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Passenger-oriented railway traffic planning and management

Presentation

Author(s):
Corman, Francesco

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Passenger-oriented railway traffic planning and management

Francesco Corman
corman@ethz.ch
Chair for Transport Systems

This talk

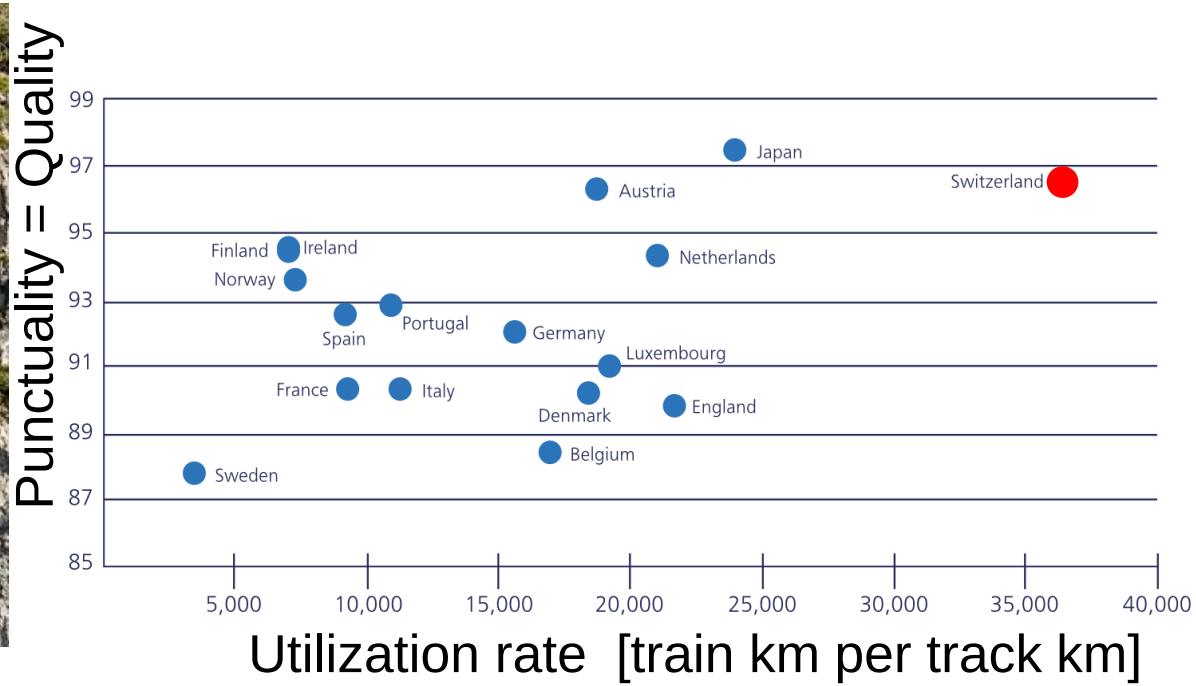
- RAS Webinar, 24.03.2022

- A major problem of public transport, and railways in particular, is to improve quality of operations by updating an offline timetable to the ever changing delays situation, in order to improve performance of the transport system. In railway systems, this relates to reducing train delays by reordering retiming or rerouting trains, and/or change connection plans and route advised to passengers, to improve their traveltime.
- Key point of research is the interaction between the problem (of the operator) to reschedule trains, and the problem (of the travellers) to find their best route in the network, given the information they might have available.
- In fact, changing passenger flows, for instance delaying services and/or dropping passenger connections, varies the setting, objective functions and constraints under which the two decision makers respectively interact. We report different methods to address this problem, also including the information one player knows about the other, by optimization approaches, agent based simulations, game-theoretical approaches, and by estimating models of human behavior based on observed actions.

What I am going to talk about

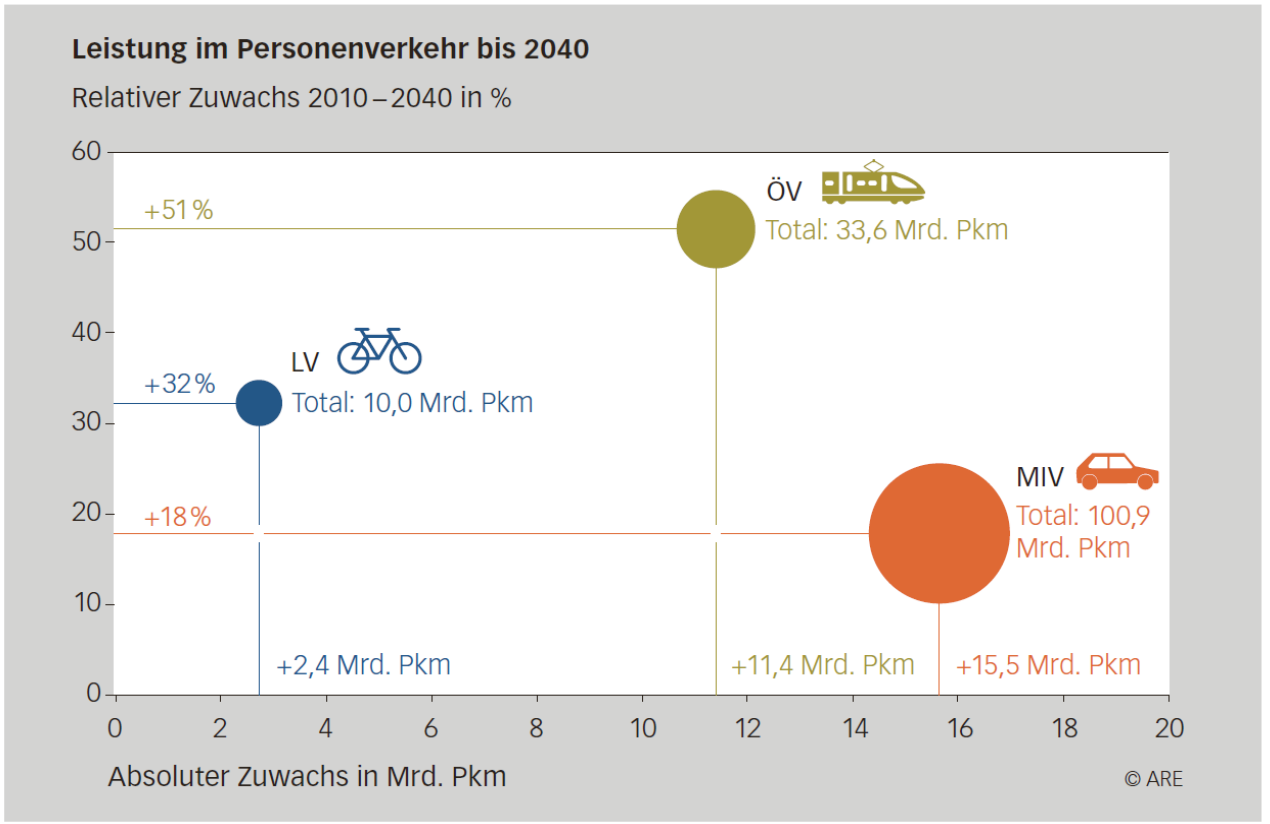
- Introduction
- Optimization for Planning and Control
- Modelling and simulation
- Living lab experiments
- Conclusions

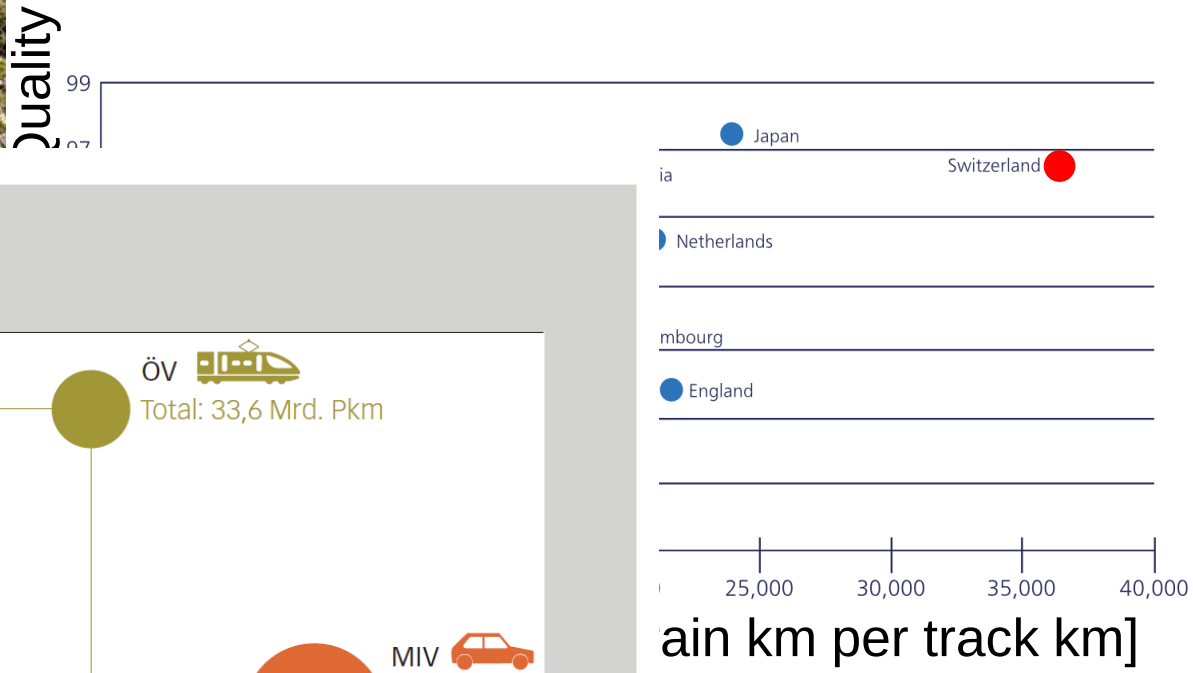
Switzerland is one of the best places to do research on railways



[Rhaetische Bahn; NS]

Switzerland is one of the worst places to do research on railways





One possibility: intelligent planning and control

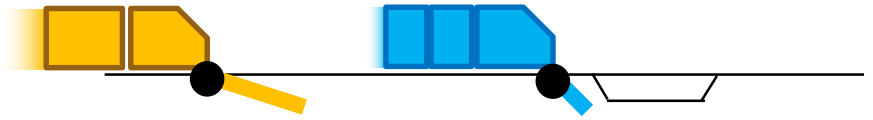
- Planning resource usage at best, in a planning stage and in real time, to manage at best unexpected circumstances
- Match rapid variations by organizing differently resources, rather than by building new resources

- Requires complex mathematical models, to be able to explore the possible solutions and find quickly the best answer to the current conditions
- In general, scheduling problems with specific extensions

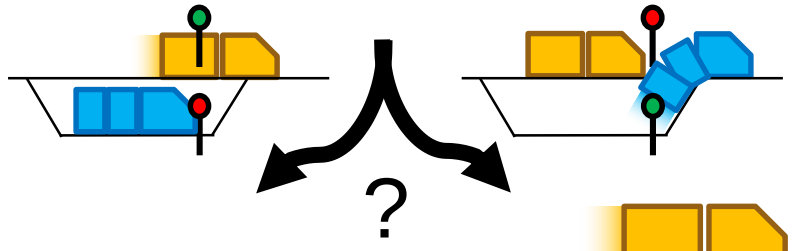
- Considering passengers is a key requirement concerning future evolutions!

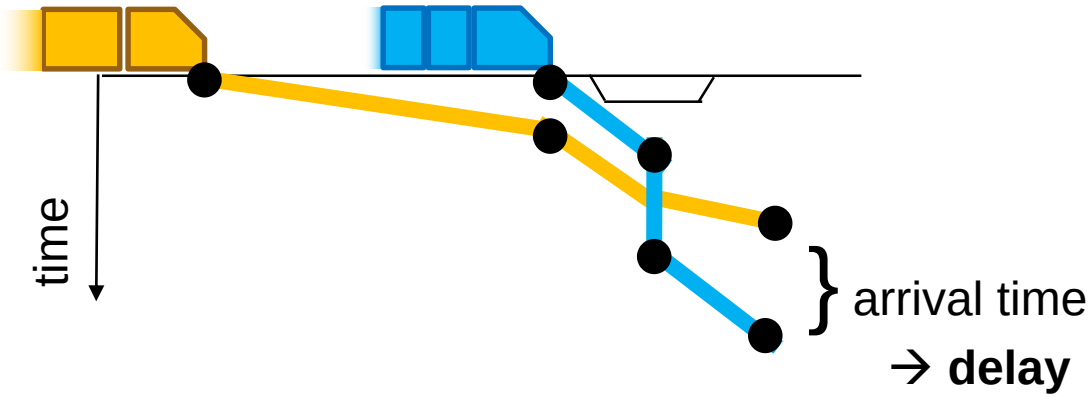
Reassigning capacity in real time: Railway traffic control

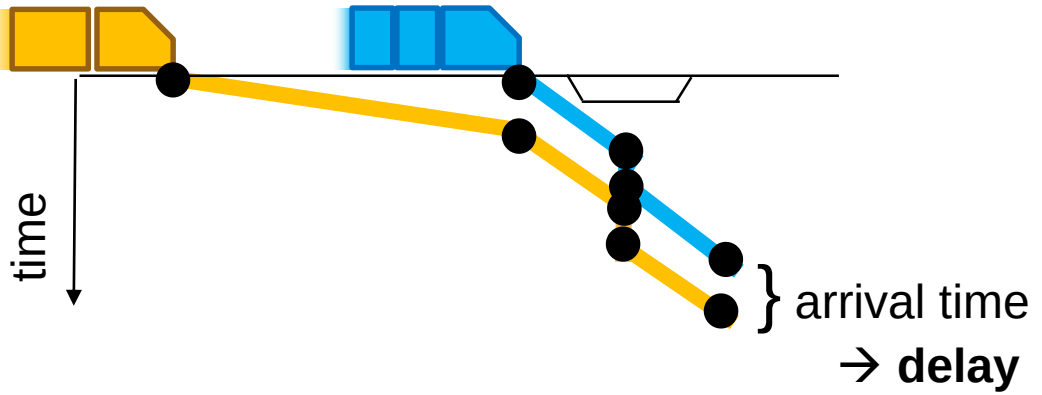
Based on a current network **state**,



determine traffic **control actions** (retiming; **reordering,** rerouting, cancelling,…)
e.g. should the yellow train overtake the blue?





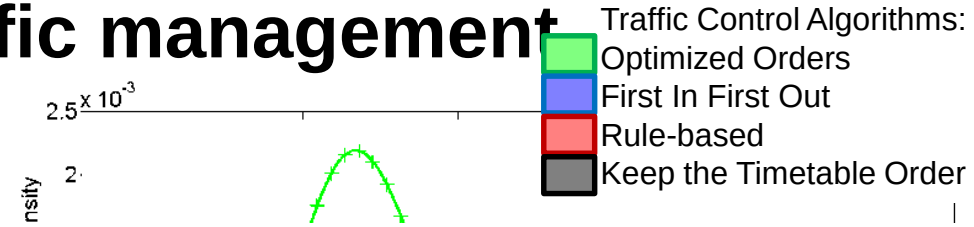


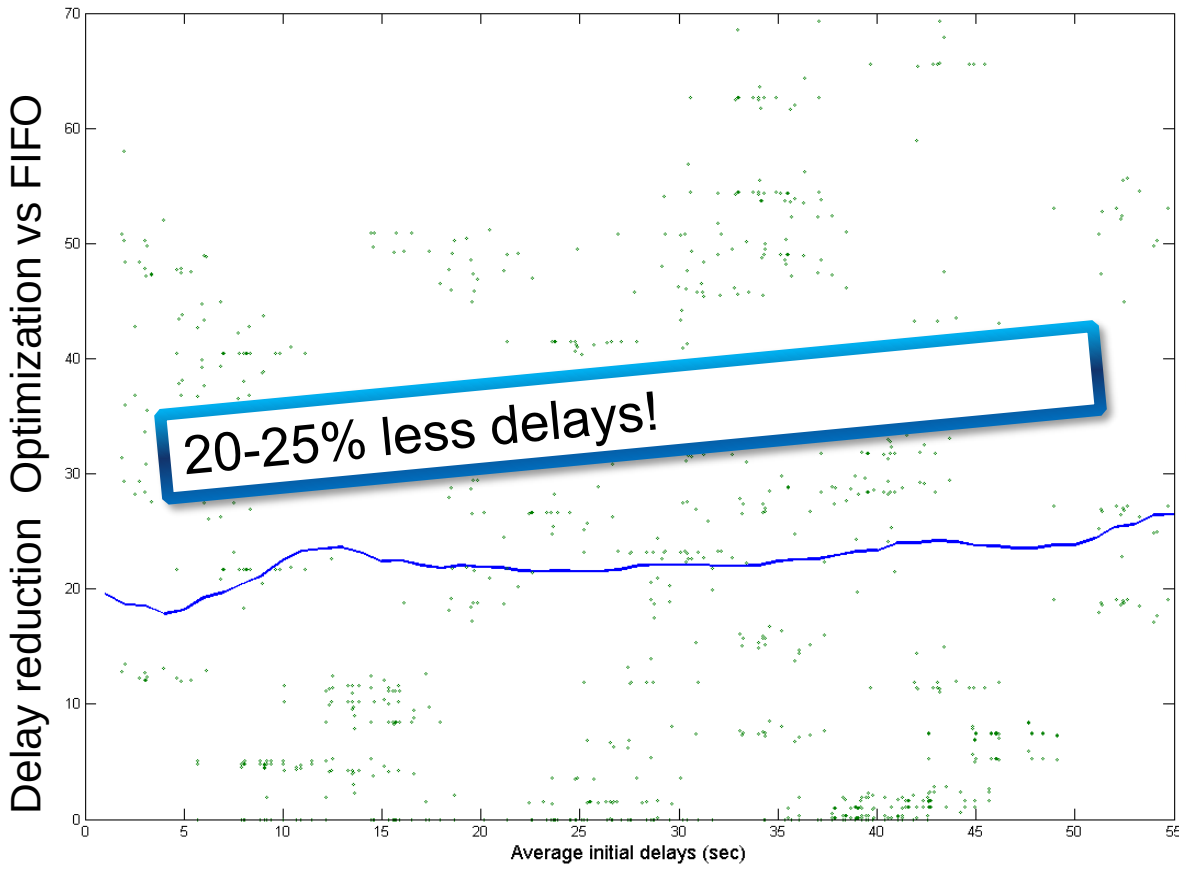
which proactively reduce **delays** and delay propagation,

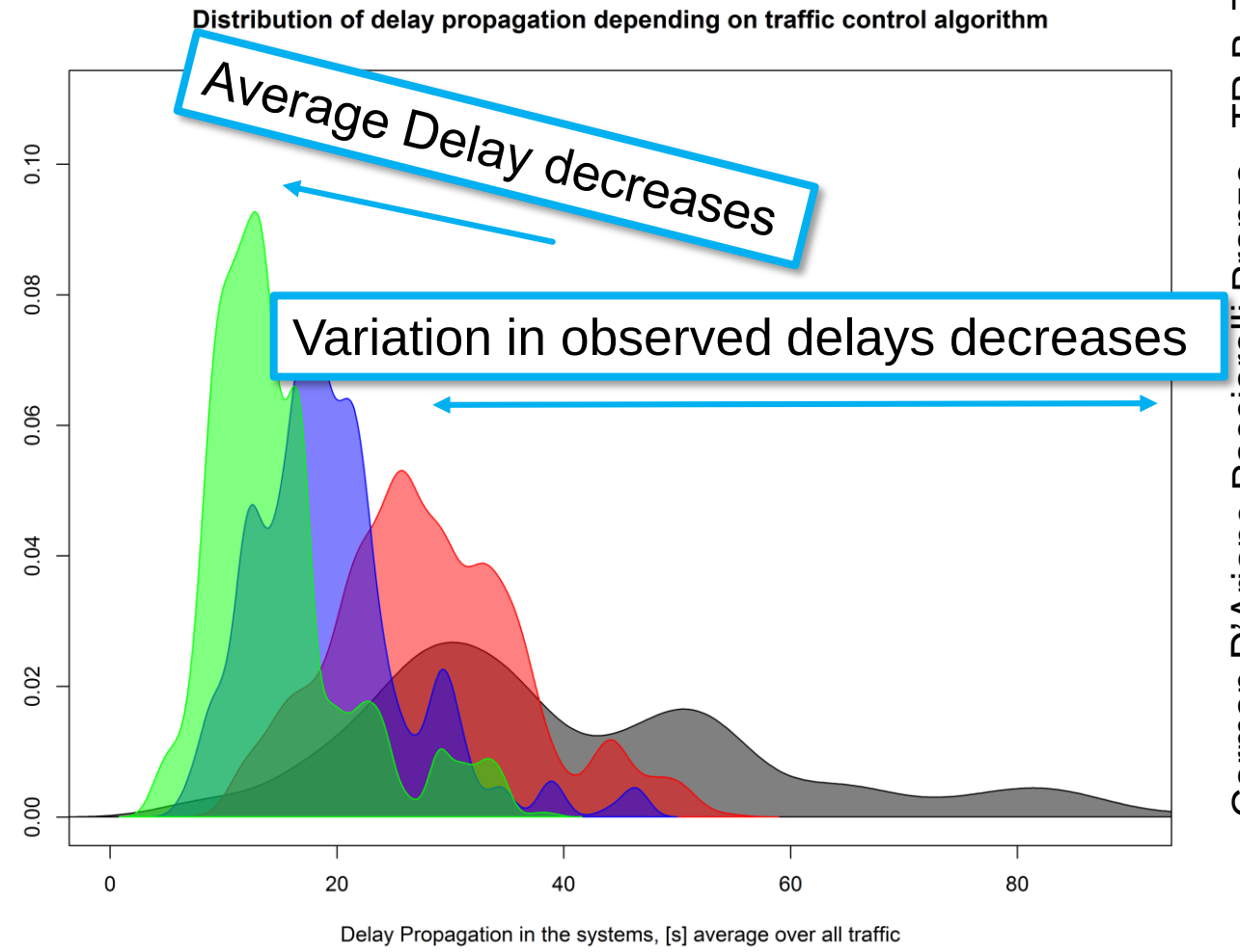
in a **short** computation time

Delay minimization via optimized traffic management

2700 block sections,
150 trains / h

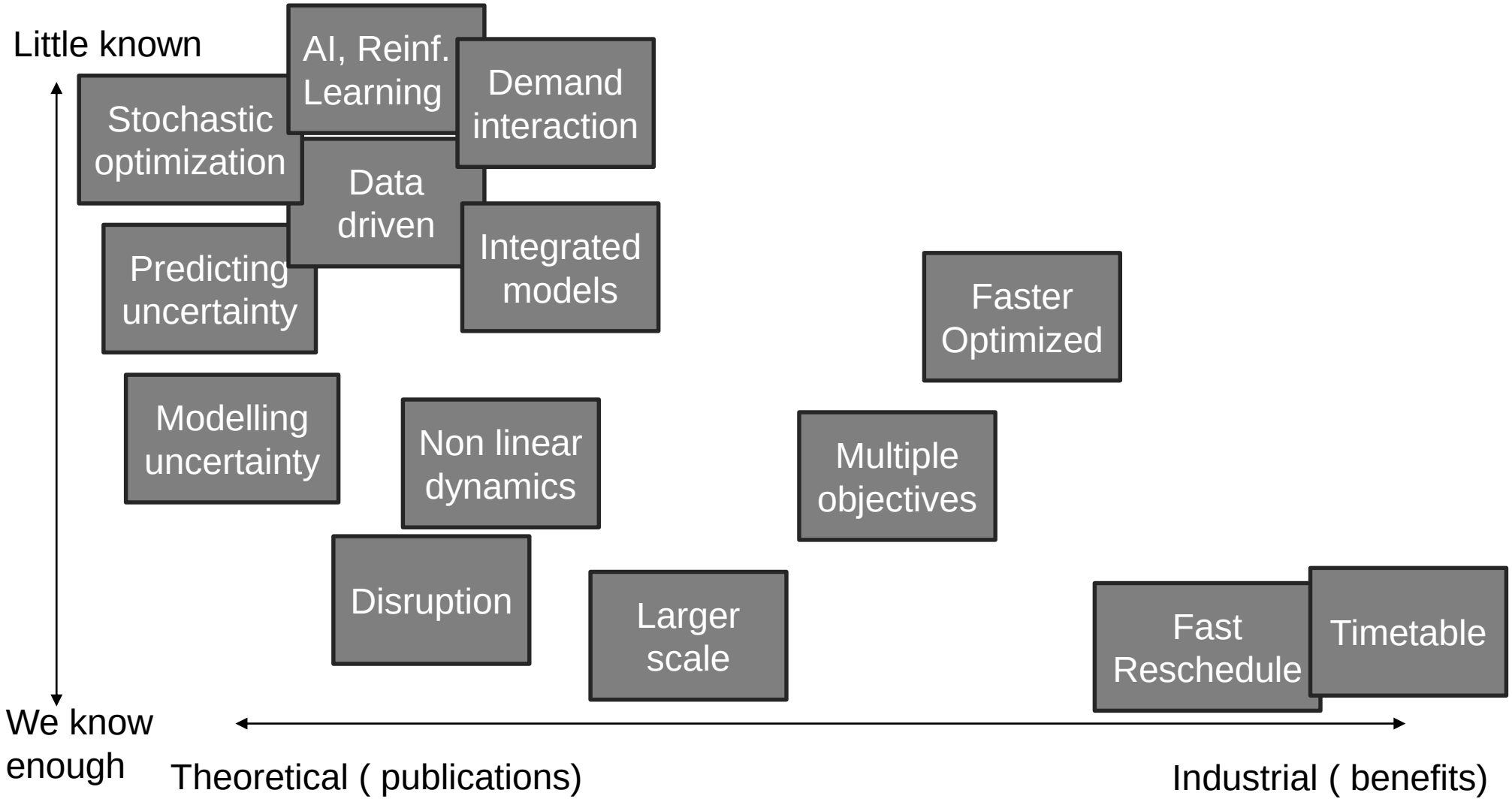






Corman D'Ariano Pacciarelli Pranzo , TR-B, TR-

Railway traffic management (incomplete, incorrect graph)



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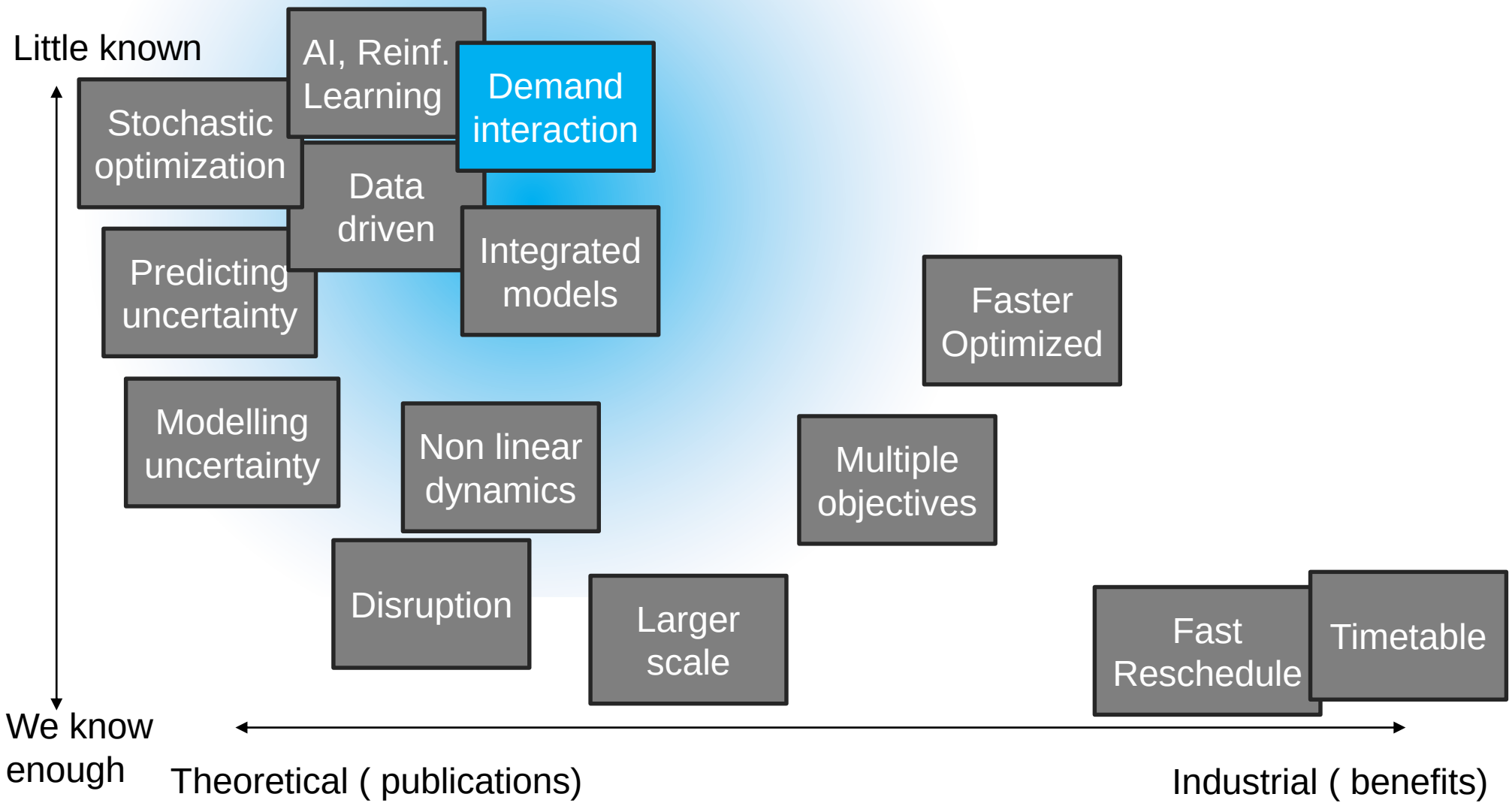

Outline of this talk

- Introduction

Optimization

Modelling and simulation

Living lab experiments

- Conclusion

which can be expressed as a set of linear inequalities by adapting

(43a) can be further rewritten as

$$\kappa_{p,f,s_1,s_2} = \sum_{\varphi\in[1,\nu-1]} r_{\varphi,p,f,s_1,s_2}\cdot\omega_{\varphi,p,f,s_1,s_2} - \sum_{\varphi\in[2,\nu-1]} m_{\varphi,} - r_{\nu,p,f,s_1,s_2}\cdot\omega_{\nu,p,f,s_1,s_2} + \omega_{\nu,p,f,s_1,s_2}\cdot\psi_{p,f,s_1,s_2} \quad \forall p\in P$$

Finally, the nonlinear co

ties obtained by using t

auxiliary variables $r_{\varphi,p,f,}$

Similar process can b

For the sake of compactn

$$w^{\min}_{f,s} = \sum_{\varphi\in[1,v-1]} y_{\varphi,f,s}\cdot\varpi_{\varphi,f,s}\cdot w_{f,i,j} - \sum_{\varphi\in[2,v-1]} z_{\varphi,f,s}\cdot\varpi_{} - y_{v-1,f,s}\cdot\varpi_{v,f,s}\cdot\bar{w}^{\min}_{f,i,j} + \varpi_{v,f,s}\cdot\bar{w}^{\min}_{f,i,j}, \quad \forall f\in F$$

where

$z_{\varphi,f,s}$

As such, the integer variables $A_{f,s}$ and $D_{f,s}$ can be represented by using binary variables $\alpha_{f,s,\iota}$ and $\beta_{f,s,\iota}$ respectively, as follows:

$$A_{f,s} = \sum_{\iota\in[0,\zeta]} 2^{\iota}\cdot\alpha_{f,s,\iota}, \quad \forall f\in F, s\in S_f, \tag{42a}$$

$$D_{f,s} = \sum_{\iota\in[0,\zeta]} 2^{\iota}\cdot\beta_{f,s,\iota}, \quad \forall f\in F, s\in S_f. \tag{42b}$$

Let $\Lambda_{p,f,s_1,s_2} = A_{f,s_2}\cdot x_{p,f,s_1,s_2}$ and $\Upsilon_{p,f,s_1,s_2} = D_{f,s_1}\cdot x_{p,f,s_1,s_2}$. We can express the bilinear terms in the following linear form:

$$D_{f,s} = d_{f,i,j}, \quad \forall f\in F, i,j\in V, s\in S_f, (i,j)\in E_f\cap E_s, \tag{14}$$

$$A_{f,s} = d_{f,i,j} - \Phi_{f,i,j}, \quad \forall f\in F, i,j\in V, s\in S_f, (i,j)\in E_f\cap E_s, \tag{15}$$

$$\Delta_{f,s} = \Phi_{f,i,j}, \quad \forall f\in F, s\in S_f, \tag{16}$$

$$s_2\in S_f, (s_1,s_2)\in G_f. \tag{42c}$$

$$s_2\in S_f, (s_1,s_2)\in G_f. \tag{42d}$$

Constraints (27) - (29) can be then respectively rewritten as:

$$\psi_{p,f,s_1,s_2} = (\Lambda_{p,f,s_1,s_2} - \Upsilon_{p,f,s_1,s_2})\cdot n_p, \quad \forall p\in P, f\in F, s_1,s_2\in S_f, (s_1,s_2)\in G_f. \tag{42e}$$

Optimization models

Corman F. (2020) Strategic interactions between rescheduling train traffic and routing passengers in microscopic delay management. Transportation Science 54 (3) pp 785-822.

Luan X., Corman F. (2022) Passenger-oriented traffic control for rail networks: an optimization model considering crowding effects on passenger choices and train operations. Transportation Research, Part B

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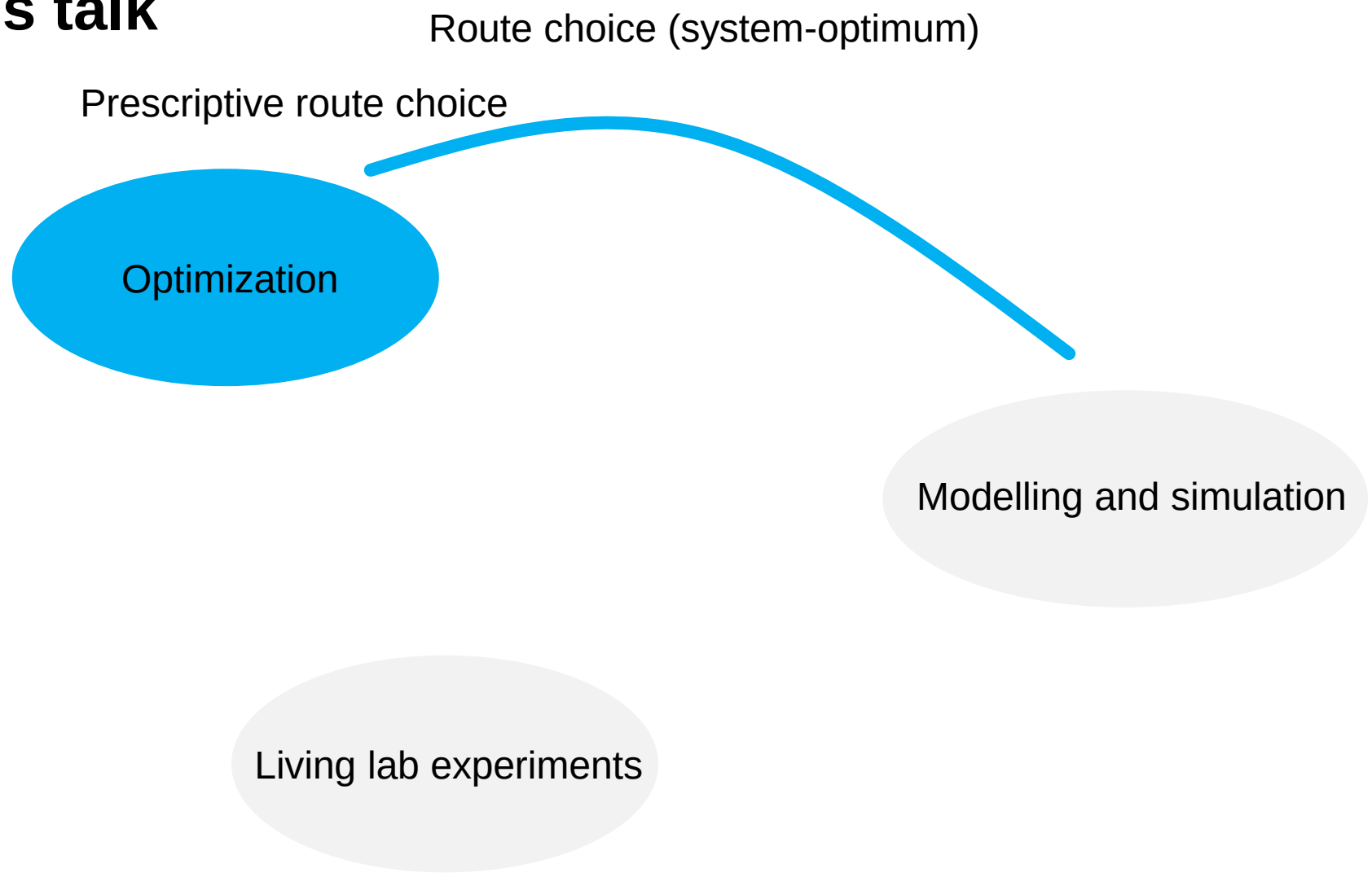
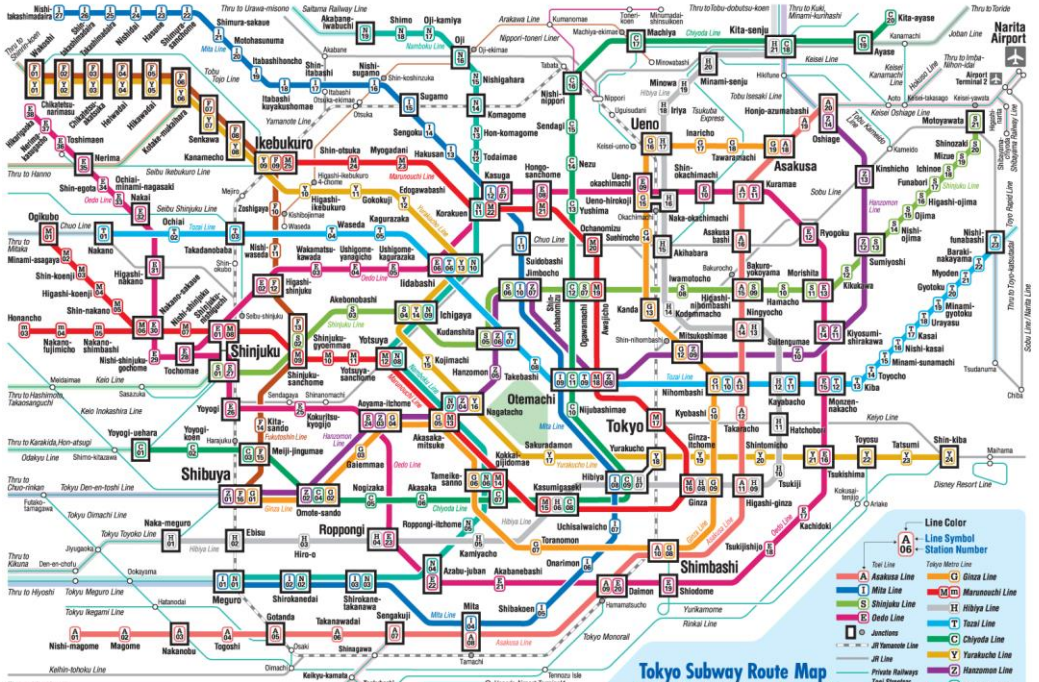
- Conclusion



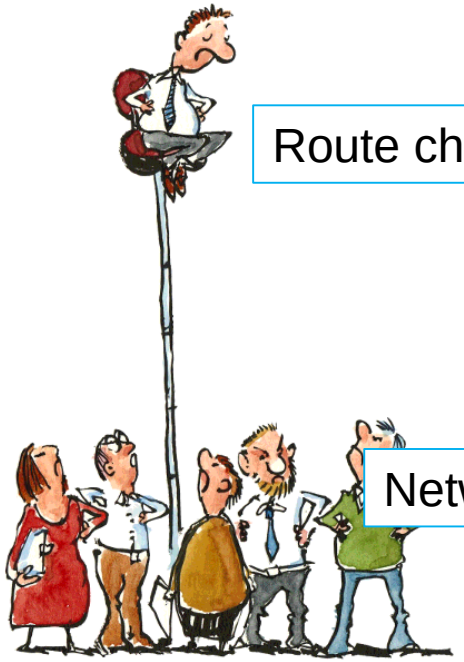
Optimization considering passenger flows in networks

- Given a planned supply
- Adjust supply: services, departure times, to match operators'objectives
  = the links of your network
- Considering passenger flows
- Considering that passenger flows will change, if the supply has changed
- Inform the users how to best change their original plan, to match their objectives



Passengers Routing in public transport networks

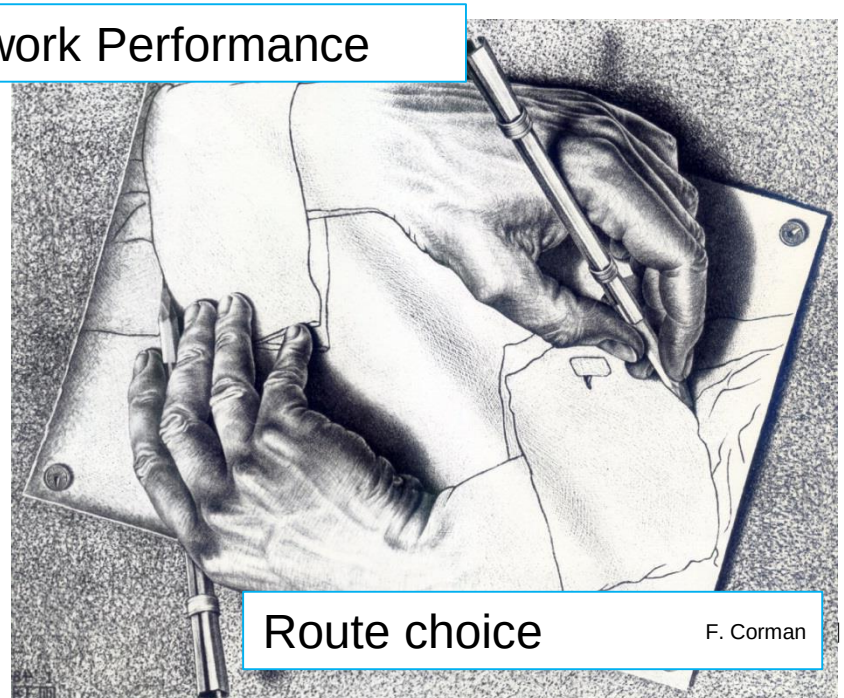
- Divide hierarchically into layers
  post process, simulate, adjust
- Equal importance given to problem: iterate coordinate, converge



Route choice

Network performance

Network Performance



Route choice

escher

Schedule-based Transit assignment

Knowing passengers demand per time

Routing of passengers is based on shortest travel time

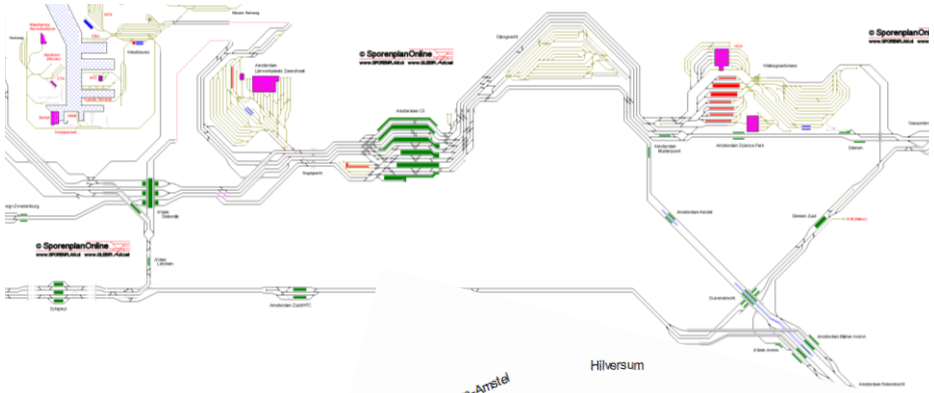
Vehicles (trains) have infinite passengers capacity

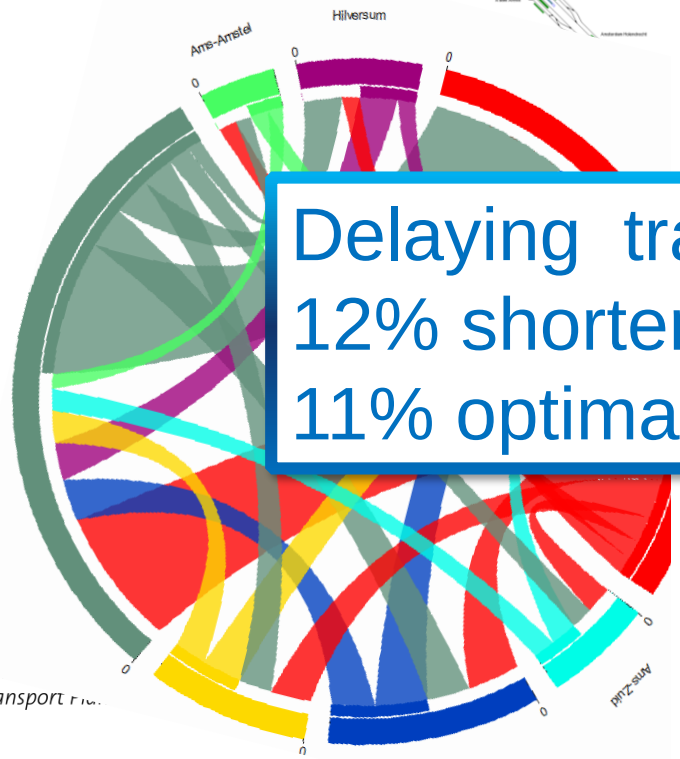
(relatively strong assumptions!)

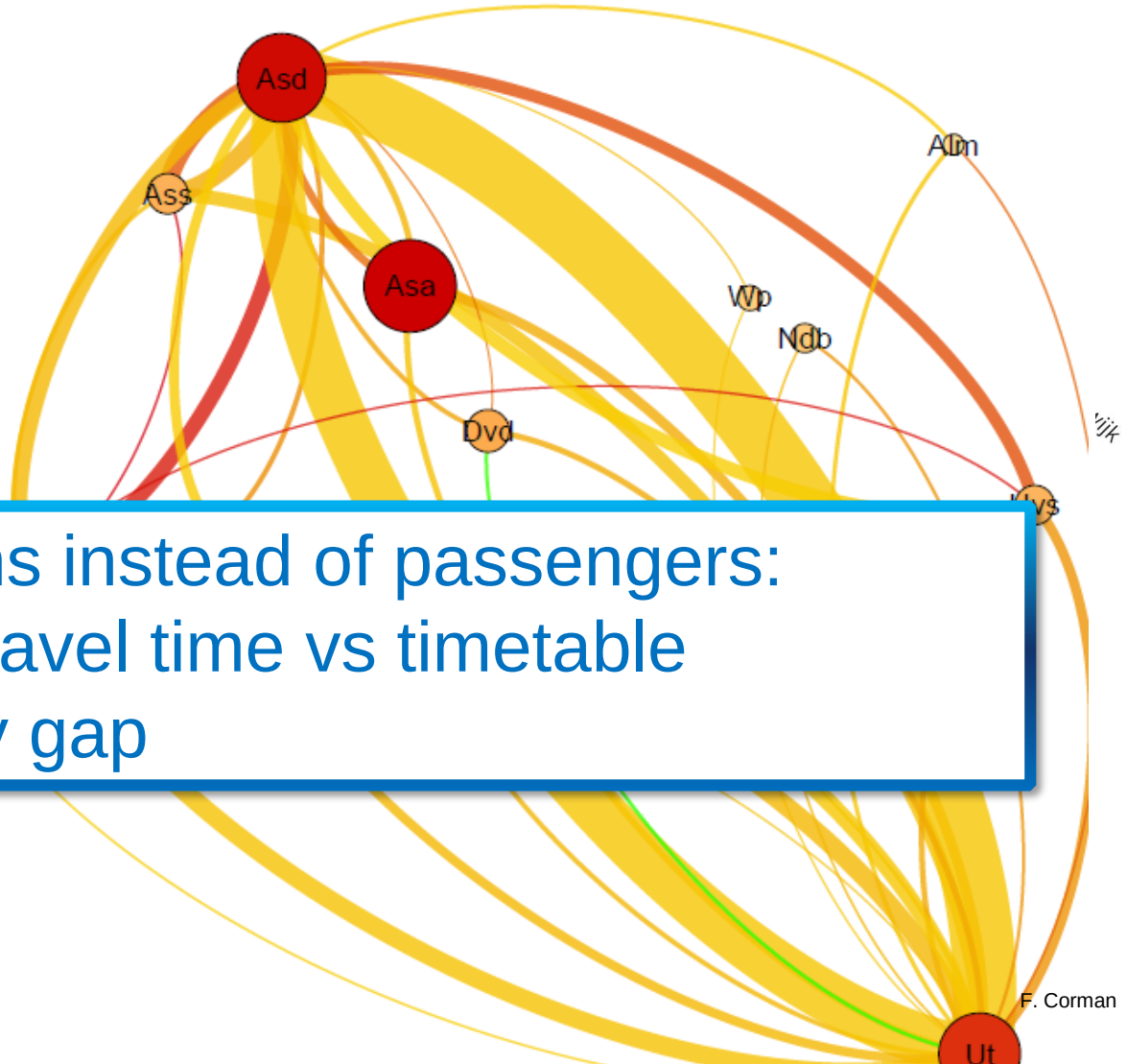
Schedule-based assignment → min cost flow problem

The schedule itself is a variable → scheduling problem

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

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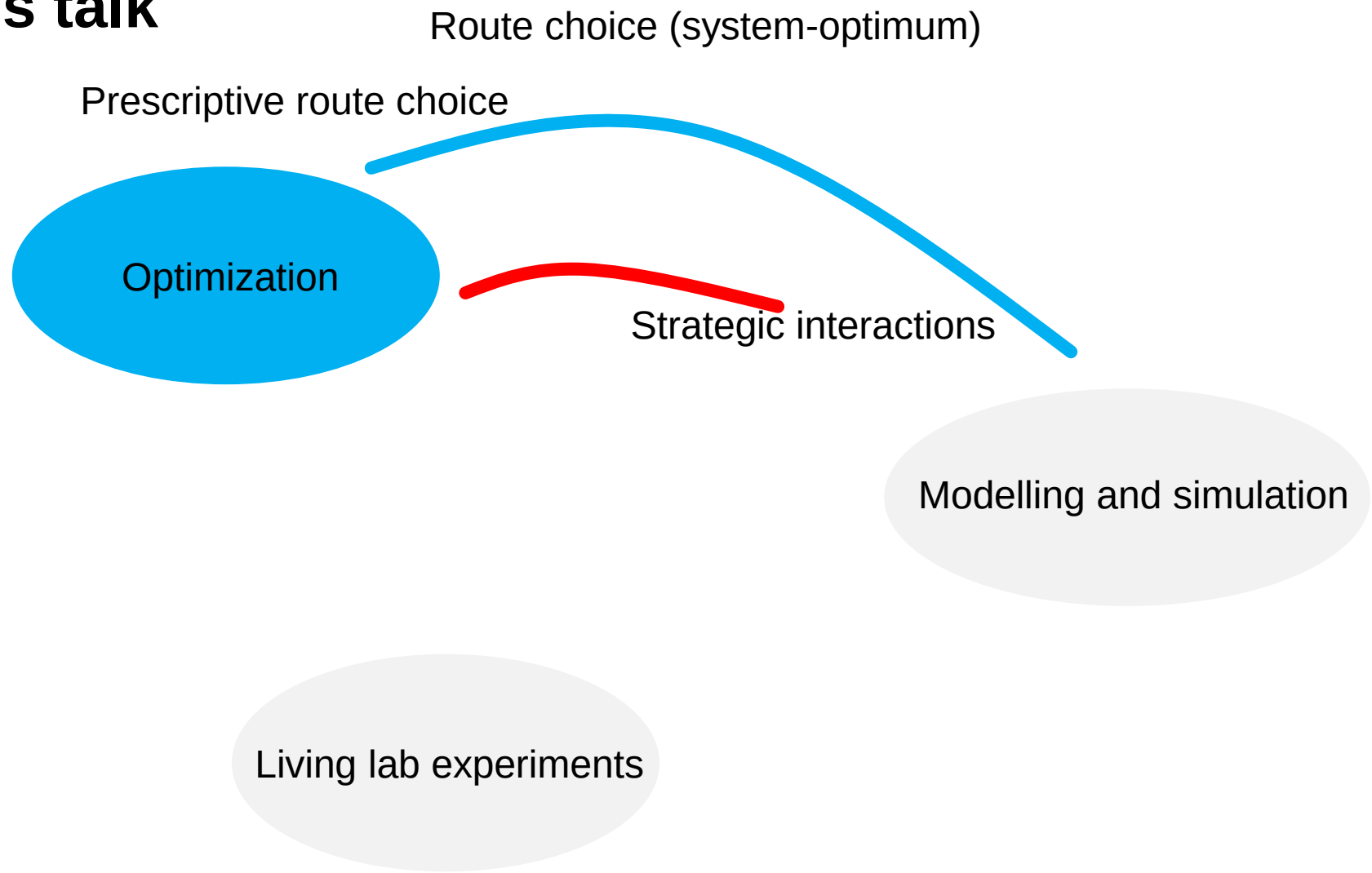
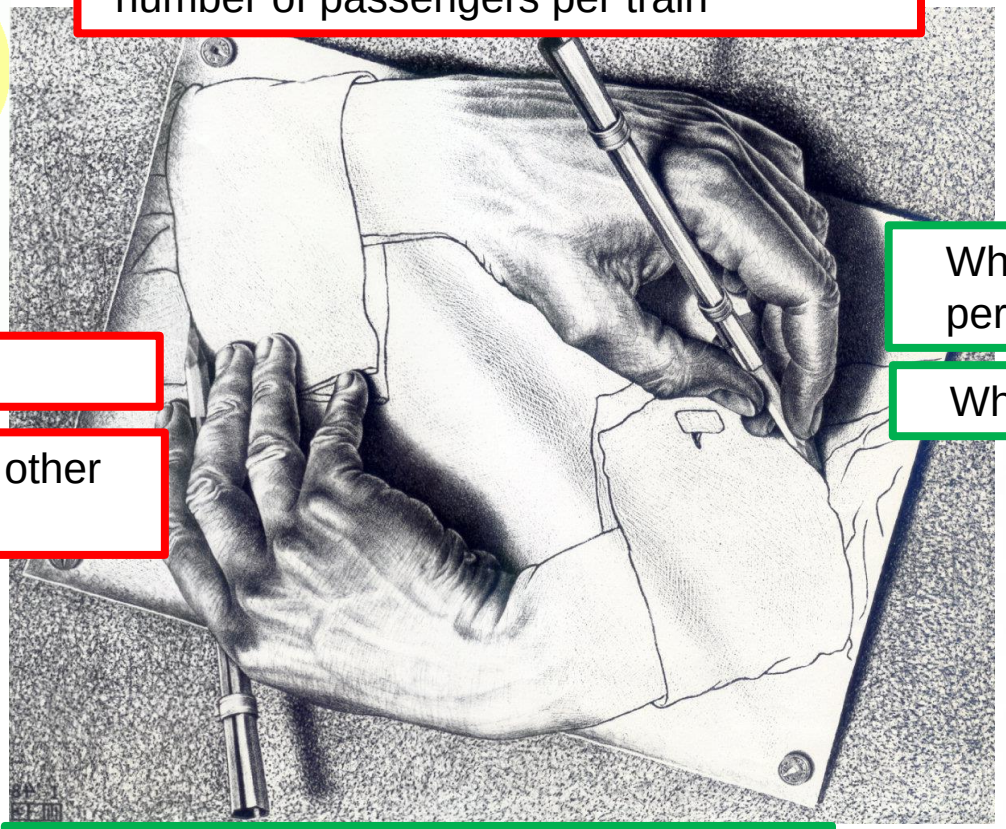


Interaction

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?

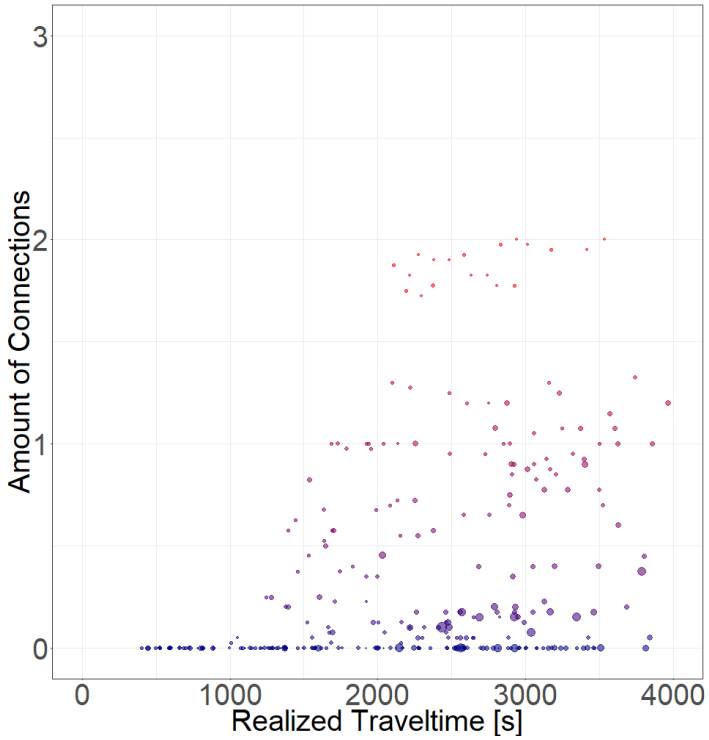
routing of passengers by taking into account the train schedule, their origin and destination, the minimization of their discomfort

Possible solutions –who does what, why?

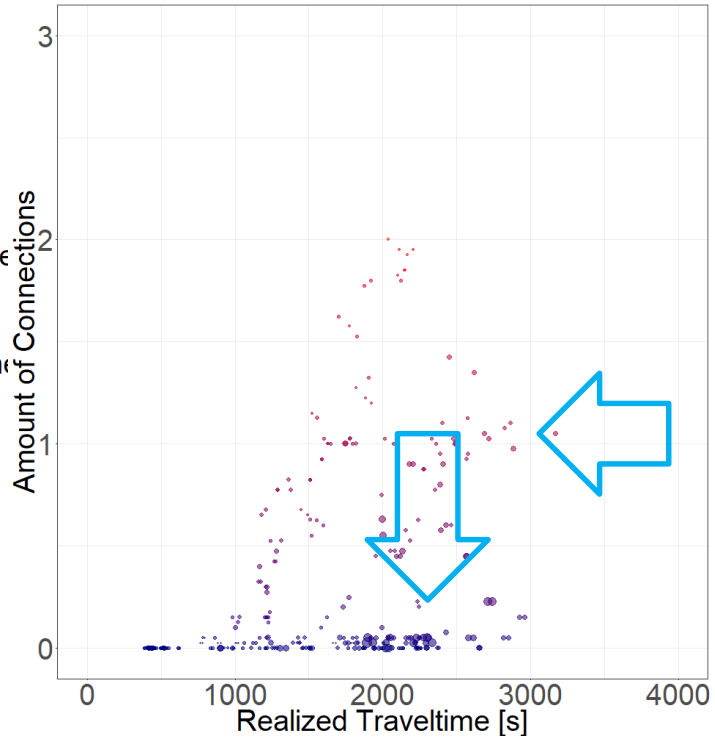
- Optimize everything (integrated model) ~System optimum
- Minimize delay weighted by passengers;
  Passengers react to schedule,
  trains react to passengers choice ~Nash
- Keep the timetable order; or optimize schedule
  Passengers adjust route choices ~Inv. Stackelberg
- Passengers publish their choices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

Different solutions, from different information assumed by users

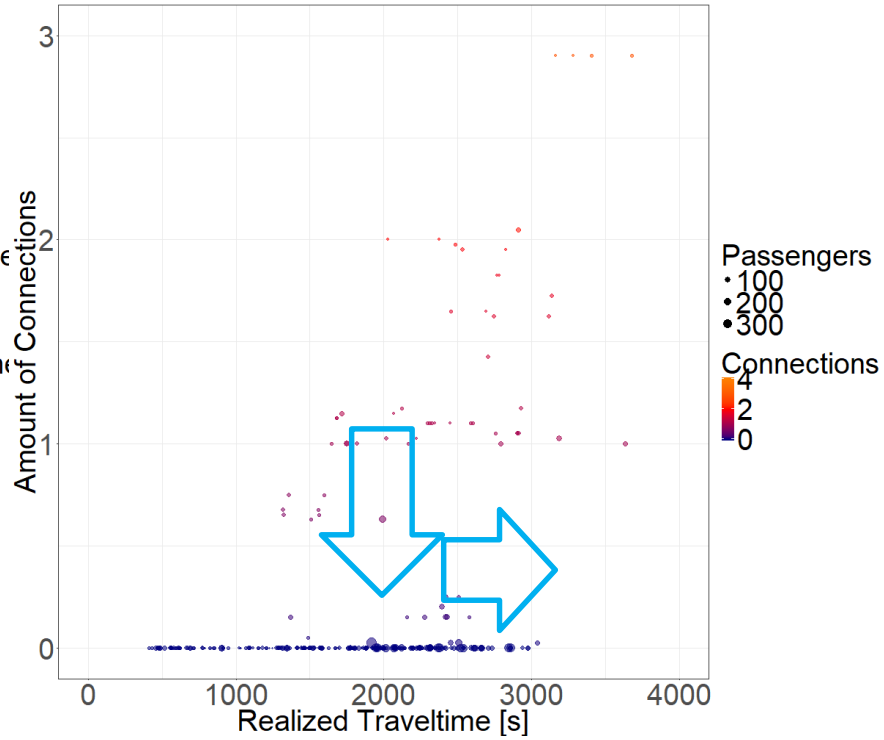
- What will happen? The system optimum or a worse user equilibrium? Depends on what the users assume the controller will do



Timetable solution
full information



Optimized solution
full information



Optimized solution,
limited user information

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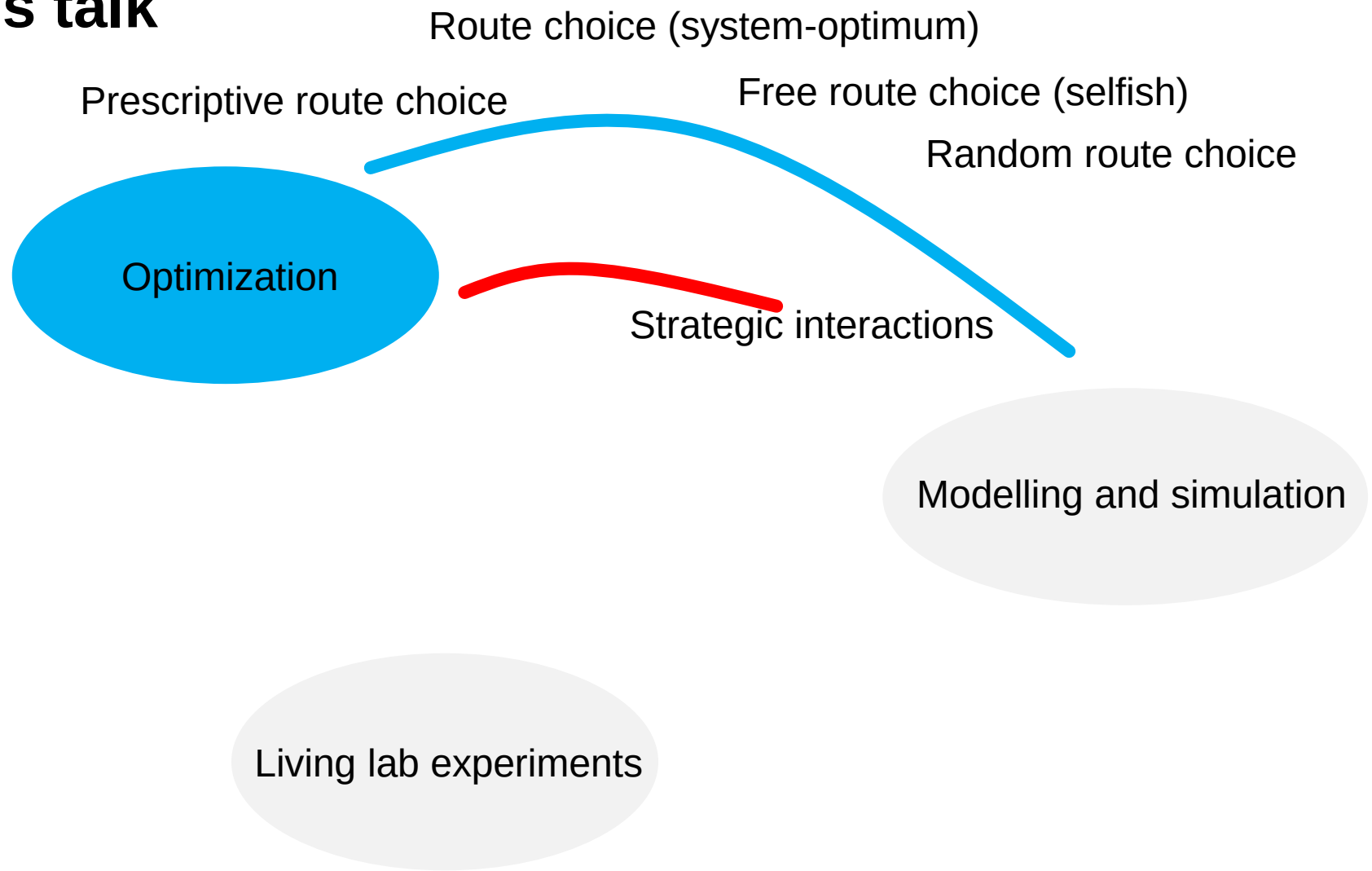
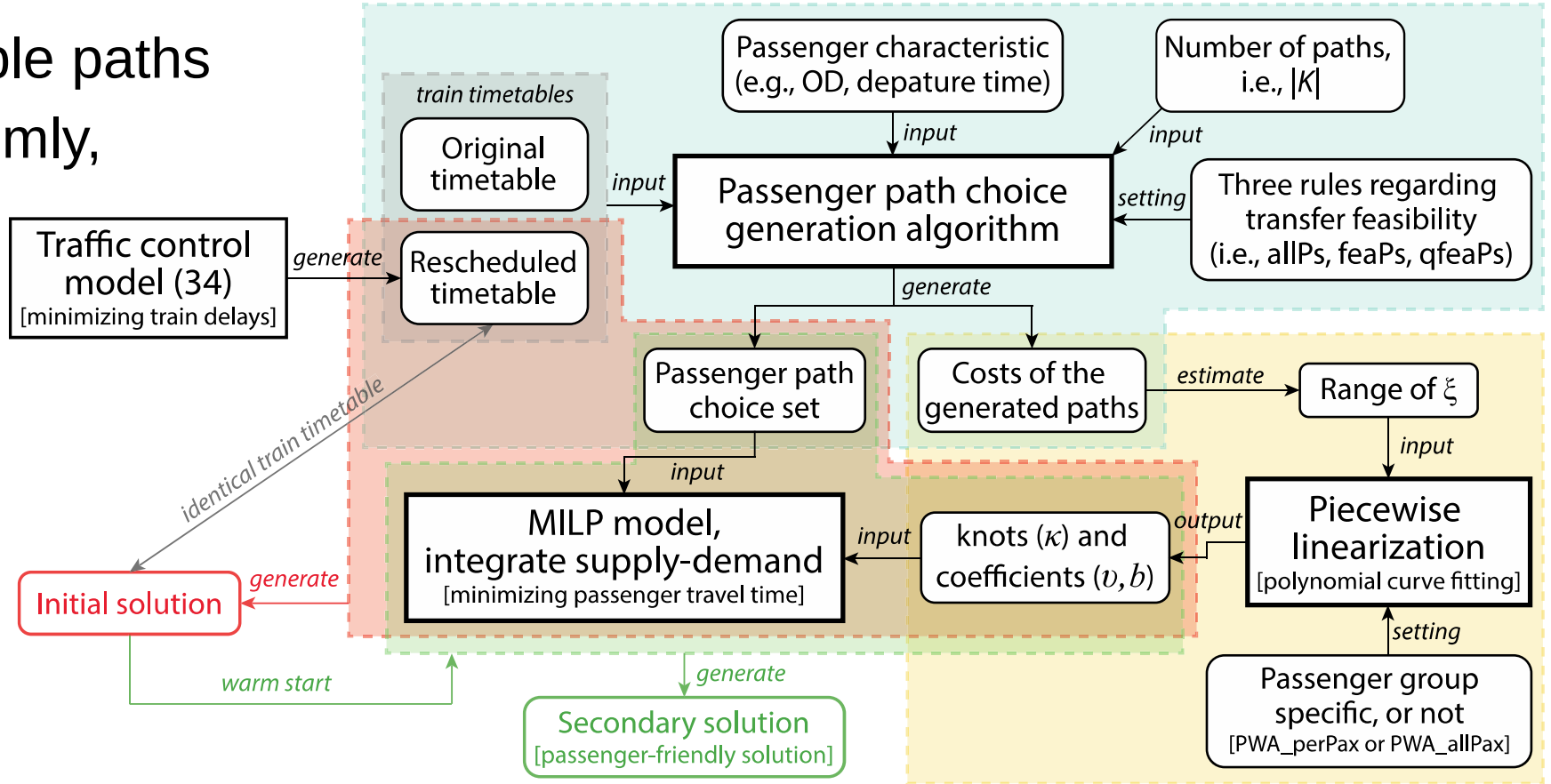


- Conclusion

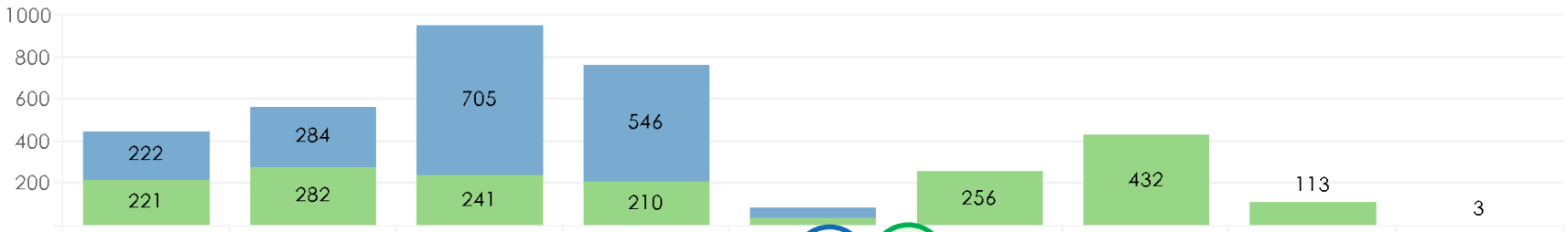
Complex choices of passengers: random utility models (Multinomial logit models, MNL)

- Given a set of available paths
- People choose randomly, proportionally to the utility assumed

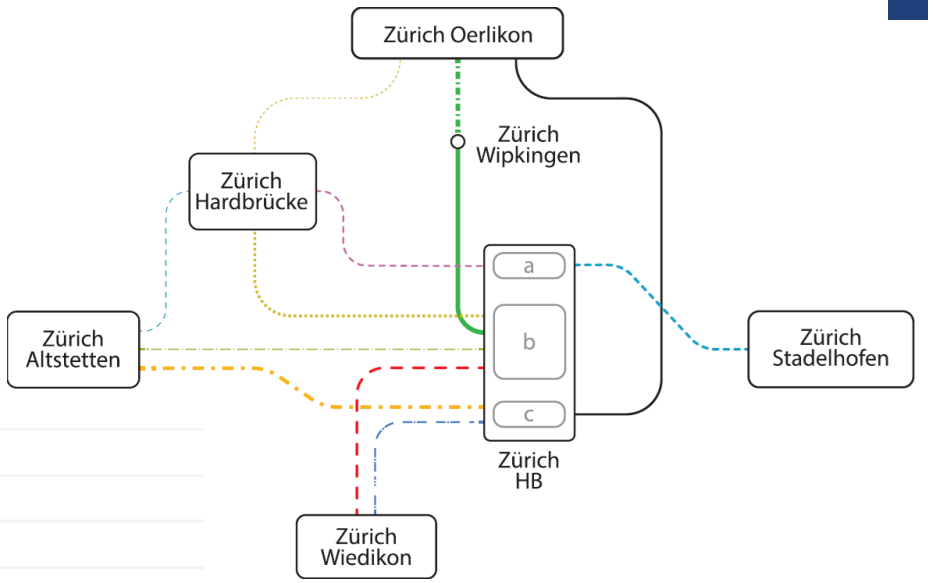


People distribute along a set of paths

- 20 trains, 30 OD Pairs, 5/10 paths in choice set



← Number of path choices per passenger group for 5 / 10 max set of path choice →



	Objective value	Total pax travel time (unit: s)	Total train delay time (unit: s)	Cost of stranded passengers
Initial	728,552.70	235,819.73	3088	492,702.25
secondary	540,358.52	237,277.83	3128	303,049.33

Interconnection between information and choices

- Optimization can solve the problems, given assumed behavior of users, and a given utility of the operators

- Operators might react to (expected) users' behavior
  →what to expect users will do?
- Users might choose the best, or spread over multiple choices
  → quality versus stability of the choice
- Users need a way to build the set of available routes
  → how to filter complexity of real life networks into few meaningful possibilities?

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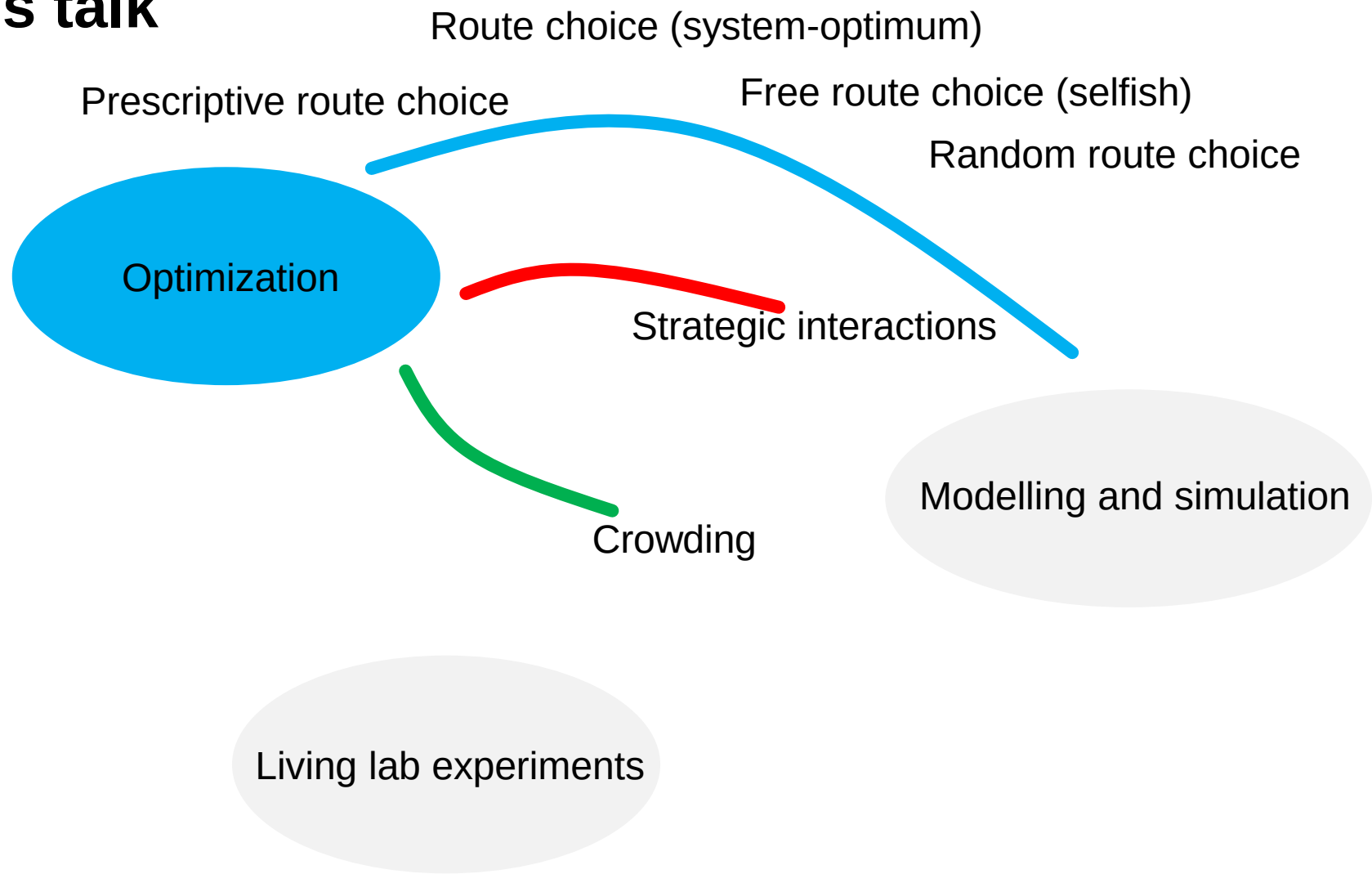


Complex effects: crowding

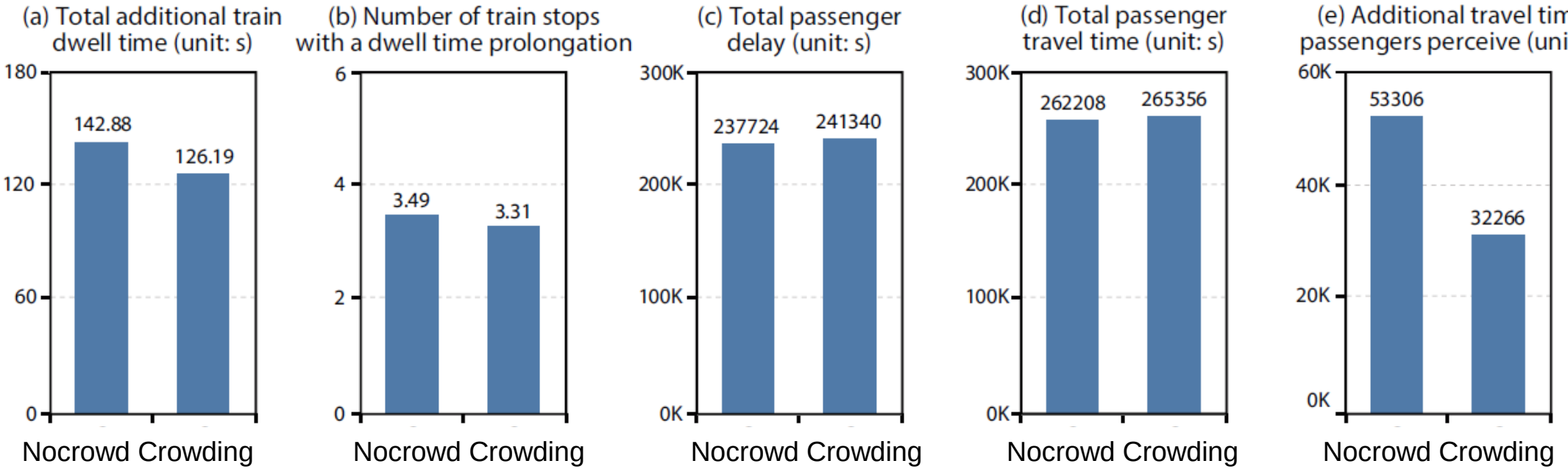
- Free split of passengers in a group
- Restriction on train capacity by penalizing train crowding
- Passenger route choices based on train crowding
- Variation in the minimum train dwell time

- Optimization models gets more complex. Way more complex. Many parameters, and configurations needed.
- But still, solvable! Details on recently published paper!

Luan X., Corman F. (2022) Passenger-oriented traffic control for rail networks: an optimization model considering crowding effects on passenger choices and train operations. Transportation Research. Part B. https://doi.org/10.1016/j.trb.2022.02.008

Estimating crowding effects

Effects on passengers / effects on train traffic / allow delays / stranded passengers



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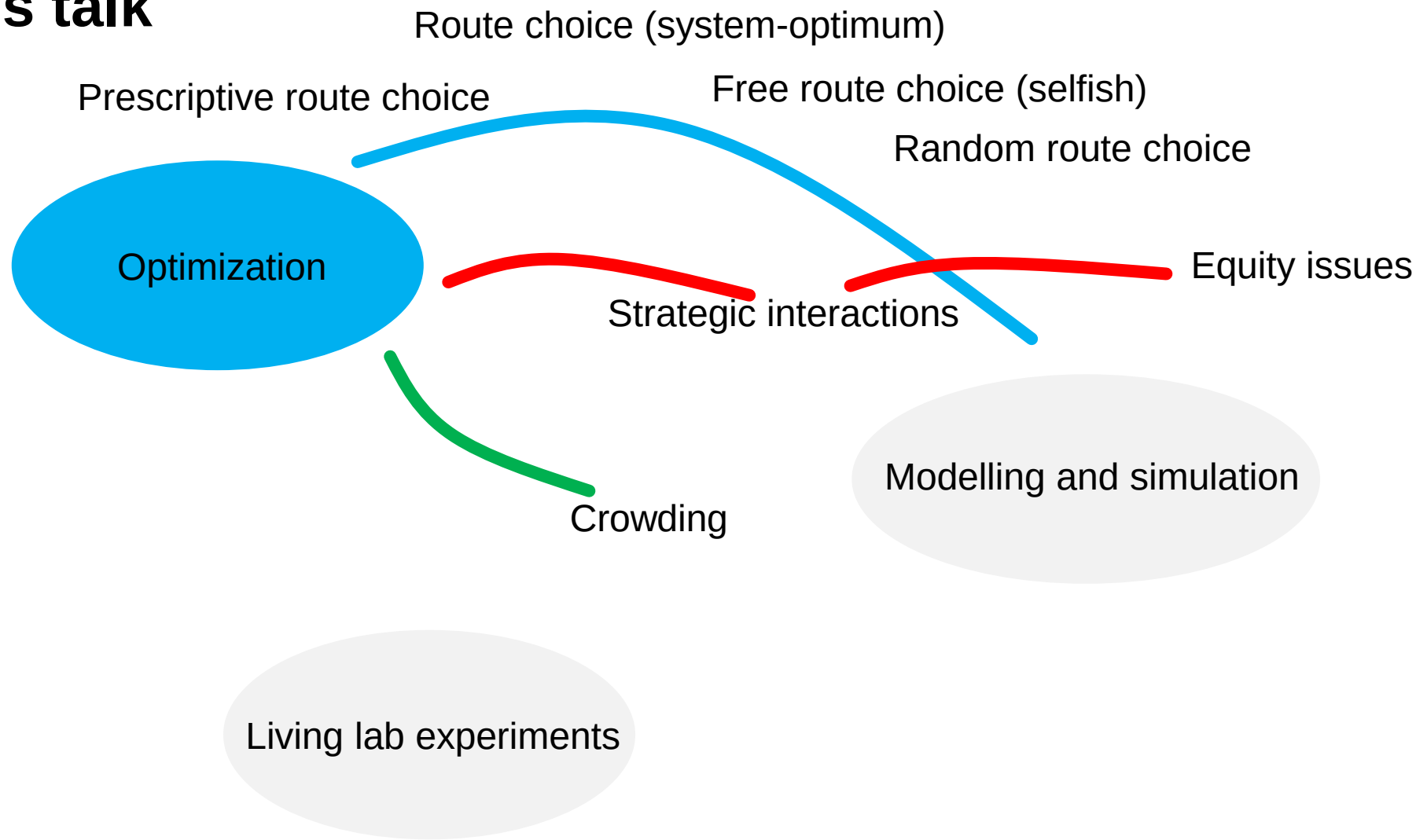
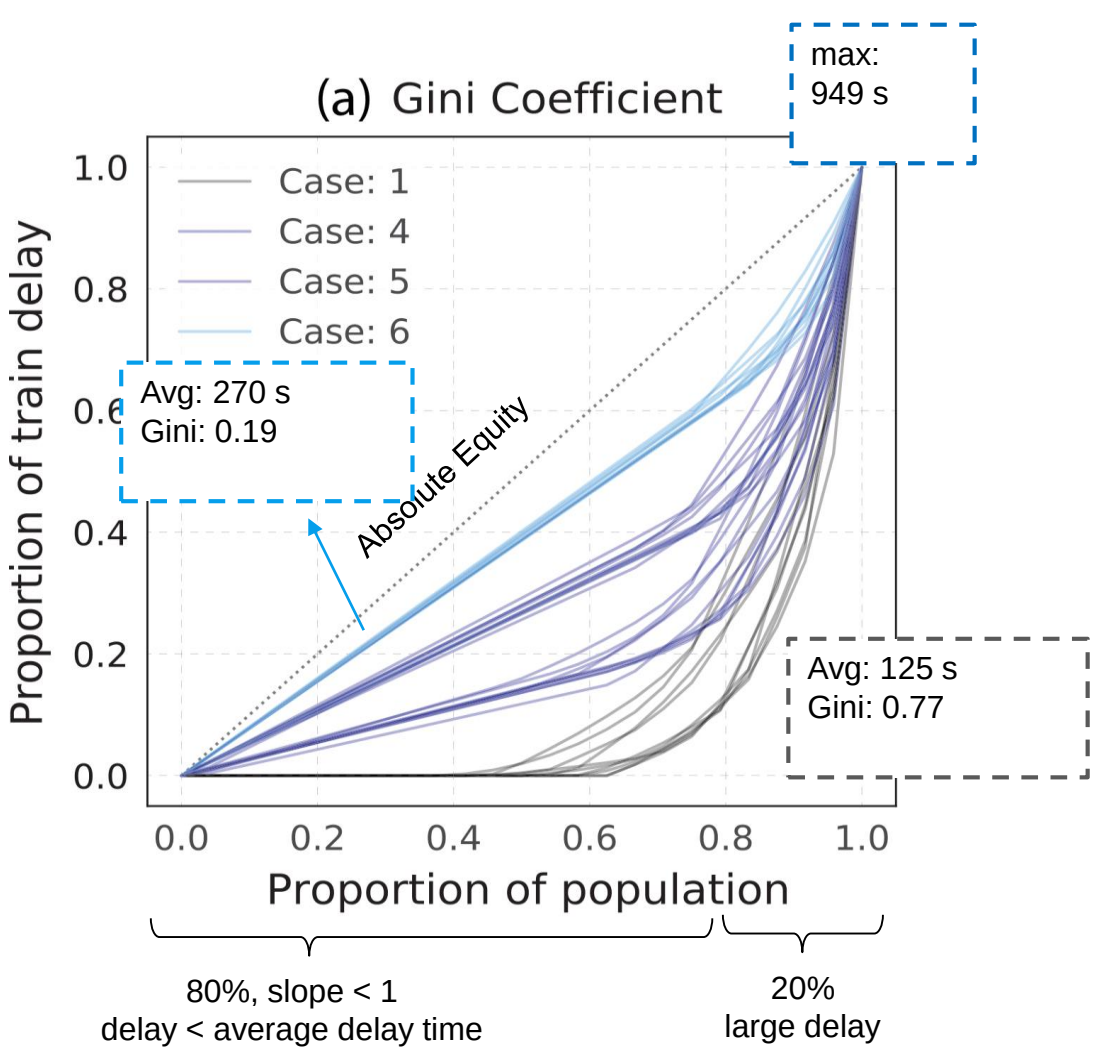
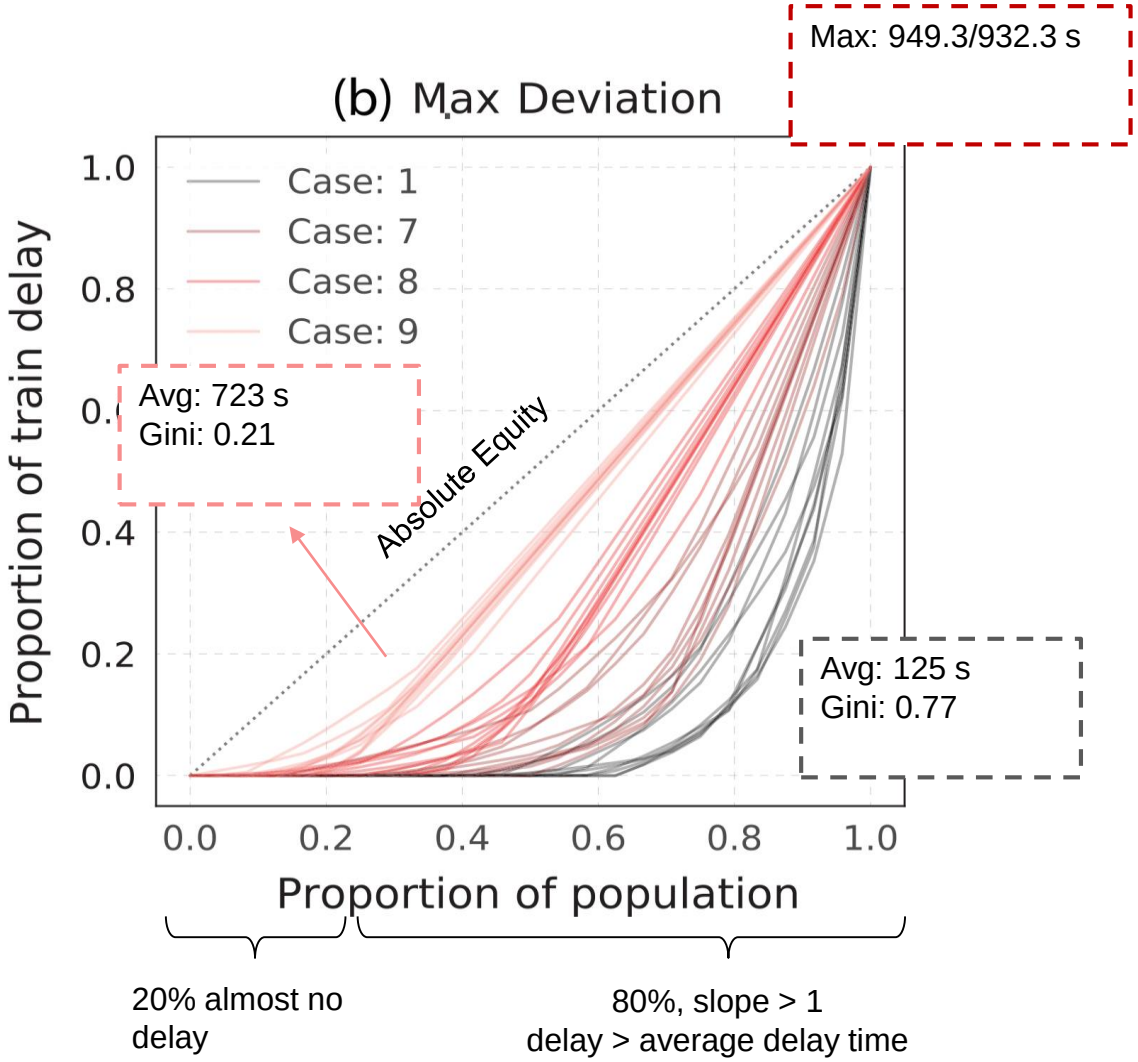


Equity between different passengers groups, and services

- Multiple users want different things. How to deal with diversity
- Within users group (who will get the last seat onboard?)
- within services of same class (economic competition in the market, non-discriminatory treatment, full versus empty)
- Within services of different service classes (integration/ harmonization of regional and long distance traffic, freight traffic)
- across different service usage (maintenance integration into train schedules)

Some approaches (equity for services): Gini, maximum deviation





What can be learned from (inequity-averse) (crowding) (choice-based) passenger flow optimization?

- In general non-linear approaches, difficult to solve to optimality
  Algorithmically, challenging. Heuristics? Optimal solutions?
- There are ineffective approaches: users are delayed to make sure all users are delayed equally.
- Possible to include it in planning (resilience). Bi-level problems, simulation-optimization
- Difficult to apply in real life:
  people still take free choices
  people do not care only about delays
  need to “artificially” make classes of passengers

Modelling passengers response to disruptions by agent based modelling

Leng N., Corman F. (2020) The role of information to passengers in public transport disruptions: an agent-based simulation approach. Transportation Research, Part A 133 pp 214-235.
Leng N., Corman F. (2021) Communicating delays and adjusted disposition timetables: modelling and evaluating the impact of incomplete information to passengers. Expert Systems with Applications.

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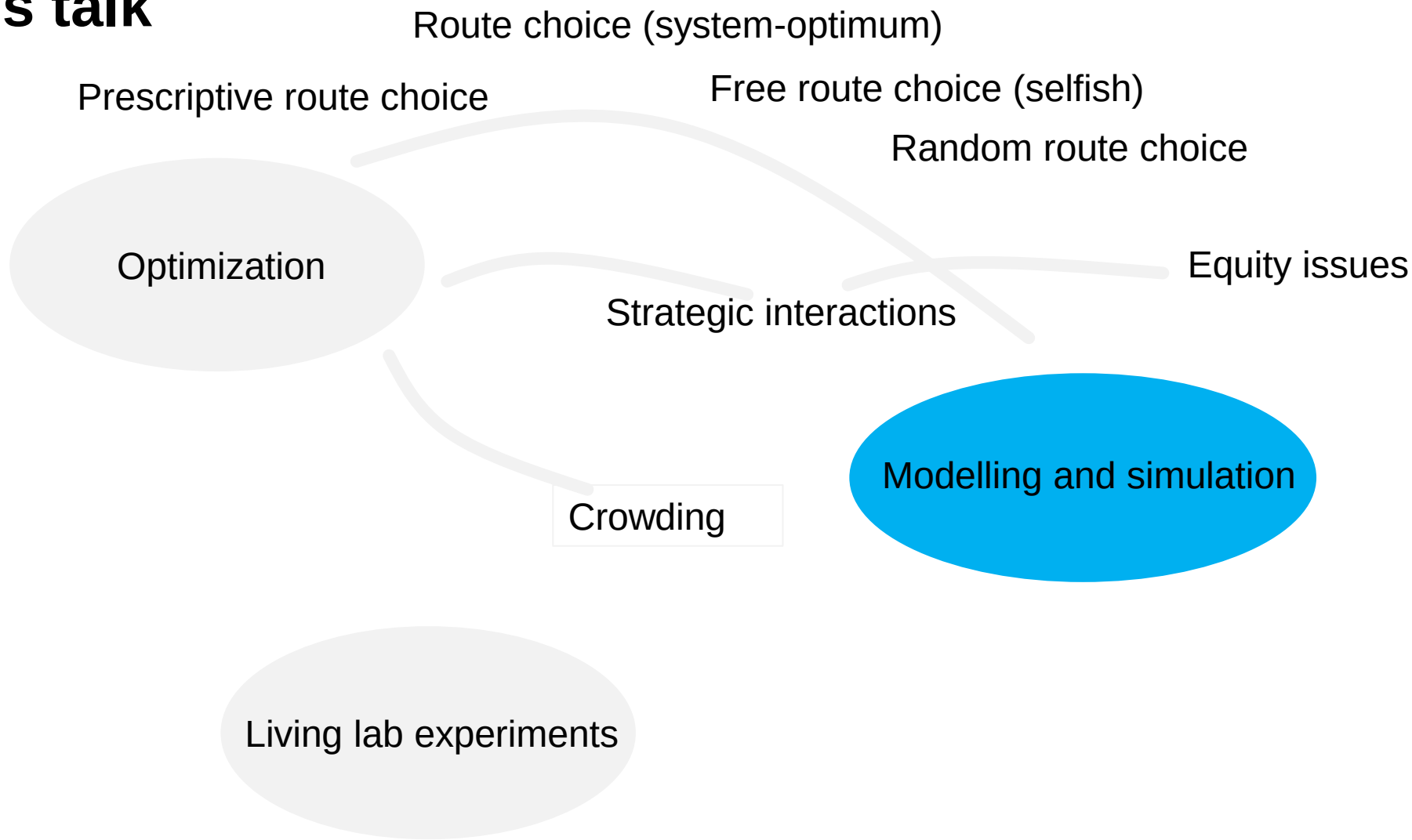
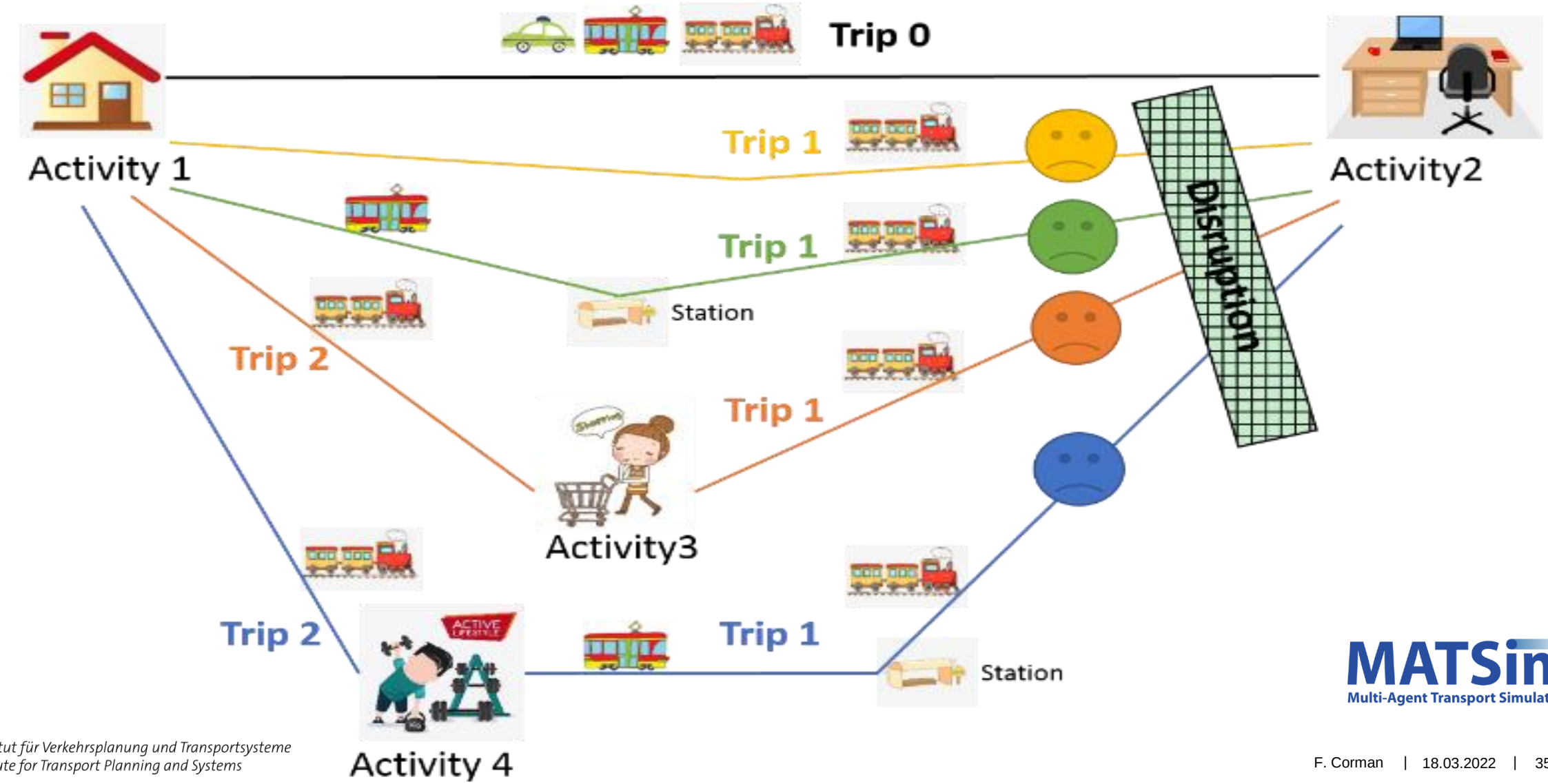


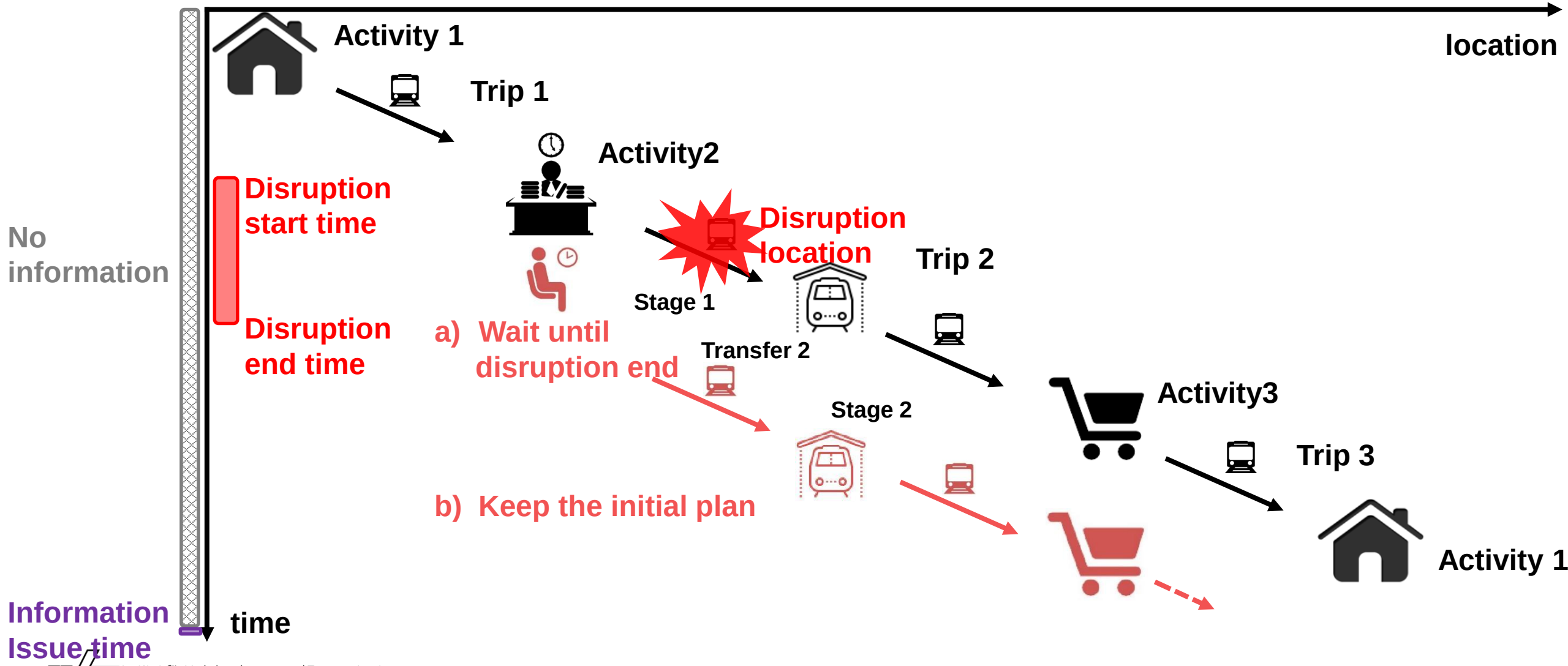
Model the impact of information towards more than just the trip?



MATSim
Multi-Agent Transport Simulation

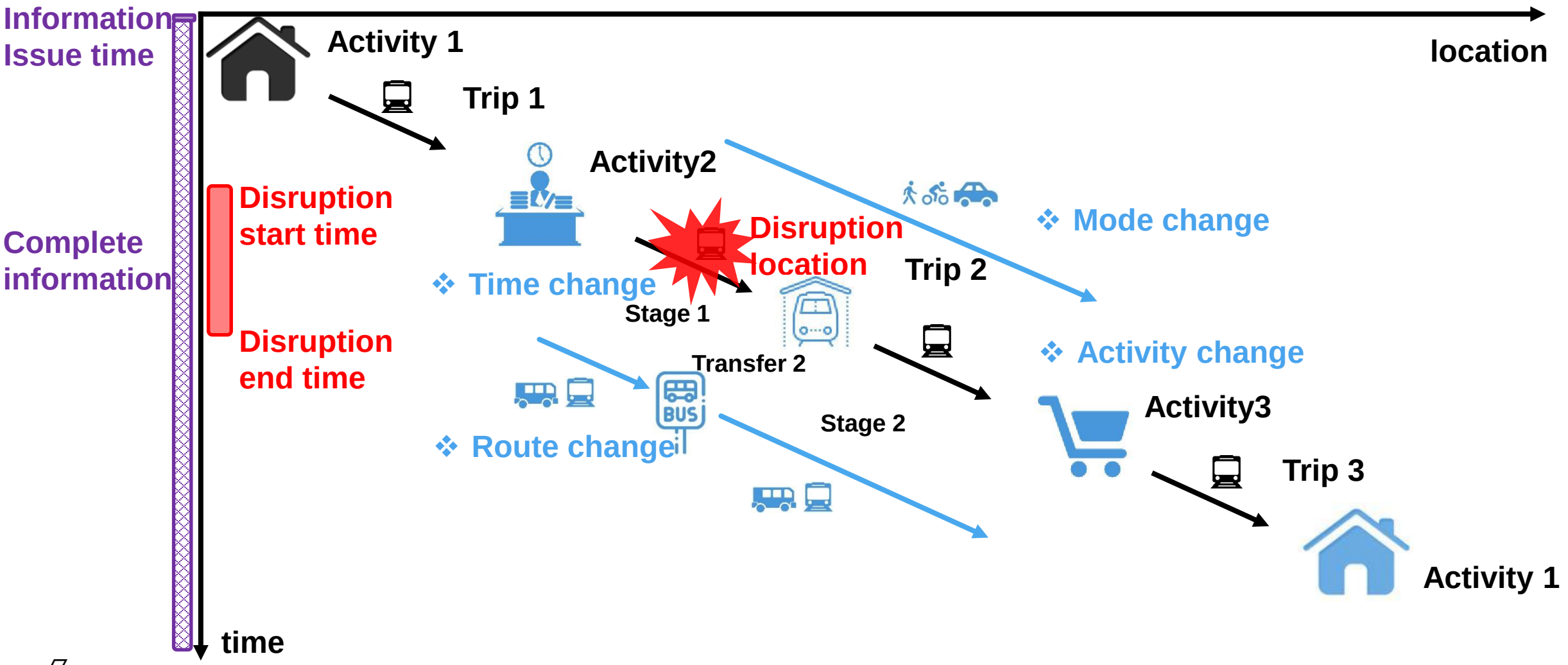
Approach

- No information



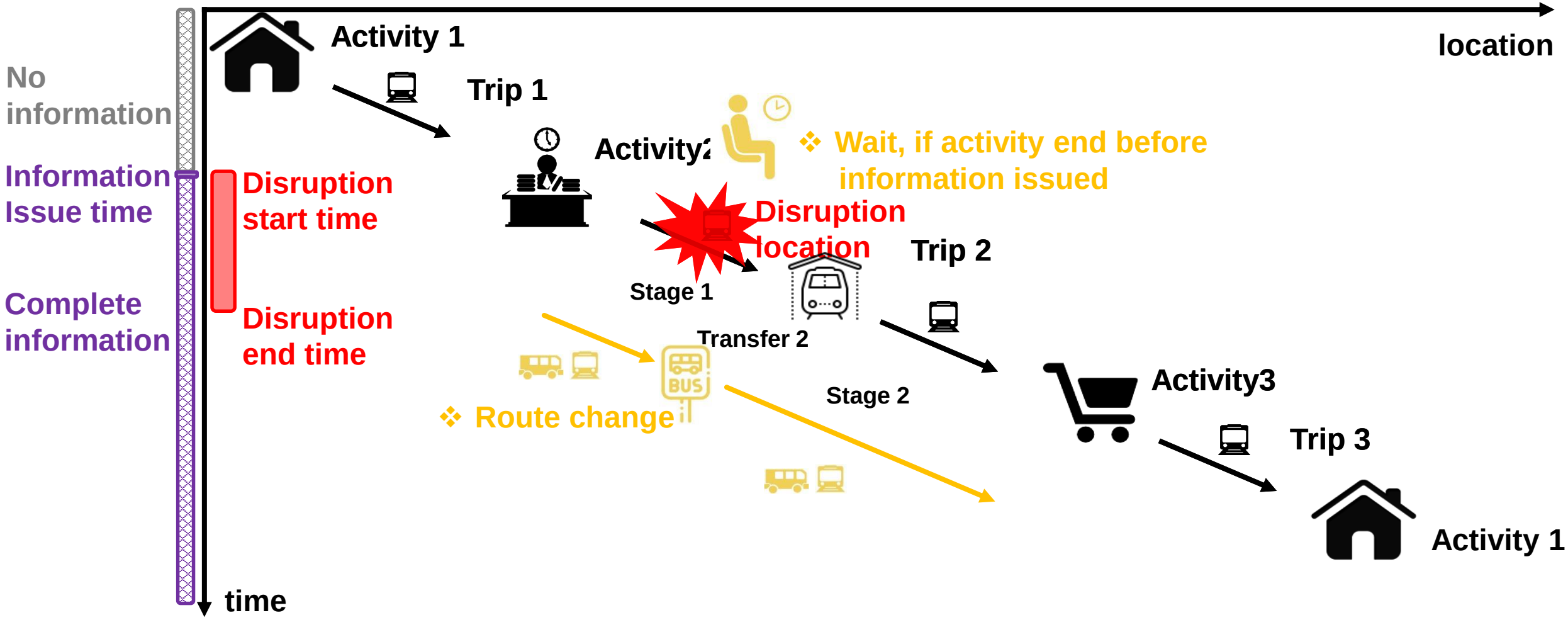
Approach

- Advance information



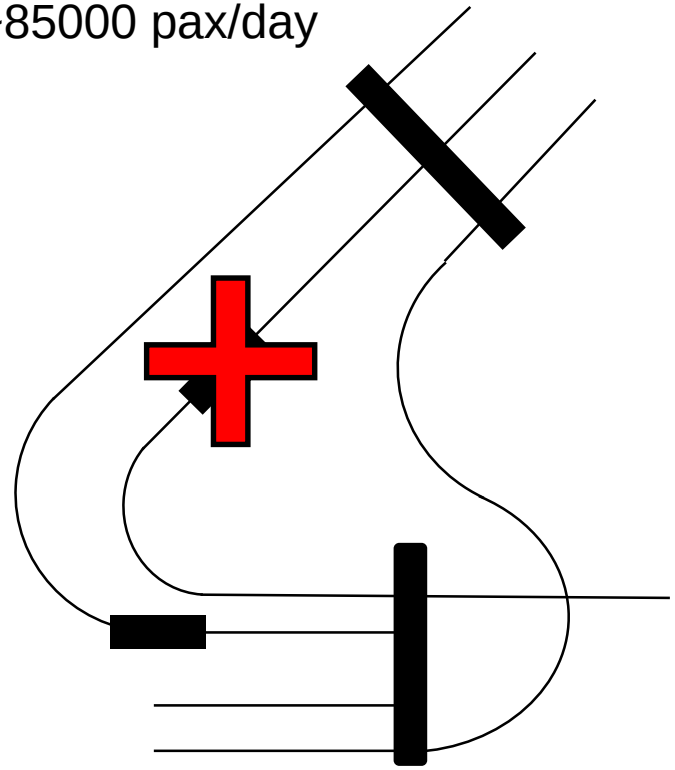
Approach

- Timely information

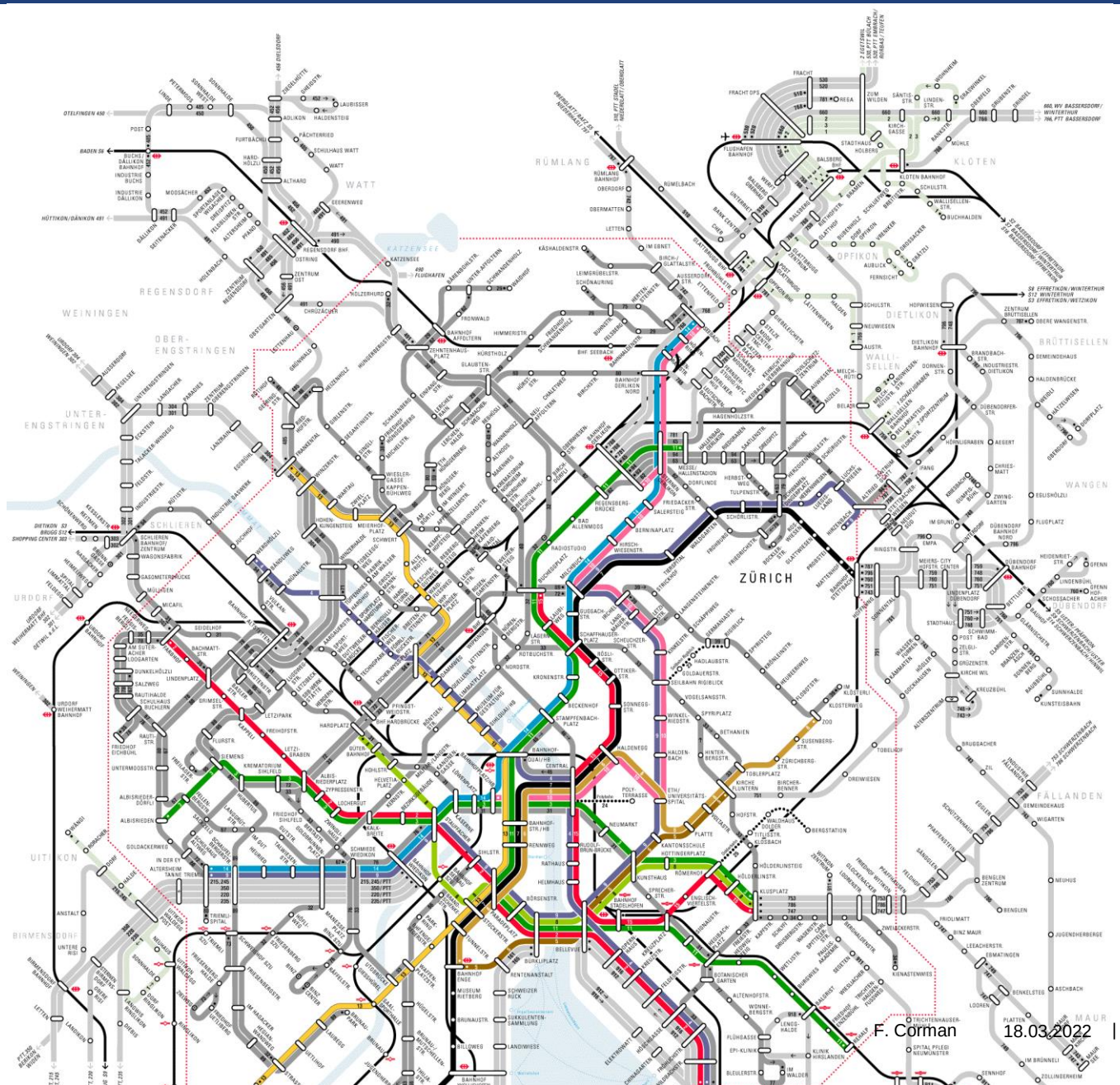


Example disruption, Zurich

Oerlikon
~300 trains/ day
~85000 pax/day



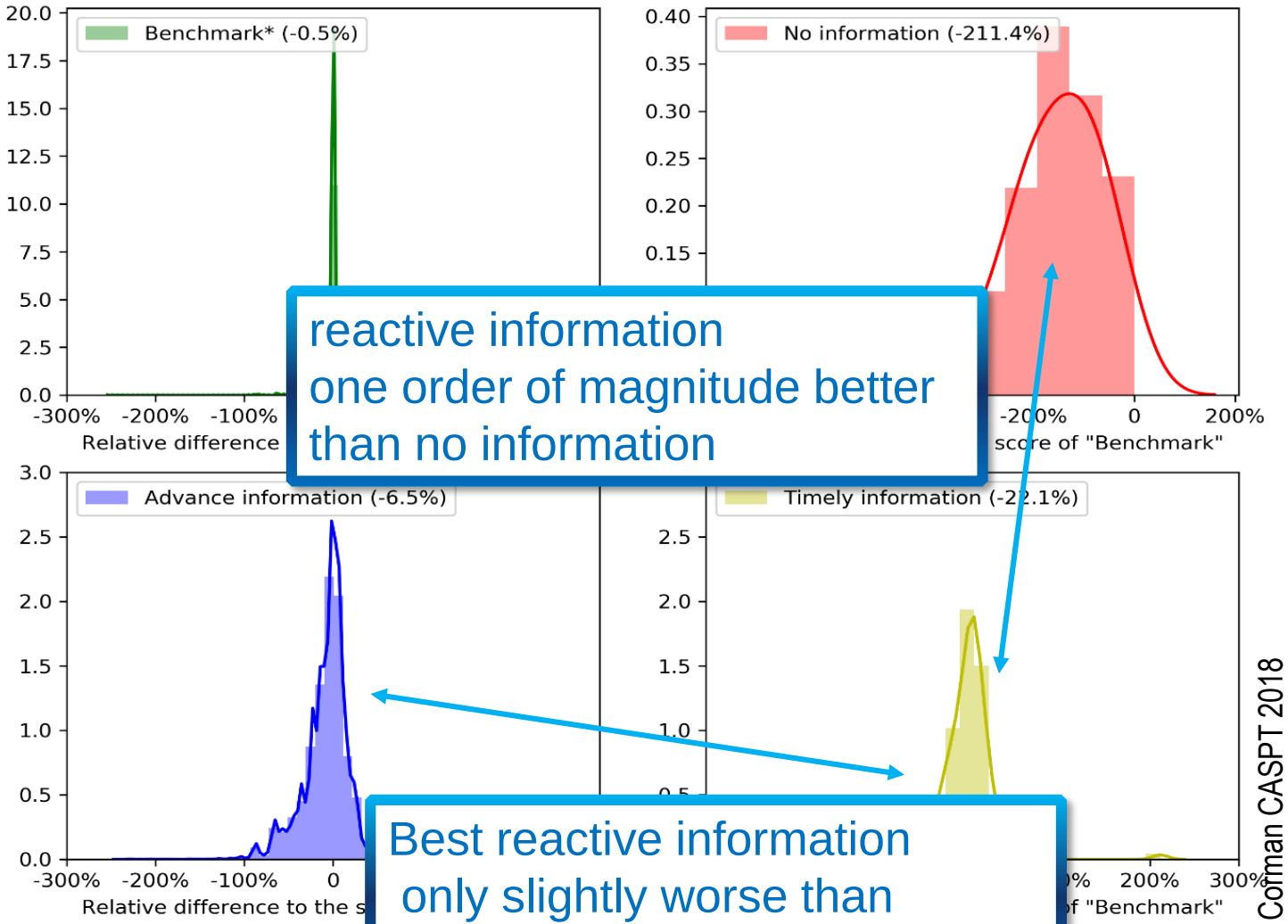
Main station
~2900 trains/ day,
450000 pax/ day



A large diversity among passengers

- Very complex information availability strategies can be modeled
- Variability in impact; somebody better off

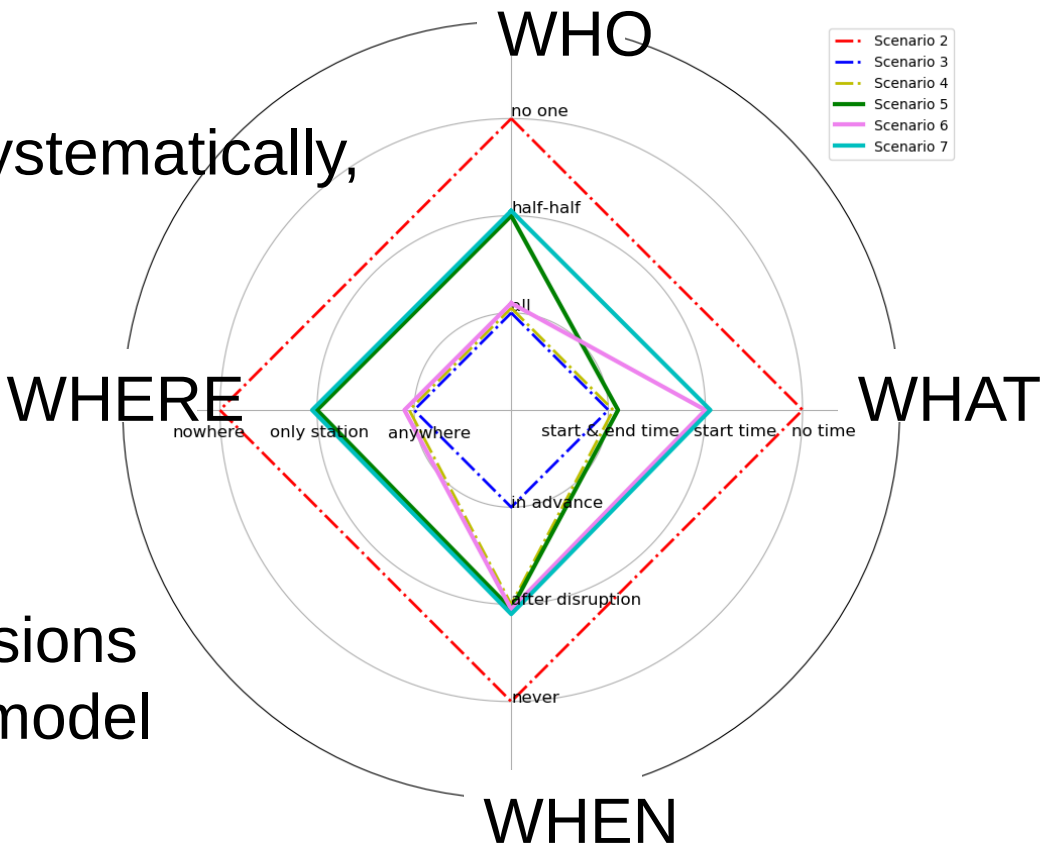
- Further potential to decrease impact changes by managing the system



Leng, Corman CASPT 2018

What can be learned by agent-based simulations?

- When information dissemination is described systematically, it can be simulated in agent-based models
- Real disruptions are complicated
  (who knows what when?
  And how correct it is?Who replans how when?
  How much is that sub-optimal?)
- Interplay between operations, passengers decisions and (limited) information is crucial, but hard to model
- Diversity among user groups,
  realistic spreading of information,
  disruption characteristics often unknown or uncertain



Tracking

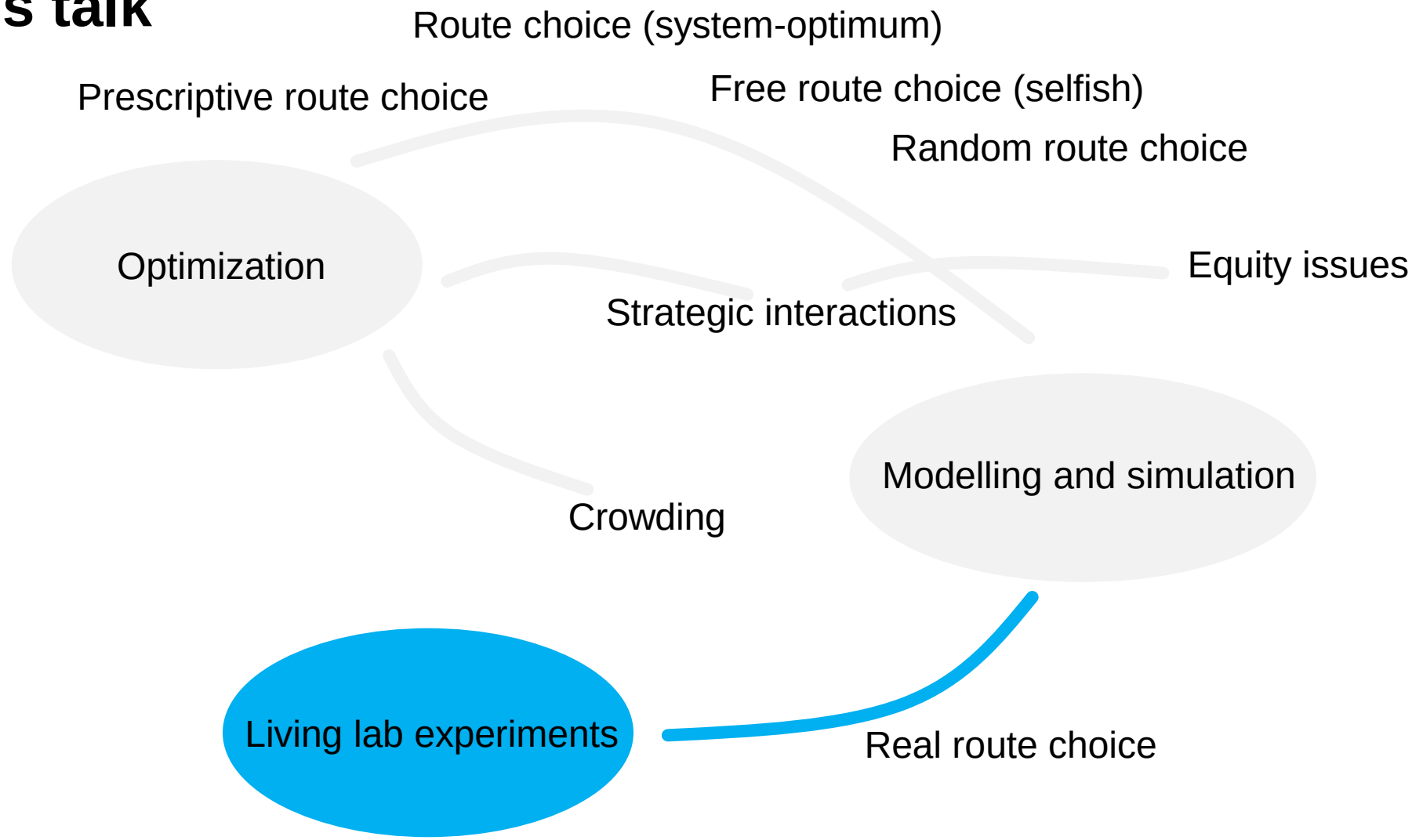
Marra A.D, Becker, H, Axhausen, K. W. Corman F (2019) Developing a passive GPS tracking system to study long-term travel behavior. Transportation Research Part C 104, 348-368

A.D. Marra, Phd Thesis

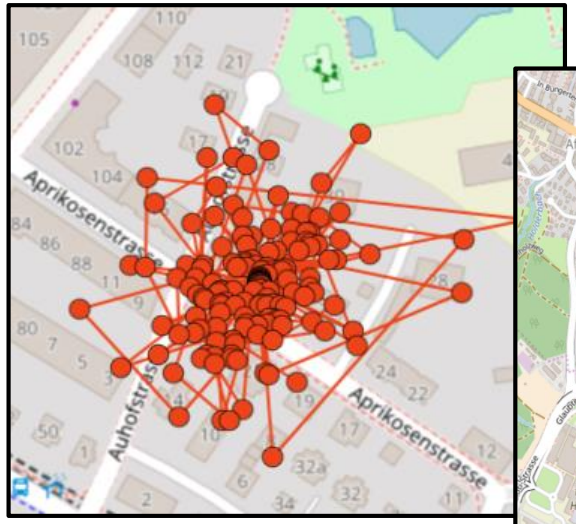
STRAVA heatmap

Outline of this talk

- Introduction
- Conclusion



Tracking approaches to understand what's going on



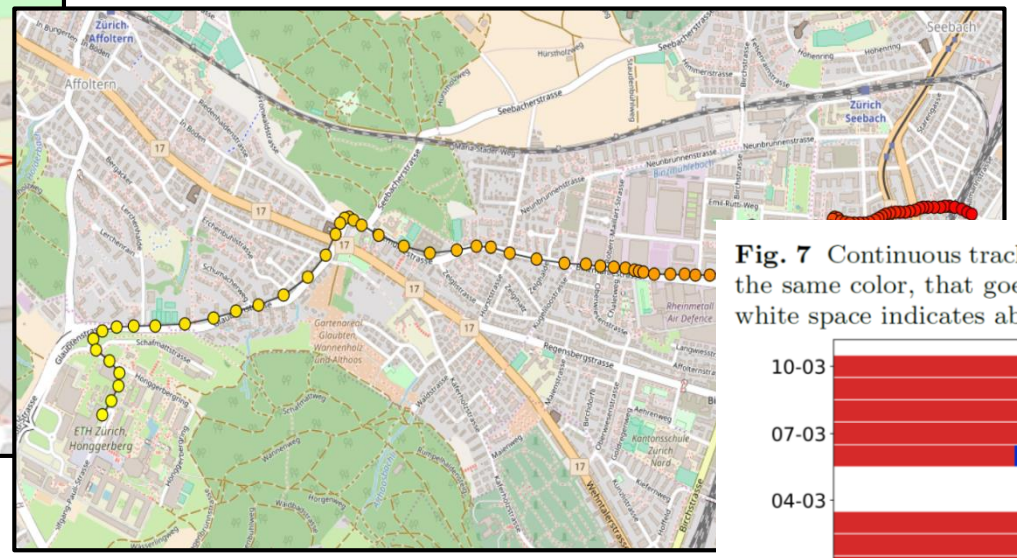
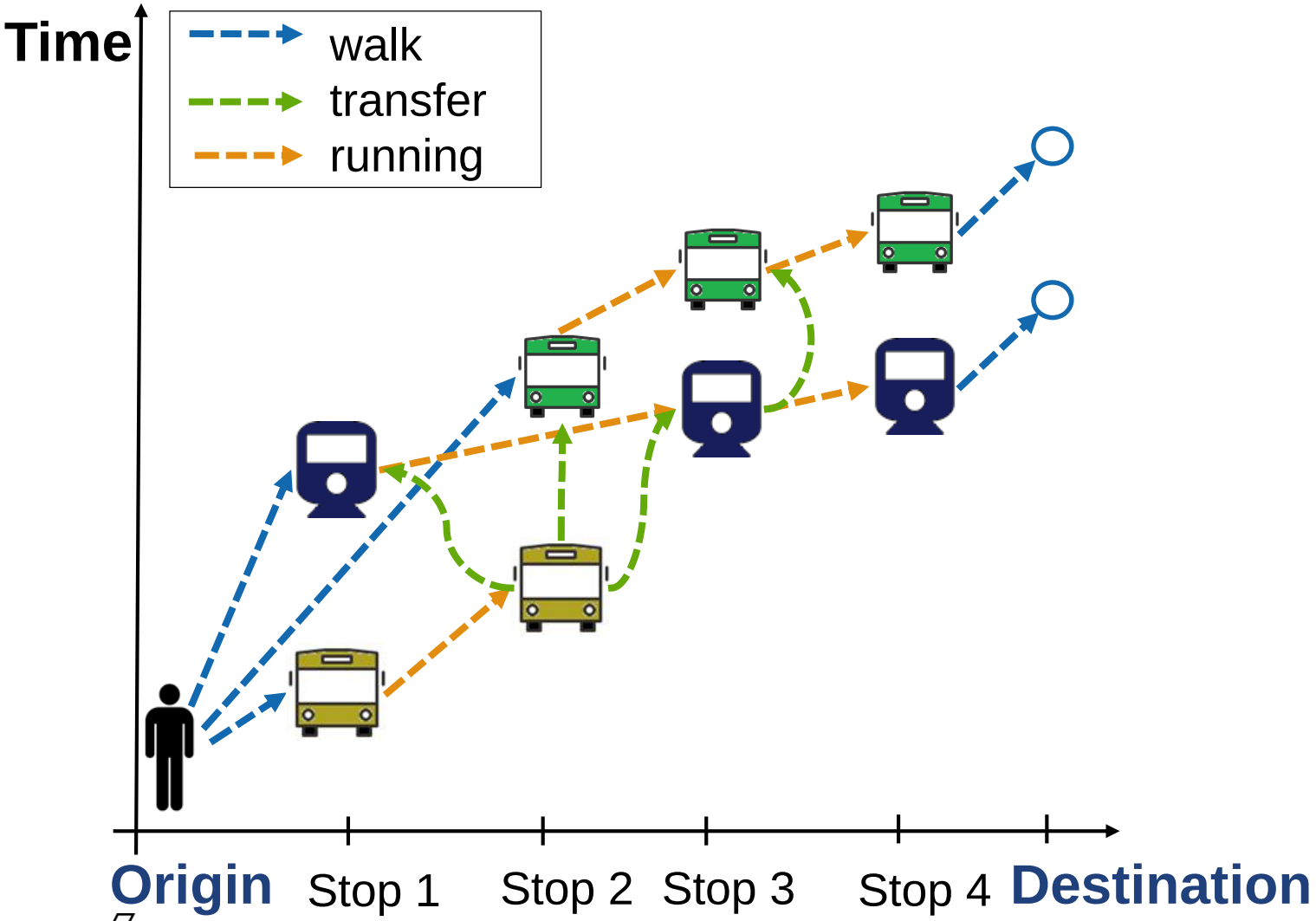


Fig. 7 Continuous tracking of a single user for one month. Activities in the same place have the same color, that goes from red to yellow according to the time spent in the activity. A white space indicates absence of signal.

Marra et al TRC, TRA

Methods: choice set generation



Information

Realized data → Real condition

Timetable data → Planned condition

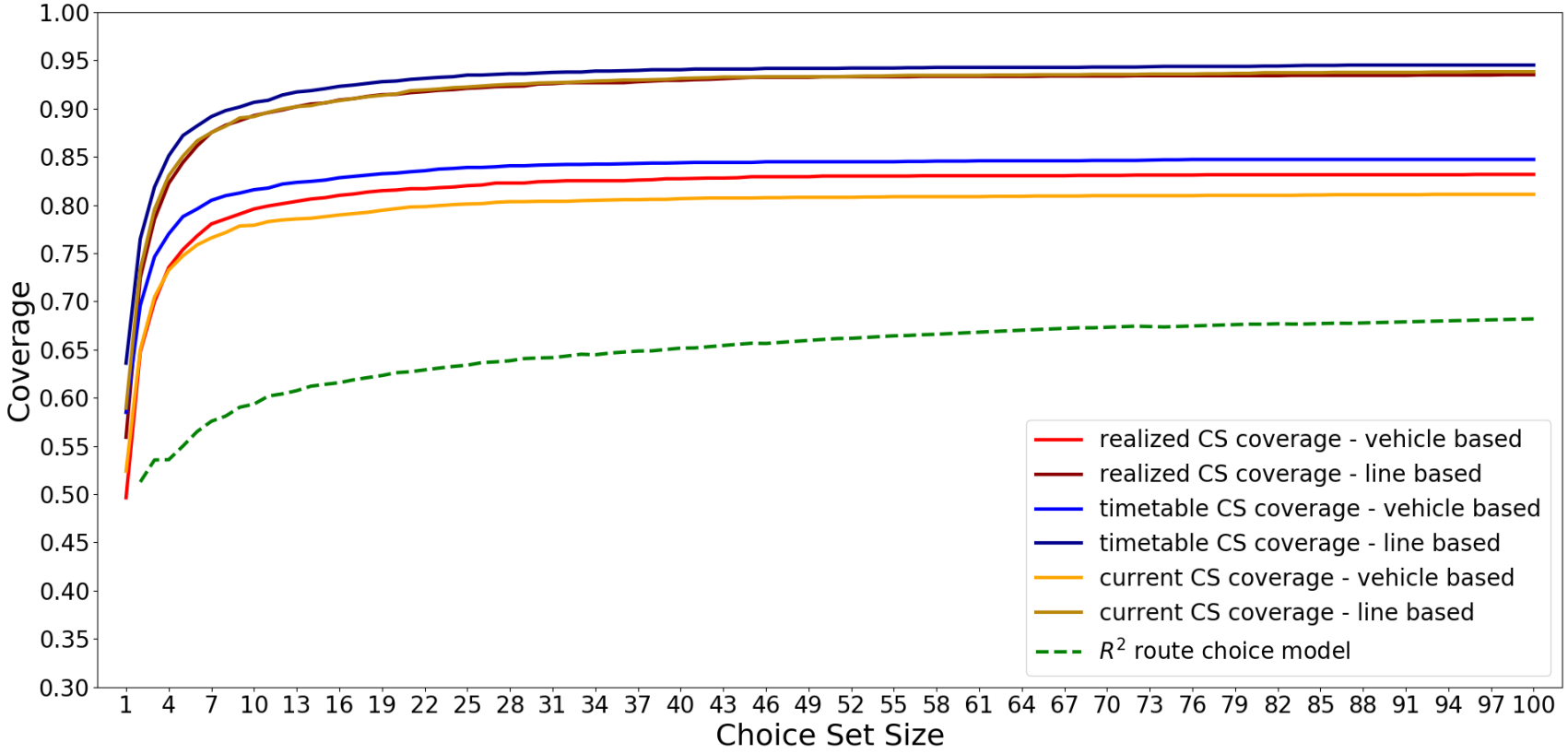
R + T data → Current condition

What can be learned by tracking? How do people choose?

- **Coverage:**
  - **95% lines**
  - 84% vehicles
- **Size:**
  - Good performances with **10 alternatives**
  - No improvements with > 40 alternatives
- **Information:**
  - **Timetable choice set** has highest coverage
  - **Large heterogeneity**

Study 2019

- 172 participants
- **2901** public transport trips in Zurich



Which choice in disruption→ what exactly is a disruption?

- Identify which delays/disruptions affect more the passengers
- Identify HOW delay/disruptions affect passengers

Disruption

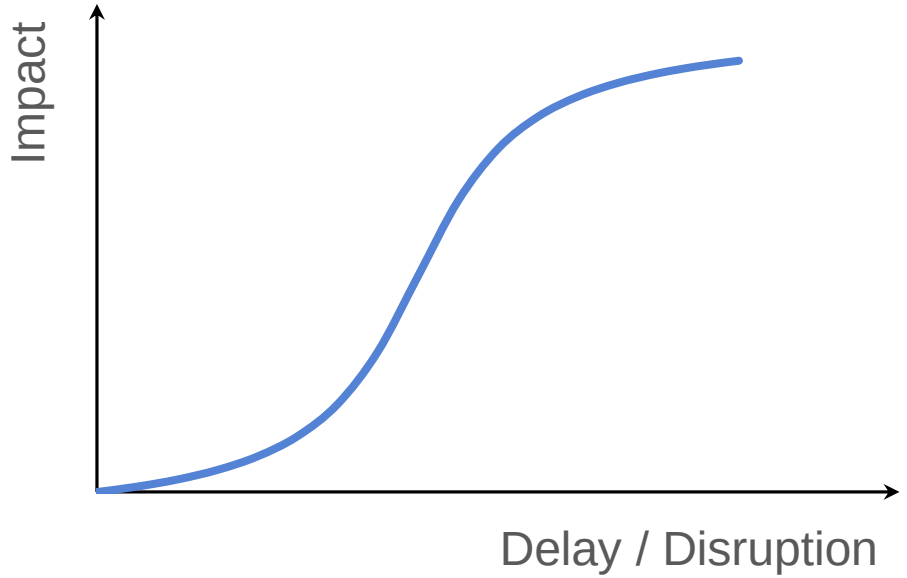
Area

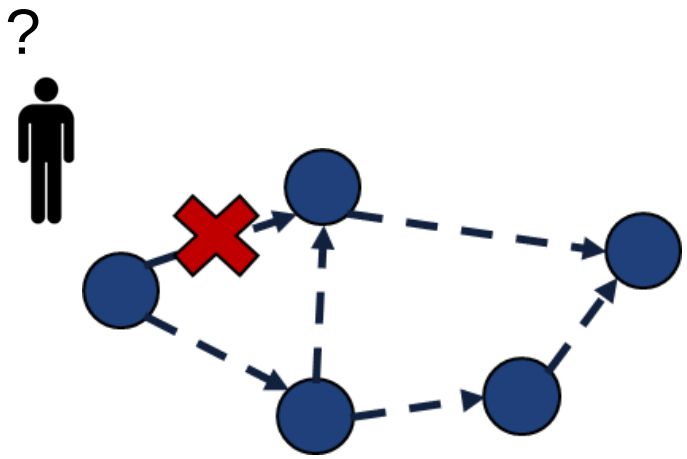
Duration

# of means

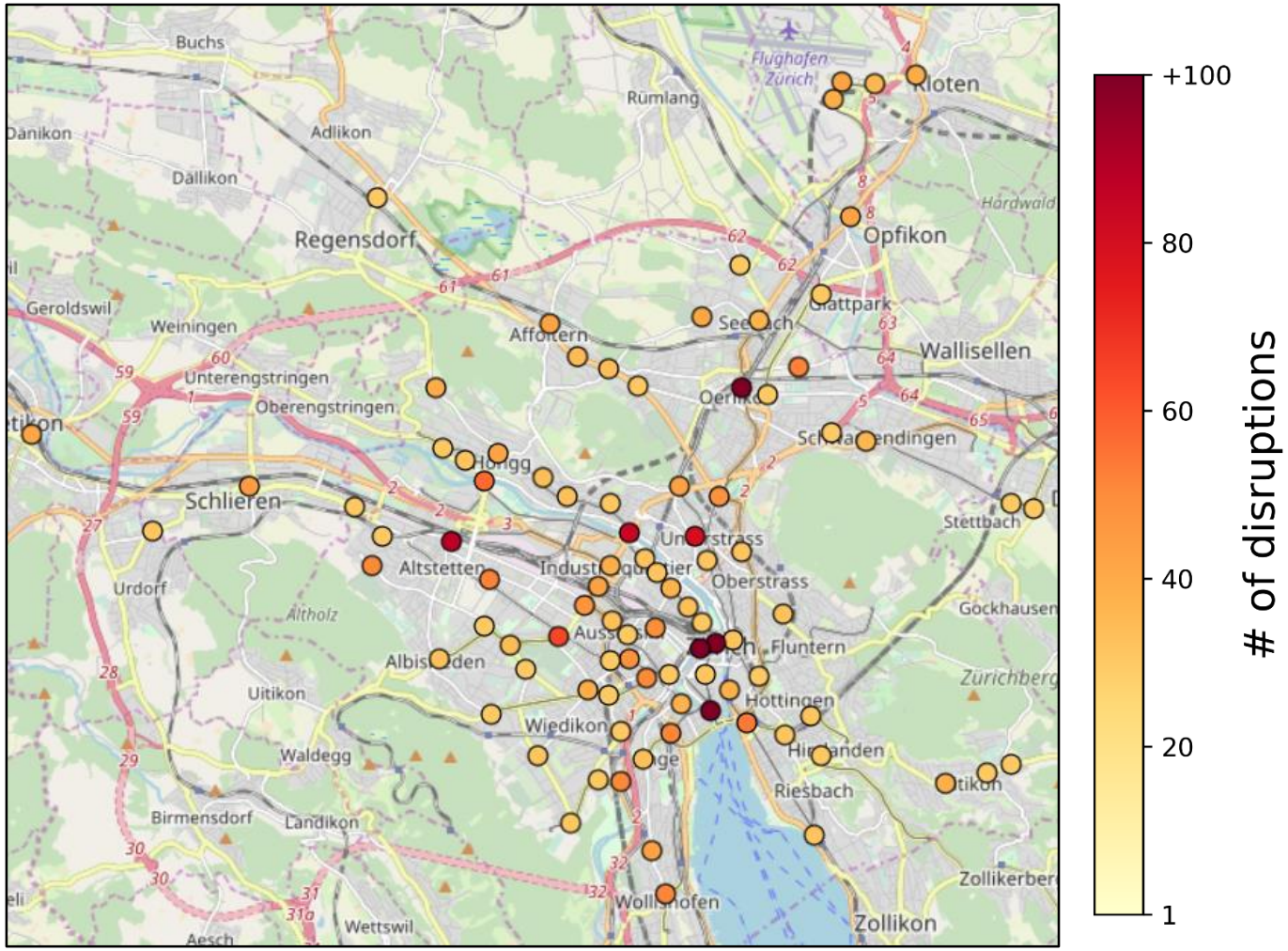
Zone

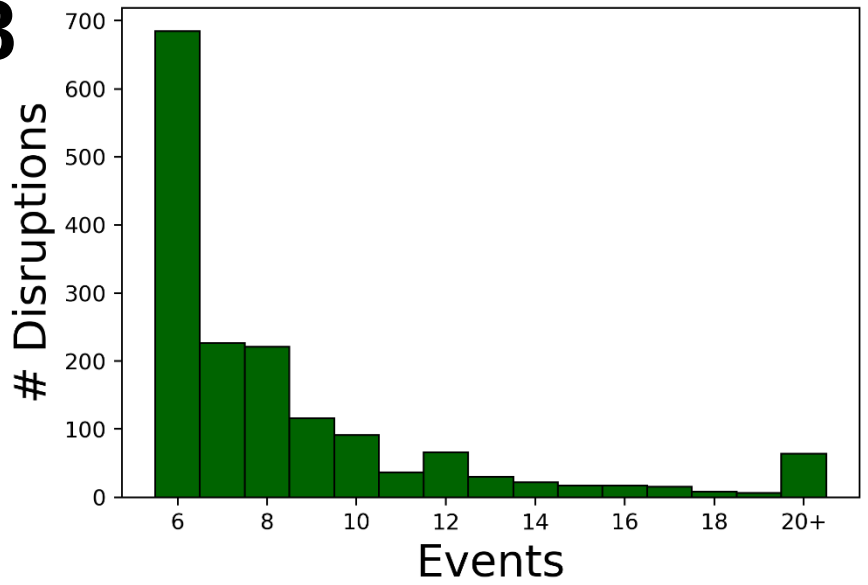
OD affected

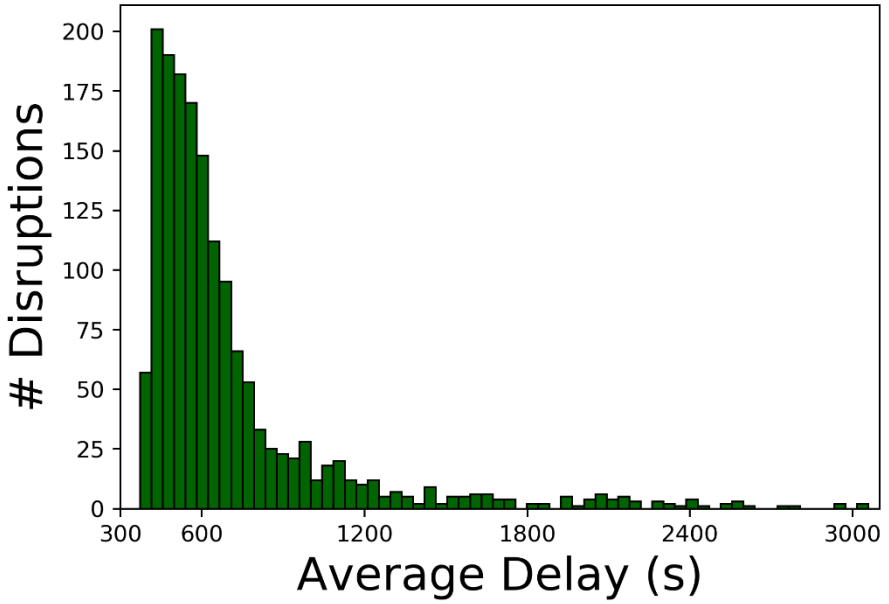




Disruption distribution Jan-Sep 2018







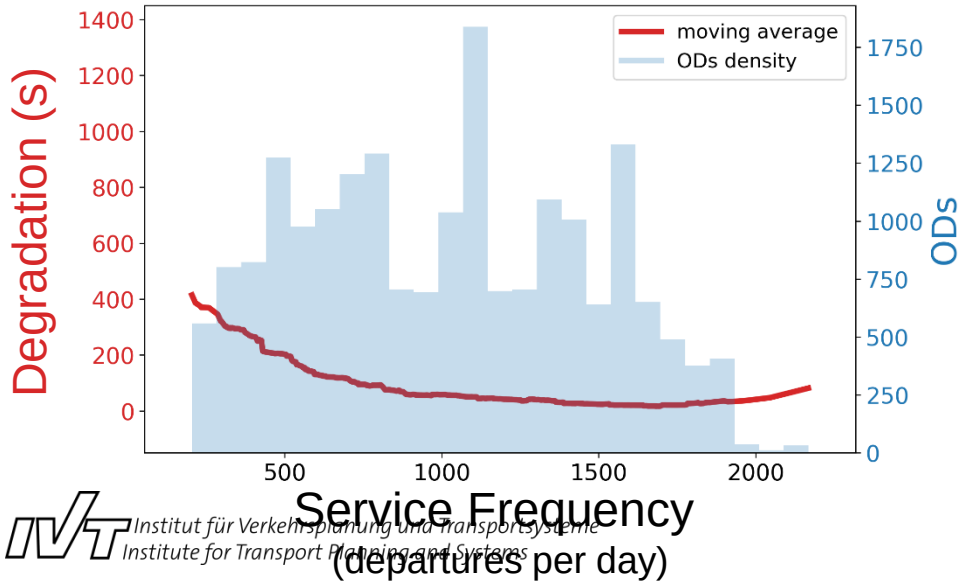
Feature Importance

Mutual Information with *degradation*

$$MI(X,Y) = \int_{y\in Y}\int_{x\in X} p(x,y)\log\left(\frac{p(x,y)}{p(x)p(y)}\right)\,dx\,dy$$

Mean Decrease in Impurity

From random forest regression (R^2 = 0.41)



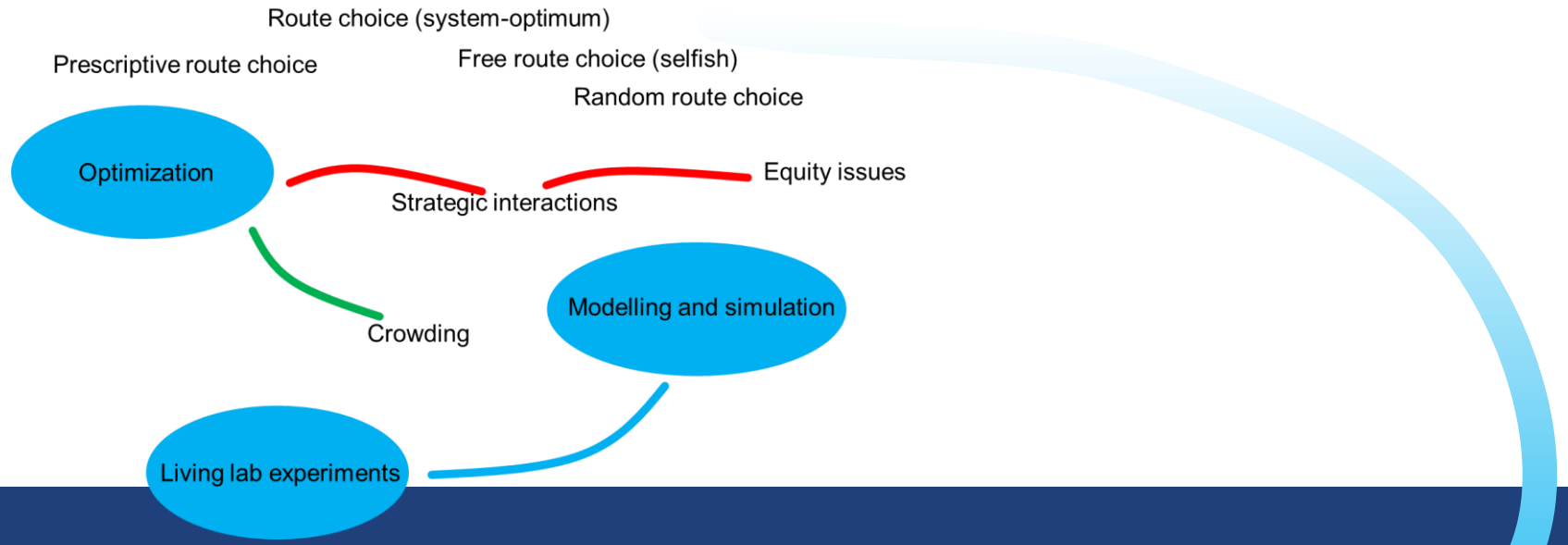
Feature	MI	MDI
service frequency	**0.203**	**0.078**
closeness	**0.203**	0.039
outDegree centr.	0.181	0.047
betweenness	0.180	0.050
# lines	0.156	**0.079**
choice set size	0.146	**0.119**
events/perimeter	0.133	0.034
dest. closeness	0.110	0.073
avg. delay	0.087	0.044
duration	0.041	0.025
# events	0.030	0.014

More → ... Importance ... ← Less

Main characteristics of disturbances

What can be learned by tracking real passengers?

- Travel surveys based on GPS tracking gives a trajectory. But difficult to identify the alternatives (choice set generation algorithm for route recommendation)
- Analysing sequences of activities, studying regularities & anomalies
- Comparing different information types allows identifying uninformed passengers
- Understanding route choices during disturbances helps to predict passengers' reaction and plan interventions
- What is in mind of the people when delays occur and need to choose? supervised study
- Improve mode detection algorithm with machine learning; exploit longitudinal data of the same user



Conclusions

What can be learned from this talk?

- Managing passengers is not easy, but it is needed!
- Most of the realistic phenomena require models we are not yet able to solve to optimality. Is an approximate solution going to be better than a perfect solution to the wrong problem?
- Understanding how people react to non-planned situations, and optimized solutions is already complicated enough
- Understanding diversity of people is crucial: profiling a priori or based on realized behavior. Interaction to/from/with transport planning models
- Complicated interactions, when people decide autonomously or based on the expectations of decisions from others!

What to do for future research?

- Consider test cases under different conditions, large/small delays, small/ large networks
- Analyse ground truth from simple simulation
  Analyse complex ground truth from complex simulation
  Analyse reality
- Predict system evolution assuming no change (delay, crowding)
- Understand + model supply
  Understand + model demand: how reliable information was? How people adjust?
- Understand which information was actually used when
- Integrate with other modalities (walking, bikes, cars,…)

Passenger-oriented railway traffic planning and management

Francesco Corman
corman@ethz.ch
Chair for Transport Systems

Who am I

←China

← US

← Japan

Assistant Professor Transport and Logistics,
Delft University of Technology

PhD in Real-time Railway Traffic Control,
Delft University of Technology

Post-Doc in Transport and Logistics,
Catholic University Leuven
Chair of Transport Systems
ETH Zurich

Bachelor in Computer Science Engineering;
Master in Management & Automation Engineering