TRA

TRANSPORT
RESEARCH
ARENA
BUDAPEST

18-21/05/26

Scanning for infrastructure in early planning

Generating and assessing possible rail infrastructure development under uncertainty in early planning stages

Arnor Elvarsson, S. Fuchs, B. T. Adey

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Arnór Elvarsson

Civil engineer and planner.

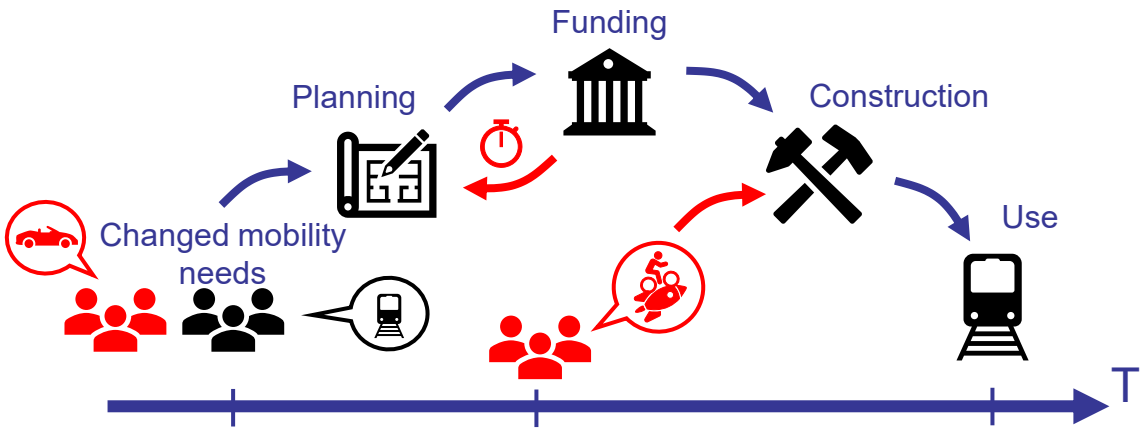
Focused on the management of the built environment.

Lecturer and researcher at ETH Zürich (CH).

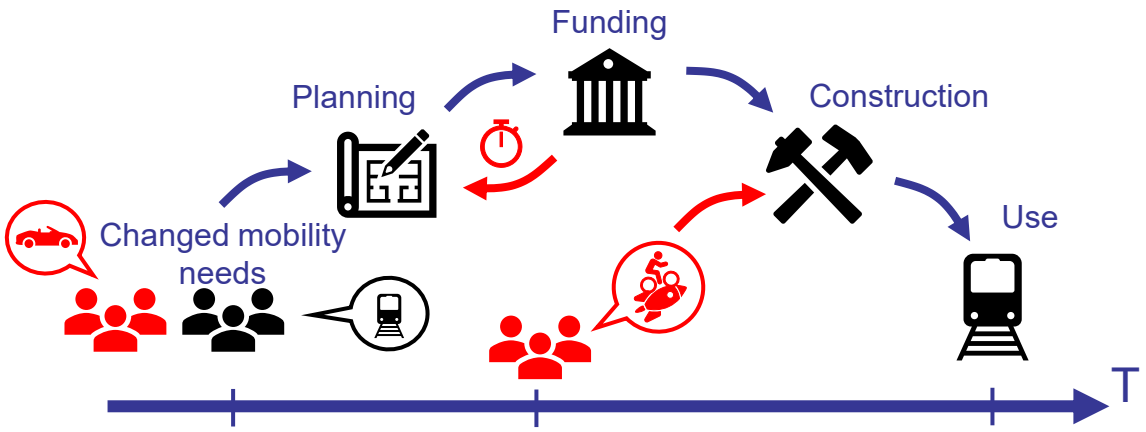
Professor of Infrastructure Planning and Projects, Bifröst University (IS).

ETH zürich
HÁSKÓLINN Á BIFRÖST
BIFRÖST UNIVERSITY

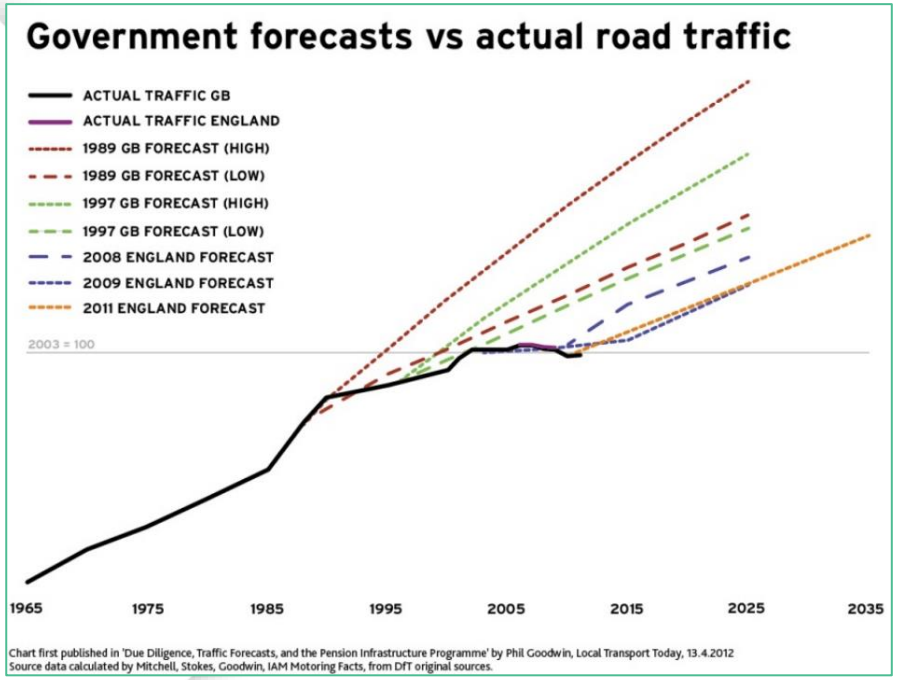
earnor@ethz.ch
arnore@bifrost.is


Funding
Planning
Construction
Use
Changed mobility needs
T

PLANNING WITH UNCERTAINTY

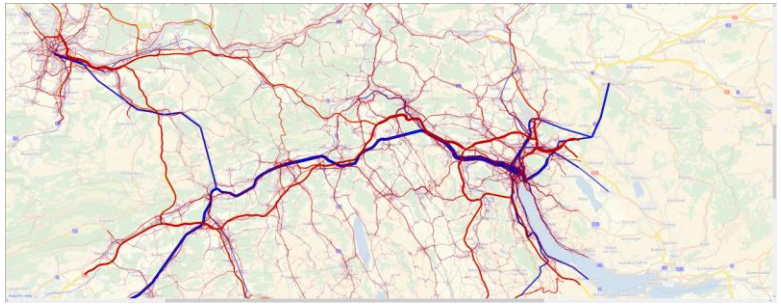


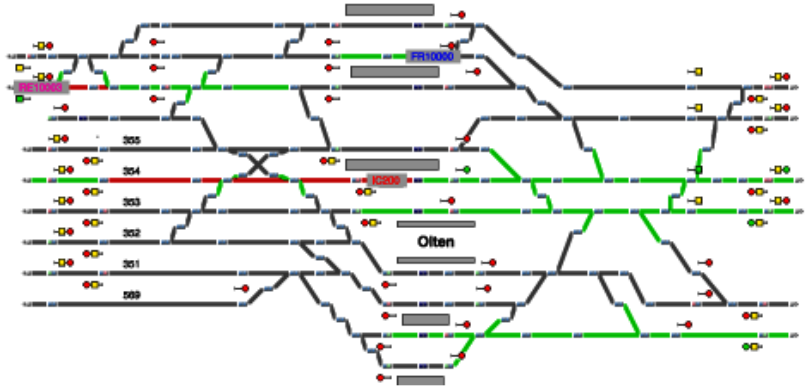
- Organisations struggle with infrastructure decisions that must serve decades of societal change
- Current planning relies on predictive, often proprietary, models



- Rapid uncertainty: population growth, automation, climate targets
- These models struggle when uncertainty is high

RESEARCH GAP





- Predictive models: data-hungry, expert-driven, slow to adapt
- Focus on “most likely future” rather than robustness

- Manual design of infrastructure alternatives
- Limited transparency and reproducibility

Image credits: ETH Zürich // San Diego Association of Governments

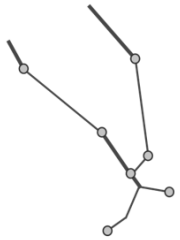
METHODOLOGY

Current state

Future state

Prediction

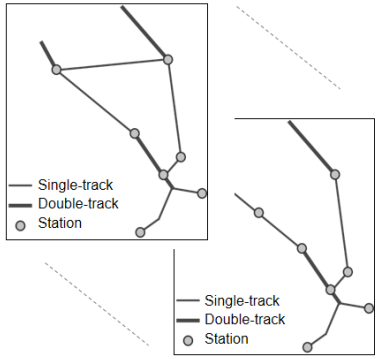
Infrastructure



Infrastructure modifications

generated

Modification 1, 2, … n

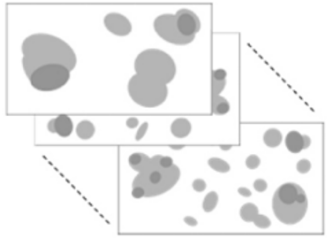


Environment

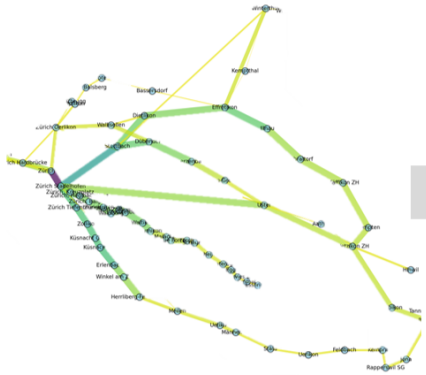
Future scenarios

Show range of uncertainty

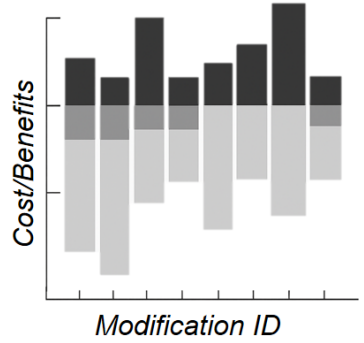
Future scenario 1, 2, … n



Map out future stakeholder needs in the infrastructure network

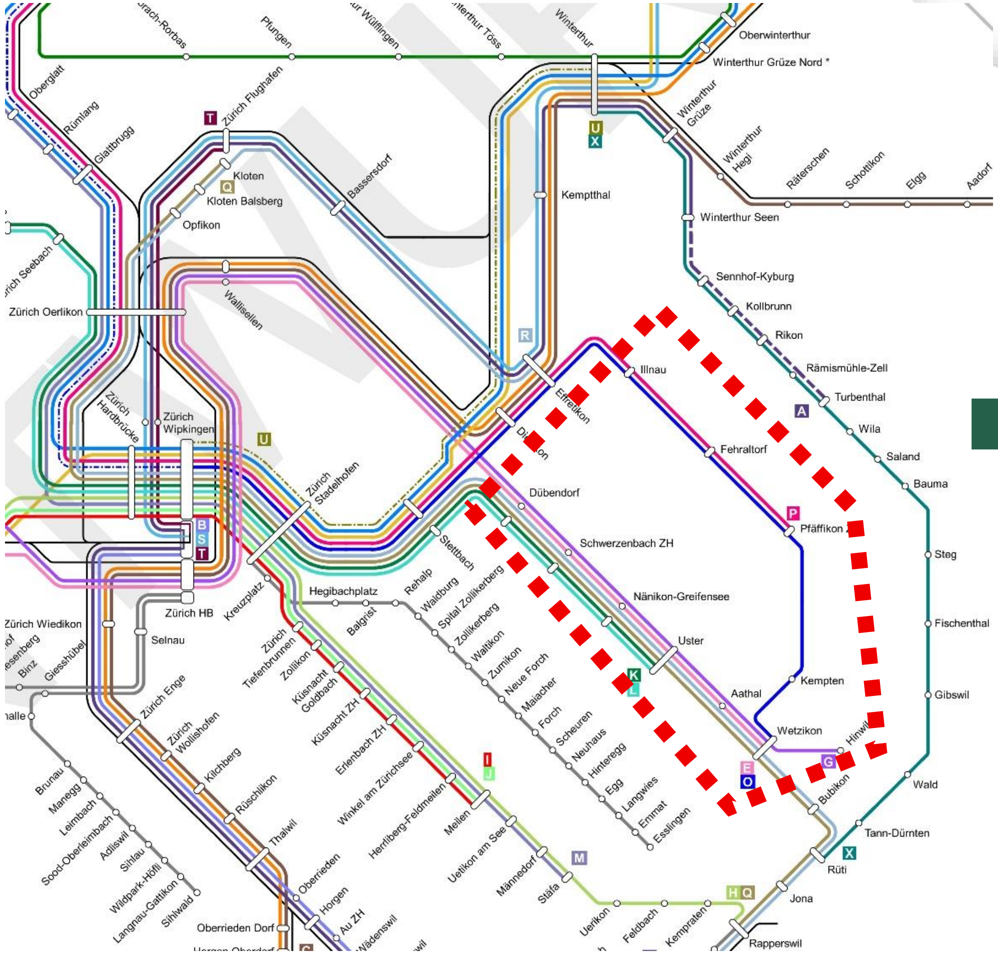


Appraisal



MODEL & RESULTS

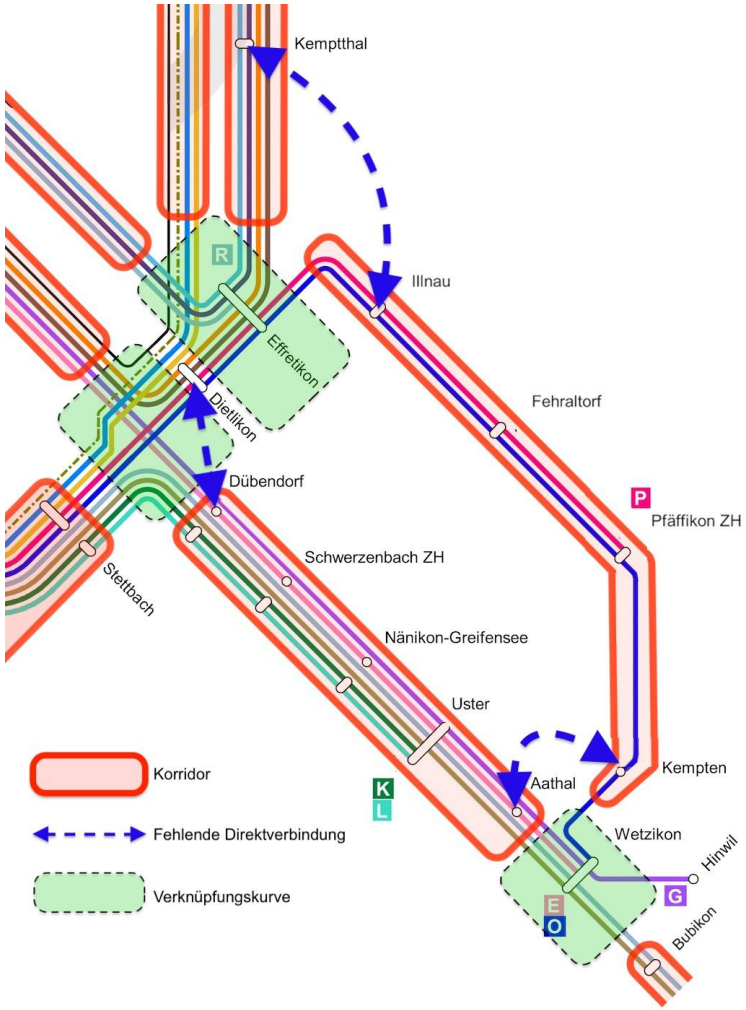
CASE STUDY

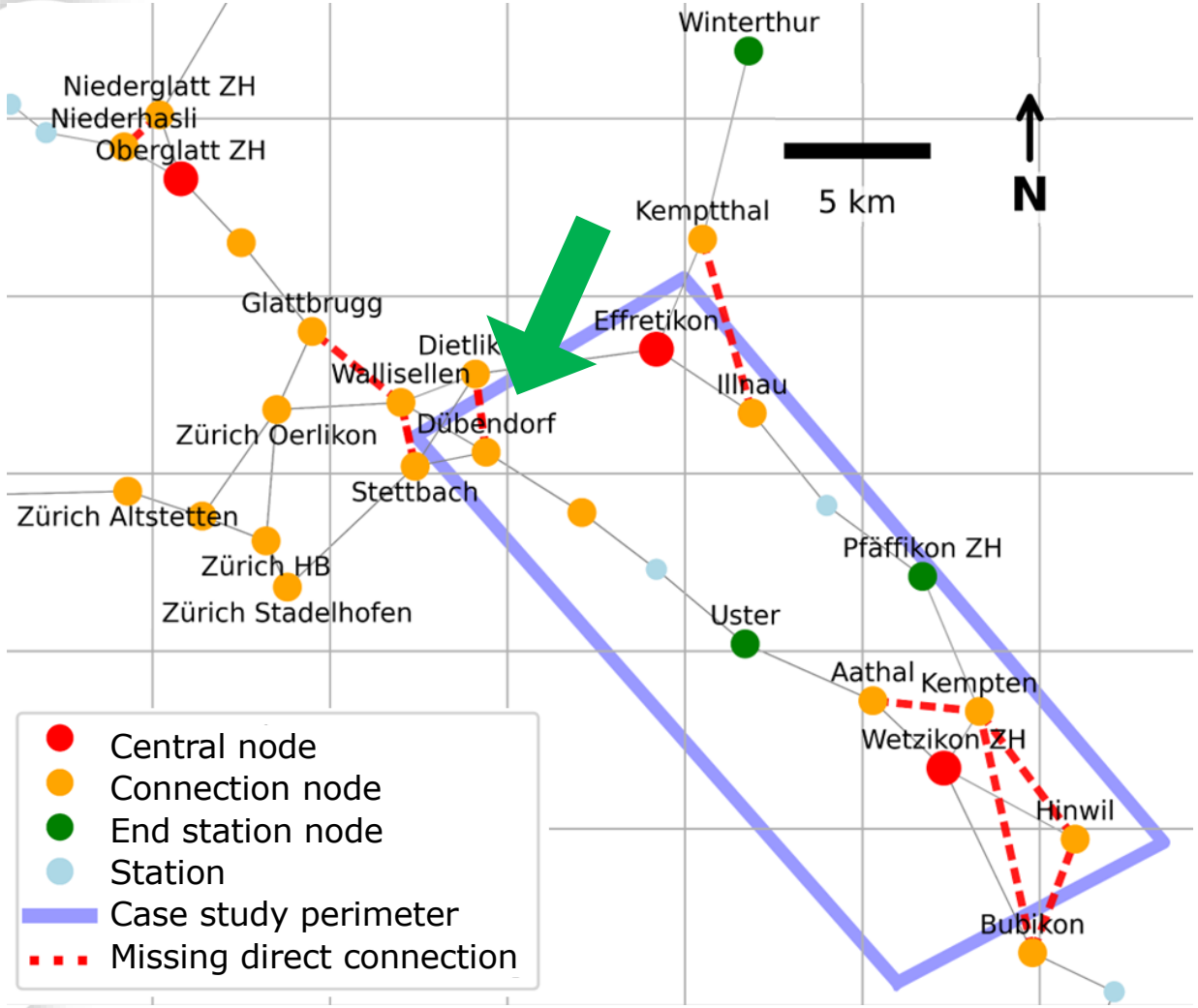


Oberwinterthur
Winterthur Grüze Nord *
Winterthur Grüze
Winterthur Hegi
Räterschen
Schottikon
Elgg
Aadorf
Kemptthal
Winterthur Seen
Sennhof-Kyburg
Kollbrunn
Rikon
Rämismühle-Zell
Turbenthal
Wila
Saland
Bauma
Steg
Fischenthal
Gibswil
Wald
Tann-Dürnten
Rüti
Jona
Rapperswil
Zürich Flughafen
Kloten
Kloten Balsberg
Opfikon
Bassersdorf
Oberglatt
Rümlang
Glattbrugg
Zürich Oerlikon
Wallisellen
Zürich Hardbrücke
Zürich Wipkingen
Zürich Stadelhofen
Zürich HB
Selnau
Illnau
Fehraltorf
Pfäffikon
Effretikon
Dübendorf
Schwerzenbach ZH
Nänikon-Greifensee
Uster
Aathal
Kempten
Wetzikon
Hinwil
Bubikon
Stettbach
Hegibachplatz
Balgrist
Rehalp
Waldburg
Spital Zollikerberg
Zollikerberg
Waltikon
Zumikon
Neue Forch
Maiacher
Forch
Scheuren
Neuhaus
Hinteregg
Egg
Langwies
Emmat
Esslingen
Zürich Wiedikon
Giesshübel
Zürich Enge
Zürich Wollishofen
Kilchberg
Rüschlikon
Thalwil
Oberrieden
Horgen
Au ZH
Wädenswil
Oberrieden Dorf
Zürich Tiefenbrunnen
Zollikon
Küsnacht Goldbach
Küsnacht ZH
Erlenbach ZH
Winkel am Zürichsee
Herrliberg-Feldmeilen
Meilen
Uetikon am See
Männedorf
Stäfa
Uerikon
Feldbach
Kempraten
Brunau
Manegg
Leimbach
Sood-Oberleimbach
Adliswil
Sihlau
Wildpark-Höfli
Langnau-Gattikon
Sihlwald

Legend
Modelled network
Rest of network
Generated connections
Case study perimeter
Traffic zones
Peripheral TAZs
Winterthur
Zürich HB
Uster
Wetzikon
Rapperswil
N
0 2.5 5 10
km

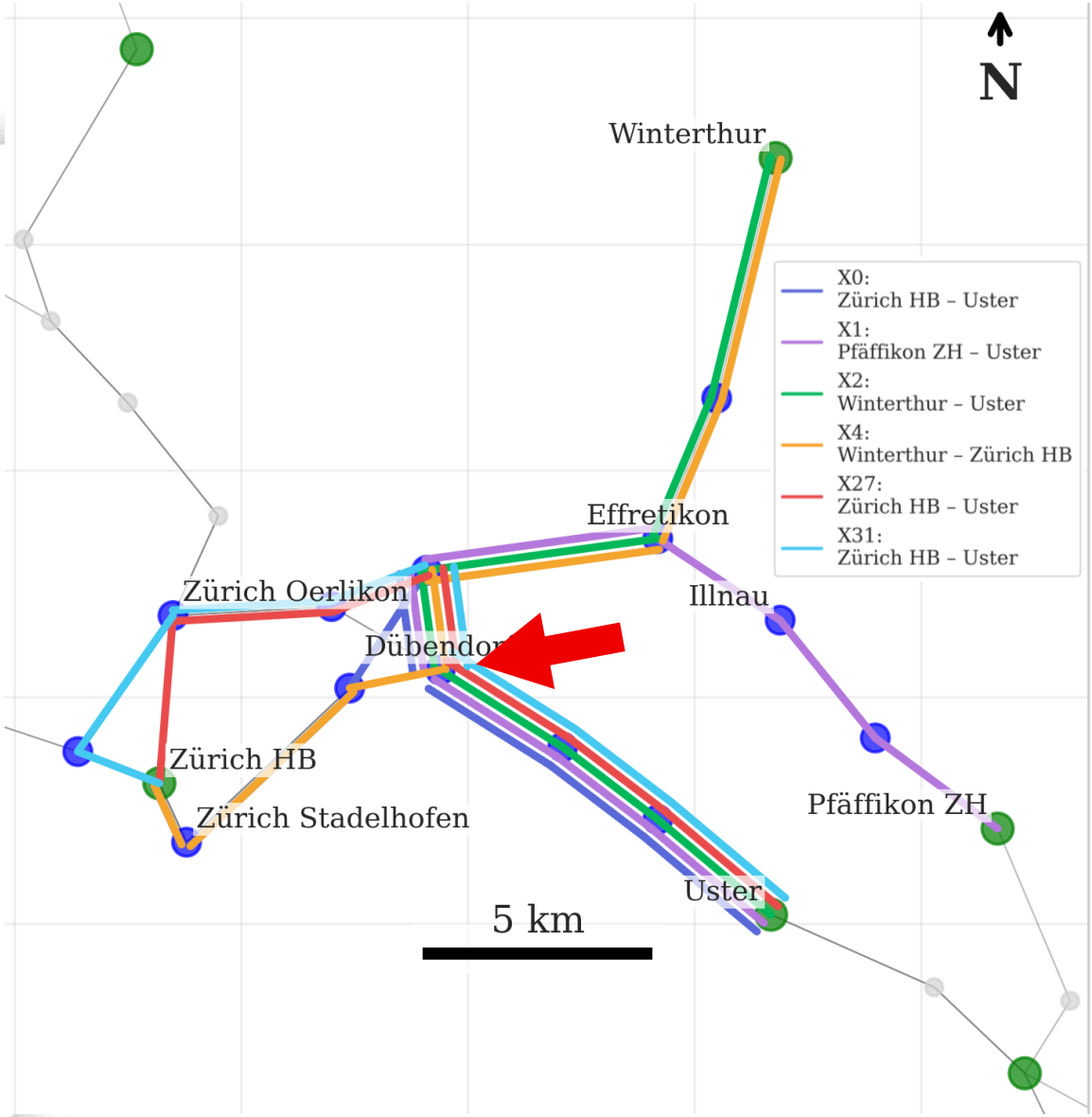
GENERATED INTERVENTIONS





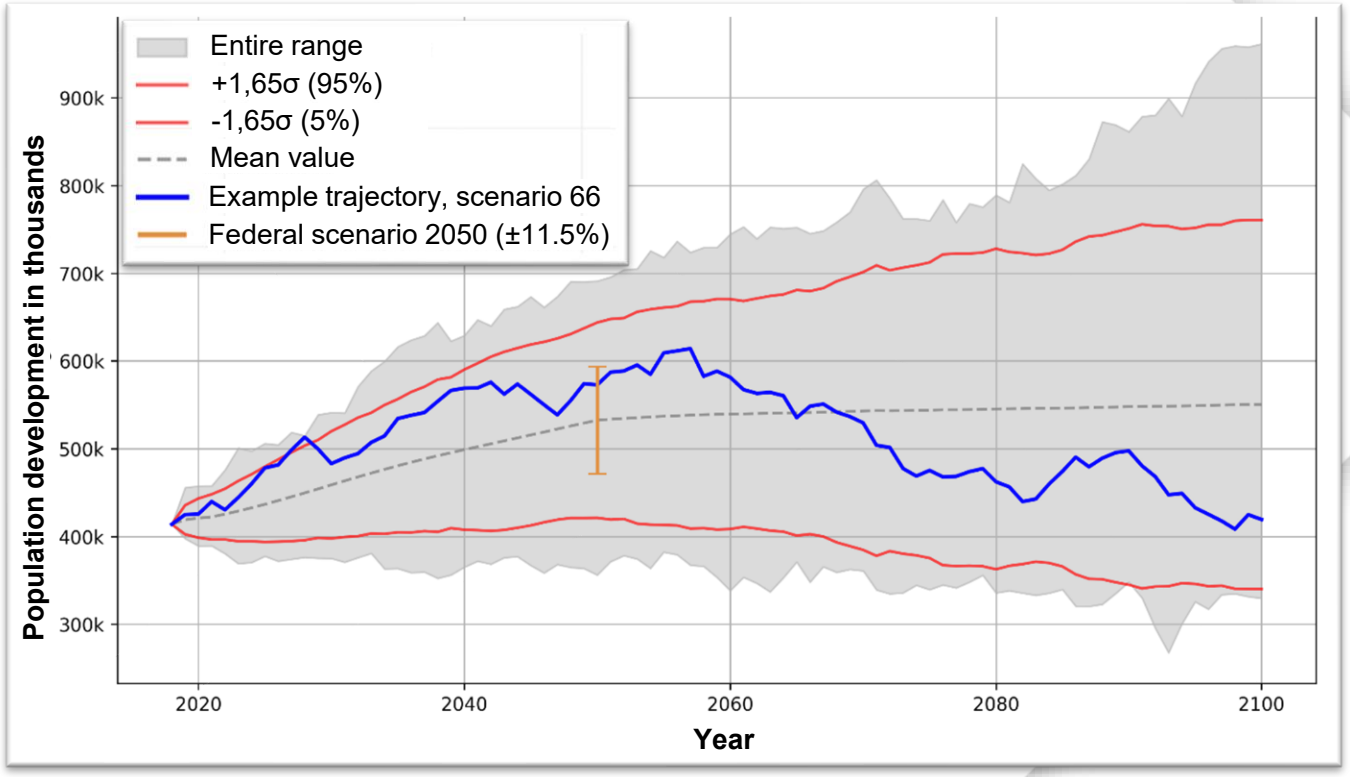
GENERATED INTERVENTIONS

- (1) Identify connection nodes between rail corridors,
- (2) Determine whether a direct link exists between each pair of corridors leading to the same node,
- (3) Identify and label any missing links or direct connections,
- (4) Grow new service lines, starting from central node and then extending the line until it reaches between two end station nodes.

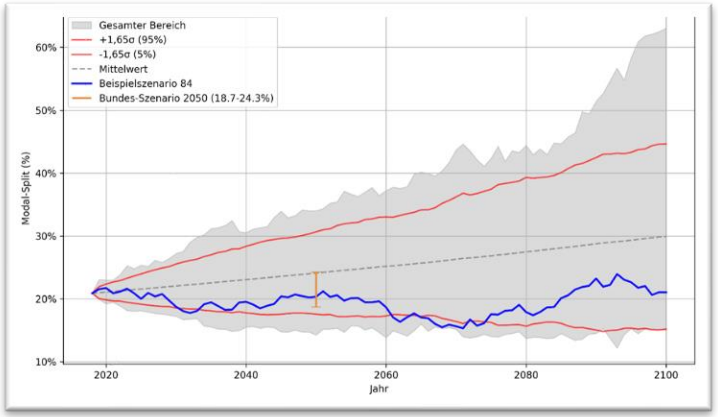


UNCERTAIN VARIABLES

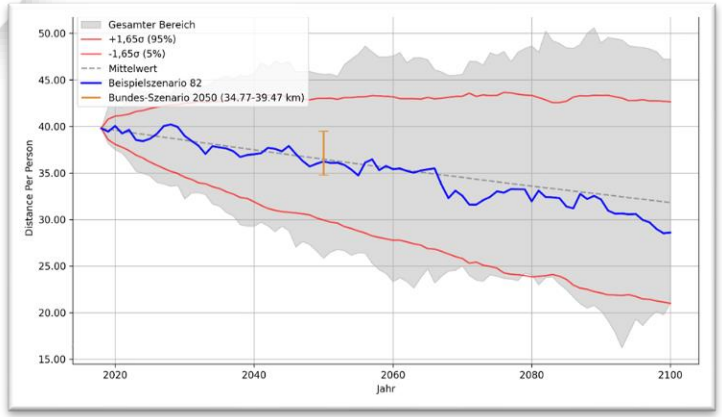
Population development



Mode share PT



Daily traveled distance



EVALUATION

Objective function includes:

- Infrastructure costs
- Track use fees
- Line operations
- User travel costs

$$C_{ij,t}^{total} = C_{i,t}^{construction} + C_{i,t}^{maintenance} + C_{ij,t}^{operations} + C_{ij,t}^{travel\ time}$$

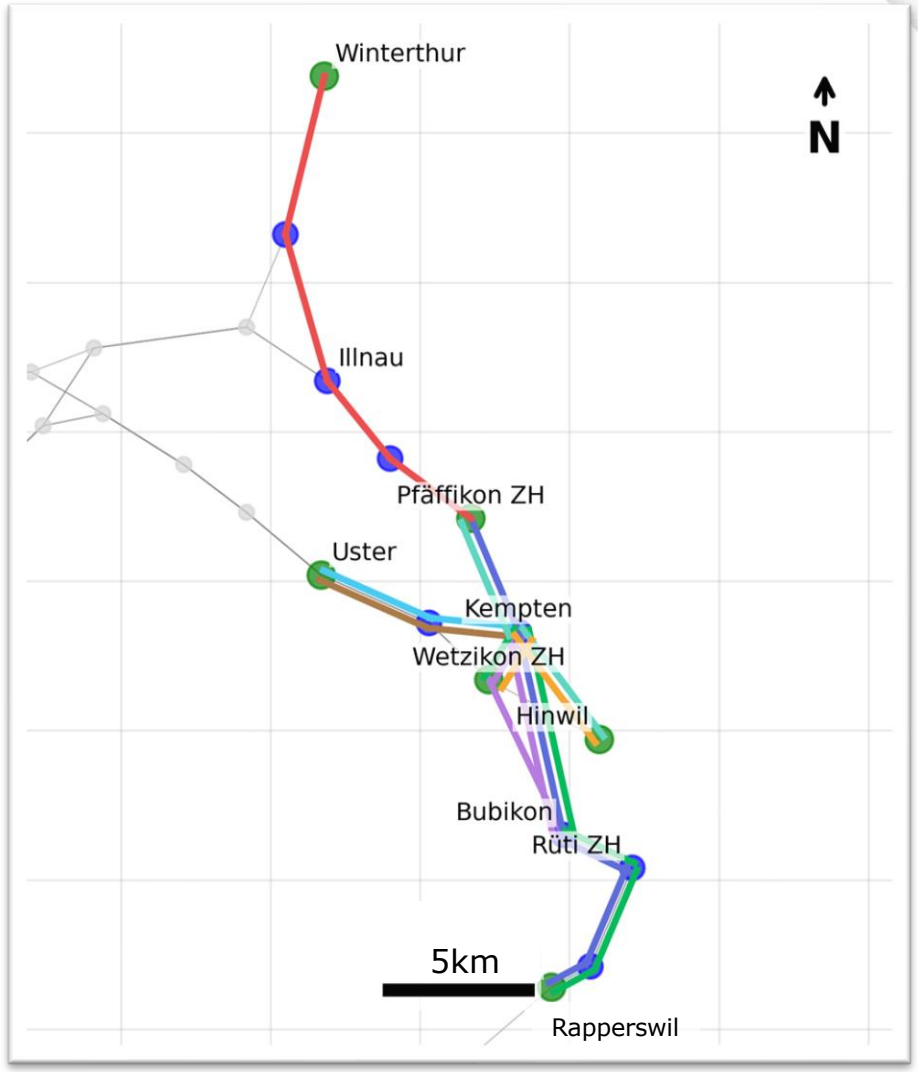
$$C_{ij}^{total} = \sum_{t=2050}^{2100} D\left(3\%, t = 2050, C_{ij,t}^{total}\right)$$

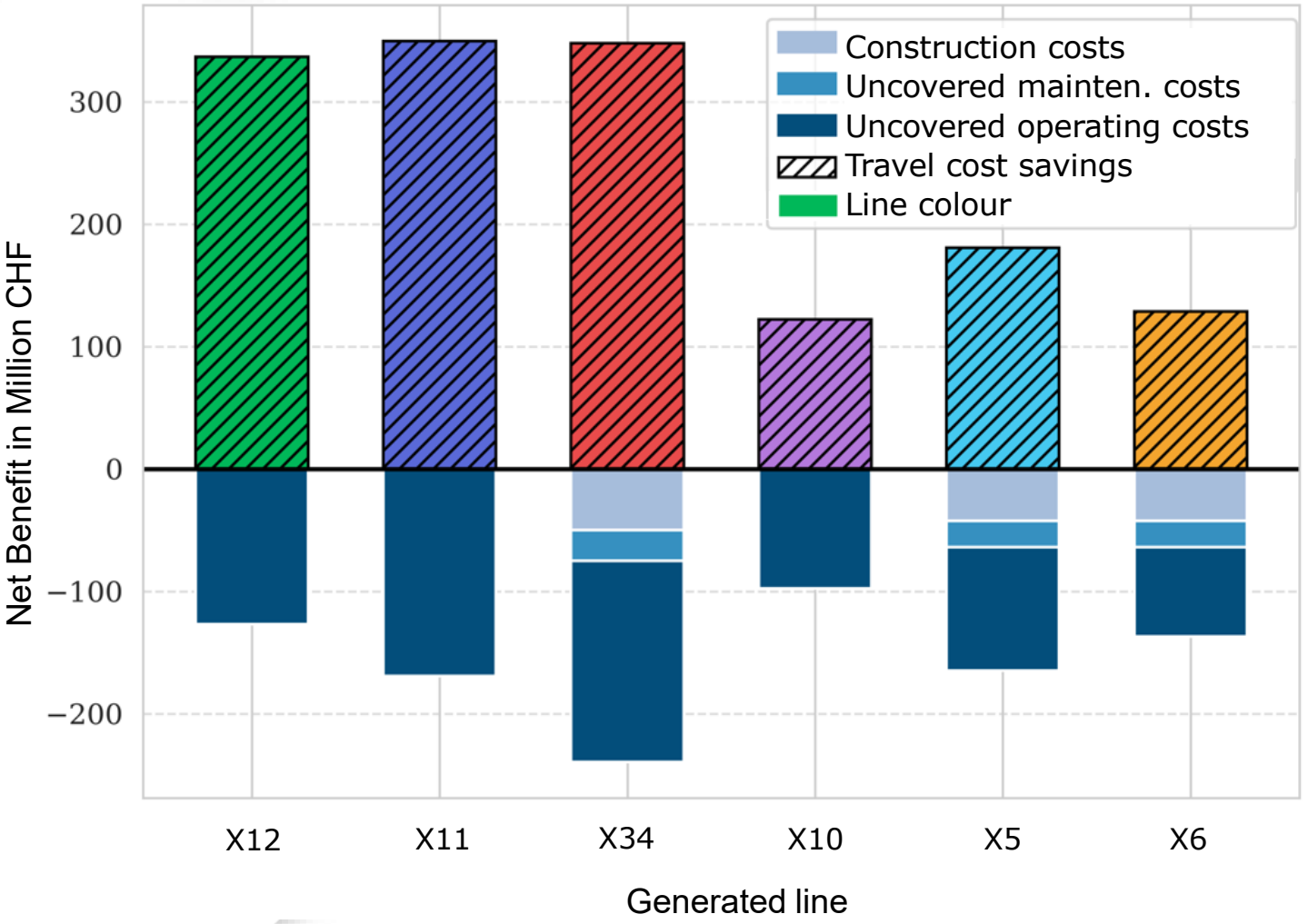
$$NB_{ij} = C_{0,j}^{total} - C_{ij}^{total}$$

where,

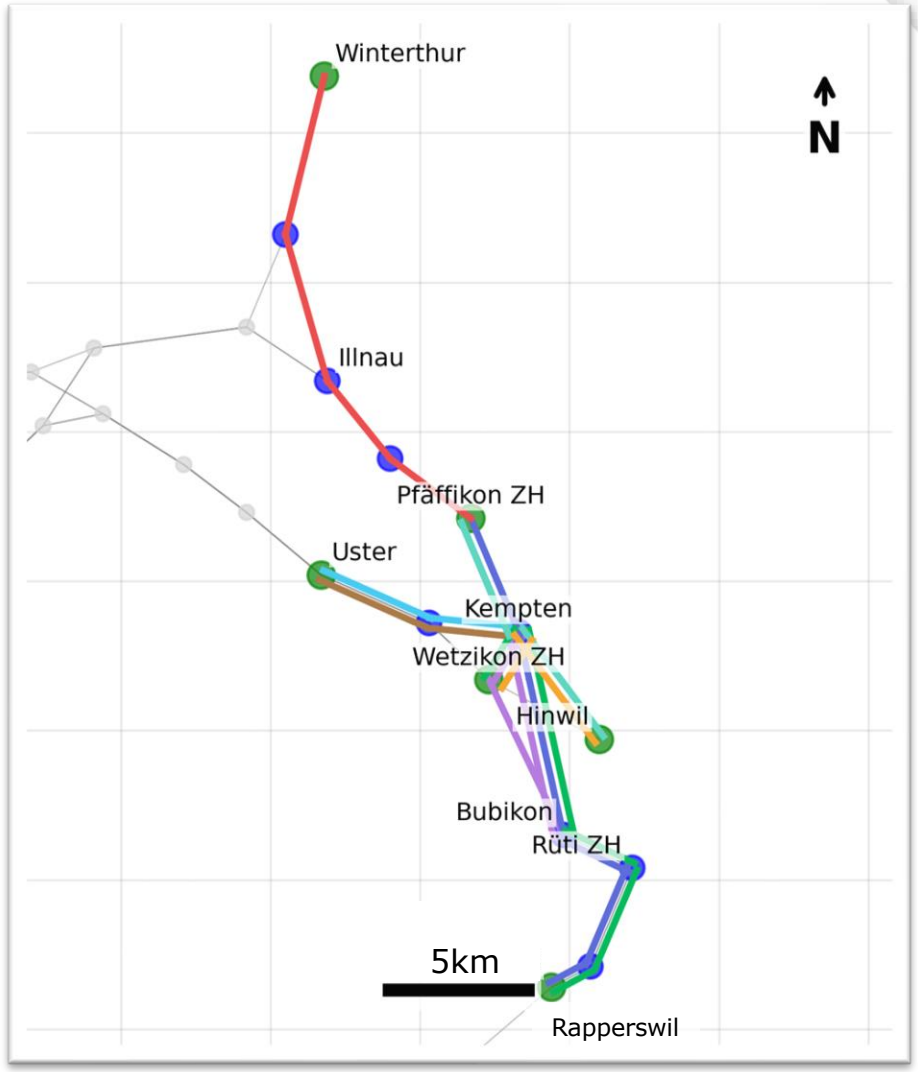
$D()$: Discounting function with discount rate 3% and price basis 2050
$C_{ij,t}^{total}$: Total costs of infrastructure development i in scenario j, for the year t
C_{ij}^{total}: Discounted total costs for infrastructure development i in scenario j for the case study corridor
$C_{0,j}^{total}$: Total costs for the status quo in scenario j
NB_{ij} : Net benefit in reference to status quo for entire appraisal period

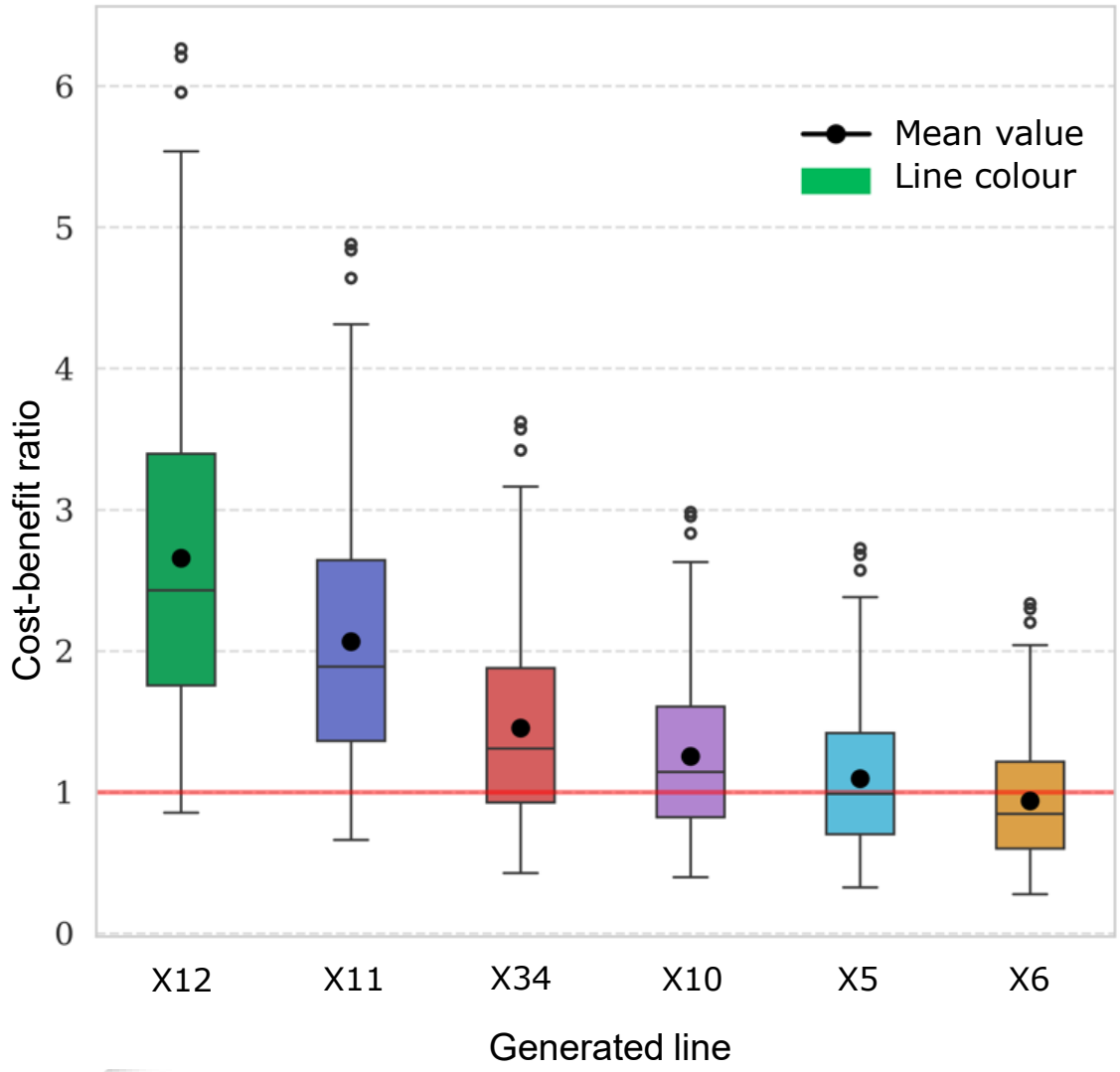
RESULTS


Winterthur
N
Illnau
Pfäffikon ZH
Uster
Kempten
Wetzikon ZH
Hinwil
Bubikon
Rüti ZH
5km
Rapperswil


Construction costs
Uncovered mainten. costs
Uncovered operating costs
Travel cost savings
Line colour
Net Benefit in Million CHF
300
200
100
0
−100
−200
X12
X11
X34
X10
X5
X6
Generated line

RESULTS


Winterthur
N
Illnau
Pfäffikon ZH
Uster
Kempten
Wetzikon ZH
Hinwil
Bubikon
Rüti ZH
5km
Rapperswil


Mean value
Line colour
Cost-benefit ratio
0
1
2
3
4
5
6
X12
X11
X34
X10
X5
X6
Generated line

FUTURE RESEARCH

OUTLOOK

- Building from a prototype to a tool
  - **Capacity corrections on unchanged parts of network**
  - **Intervention modules to cover the entirety of possibilities**
- Evaluating the changes appropriately
  - **Ensure that stakeholders are adequately represented**
  - **Consider low-effort changes that incorporate travel behaviour**
  - **Align with CBA frameworks**
- Validate planning results with planning process in practice
  - **Cooperate with rail planning organisations**
- Scalability and large-scale deployment
  - **Use RL or GeoAI methods for a ‚smarter' search or assessing benefits**

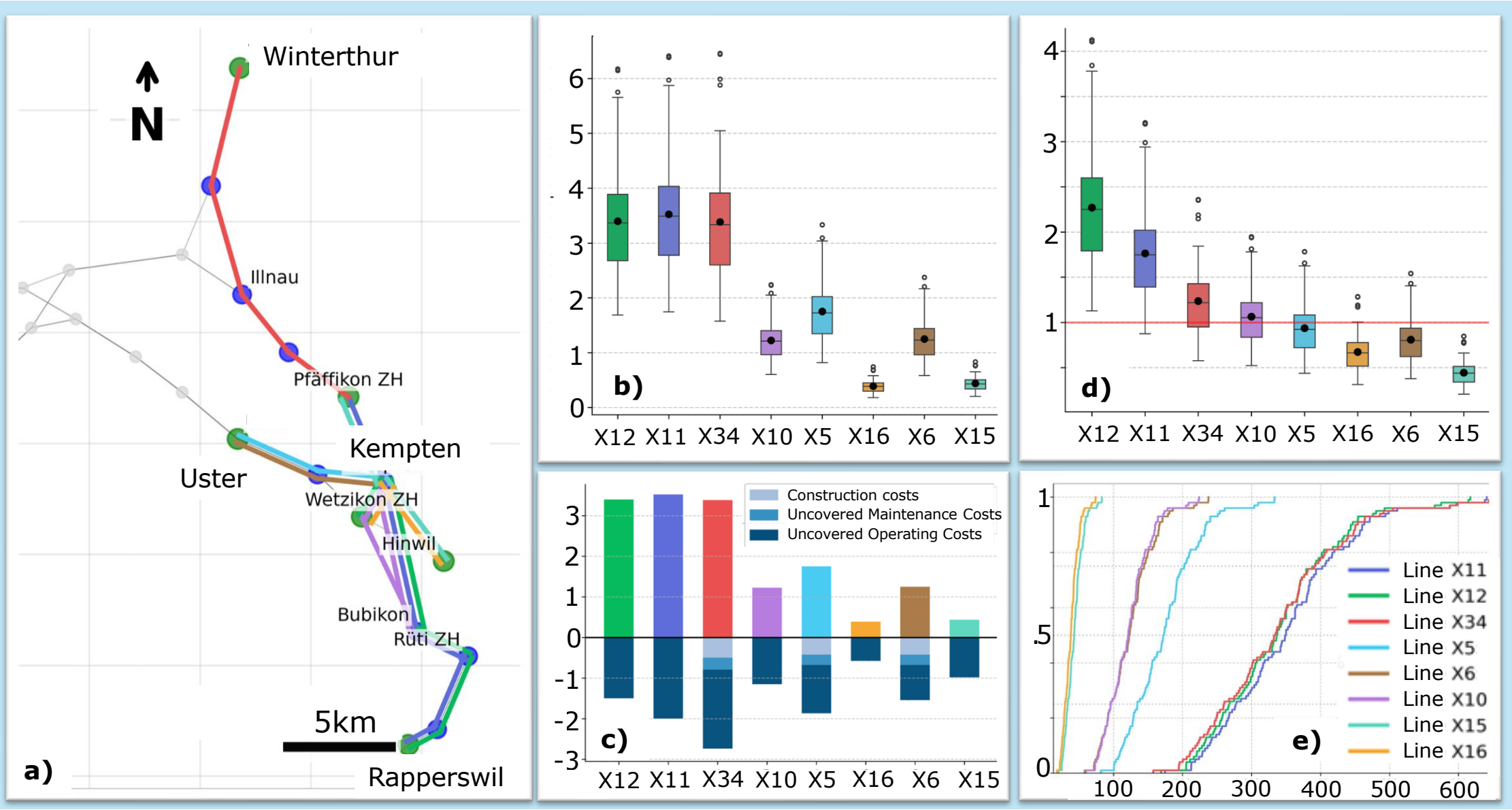
➢ Potential to inform nationwide, integrated mobility planning

With this scanning tool, planners get a speedy 'first estimate' of where infrastructure investments may be beneficial.

TRA TRANSPORT RESEARCH ARENA BUDAPEST 18-21/05/26 Re-Generation in transport

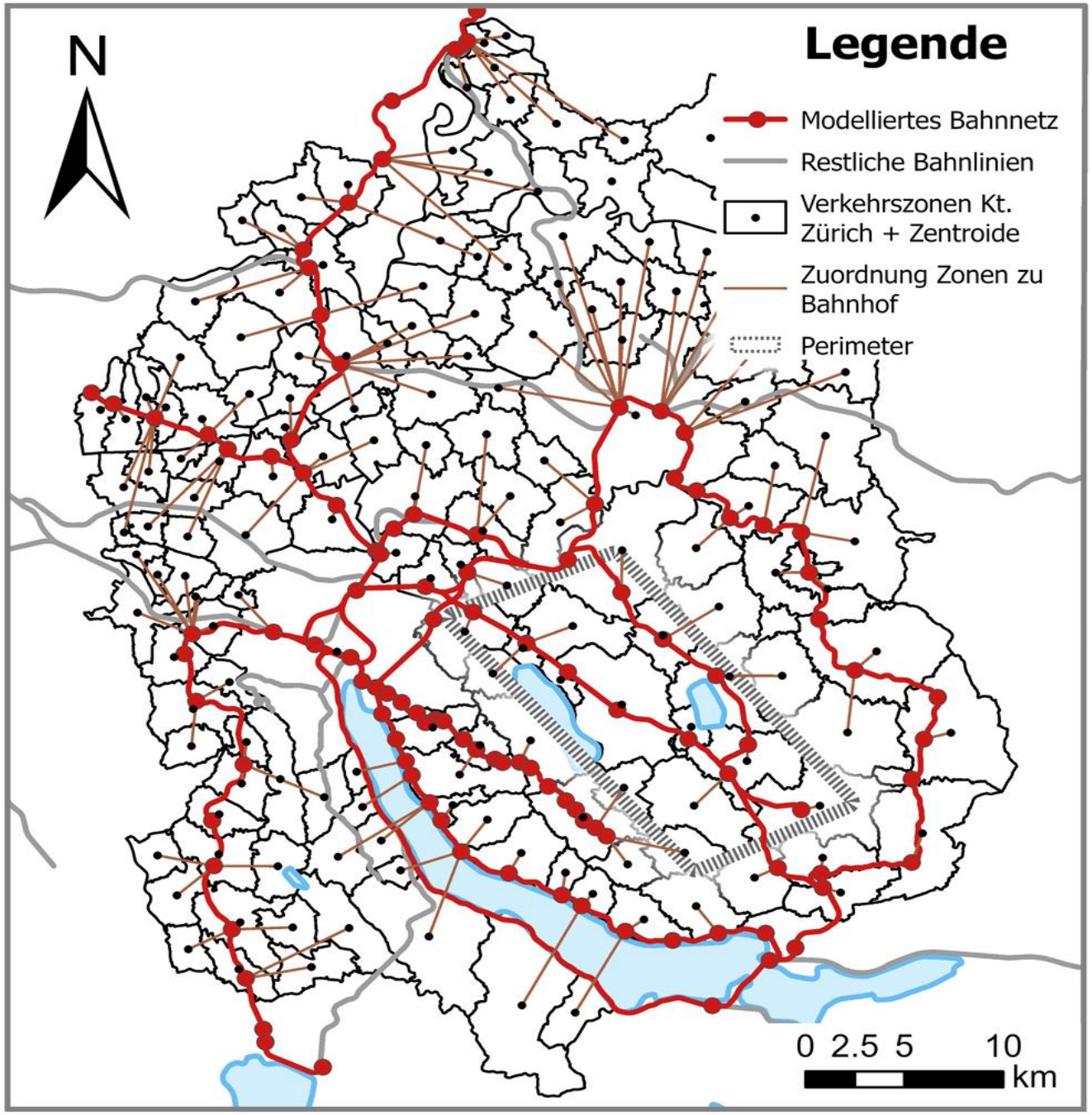
earnor@ethz.ch
arnore@bifrost.is

EXTRA SLIDES


N
Winterthur
Illnau
Pfäffikon ZH
Kempten
Uster
Wetzikon ZH
Hinwil
Bubikon
Rüti ZH
5km
Rapperswil
a)
b)
X12 X11 X34 X10 X5 X16 X6 X15
d)
X12 X11 X34 X10 X5 X16 X6 X15
c)
Construction costs
Uncovered Maintenance Costs
Uncovered Operating Costs
X12 X11 X34 X10 X5 X16 X6 X15
e)
Line X11
Line X12
Line X34
Line X5
Line X6
Line X10
Line X15
Line X16
100 200 300 400 500 600

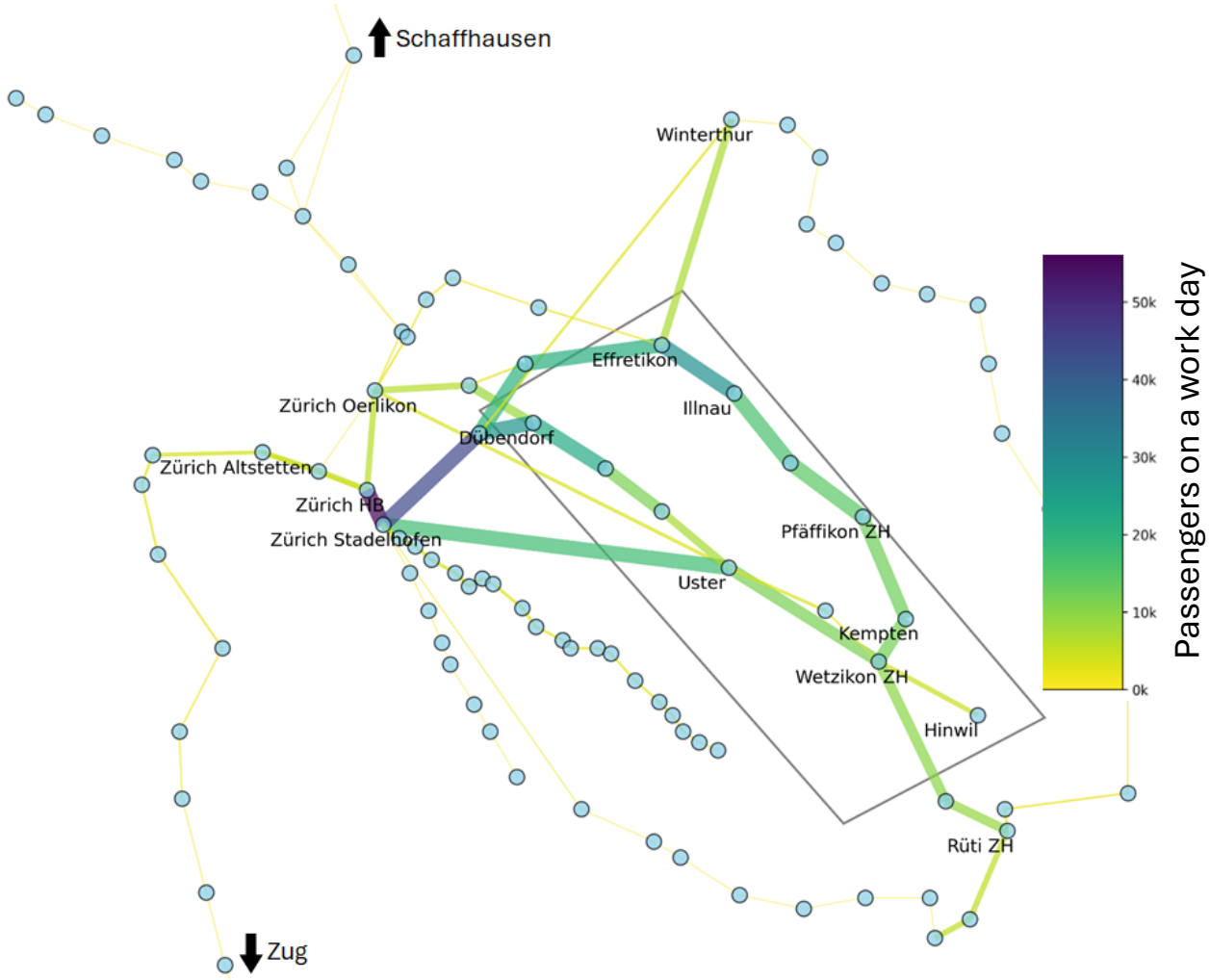
Demand allocated to network

- Communal ODs allocated to closest train station.
- Rail network as graph for travel time computation
- Routing with shortest path



Results: Passenger flow on Network 2050

Trips with Origin or Destination inside perimeter.



Results: Change in passenger flow due to changes