	14.6082	510	97.22222	4	0.959	-4	3735	3.5	4326	5.5	3010	8.5	3153	3	5502	2	3660	7
8 _0_4+shuttle	37.1944	510	14.4421	510	97.2973	4	0.948	0	3708	3.5	4326	5.5	2653	12	2440	6.5	6545	3.5	4028	9
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4_0_8+shuttle	29.3327	510	6.78802	510	100	8	0.959	0	3750	1	5471	2	2424	9	2518	6.5	8776	1.5	5592	4.5
TIMETABLE REF	26.8934	510	5.81801	510	100	0		0	3672	7	3589	8	2840	14	2540	6.5	4294	4.5	3228	11.5

Disruption management is complex

- Models can help, …

- if you know which solutions would be acceptable (automatic scenario generation?)
- if you know which constraints exist (better model, more integration)
  If you know how dispatcher would take decisions (?)
- If you know how passengers would react

- Statistics cannot help
- More integration/optimization make smaller problems disappear, bigger problems arise

Some positive thoughts, when we measure the wrong thing

T Partl, Master Thesis ETH

wikimedia

Rastatt

- Disruption for about two months, 15.08 to 02.10 2018. No traffic.

DB

Rastatt

- European corridor Rotterdam Genoa

SBB

Local cancellations lead to few cancellations in Switzerland

- Cancel train
- Buses, passengers

- Freight? (not analysed)

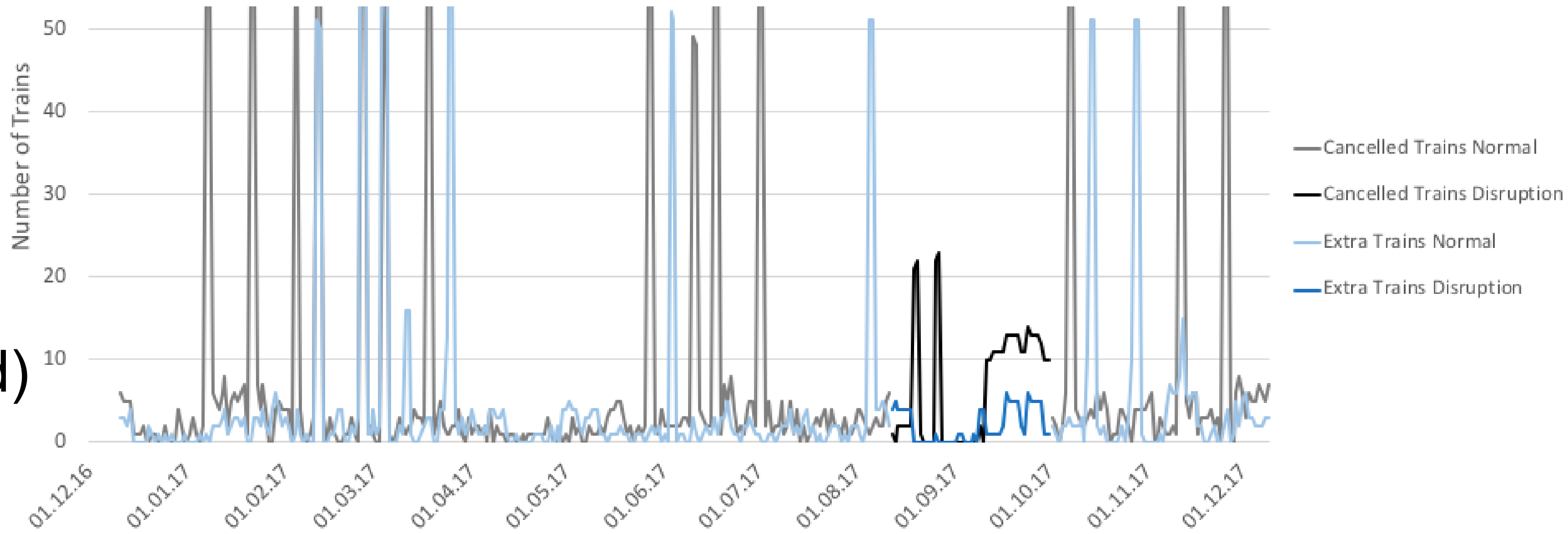
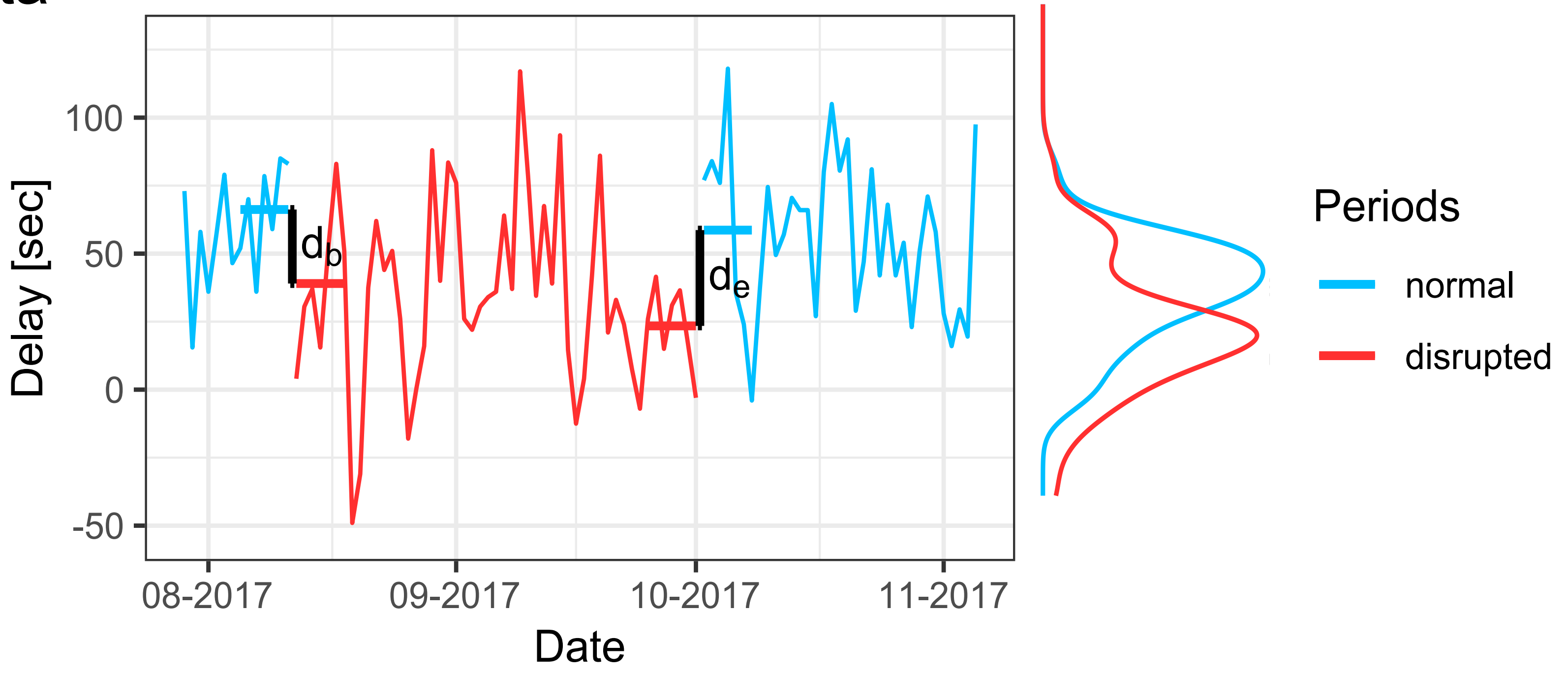


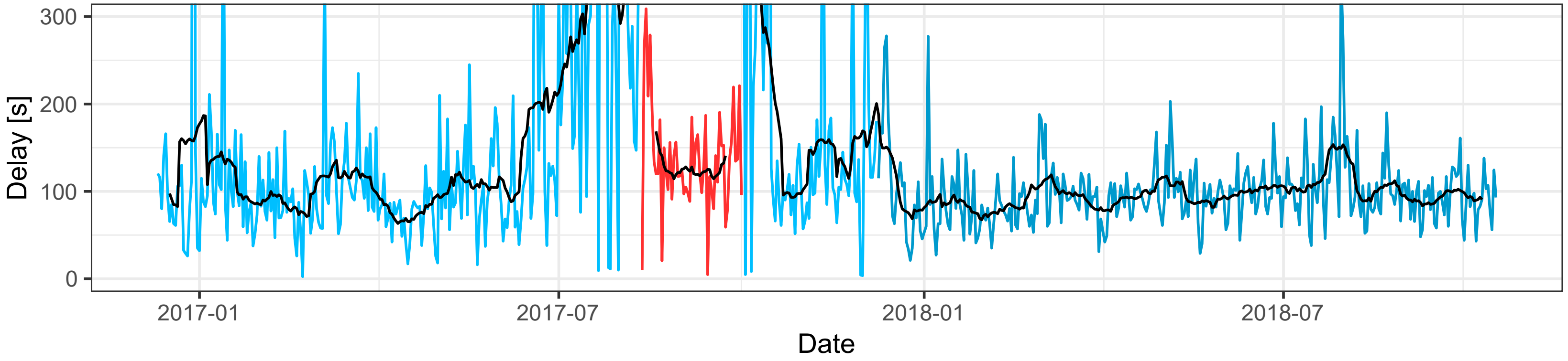
Figure 7: Numbers of extra and cancelled trains arriving at Zurich HB and Olten

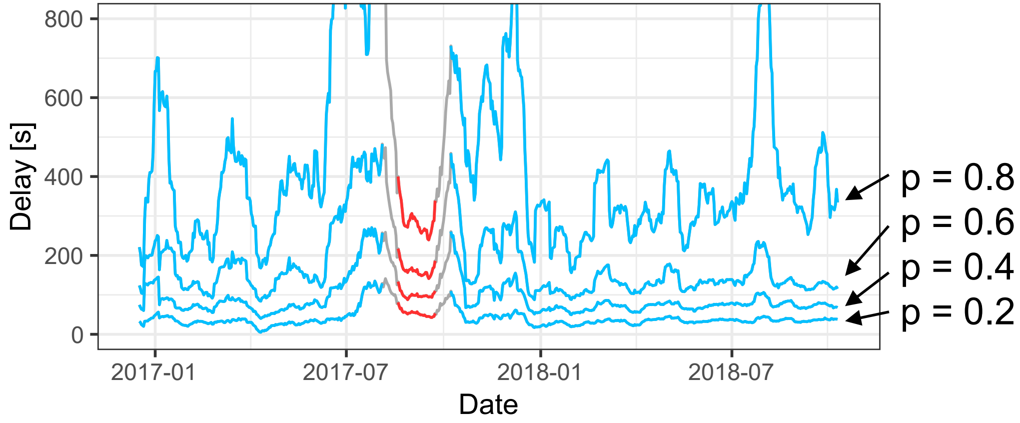
How to compare operations before / during disruptions

- Compare distributions,
  looking for jumps at beginning/ end of disruption
  through one year of data



Primary delays: Trains coming from Germany

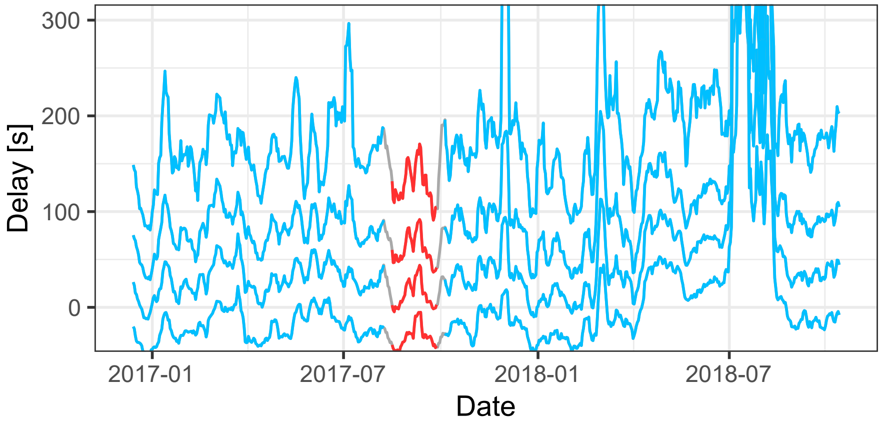




p	l_1	l_2	p-value KS-test	p-value t-test
0.2	0.86	0.80	7.2×10^{-3}	8.9×10^{-16}
0.4	0.80	0.93	2.4×10^{-6}	1.8×10^{-21}
0.5	0.81	0.93	1.2×10^{-6}	6.5×10^{-25}
0.6	0.79	0.95	3.6×10^{-7}	7.7×10^{-25}
0.8	0.64	0.70	2.0×10^{-9}	1.3×10^{-24}

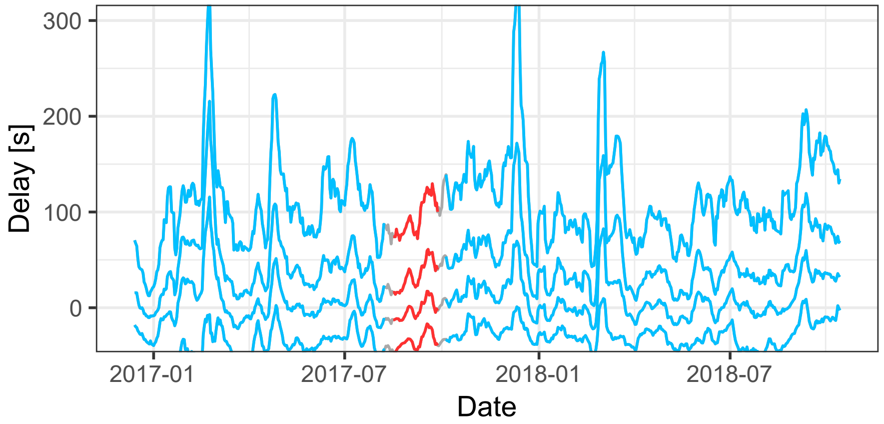
Secondary delays: indirect network effects

Indirectly affected: Olten & Zürich HB



p	l_1	l_2	p-value KS-test	p-value t-test
0.2	0.71	0.90	2.3×10^{-2}	2.9×10^{-3}
0.4	0.93	0.99	1.6×10^{-3}	1.8×10^{-7}
0.5	0.88	0.88	6.8×10^{-5}	2.2×10^{-7}
0.6	0.84	0.74	7.1×10^{-4}	2.4×10^{-7}
0.8	0.88	0.90	4.3×10^{-3}	1.6×10^{-9}

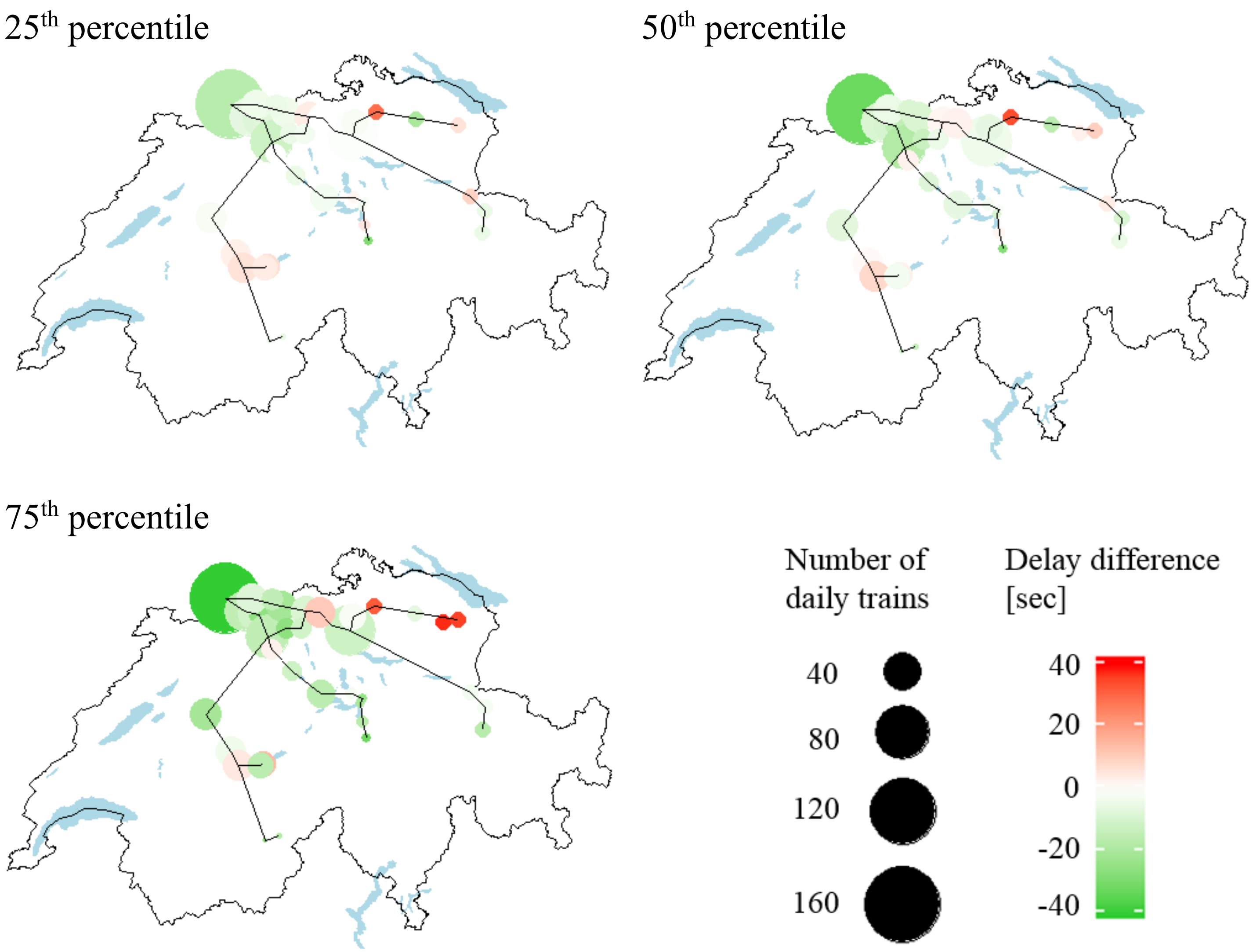
Unaffected: Yverdon & Fribourg / Freiburg



p	l_1	l_2	p-value KS-test	p-value t-test
0.2	0.70	0.80	4.7×10^{-2}	2.8×10^{-3}
0.4	0.71	0.31	2.6×10^{-1}	3.4×10^{-2}
0.5	0.59	0.32	4.1×10^{-1}	1.5×10^{-1}
0.6	0.60	0.49	8.0×10^{-2}	3.5×10^{-1}
0.8	0.58	0.15	6.1×10^{-2}	1.9×10^{-2}

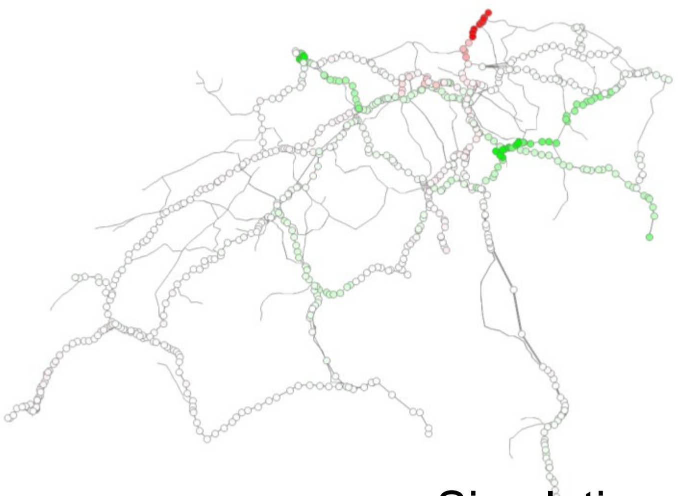
Disruptions are good, if we measure the wrong things

- Clear effect of isolation of network → less delays
- Locally outsourcing delays to passengers
- Globally observing network dynamics



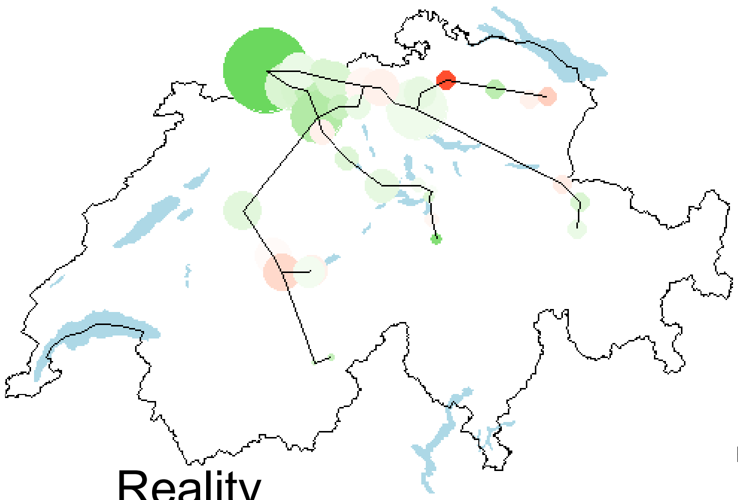
Ongoing work: replicate the dynamics in simulation models

- Challenges: real life dynamics, all possible sources of delays appear; the system changed, as a reaction to the disruption
- Unique opportunity: empirically see the performance of a railway network from a statistical point of view, over a large shock in some of its characteristics
- Quantify delay impact of factors

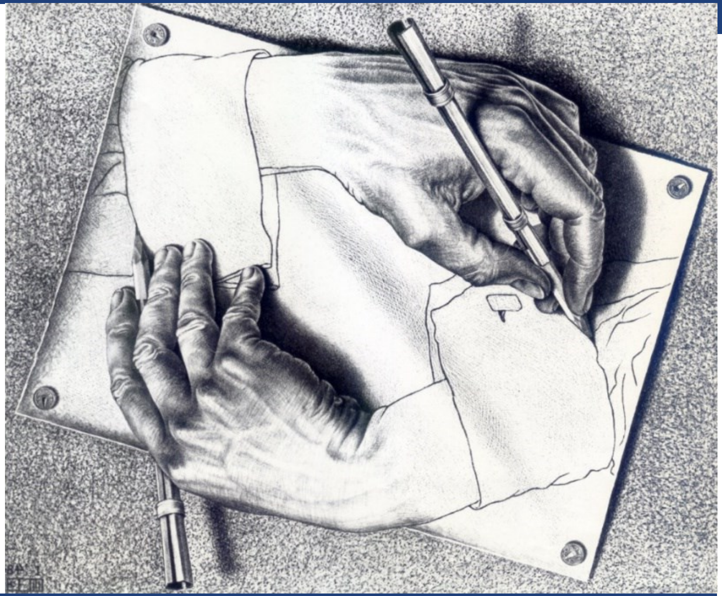


Simulation

50th percentile



Reality



Interaction modelling

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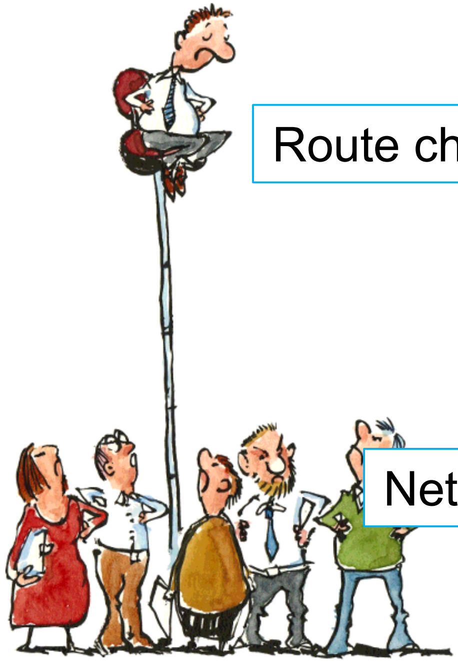
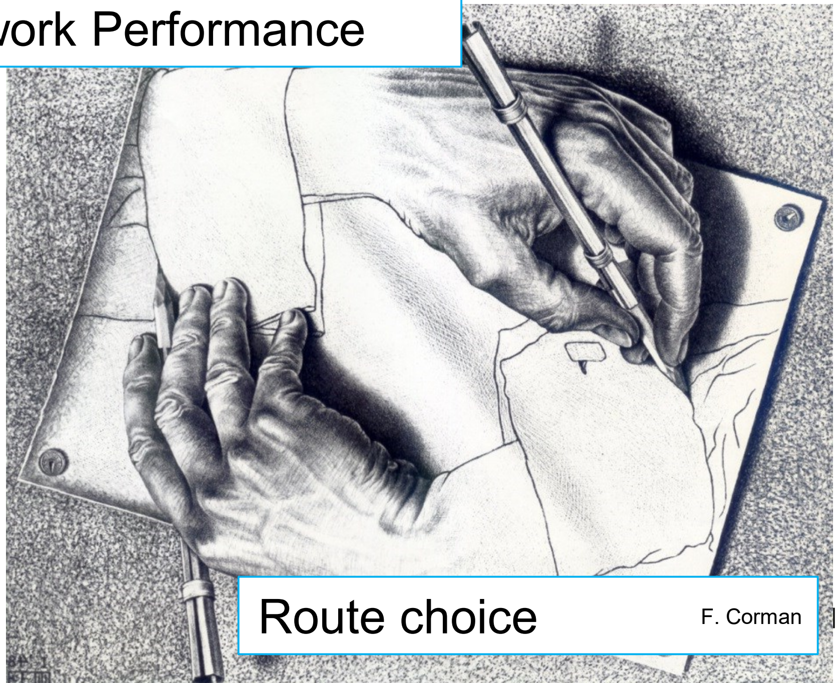
Passengers Routing in public transport networks

- Divide hierarchically into layers
  post process, simulate, adjust
- Equal importance given to problem: iterate coordinate, converge





escher

Schedule-based Transit assignment

Knowing passengers demand per time

Routing of passengers is based on shortest travel time

Vehicles (trains) have infinite passengers capacity

(relatively strong assumptions!)

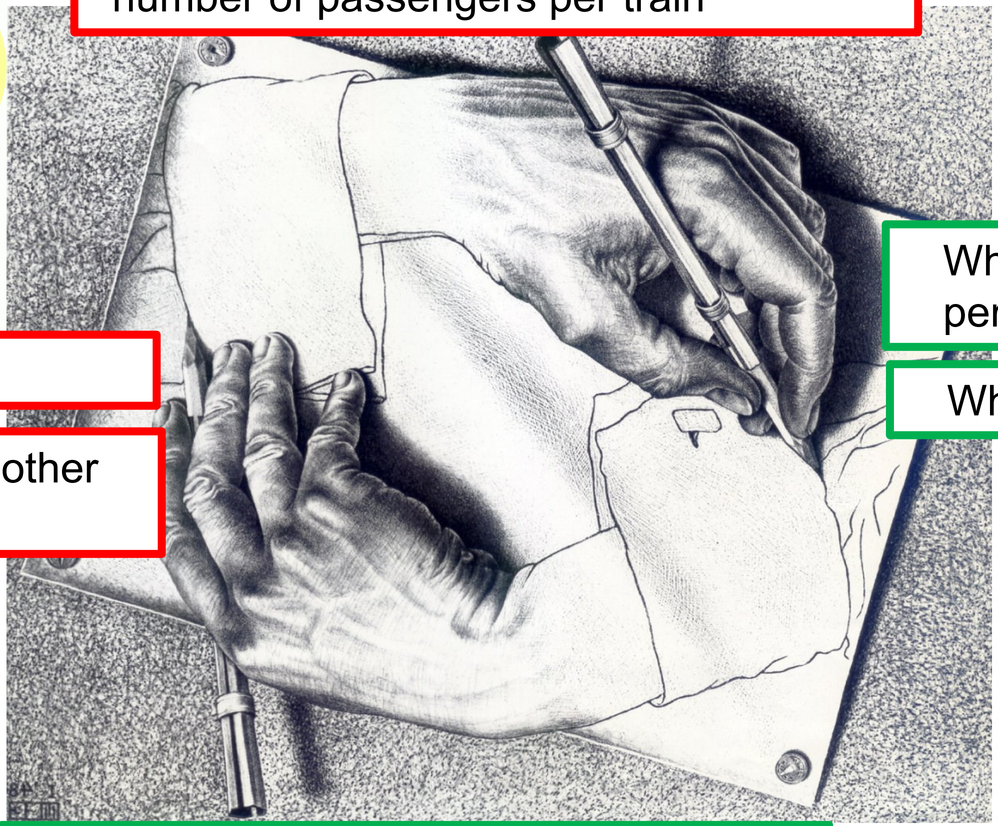
Schedule-based assignment → min cost flow problem

Interaction

scheduling trains in an infrastructure with limited capacity, taking into account the number of passengers per train

What will I do?

What I believe the other person would do



What I believe the other person would do

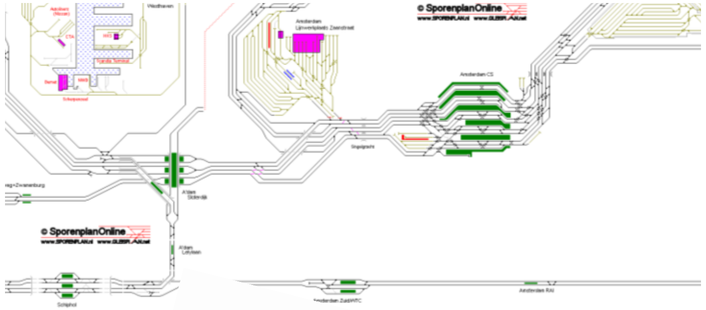
What will I do?

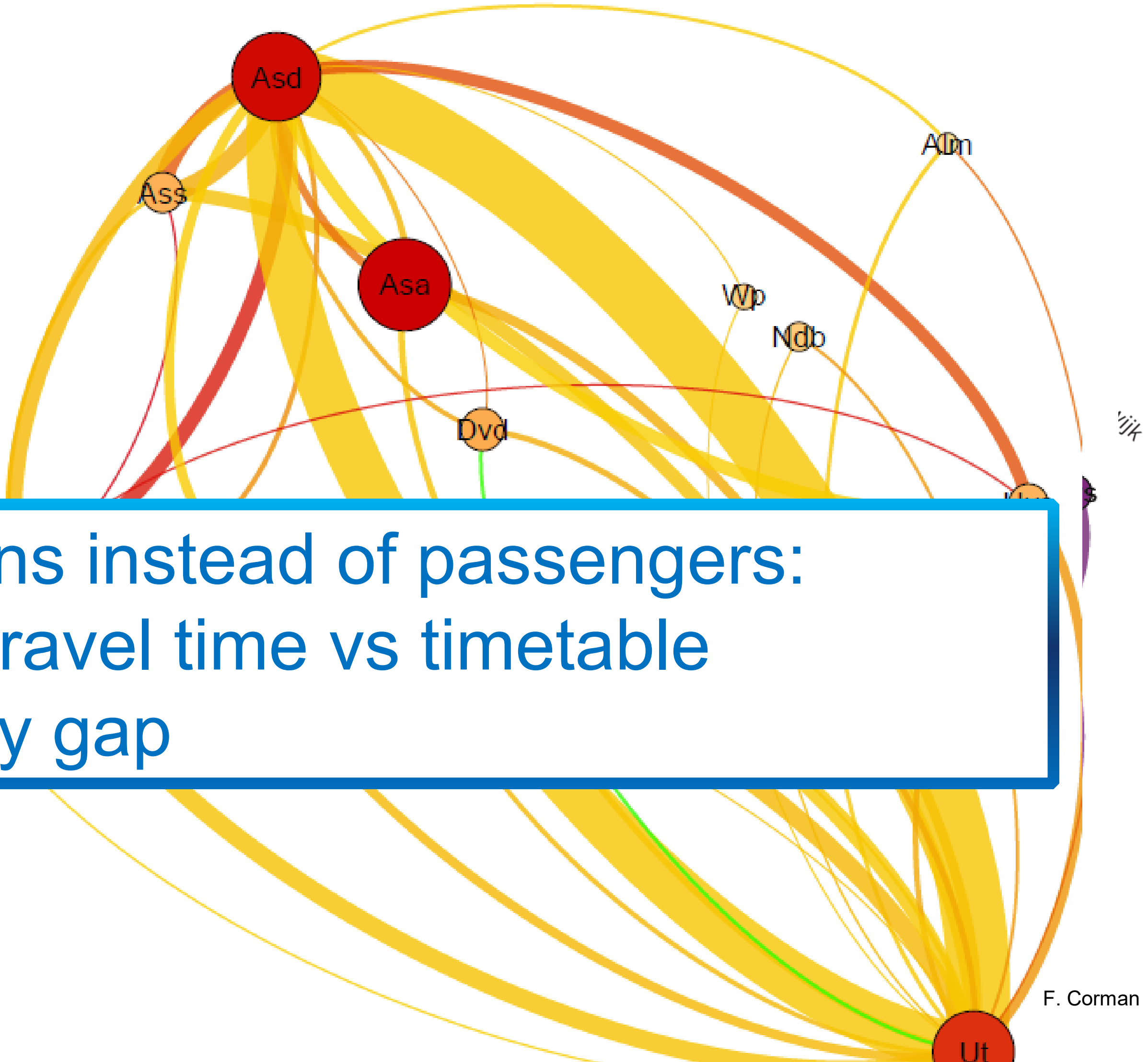
routing of passengers by taking into account the train schedule, their origin and destination, the minimization of their discomfort

Possible solutions –who does what, why?

- Optimize everything (integrated model) ~System optimum
- Minimize delay weighted by passengers;
  Passengers react to schedule,
  trains react to passengers choice ~Nash
- Keep the timetable order; or optimize schedule
  Passengers adjust route choices ~Inv. Stackelberg
- Passengers publish their choices / cost functions;
  optimize schedule to minimize travel time ~Stackelberg

Upper bound to optimum





Delaying trains instead of passengers:
12% shorter travel time vs timetable
11% optimality gap

Corman D'Ariano Pacciarelli Marra Samà TR-Part E 2016

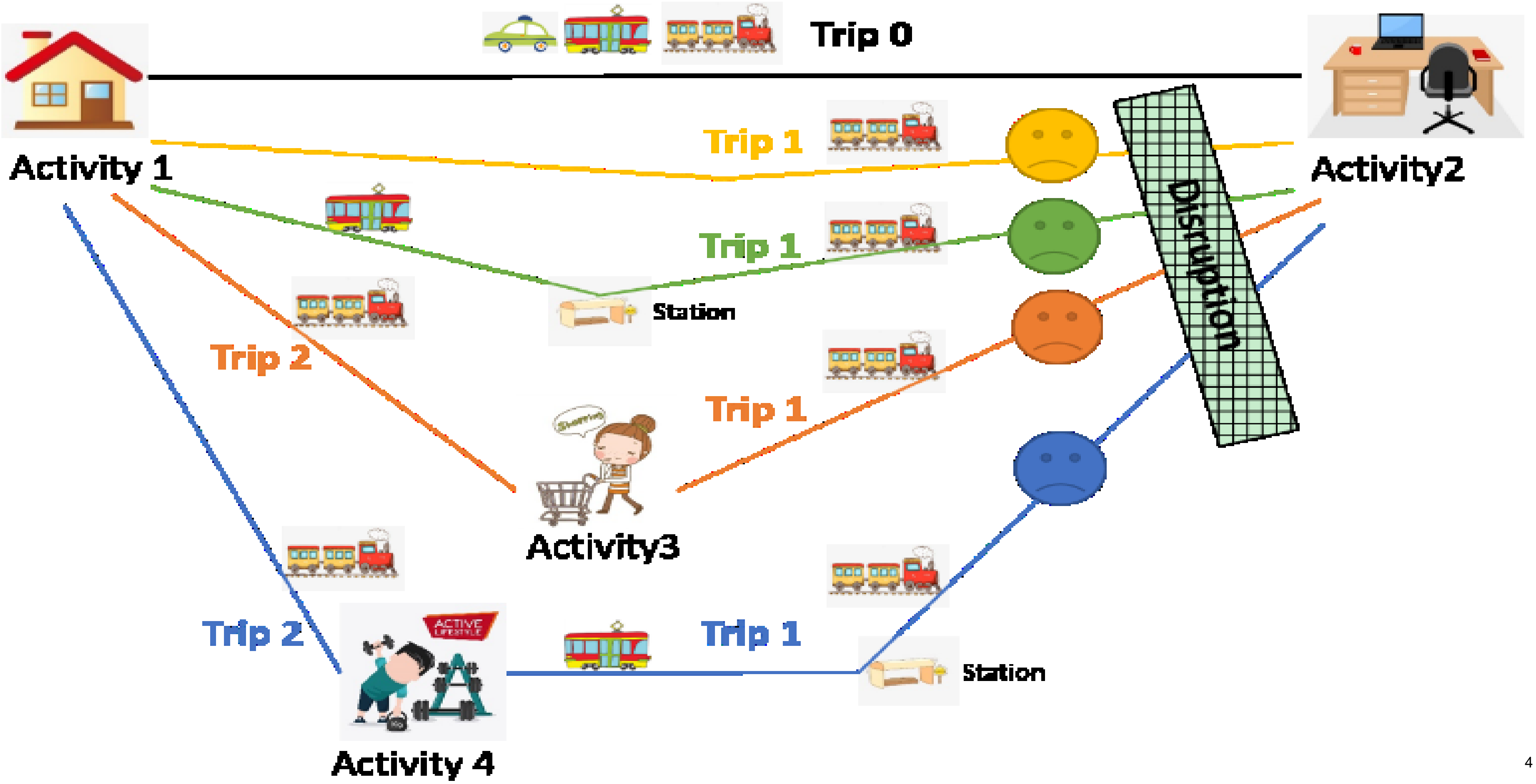
Larger/better models:
How to include demand in our models

N. Leng, Agent-based simulation approach for disruption management in rail schedule , CASPT

A, Marra, Multimodal passive tracking of passengers to analyse public transport use, STRC

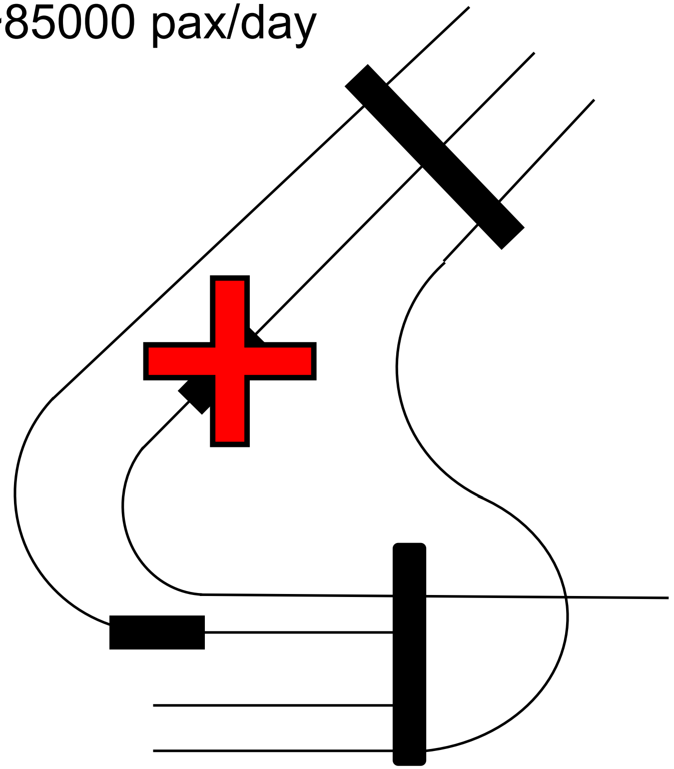
flickr

A larger perspective onto activities: agent based simulation

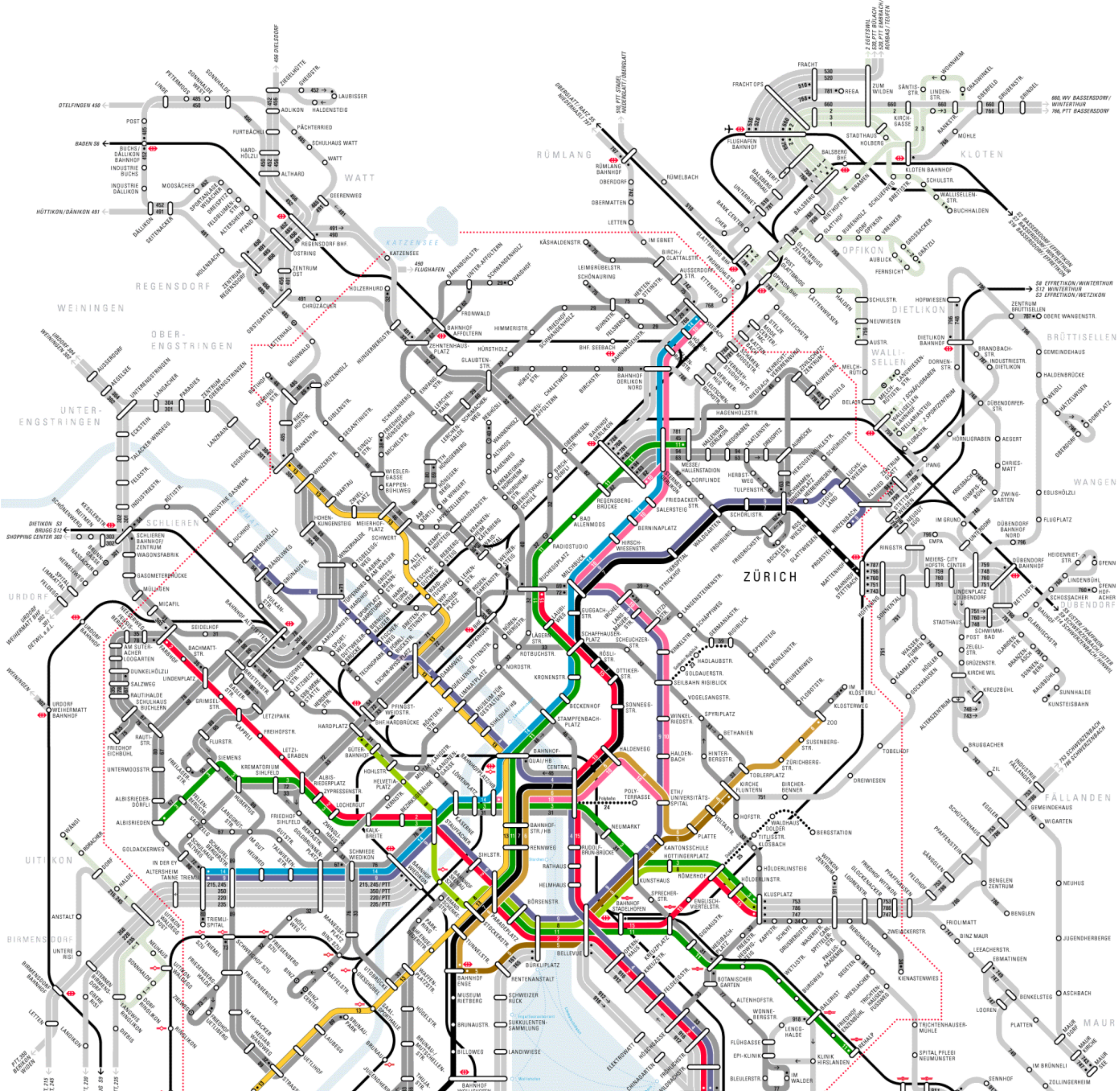


Example disruption, Zurich

Oerlikon
~300 trains/ day
~85000 pax/day

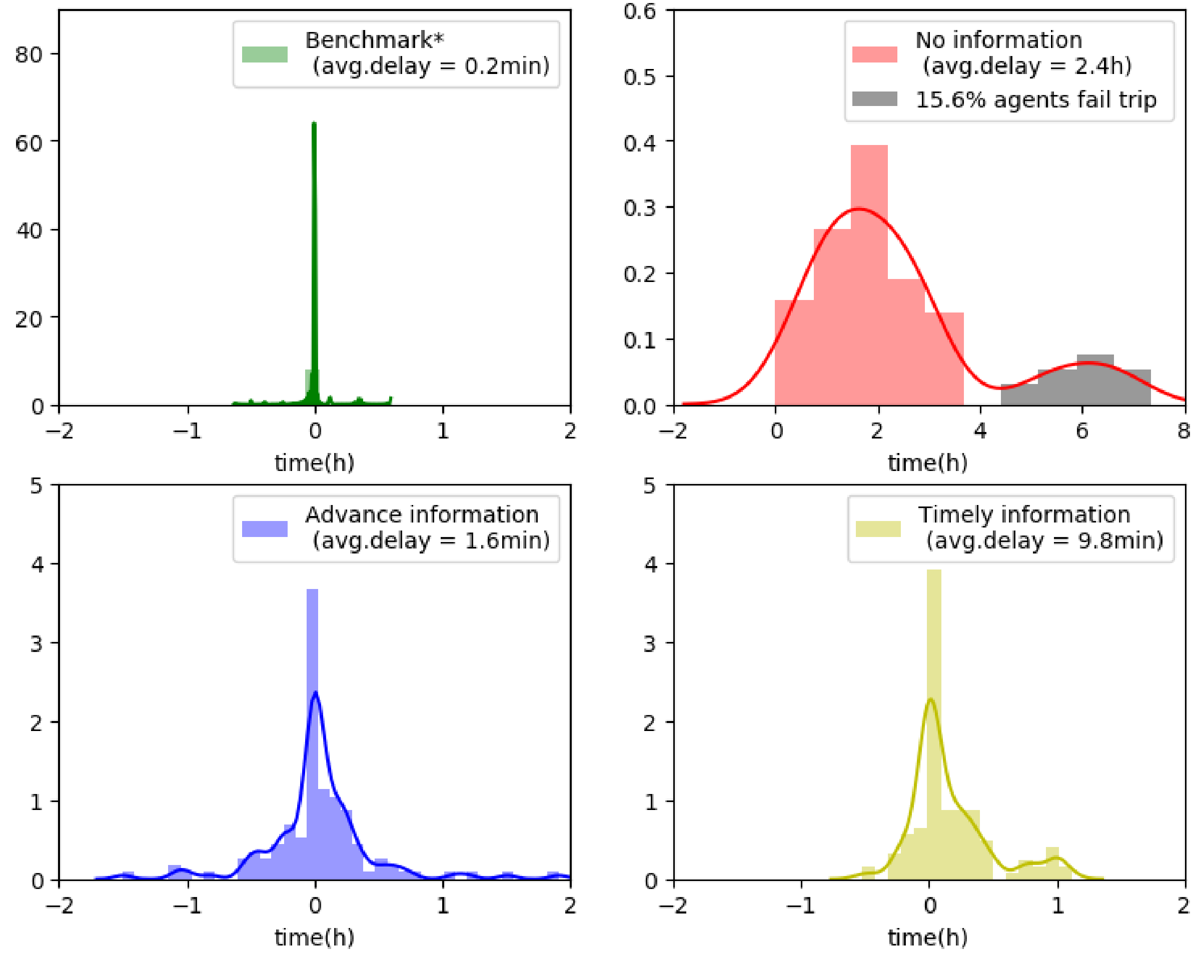


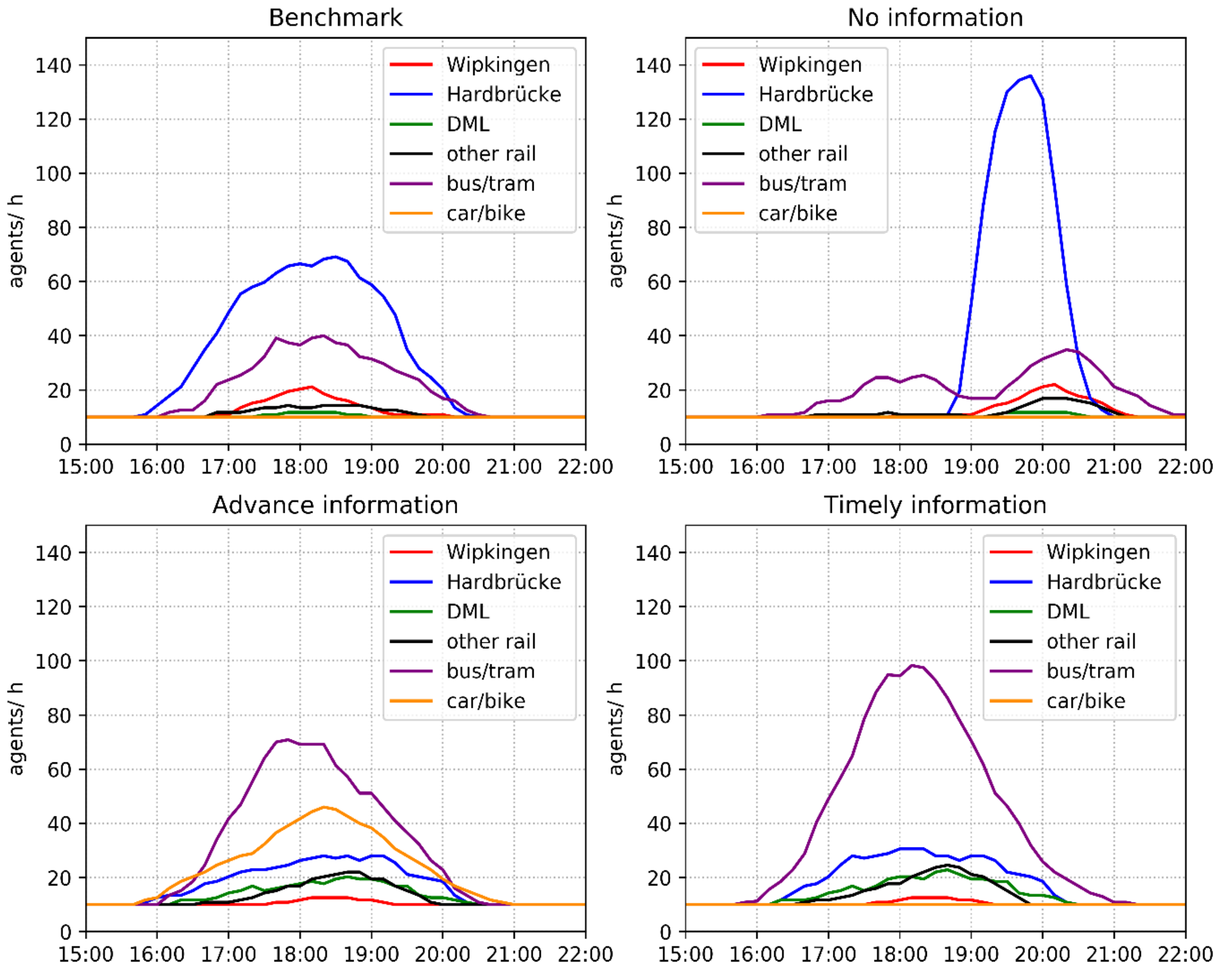
Main station
~2900 trains/ day,
450000 pax/ day



VBZ

Comparison of the cases: delays, mode usage





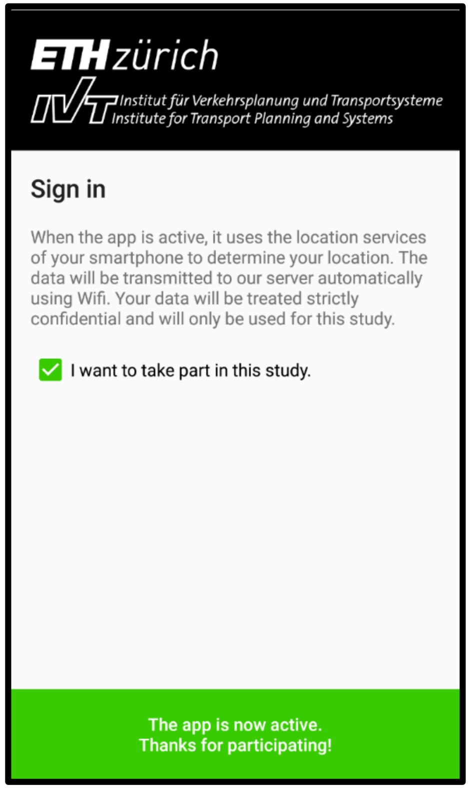
Lessons learnt

- Large (agent based) simulation models are complex
- The realistic behavior of people is complex to attain
- Interplay between operations,
  passengers decisions
  and (limited) information is crucial, but hard to model in a realistic manner

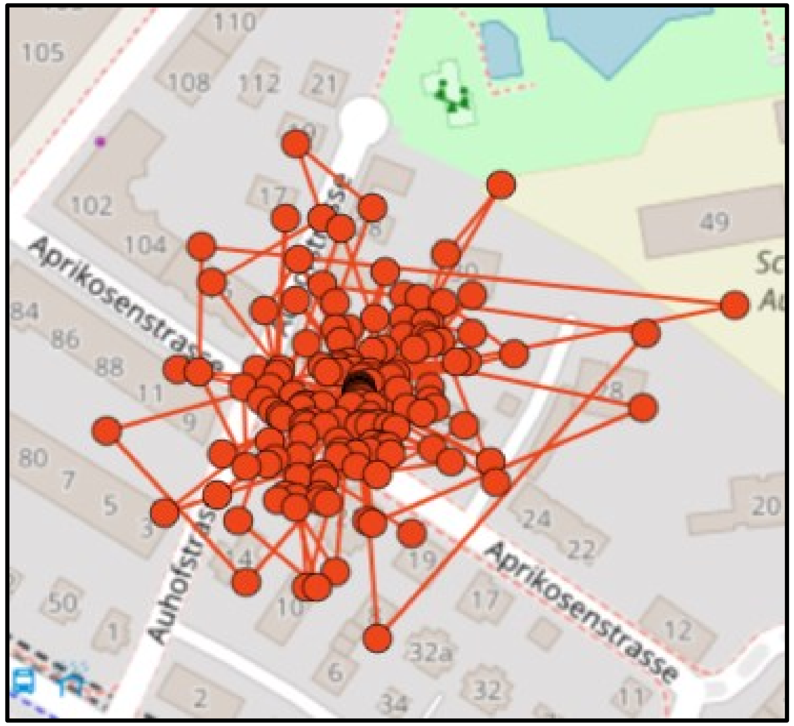
- Current work: integration of rolling stock rescheduling;
  creation of more information dissemination strategy
  (who knows what when? And how correct it is?)

Study mobility in-vivo

- Typically user interaction-intensive
- Typically battery intensive
- Own developed
- Testing ongoing

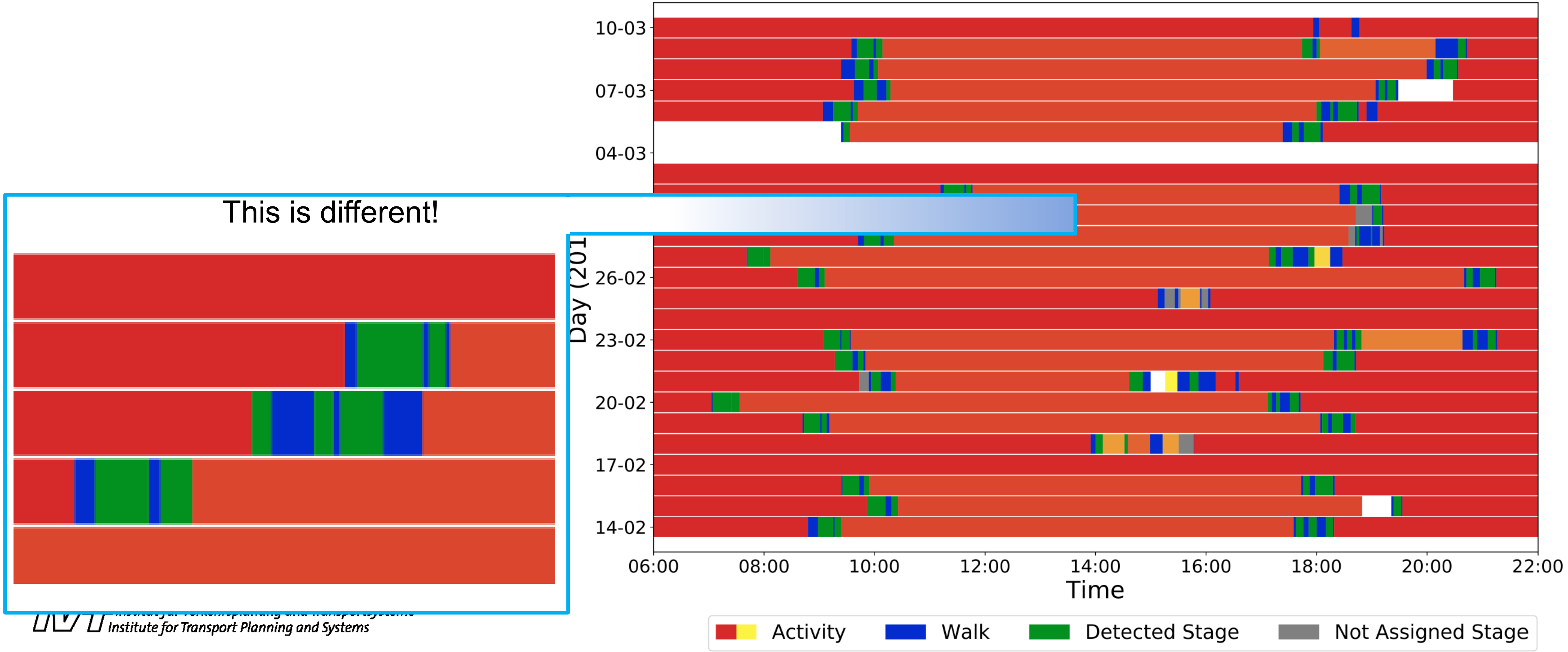


Cleaning of data



Diary

Fig. 7 Continuous tracking of a single user for one month. Activities in the same place have the same color, that goes from red to yellow according to the time spent in the activity. A white space indicates absence of signal.



Lessons learnt

- Disruptions are gray;
  a complete link closure might have an impact comparable to a delayed vehicle
- Large samples might help; data must be complemented with annotations
- Choice models can be estimated
- Mobility providers might know about us than we know

Disruptions in railway networks

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